AIC Color 01
The 9th Congress of the
International Color Association

Sponsored by

Congress Patrons

Eastman Kodak Company

RIT Chester F. Carlson Center for Imaging Science

Sun Chemical

Xerox Corporation

Event Patrons

Adobe Systems

BYK Gardner

Canon R&D Center America, Inc.

DataColor International

DuPont Performance Coatings

Flex Products, Inc. - ChromaFlair Pigments

Gemological Institute of America

Hewlett Packard Company

Illuminating Engineering Society

Imation Corporation

John Wiley and Sons

Minolta Corporations Instrument Systems Division

Pantone, Inc.

Society of Plastics Engineers, Color & Appearance Division

Technical Association of the Graphic Arts

Other Sponsors

Giordano Beretta

Colorart

Council for Optical Radiation Measurements

Detroit Color Council

Graphic Arts Technical Foundation

The 9th Congress of the International Colour Association

Rochester Riverside Convention Center
Rochester, New York USA
www.iscc.org/aic2001

June 24–29 2001

Proceedings of SPIE
Volume 4421

SPIE is an international technical society dedicated to advancing engineering and scientific applications of optical, photonic, imaging electronic, and optoelectronic technologies.

The papers appearing in this book compose the proceedings of the technical conference cited on the cover and title page of this volume. They reflect the authors' opinions and are published as presented, in the interests of timely dissemination. Their inclusion in this publication does not necessarily constitute endorsement by the editors or by SPIE. Papers were selected by the conference program committee to be presented in oral or poster format, and were subject to review by volume editors or program committees.

Please use the following format to cite material from this book:

Author(s), "Title of paper," in *9th Congress of the International Colour Association*, Proceedings of SPIE Vol. 4421, page numbers (2002).

ISSN 0277-786X
ISBN 0-8194-4128-7

Published by
SPIE—The International Society for Optical Engineering
P.O. Box 10, Bellingham, Washington 98227-0010 USA
Telephone 1 360/676-3290 (Pacific Time) • Fax 1 360/647-1445
http://www.spie.org/

Printed in the United States of America.

FOREWORD

We were very happy to return to the United States to hold the 9th AIC Congress at Rochester, NY. It was 1977 when the 3rd AIC Congress was held at Troy, NY, with Prof. Fred W Billmeyer, Jr., as the organizing chairperson. Twenty-four years have passed since, but color science and engineering, color design, color vision science, and other subjects related to color have always been active in the United States and consequently the enthusiasm for the AIC has never dropped down. Colleagues from the Inter-Society Color Council of the United States have continued to take important parts in the AIC and here we could return for the 9th Congress of AIC. On behalf of the Executive Committee of the AIC, I deeply thank the ISCC, and in particular the Rochester-based organizing committee, for inviting us and for offering this international forum where we could present most recent results of research and where we could meet friends from all over the world.

The AIC is expanding. In this quadrennial we had three new member countries: Thailand, Brazil, and Bolivia. Still another country wrote to us recently expressing their interest to join our circle. Any country is welcome as long as they are willing to be active in the AIC. We will have a new president next year, Ms. Paula Alessi from the United States, and through her strong leadership I am sure that the AIC will further prosper.

I was personally very happy to return to Rochester, as I spent six years of my young days at the University of Rochester to study for my PhD under the supervision of Prof. Robert M. Boynton. Rochester was one of the meccas of color science and engineering at that time because of universities such as UR and Rochester Institute of Technology on one hand, and of industries such as Eastman Kodak and Xerox on the other. Many eminent scientists were produced there. I was greatly stimulated by them through their lectures and finally decided to take color science as my life research work. Rochester still keeps its fame nowadays with many excellent successors, as we all know. It was quite appropriate for the AIC to go to Rochester to hold the congress.

As I strolled about near the Rochester Riverside Convention Center located in downtown Rochester, I noticed the places I once knew almost completely changed. I was so far detached from the good old days of my life in this town that I could now easily lose my way. But change is necessary for anyone to prosper. No change, no progress. In this meeting we had new subjects which were not seen in the 3rd Congress at Troy. For example, the imaging techniques of spectral estimation, the artist and digital media, digital archive, color management, 3D world, and color vision of the elderly. These subjects were all new, and demonstrate the vitality of the AIC through its ability to incorporate new topics. This growing tradition will assure excellent prospects for the future of AIC.

It was very impressive to see eleven symposia, starting with "What is Color?" and ending with "The Future of Color." We often say that color is used everywhere and the AIC can contribute to many fields. By looking at the titles of the symposia, people should be able to understand what the AIC claims. I extend a sincere appreciation to the technical program committee for creating these titles for the symposia. The AIC and the CIE have been good partners for many years. It is my understanding that the AIC is to present an international forum for scientists, engineers, designers and artists to exchange their professional ideas and opinions so that they can promote their own works in their respective rounds, while the CIE is to present them technical standards and methods for using and treating color that can be used globally. In other words, the former serves to sow our color seeds and the latter to harvest for our color needs; the two can cooperate nicely. I believed that the two international organizations could continue good relationships for the future by attending one of the symposia, "How is CIE Helping us Make Color Work?"

It took thirteen hours to fly over the Pacific Ocean and over the continent of North America from Japan to Washington, D.C., and another hour to Rochester. It was a long and expensive trip. There were many colleagues in attendance who came from other far-off countries and invested just as much time and money. Why did we go? Because we knew from past experiences that the AIC Congress was worthwhile to attend. We could touch on the most current scientific findings, new ways of color technologies, and new applications of color. We could see friends from other countries again, and we could make new friends. In these regards, I believe we were all very satisfied with the 9th AIC Congress.

There were many papers presented at the Congress, and three lecture halls were often used in parallel. Poster rooms were also very well-attended. It was good for the AIC, and the organizers should be congratulated for the success of the Congress. But at the same time I should admit that I missed many paper presentations due to the parallel sessions and to the exchange of ideas with many friends from other countries in the lobby. Therefore, I have awaited the Proceedings. It is now available here and I look forward to reading the many excellent papers collected in this volume at my leisure in my own home country.

Prof. Mitsuo Ikeda, Ph.D.
President of AIC
1998-2001

AIC Officers and Member Countries

Executive Committee

President:	Mitsuo Ikeda
Vice President:	Paula J. Alessi
Secretary/Treasurer:	Frank Rochow
Members:	Jin-Sook Lee
	Javier Romero
	Maks Tusak
	Michel Albert-Vanel

Regular Members

Grupo Argentino del Color	(Argentina)
Colour Society of Australia	(Australia)
Asociación Boliviana del Color	(Bolivia)
Associacao Brasileira da Cor	(Brazil)
Colour Group – Bulgaria	(Bulgaria)
Color Association of China	(China)
Centre Français de la Couleur	(France)
Deutscher Verband Farbe	(Germany)
The Colour Group (Great Britain)	(Great Britain)
Hungarian National Colour Committee	(Hungary)
The Colour Group of India	(India)
Associazione Ottica Italiana	(Italy)
Color Science Association of Japan	(Japan)
Korean Society of Color Studies	(Korea)
Nederlandse Ver. voor Kleurenstudie	(The Netherlands)
Norsk Farveforum	(Norway)
Central Office of Measures	(Poland)
Colour Group of the South African Optical Society	(Republic of South Africa)
Slovenian Colourists Association	(Slovenia)
Comité Español del Color	(Spain)
Stiftelsen Svenskt Färgcentrum	(Sweden)
Pro Colore	(Switzerland)
The Color Group of Thailand	(Thailand)
Inter-Society Color Council	(USA)

ISCC Officers and Member Bodies

ISCC Executive Officers

President	Jack Ladson	Color Innovation
President-Elect	Danny Rich	Sun Chemical Research
Secretary	John McCann	McCann Technologies
Treasurer	Hugh Fairman	Resource III, Inc.
Past-President	Michael H. Brill	Sarnoff Corporation

ISCC Board Of Directors

1998-2001	1999-2002	2000-2003	2001-2004
Charla S. Haley	Dan Phillips	Robert Buckley	Jim King
Craig Johnson	Art Springsteen	Alan Kravetz	Eileen Korenic
Yan Liu	Ralph Stanziola	Mary McKnight	Margaret Miele

ISCC Member-Bodies

American Association of Textile Chemists and Colorists (AATCC)
American Society for Testing and Materials (ASTM)
American Society for Photogrammetry & Remote Sensing (ASPRS)
The Color Association of the United States, Inc. (CAUS)
Color Marketing Group (CMG)
Color Pigments Manufacturing Association (CPMA)
Council on Optical Radiation Measurements (CORM)
Detroit Colour Council (DCC)
Federation of Societies for Coatings Technology (FSCT)
Gemological Institute of America (GIA)
Graphic Arts Technical Foundation (GATF)
Graphic Communications Association (GCA)
Illumination Engineering Society of N. America (IESNA)
National Association of Printing Ink Manufacturers (NAPIM)
Optical Society of America (OSA)
Society for Information Display (SID)
Society of Plastics Engineers, Color & Appearance Div.(SPE)
Society for Imaging Science and Technology (IS&T)
Technical Association of the Graphic Arts (TAGA)
Technical Association of the Pulp and Paper Industry (TAPPI)

Sustaining Members

Barr Associates, Inc.
BYK-Gardner USA
Chromatics Color Sciences Intl, Inc.
Ciba Specialty Chemicals
Color Communications, Inc.
DuPont Performance Coatings
Flex Products, Inc.
GretagMacbeth, LLC
Hewlett-Packard Company
Hunter Associates Laboratory, Inc.
Labsphere, Inc.
Minolta Corporation
Pantone, Inc.
PPG Industries, Inc.

AIC Color 01 Organizing Committee

General Chair: Paula Alessi, Eastman Kodak Company
Technical Program Committee Chair: Allan Rodrigues, DuPont Performance Coatings, USA
Secretariat: Cynthia Sturke, ISCC
Audio/Visual and Poster Papers Chair: Michael Sanchez, Xerox Corporation
Exhibitions Chair: Kevin McGuire, Tailored Lighting Inc.
Finance Chair: Geoff Woolfe, Eastman Kodak Company
Fundraising Chair: Roy Berns, Rochester Institute of Technology
ISCC Liaison: Robert Buckley, Xerox Corporation
Student Awards Chair: Karen Braun, Xerox Corporation
Publications Chair: Robert Chung, Rochester Institute of Technology
Publicity Chair: David Wyble, Rochester Institute of Technology
Social Program Chair: Cathy Daniels Cerosaletti, Eastman Kodak Company
Susan Stanger, Possible Dreams
Administrative/Design Support: Colleen Desimone, Rochester Institute of Technology
Valerie Hemink, Rochester Institute of Technology

Acknowledgments

We, the members of the AIC Color 01 Organizing Committee, would like to express our sincere appreciation to the following organizations/people. Without their assistance, this AIC 9th Congress would not have been possible.

Rochester Riverside Convention Center: Kris Hughes
Nia Gaskin
Deborah Burgart
The Rivers Organziation: Richard Rivers
Cheryl Marshall
DePrez Travel: Donna Duckett
Karen Kucio
Hale Northeastern: Sally Weisner
CMI Communications: Chip LaCure
Eric Smith
Greg Bates
Steve Flint
Greater Rochester Visitors Association: Carol Bartlett
Sharon Levine
Poster Concepts: Lorraine Wright
Jenni Day
Jeong-Jae Kim
Kathleen Schaefer
Final Poster Design: Lorraine Wright
AIC Congress Program Design: Michael Pletka
Jon Cardin
Christie Kim

AIC Technical Program Committee

Allan Rodrigues	Chair, DuPont Performance Coatings, USA
Raja Balasubramanian	Xerox Corporation, USA
Roy Berns	Rochester Institute of Technology, USA
Anna Campbell Bliss	Artist & Color Consultant, USA
Michael Brill	Sarnoff Corporation, USA
Rob Buckley	Xerox Corporation, USA
Shashi Caan	Skidmore Owings & Merrill, USA
Jose Caivano	Grupo Argentino del Color, Argentina
Robert Chung	Rochester Institute of Technology, USA
Mark Fairchild	Rochester Institute of Technology, USA
Franziska Frey	Rochester Institute of Technology, USA
Paul Green-Armytage	Curtin University School of Design, Australia
Richard Harold	BYK-Gardner, USA
Chris Hauf	Eastman Kodak Company, USA
Robert Hirschler	SENAI/CETIQT, Brazil
Georgia Kalivas	Fashion Institute of Technology, USA
Jack Ladson	Color Innovation, USA
John Locke	E. I. DuPont, USA
Joy Turner Luke	Studio 231, USA
Ronnier Luo	University of Derby, UK
Barry Maund	University of Western Australia
Manuel Melgosa	University of Granada, Spain
Meg Miele	Fashion Institute of Technology, USA
Leo Oberascher	Institut fur Angewandte Okologische Psychologie, Austria
Roy Osborne	The American State College, London, UK
Michael Pointer	National Physical Laboratory, UK
Joel Porkorny	University of Chicago, USA
Danny Rich	Sun Chemical Research, USA
Alan Robertson	National Research Council, Canada
Geoffrey Rogers	Fashion Institute of Technology, USA
Grete Smedal	National Institute of Art and Design in Bergen, Norway
Heinz Terstiege	BAM, Germany
Wade Thompson	Southwest Missouri State University, USA
Geoff Woolfe	Eastman Kodak Company, USA
Hirohisa Yaguchi	Chiba University, Japan
Paula Alessi	Ex-officio, Eastman Kodak Company, USA

Contents

What is Color For?

WHAT IS COLOR FOR?

ENVIRONMENTAL COLOR DESIGN

Symposium

ECD/ARCHITECTURE

Oral Session

Poster papers

ARCHITECTURE

Oral Session

Poster papers

ART AND DESIGN

Oral Session

Poster Papers

Poster Papers

COLOR PREFERENCE

Oral Session

Poster Papers

Other Poster Papers on “How Does Color Work?”

How Do We Control Color?

COLOR MANAGEMENT

Tutorial: The Whys and Hows of Color Management

Symposium: The State of the Art and Future of Color Management

IMAGING TECHNIQUES OF SPECTRAL ESTIMATION (SPECTRAL IMAGING)

Symposium

COLOR APPEARANCE

Oral Session

Poster Papers

COLOR DIFFERENCE

Oral Session

INDUSTRIAL COLOR

Oral Session

Poster Papers

COLOR MEASUREMENT

Oral Session

Poster Papers

COLOR ORDER SYSTEMS

Oral Session

How Should We Teach Color?

HOW SHOULD WE TEACH COLOR?

TEACHING AIDS

COLOR EDUCATION

THE FUTURE OF COLOR

PREFACE

The 9th Congress of the *International Colour Association, AIC Color 01*, was held in Rochester, New York, USA on June 24-29,2001.

The Congress was organized by the *International Colour Association* and the Rochester Organizing Committee of the *Inter-Society Color Council* in cooperation with the Greater Rochester Visitor's Association, Deprez Travel, The Rivers Organization, CMI Communications, and Hale Northeastern.

The Technical Program Committee composed of 36 members from around the world handled the paper abstracts and proceedings papers.

The venue of the Congress was the Rochester Riverside Convention Center, which also housed an Exhibition. The attendance was 440 registered participants, 29 accompanying persons, and 72 students from 29 countries. There were 56 exhibitors representing 25 companies/products.

The *Opening Ceremony* started on Monday, June 25 with a welcome address from Paula Alessi, General Chair of the Organizing Committee of AIC Color 01 Rochester, which was followed by a description of the Technical Program by Allan Rodrigues, Chair of the Technical Program Committee. Then Jack Ladson, the President of the *Inter-Society Color Council* welcomed the participants to the Rochester Congress. Finally, Prof. Mitsuo Ikeda, President of the *International Colour Association* officially declared the Congress open.

The *Opening Ceremony* was followed by two keynote addresses. Rochester, New York is known as the World's Image Center because it is the home of such companies as Eastman Kodak Company and Xerox Corporation, where images are key to their business. Thus the keynote addresses were given by top management from these two companies to start the Congress with stimulating talks on color and images in photography and documents. The first keynote speaker was Hervé Gallaire, Corporate Senior Vice President and Chief Technology Officer of Xerox Research and Technology. His presentation was entitled *"The Future of the Document"*. This talk described the new and evolving possibilities for color and images in the document. The second keynote speaker was James C. Stoffel, Senior Vice President and Chief Technical Officer, Eastman Kodak Company, and Director, Research and Development. His presentation was entitled *"COLOR IMAGING: Requirements for Growth"*. This talk described the explosion of color imaging into systems and businesses other than traditional silver halide photography.

Five themes were used in constructing the technical program; What is Color, What is Color For, How do We Control Color, How Does Color Work, and How do We Teach Color? These Proceedings are arranged according to these themes.

The Technical Program Committee arranged 11 symposia and one tutorial featuring 33 invited presentations, and also some contributed papers. These were scheduled at various times throughout the week. On Monday, the tutorial entitled *"The Whys and Hows of Color Management"* was moderated by Robert Buckley from Xerox Corporation and featured Jim King from Adobe Systems Incorporated as the invited speaker. Also on Monday, the symposium entitled *"What is Color?"* was coordinated by Paul Green-Armytage from Curtin University of Technology in Australia and moderated by Larry Hardin, an Emeritus Professor from Syracuse University. On Tuesday, the symposium entitled *"Imaging Techniques of Spectral Estimation"* was moderated by Roy Berns from Rochester Institute of Technology. In parallel on Tuesday, was the symposium entitled *" The Artist and Digital Media"* moderated by Joy Turner Luke from Studio 231. Tuesday also featured the symposium entitled *"The State of the Art and Future of Color Management"* moderated by Robert Buckley from Xerox Corporation. The last symposium for the day on Tuesday was *"What is Color For?"*, moderated by ISCC Interest Group III, Art, Design and Psychology, coordinators Georgia Kalivas and Meg Miele from the Fashion Institute of Technology. Thursday featured four symposia. The first was entitled *"Color Issues for Digital Archives"*, which was moderated by Franziska Frey from Rochester Institute of Technology. The second was entitled *" How is CIE Helping Us Make Color Work?"*, which was moderated by Michael Pointer from National Physical Laboratory. The third was entitled "*Environmental Color Design*", which was moderated the co-chairs of the AIC Study Group of the same name, José Caivano from Buenos Aires University and Leo Oberascher from ÖKO-PSY. The fourth symposium was entitled "*How Should We Teach Color?*", which was moderated by Geoffrey Rogers from the Fashion Institute of Technology. This symposium was coordinated by Geoffrey Rogers as chair of the ISCC Education Committee and by Manuel Melgosa, University of Granada. The last two symposia were on Friday. The first was entitled "*The Future Role of Color in the Three-Dimensional World*", which was moderated by Sashi Caan from Skidmore, Owings and Merrill, Architects. The second and last one was entitled "*The Future of Color*", which was moderated by Jack Ladson, ISCC President.

In the parallel sessions running in two and sometimes three rooms, 106 contributed papers were presented orally. Contributed poster papers were displayed all week and four author-present sessions were offered to highlight the 98 contributed poster papers.

On Wednesday there was a General Assembly meeting, where AIC member countries voted in the new AIC Executive Committee to start their term in January, 2002. They are Paula Alessi (USA) President, Paul Green Armytage (Australia) Vice President, Frank Rochow (Germany) Secretary-Treasurer, José Caivano (Argentina) Executive Committee member, Joaquin Campos (Spain) Executive Committee member, Hirohisa Yaguchi (Japan) Executive Committee member, and Aran Hansubei (Thailand) Executive Committee member. Current President, Professor Mitsuo Ikeda thanked the outgoing Executive Committee members for their valuable contributions over the last four years.

An Exhibition featuring the newest developments and literature in the fields of color and color technology took place at the same venue of the Congress on Monday and Tuesday. All participants attended it.

Social events at AIC Color 01 included a Welcome Party hosted by the Center for Imaging Science at the Rochester Institute of Technology, tours of the George Eastman House, Memorial Art Gallery Tour, Horses on Parade Tour, Rochester Red Wing Baseball Game at Frontier Field, an excursion to the Genessee Country Museum and Village, and the AIC Judd Award banquet. On Thursday evening, the AIC Judd Award banquet was held at the Congress venue. The recipient of the 2001 AIC Judd Award was Lic. Daniel Lozano from Argentina. The citation was given by his fellow countryman, José Caivano. Then a touching acceptance speech was given by Lic. Lozano. An extensive accompanying persons program featured a Landmark Society Historic House Tour, a tour of Pittsford Historic Village with a walk along the Erie Canal and shopping, and a Casa Larga Winery Tour and Tasting.

The *Closing Ceremony* featured summarizing comments from Paula Alessi as General Chair of the AIC Color 01 Organizing Committee. Then Vera Golob shared information and a beautiful video of Slovenia to introduce the 2002 AIC Interim Meeting, which will take place in Maribor, Slovenia covering the topic of Color in Textiles. Next Javier Romero gave a wonderful speech, including a very detailed video to welcome the AIC 10th Congress to Granada, Spain. Professor Ikeda, as AIC President, thanked the Rochester Organizing Committee and all participants for a very successful 9th Congress before he officially declared it closed.

Paula J. Alessi
General Chair, Rochester Organizing Committee

Allan B. Rodrigues
Technical Program Committee Chair

Opening Address

Paula J. Alessi
AIC Color 01 General Organizing Committee Chair

Here is the largest welcome embrace I can offer to you, the participants of the AIC Color 01 9th Congress. On behalf of the Rochester-based Inter-Society Color Council AIC Color 01 Organizing Committee, it is my distinct pleasure to welcome you to Rochester, New York, the World's Image Center. Please allow me to introduce myself. I am Paula Alessi, Chair of the AIC Color 01 Organizing Committee.

Four years ago at AIC Color 97, the 8th Congress in Kyoto, Japan this 9th Congress in Rochester was just a dream. Roy Berns, Mark Fairchild, Geoff Woolfe and myself were sitting in the audience knowing that we were going to be intimately involved in planning this 9th Congress. We sat back in awe at the spectacular job the Color Science Association of Japan did planning the very successful 8th Congress. Little did we know how big our task would be in planning AIC Color 01 in Rochester. Our Japanese friends started us off on the right foot by offering advice based on what they had learned in putting together a very successful Congress. So we started working four years ago, while it was still fresh in our minds and here we are four years older, four years wiser and ready to see our dream unfold.

This has truly been a group effort by committee and it is my pleasure to introduce them to you now. As I announce the members of the AIC Color 01 Organizing Committee please stand to be recognized and remain standing until everyone has been called.

Technical Program Committee Chair: Allan Rodrigues, DuPont Performance Coatings
Secretariat: Cynthia Starke, ISCC
Audio/Visual and Poster Papers Chair: Michael Sanchez, Xerox Corporation
Exhibitions Chair: Kevin McGuire, Tailored Lighting Inc.
Finance Chair: Geoff Woolfe, Eastman Kodak Company
Fundraising Chair: Roy Berns, Rochester Institute of Technology
ISCC Liaison: Robert Buckley, Xerox Corporation
Logo/Poster Design and Student Awards Chair: Karen Braun, Xerox Corporation
Publications Chair: Robert Chung, Rochester Institute of Technology
Publicity Chair: David Wyble, Rochester Institute of Technology
Social Program Chair: Cathy Cerosaletti, Eastman Kodak Company
Susan Stanger, Possible Dreams
Administrative/Design Support: Colleen Desimone, Rochester Institute of Technology
Valerie Hemink, Rochester Institute of Technology

Two important names not on this list are Mark Fairchild and Raja Balasubramanian, both of whom served on the Technical Program Committee and the Rochester-based Organizing Committee.

My heartfelt thanks go out to each and every one of you. I hope that all AIC participants will recognize that everything they see unfold before their eyes this week has been accomplished due to the hard-working volunteer efforts of all these Organizing Committee members over the past four years. Please take note that all the members of the AIC Color 01 Organizing Committee are wearing a yellow name badge. If you have a question about anything, please do not hesitate to ask anyone wearing a yellow badge. If they don't know the answer to your question, they can certainly point you to someone who does.

Now let's discuss some important information that will be very useful to you throughout the week. We have over 260 invited, oral and poster papers filling our daily schedule from 8:30AM to 6PM everyday. In fact on Monday and Wednesday evenings we have two very important author-present poster sessions.

We welcome you to enjoy breakfast at 7:45AM, coffee breaks and lunch from 12 to 1PM right here at the Convention Center. This convenience is offered to you so that we may adhere to our very tight daily time schedule.

Please take notice of the signs placed throughout the Convention Center indicating that each of our coffee breaks and lunches have been sponsored by the many individuals and corporations listed in your Program Book on page 4. The AIC Color 01 Organizing Committee wishes to thank each and every one of our event patrons and sponsors. You will also notice that page 4 lists our Congress Patrons who have given at least $5,000 to support our cause. These patrons are Eastman Kodak Company, RIT Chester F. Carlson Center for Imaging Science, Sun Chemical and Xerox Corporation. Some of these Congress Patrons provided seed money as long as three years ago to get our planning efforts started. Without these Congress Patrons, we would not have been able to do such things as produce our first and final circulars. We owe each of them a debt of gratitude and as our way of showing our thanks and appreciation, we are honoring them with the signs containing their logos that you will see placed throughout this floor in the Convention Center.

This Congress will also feature an Exhibition on Monday and Tuesday from 9AM to 5PM in Highland Rooms AKBJCH. You have a listing of all the Exhibitors and their booths in your tote bags. Please find the time to visit these booths on Monday and Tuesday.

Next we have a Message Board out by the Registration area. If someone needs to contact you in case of an emergency, we have a phone specifically for this purpose in the Registration area. The phone number is 716-454-7607. Please give this number to your loved ones and your work place. We will post all messages received on the Message Board, so please check it every day.

Now it is time to call your attention to the Social Program on page 3 in your Program Book. We have activities planned for companions during the day and for all participants during the evenings. It is not too late to sign up for many of these activities. I would especially like to encourage you to attend the Wednesday excursion to the Genesee Country Village and Museum to visit 57 buildings restored to their original condition. Also please don't miss the AIC Judd Award banquet on Thursday evening. This promises to be a special evening with delicious food, wonderful entertainment for your dancing pleasure and an open bar. I must also call your attention to a new tour we are offering on Wednesday evening. It is our Horses on Parade tour, which is a community art project sponsored by the Empire Brewing Company. Chicago had its cows, Toronto its moose, Cincinnati its pigs and now Rochester now has its horses. They just arrived in May and they will be sold & auctioned off in September so timing could not have been more perfect. This tour will allow you to see approximately 40 of the 159 horses on parade in the Rochester area. This is a very special art project that promises to be a very colorful experience. This tour will also include dinner. You can sign up for it outside at the Registration Tables.

I hope all of you have had a chance to see our poster. It was beautifully designed by a group of artists, Lorraine Wright, Jenni Day, Jeong-Jae Kim and Kathleen Schaefer as part of a design class project at RIT. We would like each of you to go home with your own poster. Please stop by the MailBoxes Etc booth today at the Exhibition to pick up your poster. For your convenience, you will also be able to purchase a mailing tube and have your poster sent home so you don't have to worry about carrying it around and damaging it.

Now I would like to get into the Technical part of our program. It features two key elements, which are unprecedented in AIC Congress history. The first is student awards for the best oral paper. This will become an AIC Congress tradition. AIC President Professor Ikeda, who wanted to honor students for their excellence in color, inspired the establishment of these student awards. The second is 12 symposia featuring over 30 invited speakers as well as many contributed paper authors with presentations pertinent to the symposia topics. This is the largest number of organized symposia topics ever to be featured at an AIC Congress.

I will close my opening remarks with a quote from Thomas Kinkade. "The color within us can color the world around us." If our Organizing Committee has been successful this week, you will all leave Rochester feeling that we have colored your world with new knowledge and memorable experiences that you will treasure forever. Now it is my pleasure to introduce you to Dr. Allan Rodrigues, our Technical Program Committee Chair. He will provide you with more insight into what the week has in store for you regarding the technical portion of this 9th AIC Congress.

The Future of the Document

Hervé Gallaire

Corporate Senior Vice President and Chief Technology Officer,
Xerox Research and Technology

Abstract

The document—recorded information, structured for comprehension—is one of the two main forms of communication among humans, speech being the other. Over the millennia, the media, format, style and production used for documents have evolved along with the technological capabilities of the societies that create and use them. The evolution has accelerated dramatically over the last 50 years in the digital age.

The document life cycle has traditionally meant the creation, production, distribution and archiving of printed matter, such as books, newspapers and memos. Electronic publishing is changing both the ways in which people and machines interact with documents and the document life cycle itself. The increased affordability and accessibility of color and images in documents, and the ability to produce customized documents on a massive scale have created new document genres. Documents are no longer always the end product, but can now be portals into knowledge collections. This keynote talk will describe the new and evolving possibilities for the document.

Introduction

I am here today to talk about the future of the document. As you all know, color can be a significant attribute of a document, and I expect color will play an important part in the future of the document. Let me begin by describing what a document is. A document is recorded information, structured for human comprehension. This is a very general definition, covering much more than just paper documents, and including video, audio and things yet to come. But I will focus on visual documents, produced to be read, as Xerox is very interested in making reading easier and better.

A Look at the Past

Before discussing the future of the document, it's useful to look at the past and how we arrived at where we are today. The history of document technology can be roughly divided into three eras. The first era, from about 3500 BC to 1450 AD saw the emergence of writing, the invention of alphabets, paper and books, the creation of libraries, and the production of illuminated manuscripts.

The second era, from 1450 to 1950, began with the invention of the printing press and mechanizing the process of producing documents. This was a watershed event in human history and quite possibly the most significant invention of the second millennium, enabling the widespread dissemination of printed information. This era saw continuous improvements to the printing process, including the 3- and 4-color printing, the integration of images through photographic processes and halftones, and the development of lithography and rotary presses.

The third era, beginning in 1950, started with the invention of the office copier, an analog photomechanical device, but also encompasses the development of electronic and digital document technologies, including the non-impact printer, word processors, personal computers, the Internet and the World Wide Web. The transition from one era to the next had an enormous and lasting affect on how people worked and on the role and use of documents in their lives.

The history of documents properly begins with invention of writing. The early forms of writing—cuneiform, hieroglyphics and Chinese ideographs—began with pictures, which evolved into stylized symbols. None of these were alphabets, but they were "standardized" symbols, organized into rows or columns and structured with a layout. Hieroglyphics could be colored, with the colors usually following the conventions of the time, but color was not necessary for reading or interpreting them.

Writing in ancient Egypt is a good illustration of the evolution of writing and scripts. It started with hieroglyphics, which the ancient Egyptians called "God's Words" and considered a gift from their god of writing and knowledge. However, for ease and speed in everyday writing, scribes used hieratic, a cursive script based on hieroglyphics, much like handwriting. Around 700 BC, demotic came into use, based on hieratic, but simpler and standardized. The Egyptian name for demotic translates as "writing for documents." The trend here and everywhere was toward something simple and standard for everyday use. Although none of these were alphabets, one modern theory attributes the origin of the alphabet to the interactions between the Egyptians and the Semitic-speaking peoples to their east.

The invention of the alphabet represented a significant shift in writing. An alphabet is a few dozen symbols, each representing a sound in the language. They are highly stylized symbols, which can come in different forms (fonts, styles and sizes) and sometimes with marks (accents). What's important to an alphabet is the shapes of the symbols, not their color, although color affects the legibility of text.

While documents use alphabets, alphabets don't need color. However, hand-produced, illuminated manuscripts from the Middle Ages are beautiful examples of the use of color in books, combining text with colored illustrations and decorations. The text was typically black, but often some words or characters would be color coded. As beautiful as they were, illuminated manuscripts were more art than technology.

It was the printing press that mechanized the production of document and books. The first printed book, the Gutenberg Bible, was printed in black ink, with space left for the colored letters that were added later by hand. The Mainz Psalter is generally considered to be the first color book, where the colored letters at the start of each sentence were printed mechanically. The new technology was used to produce books that looked like what had come before—new technology applied to the same document genre. Colored designs and illustrations were added later, probably using woodblock printing. This pointed to a difference between the treatment of text and images in documents that mostly persists to this day.

The printing press was a disruptive technology. The next 500 years saw evolutionary more than revolutionary improvements in printing technology: realizing that three colors were sufficient for color reproduction (adding a 4th black color had practical advantages); adding pictures (hand-drawn, engraved and then photographically); mechanizing the reproduction of color and pictures; and developing new processes, such as lithography. These technology advances led to changes in other aspects of the document, evident in distribution channels, copyright laws, new genres such as newspapers and pocket books, and lending libraries. Altogether, the result of these changes was the democratization of the document and the widespread dissemination and sharing of knowledge.

A Glimpse into the Future

The pace of change has only accelerated in the last 50 years of the digital era, and as we look around we can see documents that belong to the old era and its genres (though produced with modern methods) and ones that belong to the new era, such as web pages and MP3 files. These modern documents can be active, enabling a wide range of possibilities for human and machine interactions—from scanning a bar code, to using links in a document to access additional documents, to using a person's image in an electronic document to place a telephone call to them.

This discussion of the future of the document will refer to the traditional document lifecycle and its three basic stages: input, including creation; management and access; and output. But as we will see, not only is the nature of the document changing, but also the document's lifecycle and how we process, view, print and access documents.

Let's start with the creation of documents that enable machine-driven document processing. For these applications, we have developed dataglyphs, machine-readable symbols that can be used to encode virtually any kind of data. For example, dataglyphs can be used to encode image information in applications such as check signature verification. They use a coding method that is robust and allows error recovery in the face of defects in the media.

Figure 1. Dataglyph Example: Check with (a) dataglyph and (b) dataglyph decoded

In another application, dataglyphs can be used to encode the structure of a document, something that is difficult to recover using OCR but that is easy to specify at the time a document is electronically created. Knowing the structure of a document is a powerful and important aid in document exchange and understanding for machines as well as people. Dataglyphs represent a way of creating an "automatic" document, with links to future intelligent documents.

When printing was originally mechanized, it was really the text that was mechanized and for a long time it was difficult to add images to documents. With digital technologies, images are more common in documents, and will become even more prevalent in the future, enabled by the increased access to images driven by inexpensive scanners, digital cameras and the Internet. Users can be demanding when it comes to image quality, but images can be complex and few users have the skills to edit images, especially when they have digital artifacts, are faded or have too much (or too little) contrast.

What's needed is automatic image enhancement, a one-click technology that can analyze an image and automatically adjust its quality as needed. The "as needed" part is important since users don't want the quality of already acceptable images to be adjusted. We expect to see this technology embedded in most document processes in the future. It can be used, for example, to remove digital artifacts from an image or improve the appearance of faded images.

Scanned documents can be a challenge, especially when they contain images and color, which makes them large and increases the demand for network and storage resources. A new way to deal with scanned documents uses mixed raster content technology. Instead of treating a document as a flat object, it separates the document into different dimensions for text, images and graphics, and then adapts the compression of each dimension to the type of content it contains. So the text, where the shape and edges are important, is compressed differently than images, where the color is important. For example, JBIG2 can be used for compressing the text. JBIG2 is a new compression technology, based on extracting the regular shapes of the text symbols that occur in a scanned document. For images, there is JPEG, a familiar image compression method, but now also JPEG 2000, a wavelet-based follow-on that improves on JPEG and adds features that support new ways of interacting with compressed image data.

These technologies enable active documents and new ways of interacting with images and documents on the web. For example, they make it possible to download and obtain a quick view of a document, with a low-quality or low-resolution rendering of the images. The user then has the option to selectively request progressively more data, refining the images to the point where their quality is acceptable for the purpose at hand.

Let me talk now about document management and access. In this area there is Smart Printer technology, which uses the printer and in particular the print server as a document repository, and not just as a transient stage between the user and hardcopy output. Significant documents are usually printed, but what can be done to reduce the amount of paper we need to carry around while still providing access to important documents?

Besides storing a printable form of the document, Smart Printer stores information about the document. It also prints a Smart Coversheet, a one-page form that is human-readable, can be annotated and uses dataglyphs to make it machine-readable also. Instead of carrying around a collection of printed documents, a user can carry around a book of Smart Coversheets, and print out the desired document when it's needed by simply scanning its coversheet—another example of an active document.

As a document repository, Smart Printer can be accessed via the Web or through a paper interface using Smart Coversheets. It can change the way a workgroup works and how its members share knowledge across the documents they print.

So far, I have talked about documents that are either output on paper or viewed on a monitor. But let's consider a radically different kind of medium: electronic reusable paper or gyricons. It uses charged, bichromal balls, with each hemisphere having a different color and a different charge. By manipulating electric fields, one hemisphere or the other of the balls in a flexible plastic sheet can be presented to the viewer and an image of the document created and displayed.

Figure 2. Bichromal balls

One of the first applications for electronic reusable paper is in electronic store displays, available over a range of sizes. But by combining the advantages of electronic displays and paper, this technology opens up new possibilities—flexible e-newspapers, bound multipage e-books, or electronic clipboards to which documents can be downloaded. Beyond that, electronic reusable paper can turn the surface or your desk into an active display—combining the best features of your electronic desktop and your physical desktop.

The future will include changes in document genres as classic and enduring as the book. Book production has migrated over the millennia from scribes writing on papyrus rolls or wax tablets, to monks working in a scriptorium copying and illuminating manuscripts, to modern printing presses making thousands of impressions an hour. With mass production and mass distribution, an estimated 20% of the books produced today end up being scrapped. Digital presses have the potential to change this and the value propositions around books and publishing.

In the last decade, we have seen the emergence of digital presses—high-speed digital printers that have led to new opportunities in publishing and printing books. And now we are seeing book factories that manufacture perfect bound books. In a book factory, a book block (black-and-white or color) goes through a digital production printer. The resulting printed signatures are rotated, perforated and folded, and then merged in an on-line finisher with color covers printed on a digital color printer.

Figure 3: Book Factory: Production Digital Printer with On-line Finisher

While a digital press may not be a replacement for a traditional printing press in all situations, it does create new value propositions: short run books, books on demand, and custom or personalized books. It is interesting to note how we have come full circle here. Book production started with scribes and a one-person technology, totally customized and producing books for hire or on commission. The printing press followed and enabled mass production, democratized but not personalized. With digital presses, we can get back to personalized books and mass customization.

In the modern digital era of document technology, personal computers have been a fixture for the last 20 years. But now we can talk about a post-PC world, populated by information appliances, such as cell phones (always connected, which will make a significant difference), personal data assistants (PDAs) and personal communicators. This is the world in which we will operate and that will increasingly affect how we interact with documents.

One example is Mobile Documents, which will benefit from an information appliance-oriented world. It will allow mobile professionals to access documents, not on a screen, but via a personal information appliance. Using appliances such as cell phones, users will be able to access and navigate through document repositories, and then select documents for faxing, printing or e-mail. Besides having access to the documents themselves, users will also have access to document repository services, such as summarization, searching and notification.

Figure 4: Mobile Documents: Documents Anywhere, Anytime

Conclusion

We have reviewed the journey of the document and its transformations over the ages, and we have talked about its future. In summary, we see a networked document workscape—you will be on the network and so will your documents. The connectivity in this new workscape will provide a positive experience and let you get the most out of what you do and how you work, no matter where you are.

Color imaging: requirements for growth

James C. Stoffel, Eastman Kodak Company

ABSTRACT

Color imaging can be defined as the capture, processing, communication, storage, and output of multicolor pictorial information. So it spans the space from drawings and snapshots, through displays, books, and new media. Throughout history, color imaging has seen an ever-increasing growth in performance and reach owing to various technology breakthroughs. From studies of these historic advances it is possible to derive two key observations. First, we are at a unique position in history with the confluence of maturing information and imaging technologies that will create an explosion of possible color imaging systems and businesses. Second, these observations can help us set priorities among the key technological advances that can most effectively drive the growth of color imaging in the next century.

Keywords: systems, imaging chain, hardcopy, soft display, OLED

1. INTRODUCTION

First, I want to thank the organizers of this AIC Congress. More than 30 years of attention to color is impressive and important, and from my review of the papers and from the list of participating organizations, I can see that this is an excellent Congress. So I especially want to thank Paula [Alessi] for her organization activities and Ikeda-san for his leadership and finally, all of you on the committee for this fine event.

I have three key messages to share with you. They parallel much of what Herve has said. And I trust you will see the parallels in some of the themes. Color and color images have played critical roles in our history, and the picture has always been a key enabler for communications. I first want to emphasize the importance of pictures in enabling growth—of the important role they play in our lives and in our history, and as a signal to where I think we are going. Second, I want to share with you why I believe we are at a critical point in history relative to pictures—color pictures in particular. The third thought that I want to share deals with our responsibilities, and the importance of a conference such as this where we are focused on color and on the important issue of making our technologies useful in the future.

2. THE IMPORTANCE OF PICTURES

Pictures have clearly played a key role in communication—in describing the moments, if you will, in people's lives, whether on the walls of ancient caves or on an early papyrus, color images have really moved on the technology advance phase. One thing we can see is that the reach of pictures has grown geometrically as technology has enabled it. That's because of the impact of pictures, not necessarily the technology. Figure 1 illustrates this growth.

We start with this picture of St. Christopher, a wood block print in book printed wholly from wood blocks dating from about 1423. And in those days you could take a wood block print, which is a relief image, of course, and you could really reach maybe a few hundred people before it became less effective. And in terms of reach, along the y axis, I just want to give some sense of the extent, the numbers of people, to which the message can be shared. The horizontal axis is time, and on top of this temporal axis are a series of developing technology spaces.

In the middle of the 15th century, again as Herve indicated, Gutenberg developed moveable type and we began to get even greater reach from the press in that pieces of type could be reused to create wholly different texts. More books, pamphlets, broadsheets could be printed.

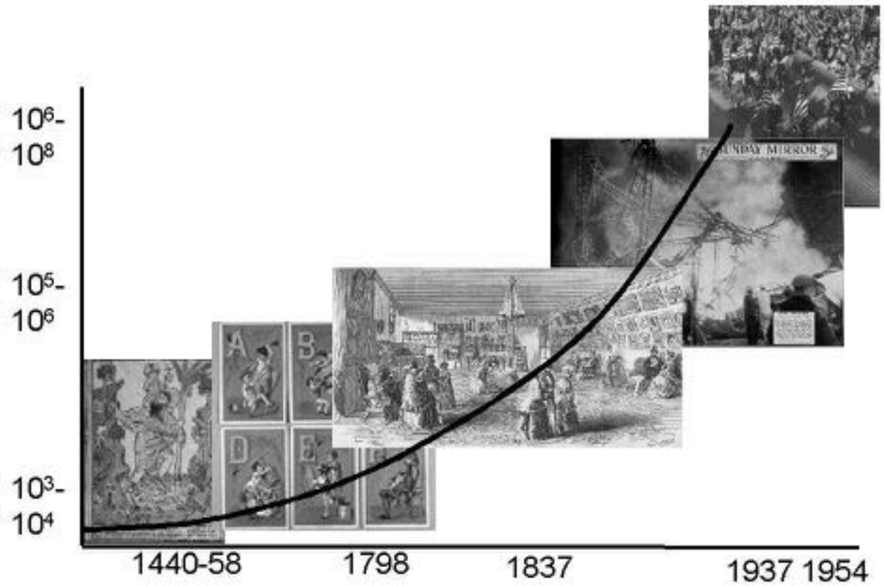


Figure 1. The growth of picture reach through key technological developments

In Germany, Alois Senefelder invented lithography in 1798, providing the next basic step in printing pictures. His planographic technology—based on the repellence of oil and water—furthered the reach of pictures dramatically. The next picture in the sequence is a little different. It's also a European innovation, dating from around 1835. There is a story about a famous scientist who was doing some developing of images and found, by happenstance, with some mercury vapor in his cabinet, that he could develop latent images on his glass plates. Many of you who recognize the scene, the daguerreotype represented a fundamental shift, enabling both easier creation and broader distribution. Daguerre enabled us to capture images very cost effectively. He and his followers enabled a huge expansion in the middle of the 1800s, capturing moments in history in a novel way.

As technology matured, each of these breakthroughs enabled us to reach up that y axis to communicate to more people. The next picture represents another big event in color imaging. It's 1937, and the *Sunday Mirror* ran its first color photographic image—of the Hindenberg disaster. Again, color printing technology extends the reach of a single picture to millions of readers. The final picture is from the first national color telecast in the United States—of the 1954 Rose Parade. Television further expands the reach of pictures to tens and even hundreds of millions of people.

With the Internet, for example, pictures could initially be shared through the ftp, or file transfer protocol. As more picture-friendly browsers like Mosaic began to appear, images greatly magnified the capability of the Internet and the World Wide Web was born and the potential reach and impact of pictures continues to expand.

As desktop color printers approached photo-quality capability, the number of pictures in our lives increased, and the reach of pictures expanded even further—as the files attached to email or downloaded could become prints. In addition, pictures in digital form expanded our ability to use pictures by enabling not only the easy transfer but also the color proofing and writing of the plate. Sophisticated digital proofing technology enables color-managed, 2400-pixel-per-inch proofs that allow commercial printers to not only improve color accuracy but also deliver accurate color proofs to output devices in their customers' offices, thereby streamlining the process and making color printing more ubiquitous. Similarly, the addition of pictures to e-business got more pictures into people's lives and drove sales.

In terms of economics, many of the people have not just tracked the technology, but have really paid attention to its effect. Figure 2 illustrates the effect of pictures in various media.

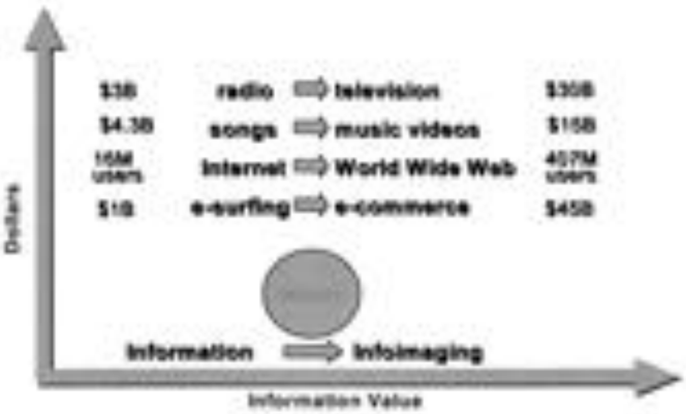


Figure 2. The value pictures bring to media markets

As Figure 2 illustrates, the radio industry is a $3 billion industry. Add pictures, you get television and a $30 billion industry—television. In music, the story is similar, growing from $4 billion for recordings to include a $15 billion music video market. Add pictures to the Internet and you get the World Wide Web, growing from 16 million user in the early '90s to well over 400 million users on the web today, with the advent of easy access, appealing visual content, and a network of compatibility that allows easy communications. The combination of content and the technology to deliver it drove—indeed, exploded in my view—the popularity of this medium. In parallel, what was a billion dollar business in the early days of e-surfing has become a $40 plus billion industry.

So technological changes continue to expand the reach and use of pictures, and pictures are enabling significant economic growth in various communications industries. That's my first message: that pictures make a huge impact in communicating all manner of information in our world, in our business, in our lives.

3. CONFLUENCE OF TECHNOLOGY BREAKTHROUGHS

My second message deals with this unique point in time. I want to use this model (Figure 3) of the imaging chain as a backdrop for this part of the discussion. I want to focus on what I call the technology enablers that today can bring about enormous growth of both hardcopy and electronic communications, a growth unprecedented in the thousands of years of improvements and growth I've described. There's not time to discuss all of them within the scope of this address or even this whole congress. So let me describe just some of these in terms of the potential impact pictures might have on our lives.

Among the impressive things going on around us—that, in fact, many of us actually work on—are several capture technologies. Solid-state sensors are exploding in terms of both cost-for-performance and capability. I've spent a lot of time studying and working on solid-state sensors over many years. But today's CCD technology has yielded astounding performance capability for relatively low-cost digital cameras—35 percent cost-performance improvements year over year. This kind of improvement is enabling digital capture in a variety of forms. CMOS imagers, for example, allow us to get $15 capturing devices almost anywhere, whether they're in our automobiles or out in the Web cam that people have watching their boats out on the harbor. These are incredibly steep cost-performance curves, and the sensors are available now.

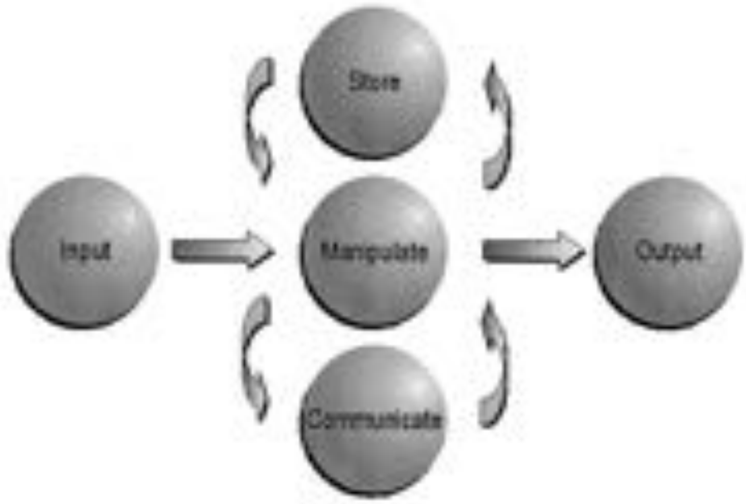


Figure 3. The imaging chain

Silver-halide continues to grow in terms of capability. Many of you who are working in this technology are aware of breakthroughs in two-electron sensitization, which promises higher speed, lower grain films. This work continues the expansion of something that started in the 19th century.

In the medical imaging area where we need not only high resolution but also the ability to detect x-rays as a form of image capture as well, selenium photo conductors have become low-cost. And amorphous silicon thin-film transfer technology is significantly improving the performance of electronic display in market.

The creativity and growing reach of these technologies over the last 2000 years has began to explode in just the last ten. In fact, in areas like storage, the data on cost/performance growth of magneto-optical storage exceeds Moore's law. The capacity we need in this technology and the materials that are associated with the volume get 100 gigabits per square inch of storage. One hundred gigabits on a little small cartridge! We can now store a lifetime of pictures for less than $10 with these kinds of technologies at these levels of cost. Solid-state storage technology, such as Flash memory, is on a similarly steep cost/performance curve. And it's available today in very large quantities.

In processing and manipulation technologies, the story is similar. It should impress you—it does me—that anyone can go to CompUSA and buy 1.7 GHz processor. In fact, some of you may have seen over the weekend, that IBM demonstrated a 200-plus GHz transistor.

So the processing power and the capability to perform such tasks as digital watermarking is readily available. Steganography is no longer constrained in the life of a picture. In the communications technologies, we are also in breakout mode, one that is driven by photonics and RF. We have terabyte fiber optic cables with multiplexers conditioned for dense wavelengths at both ends. We are rolling out 10-Gbit/sec single-fiber/channel cables in many locations. It literally is a huge breakthrough in terms of enabling transducers for communications, and it's available today at a reasonable cost.

Similarly, the RF technologies that most of us carry around with us are extremely powerful. While still fairly awkward in the United States, cell phone technology has advanced dramatically in the European community and in the Far East. Even local area network and personal area network technologies are exploding to give 10, 20, 50, and even 100 Mbit/sec technology, exemplified in the IEEE standards, 802.11 and 802.15. And the cost-effectiveness of these technologies that enables digital pictures, whether you're going to store them, process them, or send them someplace, makes them readily accessible.

As this congress is focused on output, I want to give you some examples of what I see as a similar explosion in output. In the area of hard copy, it is pretty clear that the offset technology continues to grow and expand in terms of computer-to-plate and computer-to-press technologies. Silver halide and photo-thermographic output, and digital silver halide combine to provide prints of the more than 85 billion pictures that consumers shoot a year. Thermal dye transfer and dye sublimation technologies continue to grow, such as the SWOP color-enabled thermal dye transfer proofing technology that offers 2400 plus pixels per inch that I spoke of a few minutes ago.

Earlier I alluded to the major effect of inkjet technology: it's impressive that for less than $200 you can get an inkjet printer that delivers drop sizes of less than 8 picoliters with low-cost inkjet printheads and large color gamuts at frequencies of 20+ kHz. The capabilities of this technology have simply exploded, and it's on people's desks at home and in the office. In addition, electrophotography continues to grow for print-on-demand applications, also yielding an excellent cost/performance improvement.

Soft display—electronic display—has also exploded. Figure 4 gives some idea of the size and scope of the markets for flat panel display technologies. A lot of credit goes to Sharp, who about 25 years ago brought LCDs to commercial reality in a calculator. Then in the '90s we got color LCD technology on amorphous silicon substrates.

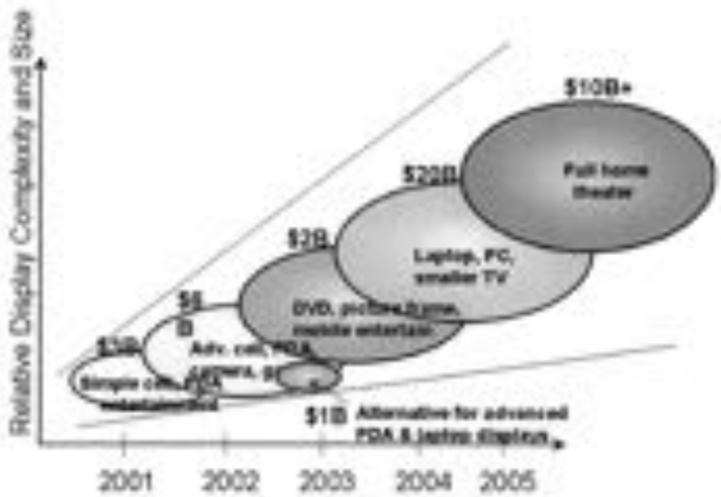


Figure 4. Potential market sizes for flat panel displays

I encourage you to visit the exhibit area and take a look at the organic light-emitting diode (OLED) displays, a potentially disruptive technology. These full-color, active-matrix screens represent an incredible breakthrough in soft display technology. Here is a technology that is simpler than LCD, on a substrate that is as thin as a dime. OLED is a simple combination of unique materials: an electron transport layer on the order of a 0.1 µm and a hole transport layer about the same thickness, combined in an aluminum chelate dopant structure. This simple diode structure can form a very high-performance display technology.

OLED *is* a breakthrough in the flat panel display technology, one that will enable more applications as the technology expands into markets illustrated in Figure 4. Its viewing angle is >170 deg: that's a Lambertian radiator! It's portable, it's thin, it's lightweight. The color materials are self-emissive, requiring no backlight. And obviously, because it's a simple diode structure, on low temperature polysilicon and similar substrates, these devices have the potential to be lower cost to manufacture than LCDs.

Color output is also going to grow in new directions as well. For example, given a regular consumer photograph, a simple portrait, we can use the processing power available to us to create an avatar, in collaboration with a company called Life FX. We're basically taking the digital image and animating it, adding sound and motion so that it represents its subject in new ways.

4. THE NEED FOR SYSTEMS

So there really is an explosion of technologies across the imaging chain. This is not a bunch of PowerPoint slides about what could be done sometime in the future. This is about the stuff that we all do—and do well—designing and assembling imaging systems. And that leads to my third point: while pictures enable so many things in terms of communication and growth, we still confront a huge set of barriers in taking advantage of this potential. There is enormous power in these technologies, and that has a lot of our attention.

Many of us are working on driving down the cost for performance in one or more of these technologies. Not enough of our energy, though, is devoted to enabling the interaction between them. We face critical barriers in building systems—the lack of parallel effort around the overall system engineering. In fact, what I think is holding back these technologies and their potential growth is really the interoperability of the color imaging system. In fact, that's key to a number of the sessions in the technology program for this conference—to help us with those kinds of rules and methods to do the systems engineering, to establish what metadata comprises, to define standards of interoperability, and to achieve true ease on use.

All this technology is coming to bear to help us get the pictures we want and present them the way we want them. But many of the systems we all try to create are simply too hard for most people.

So let me share my final point: we are potentially creating a new Tower of Babel. We have great technologies that we love to demonstrate, that we love to talk about. But unless we can get them to interact easily and consistently, all the great breakthroughs in solid-state physics or in output technologies and the like will really *disable* the imaging business. They *will* disable our growth—technologically and economically. These technologies can be great enablers, but we have a responsibility to devote a significant portion of our energy to making them work together to be effective as imaging systems. I hope you will join me meeting in this challenge.

Citation for 2001 Deane B. Judd - AIC Award

José Luis Caivano
Buenos Aires University and National Council for Research

Since 1973, when Betty Judd proposed to establish an AIC award in memory of her husband, Deane B. Judd, to recognize outstanding work in the field of color science and technology, the International Color Association has been carrying out the process of selection of the recipients for this award every two years. The selection is an arduous procedure that includes nominations presented by AIC members, and analysis of antecedents of the nominees by a Committee mostly composed by previous recipients of the award. Together with the present award, 18 personalities in the field of color have received the gold medal with a portrait of Deane B. Judd that is presented at the AIC quadrennial and midterm meetings. Most of them were single recipients, but in cases of scientists that have worked in close cooperation the award was given jointly. Here is the list to date (in parentheses, the countries where these personalities have lived and developed their work):

1975 Dorothy Nickerson (USA)
1977 William David Wright (Great Britain)
1979 Gunter Wyszecki (Germany, USA, Canada)
1981 Manfred Richter (Germany)
1983 David L. MacAdam (USA)
1985 Leo M. Hurvich, Dorothea Jameson (USA)
1987 Robert W. G. Hunt (Great Britain)
1989 Tarow Indow (Japan, USA)
1991 Hans Vos, Pieter Walraven (The Netherlands)
1993 Yoshinobu Nayatani (Japan)
1995 Heinz Terstiege (Germany)
1997 Anders Hård, Gunnar Tonnquist, Lars Sivik (Sweden)
1999 Fred W. Billmeyer Jr. (USA)
2001 Roberto Daniel Lozano (Argentina)

It is a great pleasure to me to announce Roberto Daniel Lozano as the recipient of the 2001 Judd Award, at this AIC 9th Congress in Rochester, USA. The contributions of Lozano to the measurement of color and appearance in a great variety of industrial applications, as well as the huge efforts he has made to spread the understanding of the fascinating problems related to color in Latin-American countries, make him wholly deserving of the highest honor bestowed by the AIC.

ROBERTO DANIEL LOZANO: RECIPIENT OF THE 2001 JUDD AWARD

Roberto Daniel Lozano was founder and president of the Argentine Color Group, where he is now an honorary member. He has also been chairman of the Argentine Association on Illumination, president and vice-president of its Buenos Aires branch, and chairman of its Committee on Colorimetry. Also, chairman of the Committee on Colorimetry of the Argentine Institute for Standardization, and member of the Board of Directors of the Argentine National Committee on Illumination. With regard to the organization of meetings, he was chairman of the Organizing Committees of Color 89, the 6th Congress of the AIC, the 3rd Meeting of the Argentine Association on Illumination, and the 1st National Symposium on Color in Food, as well as secretary of the Organizing Committee of the 1st National Meeting on Optics, and member of the Organizing Committee of the 2nd National Meeting on Optics.

With regard to international activities, Lozano served as expert of the United Nations, invited member of the Consulting Committee on Radiometry and Photometry of the International Office of Weights and Measures, member of the Editorial Board of the journals *Color Research and Application* and *Optica Pura y Aplicada*, invited lecturer at the Venezuelan Institute of Scientific Research, and the National Institute of Optics in Puebla, Mexico. At the AIC, in addition to having organized the 6th Congress, he was a member of the Executive Committee, and member of the Advisory Committee of the 8th Congress, Kyoto 1997. At the CIE, Lozano has been chairman of the Technical Committee 2-20: Visual Gloss, consultant and Argentine delegate in the Technical Committees 1.2: Photometry and Radiometry, 1.3: Colorimetry, 1.4: Vision, and 1.6: Visual Signaling, consultant of the Technical Committees 2.2: Detectors, and 2.3: Materials, Argentine delegate in the Division 2: Physical Measurement of Light and Radiation, and consultant of the Divisions 1: Vision and Color, and 4: Lighting and Signaling for Transport.

Since 1967, Lozano has been teaching several courses on optics, color measurement and color technology in different companies and institutions in Argentina, Brazil, and Uruguay; among them: National Institute of Technology, University of Tucumán, Argentine Association of Illumination, Argentine Association of Textile Chemists and Colorists, Association of Technicians and Engineers of the Pulp and Paper Industry, Center of Art and Communication, Argentine Color Group, University of Rosario, University of Northeast at Corrientes, and University of Litoral at Santa Fe. At Buenos Aires University, he was a professor in the Mathematics Department of the School of Engineering. He was also a lecturer in the Technological Institute of Buenos Aires, the State University of Sao Paulo, Brazil, the Ceramic Research Institute at Blumenau, Brazil, the School of Engineering at the State University of Uruguay, and the State University of Campinas, Brazil. Lozano has directed six Master thesis and one Doctoral thesis at Buenos Aires University.

In 1956 Lozano began to work in the industry. During 1960-1963 he was in charge of the laboratory for measurement of cosmic rays at the Ellsworth Scientific Station in Antarctica. From 1963 until his retirement, he worked at the National Institute of Industrial Technology, as head of the Optical Division of the Physics Department —dealing with radiometry, photometry, colorimetry, optical instrumentation, and physical optics—, and head of the Industrial Physics Sector —which includes acoustics, materials, and optics. Simultaneously, from 1989 to 2000, he was a consultant in his own company, Color Consulting International SRL, and since 2000 he is a consultant in his new company, Tecnologia del Color SA.

The list of Lozano's publications includes over 180 items, among books, papers, technical reports, translations, and compilations:

Books:

1968 *Color. Measurement of color* (in Spanish), edited by CIME, INTI, Buenos Aires, 110 pp.
1970 *Bibliography on color and vision*, Publ. INTI 4, Buenos Aires, 25 pp.
1978 *Color and its measurement* (in Spanish), Américalee, Buenos Aires, 640 pp.

A selection of papers in English:

1967 "The additivity of large-field colour matching", with D.Palmer, *Vision Research* 7 (9).
1968-69 "Large-field color matching and adaptation", with D.Palmer, *J.Opt.Soc.Am.* 58 (12), and 59 (4).
1972 "A transimpedance circuit for use with selenium photocells", with R.Garcia & E.Martinez, *J.Phys.E.Sci.Inst.* 5 (8).
1973 "The measurement of color of retro-reflective adhesive sheets used in road signs", with J.Prià, *Proc.Conf.Int. Photometry & Colorimetry*, Varna.
— "Radiometry, photometry and colorimetry at INTI", with J.Prià, *Proc.Conf.Int. Photometry & Colorimetry*, Varna.
1975 "The problem of retro-reflective materials", *Die Farbe* 24 (1/6).
1976 "Measurement standards for retro-reflective materials used in road signs", *Lighting Res.& Tech.* 8 (2).
— "Evaluation of different color difference formulae by means of an experiment on color scaling. Preliminary report", *Color Res.Appl.* 2 (1).
1977 "Measurement of errors in an automatic registring spectrophotometer", with O.Nejamis, *Proc 3rd Session AIC*, Troy.
— "A psychophysical study of whiteness", with M.Matticllo, *Die Farbe* 26 (1/2).
1980 "Comparison of radiative-transfer theory for practical colorant formulation", *Die Farbe* 28 (3/6).
— "Evaluation of color difference formulae by means of an experiment on color scaling. Final report" *Col.Res.Appl.* 5 (1).
— "The visibility, colour and measurement requirements of road signs", *Lighting Res.& Tech.* 12 (4).
1981 "An algorithm to speed the search of correlated color temperature", *Color Res.& Appl.* 6 (4).
— "Psychophysical evaluation of gloss of paper samples", with D.Jungman, *Proc.4th Session AIC*, Berlin.
1983 "Performance of a 7.5m moving arm gonio-photometer for measuring the spatial distribution of light of luminaires", with C.Carabat & E.Yasin, *Proc. 20th Session CIE*, Amsterdam.
— "Lamp total flux measured with a spiral-gonio-photometer. Evaluation of theoretical and experimental errors", with J.Cogno & E.Etchechoury, *Proc.20th Session CIE*, Amsterdam.
1984 "Measurement of color on foods: Some experiences at INTI, Buenos Aires", with D.Jungman & C.Melcón, *Proc.ASTM Symp. Evaluation of Appearance: Methods and Techniques*, Montreal.
1985 "Color as an indication of maturity of salted anchovy", with C.Melcón, J.Sanchez & R.Trucco, *Die Farbe* 31 (1/3).
— "Kinetics of deteriorative reactions in model food system of high water activity", with C.Petriella, S.Resnik & J.Chirife, *J.Food Sci.* 50 (3).
— "Research on color in food: Non-enzymatic browning", with M.Buera & C.Petriella, *Proc.5th Session AIC*, Montecarlo.
— "Psychophysical evaluation of gloss of painted samples", with D.Jungman, *Proc.5th Session AIC*, Montecarlo.
— "Measurement of Granny Smith apple color and development of a color test chart", with C.Melcon, *Proc. 5th Ses.AIC.*
1986 "A new gonio-photometer for measuring the spatial distribution of light of luminaires", with C.Carabat & E.Yasin, *Journal of the CIE* 5 (2).
— "Color of green apples", with C.Melcón, *Die Farbe* 32/33 (1).
— "Gloss of paper and paints", with D.Jungman, *Die Farbe* 32/33 (2).

— "Definition of color in the non-enzymatic browning process", with M.Buera & C.Petriella, *Die Farbe* 32/33 (2).
— "Effect of potassium sorbate on color changes in glucose-glycine system of high water activity", with M.Buera, J.Chirife & S.Resnik, *Lebensmitt Wiss u.Tech.* 19.
— "Non-enzymatic browning in liquid model systems of high water activity. 1. Kinetics of color changes due to caramelization of various single sugars", with M.Buera, J.Chirife & S.Resnik, *J.Food Science* 52 (4).
— "Non-enzymatic browning in liquid model systems of high water activity. 2. Kinetics of color changes due to reaction between glucose and glycine peptides", with M.Buera, J.Chirife & S.Resnik, *J.Food Science* 52 (4).
1987 "Solute effects at high water activity on non-enzymatic browning of glucose-lysine solutions", with C.Petriella, J.Chirife & S.Resnik, *J.Food Science* 53 (3).
1988 "Correlation between induction time and rate of browning in heated model solutions of glucose and lysine", with C.Petriella, J.Chirife & S.Resnik, *J. Food Science & Tech.* 23.
1989 "Color in foods", invited lecture, *Proc.6th Session AIC*, Buenos Aires.
— "General purpose non-combinatorial software for color reproduction", with J.Conno & J.Cogno, *Proc.6th Session AIC.*
— "Review on color in foods", invited lecture, CSIR, Pretoria, South Africa.
— "Photometric appearance of materials: Physical vs. psycho physical measurements. Are we measuring what we see?", invited lecture, National Association on Illumination, Pretoria, South Africa.
1997 "Color of teeth", *Proc.8th Session AIC*, Kyoto.

Papers in Portuguese:
1995 "Some experiences on color formulation in the paint industry", *Proc.4th Congr.Int.Dyes*, Sao Paulo, Brazil.
1998 "A method to measure color of teeth", 18th Sao Paulo Int.Dental Meeting, Sao Paulo, Brazil.
— "Improvements in the measurement of color of teeth", in Futura, Asoc.Paulista Cirurgiões Dentistas, Sao Paulo, Brazil.

A selection of papers in Spanish:
1968 "Vision and color", *Luminotecnia* 3 (2).
1969 "An artificial daylight for color matching", *Luminotecnia* 4 (1). — "Errors in photometry", *Luminotecnia* 4 (2).
1970 "Photometry of discharge lamps", *Luminotecnia* 5 (2).
— "Measurement of barrier layer photocells", with R.Garcia & A.Rubinstein, *Acta Cientifica* 3 (2).
1972 "Technical agreements of the CIE", *Luminotecnia* 7 (1).
— "A method to evaluate chromatic quality of light sources", *Luminotecnia* 7 (2).
— "The 17th Session of the CIE", *Luminotecnia* 7 (2) and (3/4).
1973-74 "CIE news (I-II-III-IV)", *Luminotecnia* 8 (1/2), (3), (4). *Luminotecnia* 9 (1).
1974 "Study on different photometric heads. I-Precision", with J.Priñ & E.Yasán, *Opt.Pura & Apl.* 7 (1).
— "Study on different photometric heads. II-Sensitivity", with M.Mattiello, *Opt.Pura & Apl.* 7 (1).
— "Retro-reflective sheets used in road signaling and the problems of their measurement. Part I", *Luminotecnia* 9 (1/2).
— "Analysis of the Argentine Standard IRAM 10033: Warning signs-adhesive reflective sheets", *Tech.Rep. INTI.*
— "Technical Report on Public Lighting in roads and motorways", *Tech.Rep. INTI.*
1975 "Whiteness estimation", with M.Mattiello, *Proc.61th Meeting Argentine Physics Assoc.*, Buenos Aires.
— "The new definition of the SI fundamental photometric unity", *Proc.62th Meeting Argentine Physics Assoc.*, Rosario.
— "The new CIE color-difference formulae observed through a psychophysical experiment", *Proc.62th Meet.Arg.Phys.As.*
1976 "Retro-reflective sheets used in road signaling and the problems of their measurement. Part II: Comparison between different standards and a proposal of a simple and economic visual method of control", *Luminotecnia* 10 (1/2).
— "The new definition of the photometric unit", *Luminotecnia* 10 (1/2).
1977 "CIE news (V-VI)", *Luminotecnia* 11 (1/2) and (3/4).
— "The problem of whiteness measurements in the paper industry", *Proc.1st Tech.Congress Cellulose and Paper*, Bs.As.
— "Report on road signs setting in the Province of Buenos Aires", with D.Roig, *Luminotecnia* 11 (1/2).
— "Measurement of color in tomato", *Proc.Symp. Argentina Producer and Exporter*, CITEF, INTI, Mendoza.
— "Illumination: A forgotten subject -Color in the industrial process", *Proc.Symp.Arg.Producer and Exporter*, Mendoza.
1978 "CIE news (VII-VIII)", *Luminotecnia* 12 (1/2) and (3/4).
— "Color rendering evaluation method for light sources used in color TV", *Luminotecnia* 12 (1/2).
— "Color in meat products: an important argument for selling", *2nd Symp.Sci.& Tech.Meat Products*, Buenos Aires.
1979 "Measurement of transmittance in glass: Criteria to follow for window glasses", *Proc.Symp.2nd Nat.Tech. Convention Glass and Manufactures*, Buenos Aires.
— "Color differences", *Inv.& Ciencia (Scientific American)* 39.

1980 "The new definition of the candela", *Acta Metrológica* 2.

— "Standard IRAM 10033 and the color and photometric requirements for retro-reflective materials used in signaling", *Proc.4th Argentine Ill.Eng.Meeting*, Tucumán.

— "Almost twenty years of illumination engineering at INTI", *Proc.4th Argentine Ill.Eng.Meeting*, Tucumán.

— "Psychophysical evaluation of gloss", with D.Jungman, *Proc.4th Argentine Ill.Eng.Meeting*, Tucumán.

— "Report on the activities of the Optical Division of INTI", *Proc.Nat.Meeting Optics*, Bariloche.

— "Measurement of color of corned-beef", with C.Melcón & D.Jungman, *Proc.3rd Nat.Symp.Science & Tech.Meat Products*, Buenos Aires.

1981 "Photometric measurements of retro-reflective and catadioptric materials", *Luminotecnia* 15.

1982 "Kinetics of color grow by non-enzymatic browning in liquid model systems", with C.Petriella, S.Resnik & J.Chirife, *Proc.Symp.Color in Food*, INTI-CIC-GAC, Buenos Aires.

— "Need of an objective color measurement in foodstuffs and a summary of what has been done in this sense at INTI", *Proc.Symp Color in Food*, INTI-CIC-GAC, Buenos Aires.

— "Gonio-photometer to measure the spatial light distribution of luminaires: A developement with single characteristics in Argentina", with C.Cazabat, J.Mollier & E.Yasin, *Proc.1st Tech.INTI Meeting*, Buenos Aires.

— "Measurement of gloss", with D.Jungman & C.Melcón, *Proc.1st Tech.INTI Meeting*, Buenos Aires.

— "Whiteness measurement", *Proc.1st Tech.INTI Meeting*, Buenos Aires.

— "The Optical Division of the Physics Department. Genesis, actual situation, perspectives", *Proc.1st Tech.INTI Meeting*.

— "Measurement of color in food at the Optical Division", with D.Jungman & C.Melcón, *Proc.1st Tech.INTI Meeting*.

— "The retro-reflective sheets used in road signaling. A job of the Optical Division which have national and international acknowledgment", with J.Cogno, E.Etchechoury, D.Jungman, J.Priú & D.Roig, *Proc.1st Tech.INTI Meeting*.

— "Participation in the work of international organizations, congresses and scientific meetings", *Proc.1st Tech.INTI Meet.*

1983 "Measurement of luminous flux by means of an spiral-gonio-photometer", with J.Cogno & E.Etchechoury, *Proc.Nat. Physics Meeting*, Tucumán.

1984 "Non-enzymatic browning in liquid model systems of high water content, having hexoses and L-lysin", with C.Petriella, S.Resnik & J.Chirife, *Proc.2nd Symp.Color in Food*, Buenos Aires.

— "Color of Yerba Mate (Ilex Paraguariensis): Measurement of its variation during storage process", with G.Kanzig & C.Melcón, *Proc.2nd Symp.Color in Food*, Buenos Aires.

— "Comparative study of the reactivity of different sugars in front of non-enzymatic browning reactions for model systems with high water activity", with M.Buera, J.Chirife & S.Resnik, *Proc.2nd Symp.Color in Food*, Buenos Aires.

— "Two years after the 1st Symposium. Present situation & perspectives at INTI", *Proc.2nd Symp.Color in Food*, Bs As.

— "Technological policy at INTI: Some thoughts on its implementation", *Proc.2nd Tech.INTI Meeting*, Buenos Aires.

— "Some ideas on a technological policy for medium and small industries", *Proc.2nd Tech.INTI Meeting*, Buenos Aires.

— "Color in food: a very important subject in the activities of the Optical Division", *Proc.2nd Tech.INTI Meeting*, Bs As.

— "Study on signaling carried out in the CIE Div.6, activities", *Proc.Symp. Argentine Nat.Ill.Committee*, Buenos Aires.

— "Color: physical, psychological or psychophysical subject? (I-II)", *Color & Textura* 17 and 18.

— "Color and memory. Reflections on the subject", *Noticolor* 1 (5).

1985 "Psychophysical evaluation of gloss. I-Test and election of method", with D.Jungman, *Opt.Pura & Apl.* 18 (1).

— "Psychophysical evaluation of gloss. II-Paper samples", with D.Jungman, *Opt.Pura & Apl.* 18 (1).

— "Color and light", *Color y Textura* 20. — "Color and psychology", *Color y Textura* 21.

— "Color of mirrors", *Noticolor* 2 (9). — "Color and human behavior", *Noticolor* 2 (10).

1986 "Psychophysical evaluation of gloss. III-Painted samples", with D.Jungman, *Opt.Pura & Apl.* 19 (2).

— "Color and personality", *Noticolor* 3 (4).

1987 "Construction of a color chart for Granny Smith apple", with C.Melcón, *Tech.Rep.INTI.*

1988 "Critical review of use of color difference formulae", *Tech.Rep.INTI.*

1989 "Color in food", invited lecture, 1st National Meeting on Color, Logroño, Spain.

1991 "CAD (Computer Aided Design) system in textiles", invited lecture, Argentine Textile Chem.Col., Buenos Aires.

1992 "Color: essential aspect of the product finish. Technical and artistic view", invited lect., *Proc.ArgenColor 92*, Bs As.

1994 "Primary and secondary colors", *Proc.ArgenColor 94*, La Plata.

— "Munsell and OSA-UCS systems", *Proc.ArgenColor 94*, La Plata.

1996 "Mathematical and physical aspects of color", *Proc.ArgenColor 96*, Huerta Grande, Córdoba.

1998 "Measurement of color of teeth", *Proc.ArgenColor 98*, Oberá. Paper awarded the 1st prize to scientific work.

2000 "Quality control service with color standards in Argentina and the Mercosur", *Proc.ArgenColor 2000*, Mendoza.

Color Souvenirs

AIC 2001 Award "Deane B.Judd" Address

Roberto Daniel Lozano – Private Consultant – H.Irigoyen 2472, 1602 Florida (BA), Argentina

It took me some time to believe that I was going to receive this Award. Probably, some of you too. That was one of the reasons why I shall try to summarize what was done since my start in my colorful life.

So I went back in my own story, and I have found some details which I think could be of your interest and, in some way could explain why I am here tonight.

The history began in the middle of the 60's. At that time I was at INTI, a Technology Institute dedicated to Industry, in its Physics Department where about 15 people worked in Mechanics, Electricity, Thermometry and Photometry. Within my duties I had very different tasks. Originally, I had to do electronic maintenance, but slowly my job was oriented to make radiation measurements, mainly photometry and thermometry.

A few months after my start at INTI, in 1963, a man, from a textile industry, come asking me to measure color differences in MacAdam units, which, for me, was completely unknown, in that moment, the head of the Department, Prof. Steinberg, gave me a copy of the NBS Circular 478 on Colorimetry, written by D.B.Judd. That was my first contact with color. And that put a seed on me which last till today.

Let me tell you that that publication was almost cryptic to me, I could hardly understand what it means, particularly those strange functions called *"The 1931 ICI standard observer, Tristimulus values of equal-energy spectrum"*. I reckon that it was the start of a curiosity which never left my spirit and gave me the push along more than 30 years to know what really was that thing called color.

Later on, Steinberg gave me Ives Le Grand's book *Optic Physiologique -Lumiere et Couleur-*, which part dedicated to Light and Color I reed several times.

Then, a entirely new world was discovered, showing the marvelous complexity of the human been and its functionality, and color was the bait which I never was able to release. As much as one dig on the problem much more has to be learn. Therefore, one thing it is clear now to me: A lifetime is too short to know something about this subject.

In 1965, I got a UN fellowship to get training at the NPL in England for six months. The purpose was to learn measurement techniques in photometry and thermometry. I convinced Prof. Steinberg that I was capable to take advantage of my stay at the NPL and try to do some research on color, therefore I rushed my learning on thermometry where I worked among others with Dr. Terry Quinn, who actually is the Director of the BIPM, and photometry which was under the coverage of the Optical Division of the NPL, headed by Brian Crawford and where worked Frank Clarke and David Palmer.

As you may guess, at that time, I had not any real experience doing scientific research in the proper way that most people does. Instead, I had a high self confidence, audacity and I was very tenacious with some kind of scientific mind, and most than everything determination to follow things without thinking too much about the difficulties or possibilities. In other words, I was young and idealist. So I went to Dr. Crawford office and I proposed to do research on *the relation of mass of color with color differences*.

In that opportunity Dr. Crawford teach me one of the most important lessons I ever had: He, the very same of the Stiles-Crawford effect, simply answered me that he *"did not know about that"*, and that it would be better to ask David MacAdam, what he thought about my research proposal. I felt both things at the same time, upset and flattered. One of my references, a kind of scientific hero, was going to read my proposal...

Everything was beyond any expectation, myself, an unknown fellow from the far South America, proposed something which was going to be analyzed by one of the most important people on color in the entire world!

In fact, it was analyzed and rejected, the reason was financial as Crawford said, there was no budget available for it, but, I was very lucky, he suggested me to join the research that David Palmer was carrying on *the additivity of large field color matching* using the Stiles' NPL trichromator. Instantaneously I accepted and requested and got an extension of 3 months of the fellowship, allowing me to work for six months with David in the project.

In this moment I have to repeat what I said last year about David Palmer. He was a special person, a wonderful human being, a dedicated scientist which treat me as an equal, as a colleague, with respect and consideration, but over everything, with kindness. He was almost of the same age than me, only one year older, but he had studied with William D. Wright at the Imperial College and I had no university degree at that time. There was huge differences between us, in formation and information, but he never make it noticeable.

Let me tell you one anecdote which will describe properly the kind of person he was. Later on, when the work done was ready to be published, I made a draft naming the authors with his name in the first place. He corrected it and put my name in the first place and, justifying himself, he simply said that authors names should be in alphabetic order.

At least, in my country, many scientist argue between themselves about who had the right, or not, to be in the first place. He had all the right to be in first place, he designed and directed the research project, my collaboration was to follow his indications making sporadic comments or suggestions, but he just put the names in alphabetic order. The importance is not the envelope but the content.

That experience was one the most important I ever had. Not only because I did basic research on color, but also teach me to be conscious of my limitations and ignorance on the subject. But, over all, gave me a lesson which marked my entire life.

In 1966 I returned to Argentina and started to work properly on color. I began measuring color with a filter tristimulus colorimeter and also to do color measurements for glasses used for soda bottles using its spectral transmittance. At the same time I dedicated part of my time to learn special techniques of photometry and radiometry, which helped to know more about the basic physical properties of the visual phenomena known as color.

In 1969, I began my life together with Noemi, my wife, whose love, support and understanding, sharing all difficulties and the most marvelous moments of my life, allowing me, to be here tonight. It is my pleasure to share this prize with her and, for extension, to our children.

Also, at the same time I started to write the book on color measurement which was published after 10 years of work, and, still now, more than 20 years from its publication in 1978 still is, as far as I know, the only one on Color Measurement, written in Spanish.

In 1971 I had the opportunity to go to Europe again, this time to the PTB, in Braunschweig, Germany, but my goal was mainly to stay at the BAM in Berlin, where I knew that the group on Farbmetrik – Color Metrics- was one of the most important in the world. Was then when I meet for first time Prof. Heinz Terstiege and began our friendship.

This second stay in Europe was also very important in my formation as a scientist. I had chosen that year because there was programmed two events which were very important. One was the meeting at Driebergen, Holland, the Helmholz Symposium on Color Metrics and the other was the 17th Session of the CIE meeting at Barcelona, Spain. I also took time to go to London, at the NPL, to help Pat Trezona with her research on additivity of the large field color matching using four primaries, acting as one of the observers who has measured his own tristimulus functions in the Stile's trichromator.

The Color Metrics Symposia was held in a small town in Holland, and there I meet the most important people in color all over the world, particularly in color measurement. Among others were Bartleson, Billmeyer, Bouman, Boynton, Brockes, Clarke, Coates, Friele, Ganz, Guth, Hård, Hunt, Richard Hunter, Indow, Jaeckel, Kowaliski, MacAdam, MacDonald, MacLaren, Malkin, Nayatani, Nickerson, Nimeroff, Pointer, Reilly, Manfred and Klaus Richter, Saltzman, Schanda, Simon, Stiles, Terstiege, Tonquist, Vos, Walraven, Wright and Wyszecki. Only Judd was missed, which was already very sick in that moment and died a few months later.

The sessions last 3 days including night discussions. It was so rich and enlightening that what I learnt in those 72 hours last till today. An unforgettable meeting which was never repeated. Many of the participants have passed away and are not longer with us. They were the experts of the world and allowed me to be able to consult them since then.

The CIE meeting had other significance, it was, so far as I know, the first time that an argentine participant was present in such meetings. I took part of the Divisions meetings, which all the important things were discussed. Mainly in the E-1.3 Colorimetry and E-2.2 Materials, and commit myself to do some research on whiteness evaluation within the activities of the dedicated Subcommittee.

That was the first intervention in the CIE activities, it was followed by the participation on the AIC meetings, then it was York, England, 1973; London, 1975; Troy, N.Y., 1977; Kyoto, Japan, 1979; Berlin, 1981; Amsterdam, 1983; Montecarlo, 1985, Venice, 1987 and Buenos Aires, 1989.

Different work was done within the activities of the CIE, I took part in different Subcommittees with small pieces of work, whiteness, color differences, color of signals, visual gloss, retroreflective materials, among others, always taking the responsibility of doing some research and doing it. People in the committees learnt that my commitment meant that the job was going to be done. Now, I think that, probably, this was one of the main things that the people who has to evaluate my background considered to give me this Prize.

Let me tell you now how the Argentine Color Group was created. In 1979, just prior the Kyoto CIE Session, a Symposium on Color Appearance was organized. In that meeting I asked to the AIC President, C. J. Bartleson which things should I do to hold an AIC Session in Buenos Aires. He simply stated, *"organize a national association and ask for it"*, and that was all. Therefore, in September 1980 I organized a constituent meeting of the Grupo Argentino del Color –GAC- with 50 founders members. Having in mind that we could ask to be host of the 6th Session, because the 4th was already programmed for 1981 in Berlin and the French Committee have requested the priority for 1985.

The GAC asked in Berlin to hold the Session in 1989, and was confirmed in Montecarlo in 1985. Now it seems easy, *"a piece of cake"*. It was not. In 1979 we were in the middle of the most terrible dictatorship ever exist in our country. It was difficult to plan things for a period of one month, almost impossible for a year, to plan things for a period of eight years was simply mad. In 1982 we had the Malvinas-Falkland war. At the end of 1983 democracy was restored in our country, inflation beyond imagination, military coups, and any kind of instability that alter any normal human being. In such mess, we were trying to organize the AIC Session in Buenos Aires.

Heinz was the AIC President at that moment, and I am rather certain that he was not too convinced that we could do it. All the way, he kept an eye on our steps. I still remember that I had to present a report to him personally every year or so, before the meeting. To spread the participation of people from other latinoamerican countries I gave lectures and courses in Brazil, Chile, Mexico, Uruguay and Venezuela.

The AIC Session in Buenos Aires was a success, it would be impossible if were organized only just by myself. There were a lot of unknown people helping which made it possible. That was an achievement that many argentines did. As a testimony of that, in the following AIC meetings, different people from GAC have assisted and tonight some of them are with us, and the actual President, Arq. Caivano had presented this Award. Now Brazil and Bolivia are members of the AIC and probably soon will also join Uruguay, Paraguay, Perú and Chile.

Before finishing let me explain one thing which is very important to understand how I grew up all these years.

INTI, where I worked till December, last year, is a special place were there are Research and Services Centers dedicated to different industries, such as Electronics, Machine Tools, Leather, Food, Paper, Plastics, Milk, Packaging, Industrial Design, Buildings, Rubber, and more general laboratories as Physics, Chemistry, Computer Science, Energy and Materials. In them, worked very qualified persons in different branches of technology.

Surrounded and supported by them I was able to consider the color as a complex technology problem and the discussion with specialists gave an insight which very few people have the opportunity to access. Many problems were under my scope: Honey, tomatoes, apples, apple juice, forest, human hair, paints, leather, plastics, metals, light signals, retroreflective materials, glass, porcelain, human teeth, pigments, paper, gloss, whiteness, browning, etc. As Jorge Säbato, who was an argentine scientist dedicated to technology research, said *"basic research is much more simpler than technology research, because in the last you always need a team of specialists to solve any question"*. Their help in each case was most valuable and must be appreciated. I am most thankful to all them.

The end of this talk should be devoted, first to my family, which gave me the necessary love and understanding to be able to dedicate my life to these matters, secondly to the people along the world which helped me with their wisdom, advice and knowledge, first, those who are not any more with us, particularly to Heinz Terstiege, who was programmed to present this award tonight, but sadly is not here in person, but I still feel his presence, an special bond of friendship, helpfulness and kindness, and David Palmer, Brian Crawford, Chuck Reilly, Jürgen Krochmann, Günter Wyszecki and Frank Grum and finally to those who are my good dear old friends, such as Fred Simon, John Hutchings, Ed Cairns, Paul Tannenbaum, Lorenzo Plaza and all my good fellows of the Argentine Color Group.

To all them, and to you, Many Thanks!

Closing Ceremony

Paula J. Alessi
AIC Color 01 General Organizing Committee Chair

We will begin this closing ceremony with the AIC Student Awards. These awards were inspired by Professor Mitsuo Ikeda to honor students for their excellent work in color. We hope theses Student Awards will become an AIC meeting tradition. Two awards will be presented; the Best Student Paper in the area of Science and Technology and the Best Student Paper in the area of Art and Design. The Student Paper Awards Committee Chair was Karen Braun. Our thanks go out to her for establishing a process by which to make this happen for the first time. She arranged for at least three judges to evaluate each student paper for content and presentation style. Our sincere thanks go out to these judges who had the very important task of evaluating these papers. Now it is time to announce the winners. The winner for Best Paper in the area of Science and Technology is Caterina Ripamonte from Derby University for her presentation entitled "Perceptual Transparency". The winner for the Best Paper in the area of Art and Design is Margareta Tillberg from Stockholm University for her presentation entitled "The Russian Avant-Garde and Colour as Worldview". Before we close this Awards Ceremony, let's thank all our students who contributed very high quality papers to this AIC Congress.

Now it is time to share some very important information with you. First, all AIC Color 01 participants will receive the Congress Proceedings in the mail by the end of this year. Second, throughout the week, Lawrence Toplin, an RIT student, has been taking candid digital pictures of all Congress activities. We are going to post these pictures on the web site at www.iscc.org/aic2001. Please visit this site to see if he may have captured a picture of you or your friends. Many thanks to Lawrence for providing us with the opportunity of digitally recording this Congress so that we may keep it as our permanent record and everyone around the world can enjoy and experience what happened here. Third, many of you may have seen the video cameras in the back of the rooms recording the symposia. Since there were so many parallel symposia sessions with invited and contributed speakers, people could not be in two places at one time. So we have decided to produce videotapes of all the symposia in whatever format may be of interest. We owe Ken Pidgeon from the Colour Society of Australia our sincere gratitude for bringing two cameras from Australia so that we can provide this service. Our thanks also go out to Christian Bruncsak, who assisted in the videography. We have not yet produced the videotapes and we are still working out the details of how we can make these tapes available to the AIC color community. So please stay tuned for details on this by checking our web site at www.iscc.org/aic2001.

Now I would like to begin my closing remarks as I began my opening remarks; with an embrace. Only this time it is a farewell embrace. Here is the largest, warmest farewell embrace I can offer you, the AIC Color 01 participants. I'm not good at saying good-byes. So let's just say until we meet again. All week we have been thanking the AIC Color 01 Organizing Committee, but now it is time to thank you, the AIC participants for traveling from your homes around the world to this Rochester Congress. You have made it a success! Thank you to the oral presenters. Thank you to the poster presenters. Thank you to the invited speakers. Thank you to the session chairs and the assistant session chairs. It was your enthusiastic participation that made AIC Color 01 a unique and memorable experience!

I hope everyone is going home with some answers to our five basic theme questions; what is color, what is color for, how does color work, how do we control color and how do we teach color? I hope there has been some cross-fertilization between the science/technology and art/design communities. The one thing that pleased me the most about this Congress was the networking that went on outside the meeting rooms. I saw many people engaged in intense hallway conversations over a pad of paper or a computer. Ultimately, this is what Congresses like these are all about; people exchanging ideas with other people.

I hope you enjoyed meeting your international friends from other AIC countries and met some new international friends that you look forward to meeting at future AIC meetings.

I will close with another quote from the artist, Thomas Kinkade. "If we think of joy as colors in an artist's palette, we can say that giving joy to others actually adds dabs of joy in the form of color to our hearts." On behalf of the AIC Color 01 Organizing Committee, I hope we have added color to your hearts this week. We wish everyone a safe journey home.

aic 2001

What is Color?

"Colours in the Object are nothing but a disposition to reflect this or that sort of rays more copiously than the rest; in the rays they are nothing but their disposition to propogate this or that Motion in the Sensorium, and in the Sensorium they are sensations of those Motions under the forms of Colours."

Isaac Newton

Symposium: What is Color?

Introduction
Hardin, Color experience and the human animal*
Swirnoff, Color's perceptual dimensions*
Werner, Webster, Color vision is form and object vision*
da Pos, On the nature of colours*
Kuehni, Color: what could it be?*
Discussion

Oral Session

Roberson, Davidoff, Davies, Color categories are not universal: new evidence from traditional and western cultures
Tillberg, The Russian avant-garde and colour as worldview
Maund, The pluralist framework for colours

Poster Papers:

Serov, Semantics of color in chromatism

** denotes Invited Paper*

Symposium WHAT IS COLOR?

Coordinator

Paul Green-Armytage Senior Lecturer in the School of Design at Curtin University of Technology, Western Australia. An architect, he has also worked as an exhibition designer and set designer for television. His research interests are in color and other aspects of appearance and the relationships between verbal and visual language. He has participated in many AIC meetings, was a member of the AIC Executive Committee 1990 – 1993, and President of the Colour Society of Australia, 1993 – 1997.

Moderator

C.L. Hardin Emeritus Professor of Philosophy at Syracuse University. For most of his career his interests lay in the history and philosophy of science, but he later became intrigued by color as a way to approach the mind-body problem. He is the author of *Color for Philosophers* and co-editor, with Luisa Maffi, of *Color Categories in Thought and Language*. He greatly enjoys serious cross disciplinary enquiries. For this, he thinks, the field of color offers pleasures that are unsurpassed.

Panelists:

Lois Swirnoff Feltman Professor of Light and Color at Cooper Union for the Advancement of Science and Art in New York City. She is an artist, author and educator. She was a student of Josef Albers at Yale and has taken her investigation of color beyond the two dimensions of painting into the third and fourth dimensions. She regards color as an attribute of dimension as it influences the perception of forms and their placement in space, a theme she explores in her books *Dimensional Color* and *The Color of Cities*.

John Werner Professor in the Department of Ophthalmology and in the Section of Neurobiology, Physiology and Behaviour of the University of California, Davis. He has conducted post doctoral research at the Institute for Perception – TNO in Soesterberg, The Netherlands, and in the Department of Neurophysiology at Freiburg University, Germany. His primary research interest is concerned with the neural basis of color and spatial vision, and their changes across the life span.

Osvaldo da Pos Professor of the Psychology of Perception at the University of Padua, Italy. After graduating in philosophy and biology he worked with Professor Fabio Metelli at the Institute of Experimental Psychology in Padua. He was Director of the Centre for Colours and Art of the University of Padua for many years. His main research interests deal with color constancy, color transparency, color esthetics, and recently with color illusions and some new color effects like fluorescence.

Rolf Kuehni Associate Adjunct Professor of Color Science at North Carolina State University in Raleigh. He graduated in textile chemistry and has worked extensively in industry. He was Vice President at Bayer Corporation responsible for their textile business in the U.S.A. before transferring to DyStar LP from which he retired in 2000. He was editor of *Color Research and Application*, 1987 - 1989, and has written on many aspects of color, the breadth of his knowledge being reflected in his book *Color – An Introduction to Practice and Principles*.

Introduction

Paul Green-Armytage, School of Design, Curtin University of Technology, Western Australia

> I cannot really think of a more fascinating subject of study or one which spans such a wide spectrum of knowledge.
>
> W.D. Wright, 1967

The "fascinating subject", of course, is colour - fascinating partly because it is at the same time both simple and extremely complex. Colour vision is the ultimate in user-friendly systems: just open your eyes and look around. It is only when you try to understand and gain some control over the whole process that things get difficult. Then colour takes on the character of the many-headed Hydra of Greek mythology which grew two new heads for every head that Hercules cut off.

Perhaps it is that 'wide spectrum of knowledge' bit that makes things so difficult. It has been said that the Americans and the British are divided by a common language. For similar reasons, perhaps, an outsider might conclude that people who work with colour are divided by a common subject. We are each dealing with our own bit of knowledge and maybe missing the big picture. We can't see the wood for the trees or, to translate that expression into colour language: some of us are dealing with red, others with orange, others with yellow and so on, but we are missing the rainbow.

Ask an artist, a physicist, or a psychologist to explain what they do and they could tell you at length. But if you ask them to tell you what colour *is* there might be a pause. Perhaps they will dodge the bigger question and tell you what colour is for them: Colour is the medium through which I explore appearances; Colour is what I use to express myself; to communicate ideas; to create pleasing surroundings; to sell products. Or, colour is what I measure: in the light; on surfaces; in recipes for paints; in the response of the nervous system; in people's emotional/behavioural responses. And the heads keep growing. So, is the answer to the question 'what is colour?' a many-headed answer, a different answer depending on your interest, or could there be a single answer that would satisfy everyone? Two thousand years after Aristotle, the philosophers are still arguing.

The aim of the symposium is to give the many-headed Hydra a shake, but not necessarily to cut off any of its heads. The objective is for participants to have gained greater awareness of the different aspects of colour and how they relate, easier communication with colleagues from other disciplines, new insights, deeper understanding, and a greater sense of wonder. The AIC is a rare organisation in that it provides a forum for the different bits of knowledge to come together. At an AIC congress it is possible to get some sense of the rainbow.

The panellists represent a variety of disciplines in art and science. Here we have a wide spectrum of knowledge. Larry Hardin sets the scene with his short keynote lecture *Color Experience and the Human Animal*. This was written well in advance of the Congress and sent to the panellists with the intention that it would, in his words, 'serve as catalyst for discussion about the nature of color by asking what color vision does for the animal that has it'. Hardin posed a number of questions: 'In what sense do different species have color vision? Instinctive response to certain wavelengths of light is very different from having a 'color experience'. It is color experiences that are of chief concern to human beings. Instinctive responses can be acted upon by natural selection. But since experiences are private, how could they ever have been subject to selective pressure? What, then, do color experiences do for the human animal?'

Hardin's essay and the abstracts of papers by the panellists were published on the Congress website. The intention was that this early publication of ideas about the nature of colour would stimulate delegates to participate in the discussion. Also published on the website was a brief bibliography – mainly short essays – which appears below with one addition. Barry Maund's paper was presented at the Congress, and is published in these proceedings.

BIBLIOGRAPHY

Byrne, Alex, and Hilbert, David, R. (1997) *Readings on Color Vol 1: The Philosophy of Color*. MIT, Cambridge, Ma.

Hardin, Clyde L. (1998) 'The Philosophy of Color', in Nassau K. ed. *Color for Science, Art and Technology*. Elsevier. Amsterdam

Helmholtz, Hermann von (1871/1971) 'The Relation of Optics to Painting', in Kahl, Russell ed. *Selected Writings of Hermann von Helmholtz*. Wesleyan University Press, Middletown, Conn.

Humphrey, Nicholas (1998) 'The Privatisation of Sensation', in Heyes, Celia and Huber, Ludwig, eds. *The Evolution of Cognition*. MIT, Cambridge, Ma.
Also available online at: http://www.humphrey.org.uk/

Kuehni, Rolf G. (1989) 'What is Color? A Speculative Essay'. *Color Research and Application*, **14** (4) pp 207 – 210

Maund, Barry (2001) 'A Pluralist Framework for Thinking about Colour' in *Proceedings of AIC Color 01 Rochester*.

Riley, Bridget (1984/1999) 'The Pleasures of Sight', in *The Eye's Mind: Bridget Riley*. Thames and Hudson, London

Tye, M. (2000) *Consciousness, color and content*. MIT, Cambridge, Ma.

Wright W.D. (1967) 'Towards a Philosophy of Colour', in *The Rays are not Coloured* . Adam Hilger Ltd, London

Color Experience and the Human Animal

C. L. Hardin

Dept. of Philosophy, Syracuse University

ABSTRACT

It is one thing to understand what advantages an animal such as ourselves gains by being able to exploit spectral information in its environment, but quite another to understand how the animal benefits by having conscious color experiences. Since experiences are private, how could they confer a selective advantage? Could they do so by enabling voluntary action of a sort forever beyond the resources of the most ingeniously designed wavelength-processing robot? Or is there an ancient biological link between color experience and the emotions that colors evoke in us?

Keywords: color experience, evolution of color vision, emotional response to color

For the innocent, color is a quality fixed to the surfaces of physical objects. Perceiving the true nature of color consists simply in opening one's eyes and letting the light stream in. Sophisticated members of the AIC will have none of this. They will distinguish physical color from perceived color. Physical color is a "characteristic of a visible radiation…" whereas perceived color is an "aspect of visual perception…." Physical color, the stimulus for perceived color, is objectively quantifiable and measurable, but the qualitative features – redness, greenness, yellowness, blueness – reside with perceived color. As Newton put it long ago, "the rays are not colored."

Abandoning the innocent view of color as part of the furniture of the physical world has made color science and color technology possible, but there is a price to be paid. In what follows we shall look at some of the consequences of dividing color into distinct physical and psychological domains.

Perhaps the most fruitful way to inquire into the nature of color and color vision is to ask what color vision does for the animal that has it. Or, to put it another way, what does an animal gain by being able to exploit wavelength information in its environment? The answer is of course that the advantage depends upon the animal and its ecology. Segmenting visual scenes, spotting predators and prey in a dappled environment, determining sexual availability, finding ripe fruit, aerial navigation – these are just a few of the tasks that color vision may be asked to perform. Detailed studies of how a wide variety of animals manage to execute these tasks have been made by animal behaviorists and ethologists. Now the interesting thing about these inquiries is that all of them have been carried out in purely physical and behavioral terms, using methods that could just as well have been employed to discern the tactics used by robots to cope with their environment. Indeed, as we well know, there is a whole field of robotic vision studies, including robotic color vision. None of these investigations makes any appeal to color experiences. Nobody supposes robots to have experiences of any kind, and most of us are disinclined to suppose that simple animals that respond selectively to wavelength bands have color experiences either. However, we are inclined to think that our close relatives, such as macaque monkeys, do have such experiences, though we may find ourselves at a loss to know what to say about birds or fish.

If animals do have color experiences, what are these likely to be? We may think ourselves on safe ground in supposing our close relatives have color experiences much like ours, since so many of their measurable response parameters are close to our own. But when we venture further from our lineage, things appear much less certain. Bees are trichromatic, as we all know, but their spectral response is significantly different from ours. Perhaps their color experiences are similar, but transposed? The difference in nervous systems makes this dubious in the case of bees, but when we consider fish, birds, and amphibians that may be tetrachromatic or even pentachromatic, dimensional considerations alone show that their putative color experiences cannot be wholly identical with ours. Perhaps the difference is closely analogous to the difference between what human dichromats and human trichromats experience. If this is so, it still means that some of what these animals see is unimaginably different from what we see. Given the differences in nervous systems, however, it seems more likely that all of the colors they experience are radically different from what we experience. But if those colors are totally unlike our own, why should we call them 'colors' at all?

In the face of such perplexities, you may feel a strong urge to give up this game. Perhaps we have got into this fix by taking the question, "What colors do animals see?" to be meaningful when it is in fact meaningless, since there seems to be no conceivable way that one could gain access to the inner state of another. Unanswerable—as opposed to unanswered—questions should be regarded as bogus questions.

But caution is in order here. Can we know what other people see? We know that people don't all make the same color matches, and it has recently become clear that a considerable number of women have polymorphic cone pigments. This raises the rather distant possibility that some of them might be tetrachromatic, with color experiences that the rest of us cannot fully share. We would stand to such visual superwomen as dichromats stand to us. Dichromats cannot imagine what trichromats see, but can trichromats be certain that what dichromats see is merely a reduced set of their own color experiences? The testimony of unilateral dichromats has failed to yield an unambiguous answer to this question. More fundamentally, can trichromats be warranted in supposing that other trichromats share their color world? Couldn't the stimuli that I experience as red be experienced by you as green, with neither of us being the wiser? But if this remains a possibility because none of us can have access to the inner states of another, we face more drastic possibilities. Perhaps some people don't have any inner states at all, but just act as if they do. Might some of us be mated with automatic lovers?

This is the way to philosophical madness, so we had best suppose that the problem of access to the inner states of other organisms is in some fashion solvable. Let's back up and grant that at least some animals have inner experiences that are at least analogous to our color experiences. We are still left with a troubling question. As we have already remarked, the study of animal color vision and its evolutionary advantages proceeds without ever asking whether those animals experience color. Yet we agree that the color qualities, such as red and green, exist only by virtue of being experienced. Are studies of animal color vision a series of performances of Hamlet without the Prince?

So why did color experience evolve? The very fact that none of the answers given so far make reference to color experience suggests that having color experience may be inessential to an animal's getting about in the world. Perhaps color experience is a mere byproduct of neural activity, a drone with no biological function. Or should we conclude that it is an ornament bestowed upon us by a benign deity in order that we may enjoy gardens, sunsets, and impressionist paintings?

A clue to understanding the adaptive role of color experiences might come from studies of blindsight patients. These are people who, by virtue of damage to primary visual cortex, have a portion of their visual fields in which they have no visual experiences. They do have alternative pathways through which visual information – including color information – can be transmitted, but they have no conscious access to it. They never use this information to initiate action, stoutly maintaining that they can see nothing, but when asked to guess which of two targets has been presented to them in the blind field, they are able to answer correctly at a rate that is far above chance. Petra Stoerig,[1] who has investigated chromatic blindsight extensively, suggests that the role of conscious experience is to enable voluntary action; availability of the same information in nonconscious form does not suffice. Might the value of color experience lie in its capacity to guide deliberate behavior?

We know that what we see as color can be a powerful biological signal in animals such as monkeys to whom we are inclined to attribute color experiences. Nicholas Humphrey[2,3] found that when monkeys are placed in a room with a wall that could be completely illuminated by a light of a single color, their behavior was a function of the color that was presented. In the presence of red, they were intensely agitated, whereas when the wall was blue, they were at their ease. When they were able to choose the color of the wall, they uniformly preferred shortwave light to longwave light. There are many examples of color as a biological trigger for animal behavior in natural habitats. Most of these are bits of stereotyped behavior that seem far removed from human color affect. But is a monkey's emotional response to colors so very distant from our own? If color did not move us, it is unlikely that there would be an AIC, let alone a Color Marketing Group!

Many claims have been made about the specific affective values of this or that combination of colors for people in this or that environmental situation, and few of them are founded on anything more solid than intuition, anecdote, or bald assertion. There is plenty of evidence that what color schemes people find pleasing or displeasing is a function of fashion and culture. But under these vast cultural overlays, are there some universal color emotions for our species that have not been adequately explored? Does fact that color matters to us now reflect ancient biological imperatives that brought about the evolution of color experience in the first place?

REFERENCES

1. P. Stoerig, "Wavelength information processing versus color perception: Evidence from blindsight and color-blind sight," *Color Vision: Perspectives From Different Disciplines*, W.G.K. Backhaus, R. Kliegel, J.S. Werner (eds.), pp. 131-147, Walter de Gruyter, Berlin and New York, 1998.
2. N. K. Humphrey, "Colour and brightness preferences in monkeys," *Nature* **229**, pp. 615-617, 1971.
3. N.K. Humphrey, "The privatization of sensation," *The Evolution of Cognition*, C. Heyes, L. Huber (eds.), pp. 241-252, MIT Press, Cambridge MA, 2000.

Color's Perceptual Dimensions

Lois Swirnoff,
Feltman Professor of Light and Color, Cooper Union for the Advancement of Science and Art

What is color? In art and in the eye, color FORMS. Seen in relation to other colors, they interact, create space, transform volumes, pattern the visual field. Color informs metaphor, and within a visual context, and by association, evokes meaning.

Thus, color is a primary tool of the painter. While it offers immediate access to the intuition, as expressive signal, paradoxically it is also the substance for building visual structures.

For the visual artist a painting is comprised of two basic components; line and color, or by their Renaissance definition, "forma e colore". Conceptually, form is regarded as more significant than color, but phenomenologically light and color precede form in vision.

When drawing, the artist is aware that the delineating boundaries seen in the visual field are arbitrary. There are no lines in nature. The boundaries apparent in the visual field shift with the viewpoint of the observer, even to the discrepancy between left and right eye. To draw then, is to make lighteningly-rapid, intuitive decisions about where to mark a line.

Still more surprising to the layman, perhaps, is that there is no form visible in nature, in the absence of color. In the visual field shapes appear defined as areas of color, met at their mutual boundaries, as they are articulated by the discrepancies or contrasts between gradients of hue and brightness. Separation of shapes from one another, or figure ground, are determined by the completeness of those boundaries. Thus, light and color are fundamental to the essential experience of seeing. To the artist they form the basis of painting.

Paintings are perceptual patterns, and the painter is either endowed by nature, or learns to perceive them uniquely. However simple or complex, the artist develops or cultivates individual modalities of form, systems and color gestalts over time, in the course of working. Even mimetic art (so-called "realism") represents a particular kind of pattern-perception, or reduction. An intent look at a Vermeer painting reveals his uncanny ability to reduce complex combinations of light and color to relatively simplified areas or shapes, which, seen from a distance, read as convincing representations of "reality".

But to the artist, all painting is fundamentally abstract, whether or not it is so labeled. The artist's eye/brain effectively is the most highly adaptive organism that weighs, measures, quantifies, balances and contrasts qualities of light and color, which may be acute or infinitely supple - with boldness or subtlety - a ritual of intuitive mathematics, or what I have come to think of as quantification without number. All in the service of expression.

For the most part these capacities are not cultivated at school, although they represent a very high degree of thinking, proceeding from perceiving rather than conceiving.

Josef Albers, in the last century, presented his great work, *The Interaction of Color*[1], the fruits of his painting and decades of teaching. The contrast effect, an issue raised by Chevreul[2], and color relativity were explored, greatly extended and expressed metaphorically in this work, and in Albers' series of paintings, "Homage to the Square". He constantly challenged his students to "Search, not REsearch".

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

I accepted his challenge. For my MFA thesis I undertook a series of experiments, modeling color in a spatial context. From the two-dimensional plane represented by Albers' work, I began by testing some of his basic ideas in three-dimensional space. A question posed led to another. I departed from my mentor's base, and together with my students explored color/form, color/space, color/organization, as new issues, and their questions, added to, produced a body of knowledge. Decades of experimentation were followed in 1989 by publication of my book, *Dimensional Color*[3], as Design Science. By extension to the urban field, decades of my photographic observations resulted, in the year 2000, with the publication of *The Color of Cities*[4].

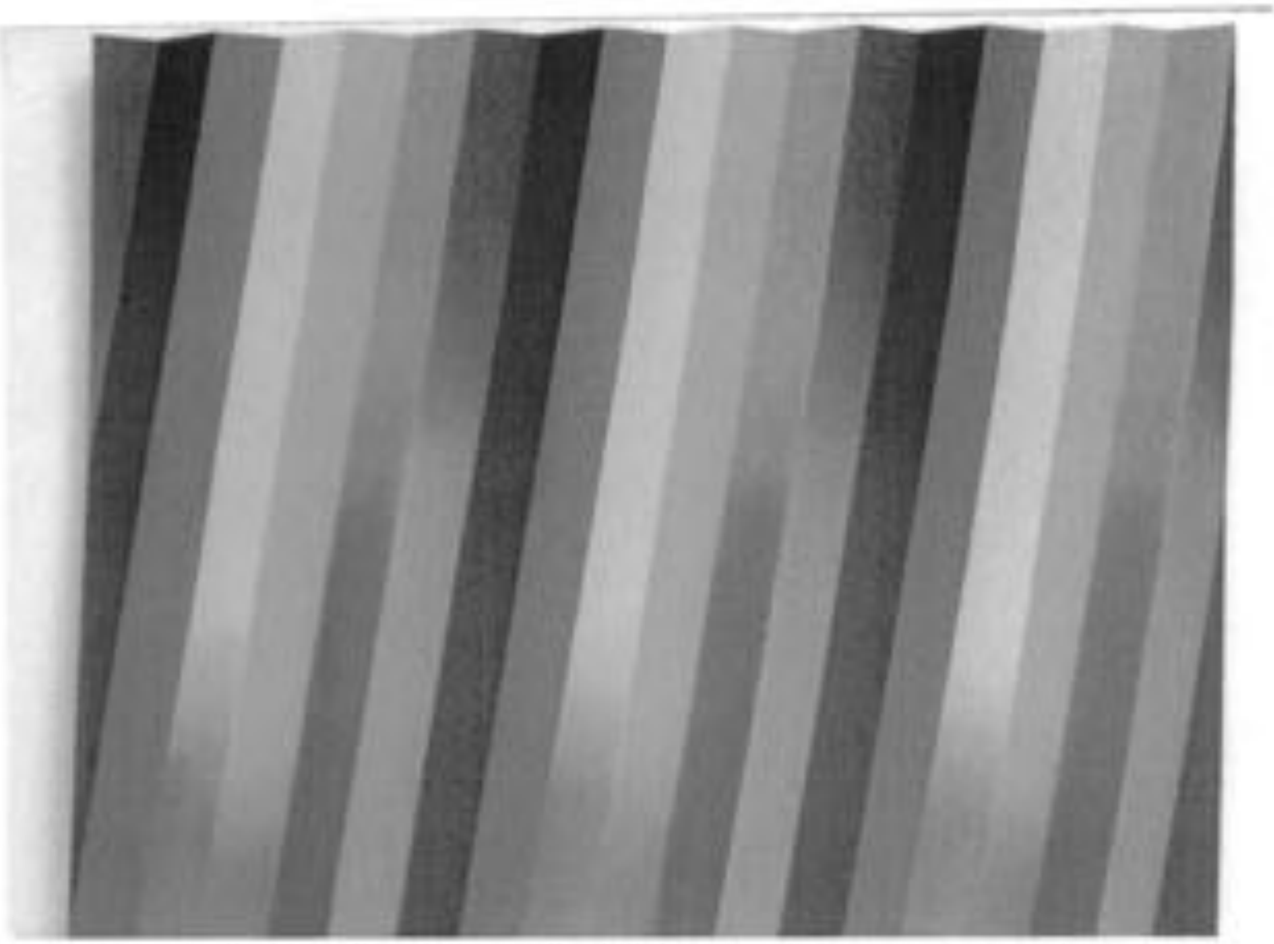
While I cannot present this body of work here, I decided to show a model or two, and my own paintings, or "color structures", as examples of color's perceptual dimensions.

These diagrams are probably familiar. One represents a 90 degree angle, the other a Necker cube. They are found in introductory books on visual psychology. Delineated, each form can be seen to be ambiguous. When grays are added to their faces, volumetric appearance is enhanced. Still, the angular junctures can appear to be forward or backward in space, or fluctuating, as concave or convex volumes; but volumes they are, not flat representations. I decided to study these. What degree of darkness/lightness contrast produces the effects of volumes? Can gray "coloration" cancel volume? (as it does in natural countershading). If so, what degree of contrast is required? This turned out not to be so simple a problem. The graph shows Fechner's psycho-physical effect: namely, a progression in value that appears arithmetic is achieved geometrically. This concept eludes most art teachers, when they construct scales of value, and many basic books on color - they still get it wrong.

We built models, illuminated them on one side, and by trial and error covered their surfaces with the intervals of Color-Aid papers, first grays, then hues, as a standard, until the illuminated and shadowed side of the model appeared equal. This is the surprising result. One slide shows the 90 degree angle, in gray and in color; the other illustrates the colors used against the angular form, to achieve the match. The discrepancies in contrast are far greater, and the color mixtures much more complex than we had anticipated. Visually the three dimensional model was highly ambiguous to the eye; its surface coloration setting up a tension with its linear (perspectival) dimensions. Experiments with cubes, clusters of angles, square pyramids, and other solids followed. Effectively, we showed, not only that color is relative, but that the perception of form is also. Relative to light and hue, both.

With this perceptual "key", an understanding of light, shadow and color on the appearance of volume, my personal work changed. From the flat picture plane, I moved to a three dimensional surface for painting. Masonite and aluminum are the grounds, the first constructed, the second shaped. I devised the diagonal angle as a module to reflect light from any direction; in this way the cast shadow is subsumed, and a clear pattern of light and dark is created. With this pattern I played with the gradients of light and color mixtures, on both sides of the projected angles, in a series of color structures. The ensuing "compositions" then were provisional. They change, to fluctuations of natural light, or the angle of incidence of artificial light - but in a regular way. As dimensional surfaces they can be seen from any position in an arc of 180 degrees.

This color structure, titled "One, Two and Many", plays upon the equality of reflected light and color with three dominant hues. The yellow ochre, blue and gray, together with white, change their appearance and frequency, from formed to flat, as the light source moves. There are more mixtures in this work than are apparent, and the numeric and rhythmic variations are revealed as the angles are illuminated. Thus, a single image provides theme and variation in light and time.



Another painting, on an identical aluminum module, presents variations between surface structure and light, with a more delicate palette. In place on a wall this work subtly changes over a period of time, as it is subject to the fluctuation of ambient light.

In "Disappearing Edge", the modular surface, equal in its dimensions to those previously shown, I work with the painted line against the metallic edge, an optical play on "illusion" and "reality". With increase/decrease in , this one seems to "breathe", or to expand or contract.

Lastly, a larger work, titled "Advent", uses glide symmetry systems to place the frequency of the color groups and their backgrounds. While rigorously conceived, this work can appear almost random; here the camera moves into the surface and around it. A work done over the months of Spring, I used the colors of New England's slowly emerging foliage, mixing/imitating the subtle daily changes in their maturation, on my palette.

As natural growth incurs the visual complexity and colorful splendor of the season of beginning, to the human eye it belies nature's rigorous underlying strategies. Natural order may appear provisional and temporal, yet is constant and recurring. Grasping this paradox has become a central metaphor in my work and thought.

REFERENCES

1. Albers, Josef. *Interaction of Color*, Yale University Press, New Haven, 1963.
2. Chevreul, M.E., *The Principles of Harmony and Contrast of Colors and their Applications to the Arts*, Reinhold Publishing Corp., New York, 1967.
3. Swirnoff, Lois, *Dimensional Color*, Birkhäuser, Boston, 1989.
4. Swirnoff, Lois, *The Color of Cities*, McGraw-Hill, New York, 2000.

Color vision is form and object vision

John S. Werner[1] and Michael A. Webster[2]
Department of Ophthalmology, University of California, Davis
and Department of Psychology, University of Nevada, Reno

ABSTRACT

Color vision is inseparable from spatial vision. Chromatic and achromatic aspects of visual experience together subserve our perception of the forms of objects. This view is supported by physiological studies demonstrating that both color and luminance are carried along with form information on the same optic nerve fibers, albeit at different spatial scales. These scale differences can be summarized by contrast sensitivity functions measured with chromatic and achromatic spatial sinusoids, and may be illustrated by digitally filtered images that separate achromatic and chromatic variations. Analyses of the chromatic content of natural images also demonstrate a close link with the chromatic and spatial tuning of neural pathways. While characteristic properties of natural scenes can predict general characteristics of visual coding, color can vary widely across individual images, and thus could not be represented optimally by a fixed visual system. However, color coding is not fixed, but rather adjusts to both the average color and distribution of colors in scenes through processes of adaptation. Such adjustments may support color constancy and coding efficiency, and may also optimize detection and discrimination of colors that are novel in an image. Finally, the spatial properties of color-coding mechanisms are essential to our perception of figure and ground. Chromatic (border) contrast enhances the difference between figure and ground, while homogenization of object surfaces is facilitated by short- and long-range processes of assimilation and color spreading.

Keywords: color and form, color pathways, adaptation, assimilation, contrast, color constancy

1. INTRODUCTION

Color vision refers to the ability to discriminate spectral distributions irrespective of brightness. It is thought that this capacity evolved independently several times so it may not serve the same purposes in all those species that have acquired it. In normal human trichromats, color vision begins with the absorption of quanta by three different classes of cone photoreceptor. These receptor types overlap in their spectral sensitivity, but differ in their peak sensitivity at short (S), middle (M) or long (L) wavelengths. Photoreceptor responses are summed or differenced by postreceptoral pathways so that variations in intensity can be decorrelated with variations in the spectral composition of object reflectance. The summing and differencing pathways are called achromatic (or luminance) and chromatic pathways, respectively.

It is possible to describe the color of an object using terms that are disembodied from that object's form or pattern. Concepts of redness, greenness, blueness or yellowness are normally understood without reference to specific forms. It might, therefore, be thought that chromatic vision serves functions that are separate from form vision. Indeed, it is common to assume that the primary purpose of color is to carry information about the "substance" of surfaces. Thus it is color that provides the capacity to judge the quality of foods (*e.g.*, whether a fruit is ripe) or of conspecifics (*e.g.*, a healthy complexion).[1] Yet such knowledge is of questionable value if it is not tied to the spatial locations of objects, and our experience of color is far richer than the detection of infrequent sign stimuli. In this paper, we present evidence from physiology, psychophysics and perception that support a different view, that primate color vision is largely about form and object vision. Although the evidence to be presented is relatively recent, the thesis is not new. Hering[2] noted in the last century that colors are always spatial: "Our *visual world* consists solely of differently formed colors.... *seen objects*, are nothing other than *colors of different kinds and forms*" (p. 1).

---

[1] jswerner@ucdavis.edu; 916-734-6817; http://trc.ucdavis.edu/psychophysics/; University of California, Davis Medical Center, 4860 Y Street, Suite 2400, Sacramento, CA 95817 USA.
[2] mwebster@unr.nevada.edu; 775-784-6820; Department of Psychology / 296, University of Nevada, Reno; Reno NV 89557, USA.

2. CLUES FROM ELECTROPHYSIOLOGY

The same neurons that make chromatic vision possible, also provide spatial constraints for the appearance of colors. Of the three major pathways from the primate retina, two (parvocellular and koniocellular) carry information about color. The parvocellular pathway includes approximately 70% of the optic nerve fibers. Each of these fibers encodes spectral information in a spatially-dependent manner due to the antagonistic center-surround organization of their receptive fields. A single cone (say L-cone) may provide the basis for the receptive field center, while the inhibitory surround is fed by M-cones, or vice versa. These M-L or L-M receptive fields respond differently for patterns varying in luminance and those varying in chromaticity (isoluminance). As can be inferred from Figure 1, when the receptive field of such a cell is uniformly illuminated, the response will be nulled for broadband or luminance-varying (black-white) stimuli, but will be strong for small spots and increase until the size of the spot matches the receptive field center. The same cell will also respond to chromatic stimuli, but its response will not be attenuated by stimuli filling the center and surround. Indeed, the center and the surround of such a cell will respond synergistically to changes in spectral stimuli.[3] These cells can extract chromatic differences that provide information related to the forms of objects that could not otherwise be detected. The net effect of this organizational scheme is that the majority of cells in primate visual pathways carry information about both chromatic and achromatic properties of images, but at different spatial scales. In general, this scheme results in chromatic processing with relatively low spatial resolution, while high spatial resolution is dependent on luminance differences.

Recent evidence shows that in the first cortical visual area, there is a transformation of signals from cells having receptive fields such as that illustrated in Figure 1 to cortical receptive fields in which the spatial selectivity is similar for chromatic and achromatic patterns.[4] Nevertheless, as shown by the right graph in Figure 1, human contrast sensitivity is different for chromatic and luminance modulation of sinusoidal gratings. The curves show contrast sensitivity as a function of spatial frequency (number of cycles per degree of visual angle) measured with sinusoidal patterns varying only in luminance (black-white) or only in chromaticity (red-green or yellow-blue at equal luminance). The achromatic contrast sensitivity function (CSF) has a band-pass shape; the visual system is most sensitive to a band of spatial frequencies in the middle of the range. The chromatic CSF is low pass; sensitivity is highest at low frequencies and decreases at middle and high frequencies. The high frequency limit for red-green chromatic modulation is similar to that for achromatic modulation, but that limit is typically much lower for blue-yellow chromatic modulation. This means that resolution of black-white and red-green equiluminant stimuli exceeds that with equiluminant blue-yellow stimuli. The poor resolution for blue-yellow stimuli may be attributed to, among other factors, the sparse distribution of S cones.

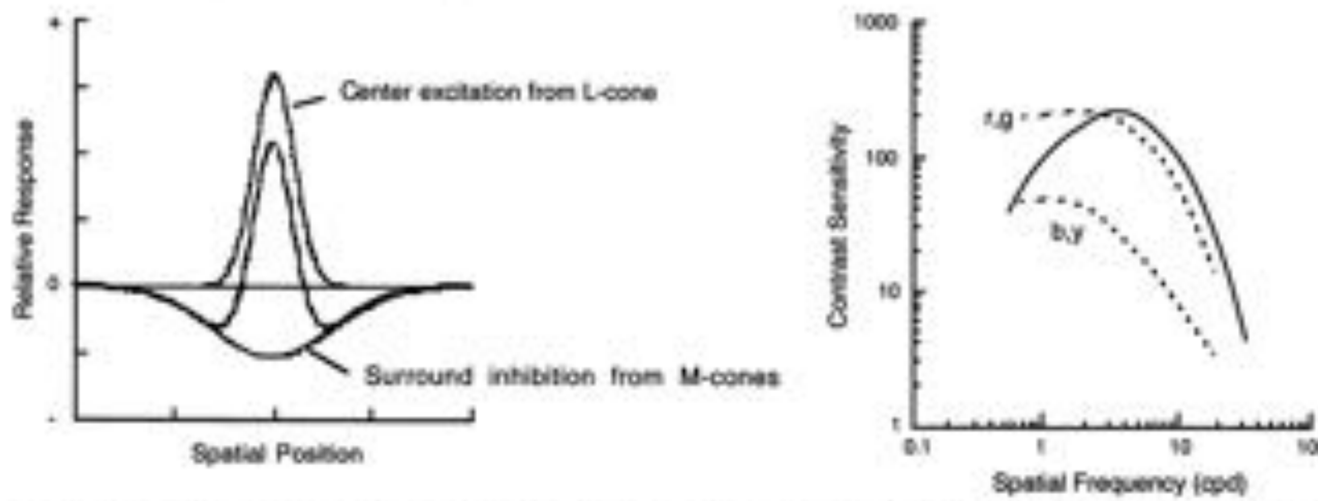


Figure 1: Left panel shows a cross-section of a circular receptive field profile of a retinal ganglion cell. The filled curve shows the measured receptive field profile, while the dashed curves show the spatial distribution of excitation and inhibition. In this example, excitatory input is from a long-wave-sensitive (L-) cone and inhibitory input is from middle-wave-sensitive (M-) cones. For a black-white (luminance-varying) stimulus, the cell will be maximally excited by a stimulus filling only the receptive field center; stimuli exceeding this size will be less effective due to the antagonistic surround. When tested with sinusoidal stimuli, the cell will be maximally responsive to a particular spatial frequency and less responsive to lower and higher spatial frequencies (band-pass filtering). Stimuli that change in dominant wavelength, say from middle to long wavelengths, will produce responses that both excite the L-cones through the center and reduce the inhibition from the M-cones in the surround. The net effect is that the response to chromatic variations at low spatial frequencies will not be attenuated (low-pass filtering). Right panel shows human contrast sensitivity as a function of spatial frequency (cycles per degree); solid curve for achromatic gratings[5] and dashed curves for equiluminant red-green and blue-yellow chromatic gratings.[6]

The spatial properties of chromatic and achromatic vision may be illustrated qualitatively with digitally-filtered images that separate the chromatic and achromatic variations, examples of which may be found in Figures 9 and 10 of Werner and Ratliff[7] and Figure 1 of Gegenfurtner.[8] In these images, we see much more detail (higher spatial frequencies) in the achromatic compared to the chromatic images. Indeed, the chromatic image can be defocused considerably with little deterioration of image quality. As with signals transmitted for television, most of the details in natural images are carried by lightness and darkness variations.

If the main job of color is really to tell us about the spatial properties of scenes, then why is the description carried by color so coarse? The answer is probably that it is as good as the retinal image will allow. Because of chromatic aberrations (a consequence of the fact that the refractive power of the lens varies with wavelength), fine spatial variations in chromatic contrast will be blurred on the retina.[9] This problem becomes pronounced for short wavelengths and may explain the paucity of S cones. A second factor is that color necessarily requires comparisons across more than one cone class. For luminance the intermixed L and M cones can be treated as a single sampling array, yet resolution within the L and M submosaics is necessarily lower.[10] Still a further factor is that the spectral sensitivities of the L and M cones are similar, with peak sensitivities that differ by only 30 nm. This similarity is probably necessary so that they can be treated equivalently for sampling luminance variations, yet it comes with the cost that the L-M difference signal on which color depends is necessarily weak, and thus may be more susceptible to noise.[11] In fact, theoretical derivations of retinal receptive fields based on the same design principles but different noise levels for luminance and color closely predict the bandpass and lowpass CSF's that are actually observed.[12] Finally, and perhaps most importantly, it should be emphasized that much of the function of spatial vision – of identifying objects and locations – is little compromised even by large losses in resolution. Thus the coarse spatial information provided by color may nevertheless be highly effective for the main tasks of form perception. Indeed, color appears nearly as efficient as luminance in supporting many spatial discriminations.[13-15]

Further evidence that color signals are used to define form may be found in a case study of a patient, M.S. He suffered a lesion in his extrastriate cortex that resulted in a loss of phenomenal color vision, a condition called achromatopsia. Achromatopsic patients describe images or scenes as appearing grey, similar to watching a black-and-white television. M.S. was completely blind in one half of his visual field and experienced achromatopsia in the other half. Tests with stimuli placed in the achromatopsic region of his visual field demonstrated that he had normal S-, M- and L-cones despite being unable to use differences in cone signals to reliably discriminate colors on standard tests of color vision.[16] He could, however, read color plates from the Ishihara test (made up of colored dots of different size and reflectances) if they were placed farther away (2 m), and he was able to detect some isoluminant chromatic borders even though he described the colors as appearing the same shade of gray. M.S. also had normal chromatic contrast sensitivity, mediated presumably by cells in cortical area V1. Thus, signals about chromatic properties were available to extract information about form even though they were not available for the conscious appreciation of hue. These results provide further support for the view that color vision is used for form vision.

3. COLOR STATISTICS OF NATURAL IMAGES

Important clues about the role of color in form perception can be gleaned from the kinds of signals available to the observer in natural images. Consider first that we live in a three-dimensional world filled with reflecting surfaces that are usually illuminated by a directional light source. Consequently, most natural scenes are filled with luminance variations that result from shadows and shading. Spatial variations in luminance are therefore potentially ambiguous, because they can arise either from changes in lighting or changes in surfaces. On the other hand, the color of the illuminant remains relatively (though not completely, see below) unaltered by shadows, so that regions of common color, though they may differ greatly in brightness, are more likely to belong to a common object. Thus one of the main advantages of color vision for form perception is that it may capture more directly the spatial distribution of objects independently of spatial variations in lighting. A particularly compelling example of this is the problem of detecting a fruit among foliage. The complex 3D structure of the variegated leaves clutters the image with luminance edges that effectively camouflage the luminance edges in the fruit. Yet the more uniform colors characterizing the fruit and foliage often allow the fruit to be readily detectable on the basis of chromaticity.

If the purpose of color is to discriminate and identify particular classes of objects, then the dimensions we have evolved to experience as color ought to be tuned to specific properties of the natural color environment. There is some evidence in favor of this view. Based upon samples of the spectral reflectances of objects in the visual environments of several primate species, and calculation of different possible photopigment combinations, it has been concluded that the spectral position of the L- and M-cone photopigments is optimized for detecting fruit[17,18] or edible leaves[19] against the background of foliage. Individuals who are lacking one class of photoreceptor, therefore, might be impaired in their discrimination of many natural stimuli. This can be appreciated from simulations by Viénot *et al.*[20] of the reduced color gamut of color-blind individuals, dichromats, who are missing one of the three classes of cone photoreceptors. Although these simulations do not permit us to know what dichromats perceive, one can see what happens to various forms with a reduced color gamut. The dichromat can match a natural scene that is missing much salient information about objects that can be discriminated by a trichromat. By this matching criterion, there can be no doubt that some individuals experience colors (and by implication, forms) differently from others. These studies reveal the importance of color for the perception of objects.

Most natural images do not contain all possible spatial and chromatic variations, and it is likely that visual mechanisms evolved to take advantage of these constraints. For example, analyses of the spatial statistics of natural scenes demonstrate a characteristic distribution of spatial frequencies in which the amplitudes are greatest for low spatial frequencies and fall off with increasing frequency at a rate of 1/frequency. This applies to both the achromatic[21] and chromatic content of natural images.[22-25] The domination of image content by low spatial frequencies implies that much of the information can be sampled by chromatic mechanisms, even though they have lower resolution. Studies of the grayscale statistics of natural scenes have provided powerful insights into the design principles underlying cortical receptive fields.[26] Similar analyses of the spatial variations in color should prove equally illuminating.

If properties that are characteristic of natural images drove the evolutionary adaptations of the visual system, what of properties that instead vary idiosyncratically across different images? In this case the visual system adapts very rapidly to match coding for the prevailing scene. Color provides dramatic examples of these adjustments. For example, the color of illuminants varies widely, yet the visual system adapts to discount these variations so that the colors of objects remain relatively stable, a point we return to in the following section. Measurements of natural images also reveal a second way in which color varies across scenes. For example, Webster and Mollon[22] examined color distributions for a large number of individual outdoor scenes. They specified these images in terms of cone contrasts along three postreceptoral chromatic axes thought to characterize second stage chromatic mechanisms [M+L, L-M or S-(L+M)]. Chromatic contrasts of most scenes tended to be biased along bluish to yellowish-green axes, but the principal color direction defining these axes varied widely, from nearly pure blue-yellow (for arid, panoramic scenes) to variations along a yellow-green axis of pure S-cone stimulation (for scenes dominated by foliage). Such color variations are too large to be encoded efficiently by mechanisms with fixed characteristics, for they often introduced strong correlations in the responses across different color mechanisms. Webster and Mollon showed, however, that the visual system adapts to the chromatic contrasts in these scenes in a manner that tends to decorrelate channel responses. This adjustment, called contrast adaptation, serves to enhance chromatic discriminations within a particular scene for objects that deviate from the prevailing gamut of colors. In this way, color mechanisms provide a basis for discrimination and identification of objects, and in particular, may serve to highlight the salience of novel objects. These adaptive processes also adjust to the spatial properties of images. For example, contrast adaptation is selective for spatial scale. Because images typically have more energy at lower spatial frequencies, we might expect the visual system to adapt to this imbalance, by reducing sensitivity to lower frequencies. In fact, something like this is observed when CSF's are measured while observers are exposed (and thus adapted) to sequences of natural scenes. Notably, the changes in sensitivity may be large and selective enough to suggest that the color CSF becomes nearly bandpass when measured under "natural" viewing conditions (*i.e.*, while adapted to natural scenes; Webster[27]).

4. COLOR INTEGRATES SPACE AND SEPARATES OBJECTS

Color can significantly enhance search and identification of information on visual displays. Human factors studies have demonstrated that in many situations, color is more effective than shape or size in helping to locate information quickly.[28] The attention-getting nature of color facilitates search while at the same time provides a good basis for grouping or organizing information on a display which may help the user segregate multiple types of information and reduce clutter.

Long-range cortical interactions may be necessary to integrate color signals across space, for without them we might well see the forms of objects as skeletons (based on receptive fields responsive only to border contrast) rather than filled-in surfaces. The filling-in of color extends beyond the boundaries of the physical stimulus as can be observed over short ranges by assimilation and long ranges by the water color effect. The latter effect is observed readily when a thin colored line flanks a border on a white piece of paper. The previously white area inside the border will now be uniformly filled with a desaturated color similar to the chromatic flank. Pinna and Spillmann[29] compared the effectiveness of the water color effect in determining figure-ground relations with Gestalt factors (proximity, similarity, good continuation, closure, symmetry) that are known to facilitate the perception of form. They found that when regions perceived as ground were filled in with illusory water color, the figure-ground organization reversed such that the area filled with illusory color was perceived as figure. These results provide compelling evidence of the importance of color perception in determining perception of form.

Better known than long-range assimilation, such as the water color effect, is long-range color contrast. When surfaces are delineated by chromatic or luminance edges, the opponent color is induced in surrounding or adjacent areas. Examples of this effect were described by Goethe[30] as colored shadows, and illustrated by Monet in his haystack series. In one haystack painting, the morning light falls upon the snow, and the yellow haystacks are surrounded with blue colored shadows. In another canvas, a greenish shadow is induced by the reddish color of a haystack in the late afternoon sun. We now regard this simultaneous contrast effect as due to the reciprocal neural-opponent responses across the visual field, and to higher-level processes that parse the perceived color and lightness according to our interpretations of shading and transparency.[31] Monet exaggerates chromatic contrast in shadows on canvas to draw attention to what normally can be perceived with no direct physical counterpart in the stimulus. It may seem from these phenomena of assimilation and contrast that the visual system is easily fooled and subject to illusion, but the mechanisms producing these effects are what make normal color vision possible. As Hering[2] pointed out: "The most important consequences of reciprocal interactions are not at all those expressed in contrast phenomena, that is, in the alleged false seeing of 'real' colors of objects. On the contrary, it is precisely the so-called correct seeing of these colors that depends in its very essence on such reciprocal interactions" (pp. 123-124). In full agreement, Monet[32] would later say: "For me, a landscape does not exist in its own right, since its appearance changes at every moment; but its surroundings bring it to life – the air and the light which vary continually.... For me, it is only the surrounding atmosphere which gives objects their true value" (p. 36). Thus, while some phenomena of assimilation and contrast do illustrate imperfect color constancy, they seldom lead to confusion about an object's identity based on color. More generally, they support correct identification of object color by accentuating differences between object and shadow, with assimilation enhancing the uniformity of a single surface and contrast enhancing differences between figure and ground. The long-range mechanisms mediating these effects are what keep us from being fooled most of the time about the appearance of objects when the spectral content of the illumination changes – they make color constancy possible. This is the experience that the colors of most objects appear to be about the same in a wide variety of lighting conditions, even though they may reflect very different spectral distributions to the eye. Color constancy would not be possible if the visual system were not able to adjust its chromatic sensitivity as the illumination varies across space and time.

5. CONCLUSIONS

Color vision is dependent on neural pathways that concurrently carry information about form. Even achromatopsic individuals who do not report phenomenal color vision are able in some cases to use chromatic information for perception of form. The utility of chromatic vision in form perception is made apparent in scenes with variegated chromatic and spatial structure. Identification of stimuli on the basis of luminance cues is often impossible, but chromatic vision renders certain objects visible. The specific characteristics of color and spatial coding can often be predicted from characteristics of the natural visual environment. However, because natural scenes vary, a fixed visual sensitivity could not in general be optimally tuned for individual environments. The visual system is capable of adapting to the global spatial-chromatic conditions and thereby shifts its tuning to optimize detection and discrimination. Finally, color vision provides a basis for form perception by filling-in and contrast, with the former promoting uniformity within a surface and the latter facilitating the separation of figure from ground.

ACKNOWLEDGEMENTS

Supported by NIH grants AG04058 and EY10834.

REFERENCES

1. S. Polyak, *The Vertebrate Visual System*, University of Chicago Press, Chicago, 1957.
2. E. Hering, *Outlines of a Theory of the Light Sense* (trans. by L.M. Hurvich and D. Jameson), Harvard University Press, Cambridge, MA, 1920/1964.
3. R.L. DeValois, and K.K. DeValois, "Neural coding of color," in *Handbook of Perception V*, E.C. Carterette and M.P. Friedman eds., Academic Press, New York, pp. 117-166, 1975.
4. E.N. Johnson, M.J. Hawken, and R. Shapley, R., "The spatial transformation of color in the primary visual cortex of the macaque monkey," *Nature Neurosci.* **4**, pp. 409-416, 2001.
5. J.G. Robson, "Spatial and temporal contrast sensitivity functions of the visual system," *J. Opt. Soc. Am.* **56**, pp. 1141-1142, 1966.

6. G.J.C. Van der Horst, and M.A. Bouman, "Spatiotemporal chromaticity discrimination," *J. Opt. Soc. Am.* **59**, pp. 1482-1488, 1969.
7. J.S. Werner, and F. Ratliff, "Some origins of the lightness and darkness of colors—in the visual arts and in the brain," *TECHNE - La science au service de l'historire de l'art et des civilisations* **N° 9-10**, pp. 61-73, 1999.
8. K. Gegenfurtner, "Color in the cortex revisited," *Nature Neurosci.* **4**, pp. 339-340, 2001.
9. R.M. Boynton, *Human Color Vision*, Holt, Rinehart and Winston, New York, 1979.
10. D.R. Williams, N. Sekiguchi and D. Brainard, "Color, contrast sensitivity, and the cone mosaic," *Proc. Nat. Acad. Sci.* **90**, pp. 9770-9777, 1993.
11. H.B. Barlow, "What causes trichromacy? A theoretical analysis using comb-filtered spectra," *Vision Res.* **22**, pp. 636-644, 1982.
12. J.J. Atick, , Z. Li, and A. N. Redlich, "Understanding retinal color coding from first principles," *Neural Comp.* **4**, pp. 559-572, 1992.
13. M.A. Webster, K.K. De Valois, and E. Switkes, "Orientation and spatial-frequency discrimination for luminance and chromatic gratings," *J. Opt. Soc. Am. A* **7**, pp. 1034-1049, 1990.
14. J. Krauskopf, and B. Farell, "Vernier acuity: Effects of chromatic content, blur and contrast," *Vision Res.* **31**, pp. 735-749, 1991.
15. W.H. McIlhagga, and K. T. Mullen, "Contour integration with colour and luminance contrast," *Vision Res.* **36**, pp. 1265-1279, 1996.
16. J.D. Mollon, F. Newcombe, P.G. Polden, and G. Ratcliff, G., "On the presence of three cone mechanisms in a case of total achromatopsia," in *Colour Vision Deficiencies V*, G. Verriest ed., A. Hilger, Bristol, England, pp. 130-135, 1980.
17. P. Sumner, and J.D. Mollon, "Catarrhine photopigments are optimized for detecting targets against a foliage background," *J. Exp. Biol.* **203**, pp. 1963-1986, 2000.
18. B.C. Regan, C. Julliot, B. Simmen, F. Vienot, P. Charles-Dominique, and J. D. Mollon, "Fruits, foliage and the evolution of primate colour vision," *Phil.Trans. R. Soc. Lond. B* **356**, pp. 229-283, 2001.
19. N.J. Dominy, and P. W. Lucas, "Ecological importance of trichromatic vision to primates," *Nature* **410**, pp. 363-366, 2001.
20. F. Viénot, H. Brettel, L. Ott, A. Ben M'Barek, and J.D. Mollon, "What do colour-blind people see?" *Nature*, **376**, pp. 127-128, 1995.
21. D.J. Field, "Relations between the statistics of natural images and the response properties of cortical cells," *J. Opt. Soc. Am. A* **4**, pp. 2379-2394, 1987.
22. M.A. Webster, and J.D. Mollon, "Adaptation and the color statistics of natural images," *Vision Res.* **37**, pp. 3283-3298, 1997.
23. C.A. Párraga, G. Brelstaff, T. Troscianko and I. R. Moorehead, "Color and luminance information in natural scenes," *J. Opt. Soc. Am. A* **15**, pp. 563-569, 1998.
24. D.L. Ruderman, T. W. Cronin, and C.-C. Chiao, "Statistics of cone responses to natural images: implications for visual coding," *J. Opt. Soc. Am. A* **15**, pp. 2036-2045, 1998.
25. M.A. Webster, A. Wade, and J.D. Mollon, "Color in natural images and its implications for visual adaptation," in *Human Vision and Electronic Imaging*, R.E. Rogowitz, B.E. and J.P Allebach eds., *SPIE* **2657**, pp. 144-152, 1996.
26. B.A. Olshausen and D. J. Field, "Emergence of simple-cell receptive field properties by learning a sparse code for natural images," *Nature* **381**, pp. 607-609, 1996.
27. M.A. Webster, "Contrast sensitivity under natural states of adaptation," *SPIE Proceedings* **3644**, pp. 58-70, 1999.
28. R.E. Christ, "Review and analysis of color coding research for visual displays," *Human Factors* **17**, pp. 542-570, 1975.
29. B. Pinna, and L. Spillmann, "Line induced color spreading – a new principle of grouping and figure-ground organization," *Invest. Ophthal. Vis. Sci.* **42**, p. 5515, 2001.
30. J.W.V. Goethe, *Zur Farbenlehre*, J.G. Cotta. Diederich, Tübingen, 1810.
31. E.H. Adelson, "Perceptual organization and the judgment of brightness," *Science* **262**, pp. 2042-2044, 1999.
32. R. Barnes, *Monet by Monet*, Alfred A. Knopf, New York, 1990.

On the nature of colours.

Osvaldo da Pos *
Dept. of General Psychology, Univ. of Padua - Italy

ABSTRACT

Colour is a visible aspect of objects and lights, and as such is an objective characteristic of our phenomenal world. Correspondingly also objects and lights are objective, although their subjectivity cannot be disregarded since they belong to our phenomenal world. The distinction between perception and sensation deals with colours seen either in complex displays or in isolation. Reality of colours is apparently challenged by virtual reality, while virtual reality is a good example of what colours are. It seems difficult to combine that aspect of reality colours have in our experience and the concept that colours represent something in the external environment: the distinction between stimulation and perceived object is crucial for understanding the relationships between phenomenal world and physical reality. A modern concept of isomorphism seems useful in interpreting the role of colours. The relationship between the psychological structure of colours and the physical stimulation is enlightened by the analysis of pseudocolours. The perceptual, subjective characteristics of colours go along with the subjectivity of scientific concepts. Colours, emotions, and concepts are all in some people's mind: none of them is independent of the subject mind. Nevertheless they can be communicated from person to person by an appropriate scientific terminology.

Keywords: colour, sensation, perception, virtual reality, illusion

1. INTRODUCTION

1.1 What is colour?

Colour is a visual characteristic of the objects, surfaces or lights we see in the environment around us such that those objects-surfaces-lights can be called red, blue, white, yellow, grey and so on. The *process* of perception is accomplished by and in the brain/mind of the observer, but the *result* of the perceptual process is seen as distinct from the observer, with a specific location in the 3D external space of the observer's visual experience. Shape, size, distance, and movement of the perceived objects are as objective as their colour.

A different problem is how accurately colours (and all the other mentioned phenomenal characteristics of objects) can be described and communicated between people. We may agree that long linguistic training is needed, while we complain about the poverty of normal linguistic ability. One may think that it is impossible to communicate our phenomenal world because no other people has direct access to our own states. One might also think that it would be possible to communicate objective notions about scientific topics because they would not be subject dependent. However, in the case of science, when it comes to communication, a great deal of subjective effort is necessary for understanding the concepts carried by the more or less specialised language used. So both kinds of communication deal with the contents of internal subjective experience, whether perceptual or conceptual.

1.2 Colour and reality.

Colour is not only a perceptive but also a *real* characteristic: it can be communicated between people as it relates to concepts and emotions. Judgements can be made about it. It appears the same for people who share a common perceptual organisation. The possibility of understanding what another person is communicating about his perception is grounded on the fact that we can experience the same things as he does. It is completely true that we cannot fully understand the phenomenal description by some other people unless we have *their* same experience.

The expression 'physical reality' seems to be a naive way to define those objects which can be grasped by different senses (normally touch and vision). While objects are still perceived entities, they can be subject to a sort of verification; information derived from one sense can be confirmed by that derived from another. This perceptual congruence gives us the subjective impression of being in front of a real object. Touch is generally privileged as the one more faithfully revealing 'reality'.

2. STIMULI AND PERCEPTS.

2.1 Physical energy and colour perception.

Kardos[1] distinguishes between contact and distance senses. In the case of contact senses, the object transmits to the perceiver an amount of mechanical or chemical energy, potentially quite dangerous. (In the case of smell a few molecules are still needed to bring about a sensation.) On the other hand, the energy transferred in the case of distance senses is extremely low and information is the most relevant aspects of what that energy brings. Sun radiation acts on terrestrial beings both ways: at high level of energy (captured by the skin) warming up the animal body, at low level (absorbed by the retinal receptors) as a source of information about distant objects.

Do we see the stimuli? There is a widespread belief that the eye is a window on the world; we only need to open our windows and take a picture of the world outside. This analogy may be accepted as a description of our experience from a phenomenal point of view, but the problem arises when we speak of stimuli. From a neurophysiological point of view the only and proper stimulus of vision is the electro-magnetic radiation which activates the receptors in the eye and initiates a series of neurophysiological events in the brain. Light cannot be both the cause and the effect of perception. Therefore, statements like: ".... the color of light that enters the eye ..." (Finlayson[2], p. 102) and other extremely frequent expressions of the same kind, should be translated into more coherent terms.

2.2 What do colours represent?

A great deal of scientific research is performed to trace either the causal links or the structural similarity between stimuli (distant and proximal) and perceived objects. The fundamental question can be formulated like this: "How do the perceived objects represent the physical object?". Although great progress has been made in trying to answer this question, there are perceptual characteristics of colours that cannot be explained by the nature of stimuli (for instance, the experience of red instead of blue, and so on). Also the basic distinction between light and surface colours seems to be triggered by an innate organisation of our visual system[3]. A radical empiricism therefore does not seem acceptable, but an interaction between subject and environment looks more reasonable.

Another point appears critical in the formulation of the previous question: what would precisely mean that perceived objects *represent* physical ones? The term representation fills the literature dealing with all kinds of perception, and of other psychological processes as well. One feels therefore authorised to investigate how this concept can be unambiguously defined. Millar[4] warns about the different meanings the word can assume (at least eight just in the field of memory processes). I have the impression that by using the word representation not only one avoids more precise terminology but also eludes theoretical implications. Perceived objects (i.e. the phenomenal world) do not represent anything else than themselves, they do not stay for something else. Certainly a good deal of scientific discoveries were done under the leading title of 'representation', although sometimes one arrives at formulating apparently paradoxical statements like "The world as its own representation"[5] which confirm the caution to be put in the topic. According to Edelman[5] in fact there are no objects, shapes, colours which represent correspondent entities in the physical world, but some similarity relationships between phenomenal contents are isomorphic with correspondent relationships between physical variables (second order isomorphism).

2.3 Psychology and phenomenology.

The animal psyche creates what we call the phenomenal world, governed by some intrinsic characteristics and laws. This perceptual world allow animals to develop an adaptive behaviour in a rather easy way. It is fundamentally subjective in the sense that not only is it experienced by the subject, but it is also governed by species specific laws. For instance, the peculiar quality of sensorial experience in a normal human subject may differ from that of another subject of a different species, like a bat or a pigeon. We have no experience correlated with detection of ultrasounds or of terrestrial magnetic field. Nevertheless it seems that living organisms, as we know them, share a rather basic common phenomenological structure.

Phenomenology is the science of experience as we live it, and is mainly concerned with the full and exhaustive description of our phenomenal world. For this reason it is also the core of psychology. All contents of our visual experience can be categorised as objects and their characteristics: all objects of our experiential world (the *real* objects) can therefore be described in phenomenological terms.

3. COLOUR SENSATION AND COLOUR PERCEPTION

3.1 Theory and dictionary.

Sometimes phenomenal experience is taken to mean an elementary sensation like the brightness of a segregated area of the visual field, as opposed to the global perception of whole objects. There is a theoretical debate on the distinction between sensation and perception. According to Helmholtz[6], neural communication between peripheral receptors and central cortex takes place without interaction between neurones: as a consequence we have simple sensations arising at peripheral levels which are strictly dependent on the local stimulation. The global organisation of many simple sensations into single objects and phenomena occurs at the central level of the cortex, where previous experience, memory, hypotheses, inferences, emotions co-operate to associate and interpret the different pieces into meaningful representations. Perception therefore shares with higher forms of knowledge their rational characteristics as it takes place at the same high nervous level; nevertheless it differs from more complex cognition being much faster as it involves a series of unconscious processes. Many researchers share this theoretical position in a more or less explicit agreement.

The consequence this theoretical position takes in the study of colour is easily traceable[7] in many explanations of colour effects: for instance discounting the illuminant on the basis of specific cues leads to a colour constant perception and is an example of unconscious inference.

Hering[8] on the other side stressed the importance of interactions at all levels of the nervous system. His aims was to explain all phenomenal aspects of perception in physiological terms, without the need of recurring to unconscious, and therefore not describable, processes[9]. From this point of view perception does not require previous experience, which is on the contrary considered as the last source of explanation when the other physical and physiological ones seem inconclusive. The difference between sensation and perception therefore can be expressed in the following terms: perception derives from a complex net of interactions between different parts of the nervous system, while sensation might be considered as one case of perception where spatial and temporal interactions are excluded or reduced.

3.2 Reduction screen.

Vision through a reduction screen (through a black tube in complete darkness) can be considered as a relevant example of source of visual sensations: all parts of the retina are not stimulated except a small area which receive the stimulating radiation. Most stimulus relationships are in this case zeroed. The neural links still exist, but they are activated at a minimum standard level. Most part of colorimetry is based on this kind of 'vision in isolation'. The concept of 'aperture vision' is slightly less well defined, because it involves a reduction screen whose shape is often not explicitly stated. It might be a very large white surface with an opening through which something else can be observed. In this case the white surface is necessarily perceived as illuminated, and the level of illumination is not necessarily explicit. In some other cases the surface which serves as background is grey: here too it must be illuminated, but according to the anchor theory of lightness[10] it should still appear as white. The use of these screens therefore does not guarantee the greatest simplicity in the stimulation.

3.3 Natural reduction screen.

Selective attention can restrict the visual field in some ways, not yet well understood, which can reproduce the effect of a reduction screen. The correspondent perception then undergoes some changes, sometimes dramatic, from what is usually perceived when one looks with a more global attitude. Different types of observers have been described by many authors as a function of their attitude: global vs analytical (sometimes also labelled as parallel vs sequential), field dependent vs independent, and so on. It is conceivable that all people can switch, with more or less effort, from one to another way of observing the environment, as a function of the kind of behavioural response which is requested. This is probably the reason of some paradoxical findings which show contrasting percepts as regard to the same stimulation (for instance impressive colour changes as a function of different 3D perceived organisation).

3.4 Colours in complex displays.

Colour interaction is what happens when the retina is differently stimulated in time and space. The colours and lights which are then perceived can be correlated with complex relationships extractable from the physical stimulation. Sometime the correlation is much simpler if one refers to a lower order of percepts, for instance perceived size, perceived distance, perceived velocity, perceived illumination, and so on. Physiological correlates of colour effects are believed to be natural explanations of the perceptual aspects: a fundamental isomorphism is supposed to exist between the phenomenological aspects and the physiological substrates. With reference to this isomorphism Hering[8] formulated the hypothesis of antagonistic chemical processes as an explanation of the opposing hues. A new step in this direction was made by Shepard[11] who advanced the hypothesis of a second order isomorphism. Not single aspects of a percept are correlated with single aspects of physical stimulation or physiological activity, but complex structures of the phenomenal world can be correlated with complex structures of the physical (or physiological) world.

4. VIRTUAL COLOURS

4.1 Pseudocolours.

Objects in the real world can be described in two different ways: by means of phenomenological (observable) or physical (not observable) linguistic expressions. (Physical expressions require the codified terminology used to describe the stimuli in the scientific domains - physics, chemistry, physiology, etc.). Both kinds of description can be objective[12] although they depend on the subjects and are therefore also subjective, for different reasons[13]: Phenomenological description comes from the species specific characteristics of the subjective experiential world. Physical descriptions are the result of a continuously evolving science which resides in some people's minds.

Pseudocolours are a nice example to illustrate the particular relationship which exists between the phenomenology and the physics of colours. When we want not only to understand a physical event which is not directly observable but also want to interact with it easily and in real time, we map some characteristics of the physical event into some appropriate characteristics of our perceptual world, for instance colours (or sounds). We can now refer, for example, to an echography. The problem is how to make the most relevant aspects of the physical phenomenon correspond with those perceptual subjective dimensions which are most salient and meaningful for the observer, so that we can have a *direct* experience of what is going on and respond appropriately.

Ultrasounds cannot stimulate nor our eyes neither our ears, and therefore we have no perception related to this physical form of energy. Nevertheless scientists are challenged today to find out not only the way of activating our sensory receptors by transforming one kind of energy in another kind, but principally to devise some correspondence between relevant relationships in the physical world and meaningful relationships in our phenomenal world[14]. A more speculative example is put forward by Revonsuo[15] who describes a 'Black planet' whose physical structure is completely inactive on human sense organs. Only an appropriate transformation make people have some perceptions which allow them to behave properly in that planet. The author[15] concludes that this is exactly the normal way of functioning of our perception: the correspondence between percepts and physical reality is only functional to an adaptive behaviour.

In the more realistic case of pseudocolours the modern concept of veridicality appears in a different perspective. The same event can be described both in terms of colours (phenomenal description) and of ultrasounds and molecules (physical description). In such cases the relationship between the two descriptions is determined by consideration of what is most useful in the circumstances. We can state that our perceptual world is not distinguishable from Virtual Reality. In fact Virtual Reality is defined exactly as the set of impressions which, although induced by not 'natural' stimulation, cannot be discriminate, on purely perceptual basis, from impressions usually evoked by 'natural' stimulation. The argument is that perception by itself cannot discriminate between Virtual and Not-Virtual Reality: to realise this distinction we need another form of knowledge which can go beyond the phenomenological aspects of perception.

4.2 Illusions.

The concept of illusion can be here appropriately treated. Keeping in mind the example of pseudocolours, or of virtual reality, how can we define colour illusions? There cannot be any discrepancy between perceived colours and physical characteristics of reality, because the two descriptions are made in different terms, phenomenal on the one side, physical (chemical, neurophysiological, mathematical, and so on) on the other side. Nevertheless phenomenal illusions do exist when we consider colour appearance: the *same* thing can look strikingly different in different contexts. The identity of an object is a necessary condition for perceiving an illusion. There is no illusion if two different objects show contrasting aspects. The illusory effect appears when an object, which is perceived in its identity in different situations, exhibits discrepant characteristics. The illusion occurs completely inside our phenomenal world: object identity must be perceived, and discrepant aspects as well. Perceptual illusions astonish because they are unexpected. Here the disagreement belongs to phenomenal descriptions, and can produce remarkable surprises. However there can be different situations in which we expect some well defined effect, and we feel surprised by realising a different perceptual result. This happened for instance when Evans[16] expected that colours of the same luminance would show the same degree of greyness. On the basis of previous knowledge, he certainly was surprised by realising that colours of different chromaticness, but the same luminance, were showing different greyness, and sometime also fluorescence. Nevertheless he[16] did not explained the phenomenon as it were an illusion, but changed his mind and corrected his previous theoretical formulation by writing: "Some years ago the writer published the statement that grey appear to be the perception of relative luminance. Since luminance is constant along any horizontal line in these diagrams, this statement is obviously not correct, except for achromatic colours" (p. 1055). The contradiction between a theoretical statement and a perceptual result only means that the theory must be corrected, and there is no illusion at all. This apply to many phenomena often considered as perceptual illusions, like contrast, assimilation, Boswell Helmholtz Kohlrausch effect, and so on[17].

5. PSYCHOLOGY AND COLORIMETRY

5.1 Colour appearance.

Psychological research is concerned with the phenomenal characteristics of colours. Studies address a number of issues: the number of hues that can be distinguished between red and blue, or between blue and green; similarity relationships between colours; the distinction between surface colours and illumination; emotional, esthetical, and motivational components of the phenomenal colour world; and so on[18]. An overall aim of psychology is to delineate the complex structure of colour, and possibly to include in it also the subject's behavioural responses (although this step seems quite difficult).

5.2 Psychophysics

Colour matching, colour detection, and colour discrimination are psychophysical procedures used to map subjective aspects of colours into physical dimensions, the reverse of the path taken by technologists when they deal with pseudocolours. Classical psychophysical procedures do not reveal the subjective appearance of colours, although they contribute to our understanding of some relationships between colours. (Colour matching does not help us to understand how colours appear[19].) The relevance so often given to colour matching, colour detection, and colour discrimination seems therefore disproportionate compared with the treatment of the phenomenal aspects of colours. More modern procedures like semantic differential, factor analysis, multidimensional scaling, magnitude estimation, and so on, seems to be powerful tools for shedding light on the psychological aspects of colours.

6. CONCLUSIONS

One can never insist too strongly in urging researchers to use correct terminology: a lot of confusion would be avoided in our minds and in science. The distinction between a perceived object (e.g. light) and the physical stimulus (e.g. radiation) should be always clearly and unambiguously mirrored in the scientific terminology. This kind of care is not an option. It will certainly bring more consensus between people, especially in so attractive a field as the world of colour.

ACKNOWLEDGEMENTS

The author wishes to thank P. Green-Armitage for his precious help; he is grateful to L. Albertazzi for the valuable discussions. This work was supported by the National Ministry of University and Scientific Research, cofin. 2000.

REFERENCES

1. L. Kardos, *The origin of neuro-psychological information*, Akadémiai Kiadó, Budapest, 1984.
2. G. D. Finlayson, "Color constancy viewed from a color-matching perspective", *Color perception: philosophical, psychological, artistic and computational perspectives*, S. Davis, **9**, 102-116, Oxford Univ. Press, New York, 2000.

3. R. Mausfeld, "Color perception: from Grassmann codes to a dual code for object and illumination colors", *Color Vision*, W. G. K. Backhaus, R. Kliegel, J. S. Werner, **12**, 219-250, Walter de Gruyter, Berlin – New York, 1998.

4. S. Millar, "Modality and mind: convergent active processing in interrelated networks as a model of development and perception by touch", *Touch, representation, and blindness*, M. A. Heller, 4, 99-142, Oxford Univ. Press, New York, 2000.

5. S. Edelman, "Representation is representation of similarities", *Behavioral and Brain Sciences*, **21**, 449-498, 1998

6. H. von Helmholtz, *Treatise on physiological optics*. (J. P. C. Southall, Trans. From the third German edition. Dover, New York, (1856-66) 1962

7. J. J. McCann, "Simultaneous contrast and color constancy: signature of human image processing", *Color perception: philosophical, psychological, artistic and computational perspectives*, S. Davis, **9**, 88-101, Oxford Univ. Press, New York, 2000.

8. E. Hering, *Zur Lehre vom Lichtsinne*. Berlin. (Republished in English translation as *Outlines of a theory of the light sense*. Harvard Univ. Press, Cambridge Massachusetts (1878) 1964.

9. N. Pastore, *Selective history of theories of visual perception 1650-1950*. Oxford Univ. Press, New York, 1971.

10. A. Gilchrist, C. Kossyfidis, F. Bonato, T. Agostini, J. Cataliotti, X. Li, B. Spehar, V. Annan, E. Economou, "An anchoring theory of lightness perception", *Psychological Review*, **106**, 795-834, 1999.

11. R. N. Shepard, "The perceptual organization of colors: an adaptation to regularities of the terrestrial world?", *The adapted mind: evolutionary psychology and the generation of culture.*, J. H. Barkow, J. H. Barkow, H. Jerome; L. Cosmides, et-al (Ed)., Oxford University Press, New York, **13**, 495-532, 1992.

12. K. Akins, M. Hahn, "The peculiarity of color", *Color perception: philosophical, psychological, artistic and computational perspectives*, S. Davis, **9**, 215-247, Oxford Univ. Press, New York, 2000.

13. M. Velmans, *Understanding consciousness*. Routledge, London & Philadelphia, 2000

14. D. Kruse, K. Ferrara, "Color flow mapping", *Ultrasound in Medicine and Biology*, **26**, S16-18, 2000.

15. A. Revonsuo, "Consciousness, dreams and virtual realities", *Philosophical Psychology*, 8, 35-58, 1995.

16. R. M. Evans, "Fluorescence and gray content of surface colours" *Journal of the Optical Society of America*, **49**, 1049-1059, 1959.

17. O. Da Pos, "Colour Illusions." *AIC Color 97*, The Color Science Association of Japan, Kyoto, pp. 34-41, 1997.

18. C. L. Hardin, "Color quality and color structure", *Toward a Science of consciousness III – The third Tucson discussion and debates*, S.R. Hameroff, A. W. Kaszniak, D. J. Chalmers, **6**, 65-73, MIT Press, Cambridge Massachusetts, 1999.

19. M. H. Brill, "Understanding color matches: what are we taking for granted?", *Color perception: philosophical, psychological, artistic and computational perspectives*, S. Davis, **9**, 141-151, Oxford Univ. Press, New York, 2000.

---

*Correspondence: osvaldo.dapos@unipd.it; phone +39049 8276680; fax +39049 8276600; Dipartimento di Psicologia Generale, Via Venezia 8, 35133 Padova, Italy

Color: what could it be?

Rolf G. Kuehni, Charlotte, NC

ABSTRACT

This article comments on the current interest in the subject of consciousness and the related subject of the nature of color experiences. Color is seen to be a special symbolic language into which spectral power distributions of areas of the visual field, arriving at the retina and related to those of other areas, are translated. With a code of five "letters," Y, R, B, G and Gray and modulation of these towards dark and light the information content of an unlimited number of spectral power distributions is efficiently conveyed to consciousness. The philosophical conundrum of "inverted spectra" is briefly addressed, as is the difference in focal and unique green and the reappearance of red at the short wave end of the spectrum.

Keywords: Color, consciousness

1. INTRODUCTION

In the last several years the subject of consciousness has become of great interest in various science and humanities fields. This interest has been prodded and supported by the ability to make many kinds of measurements that, a generation ago, were impossible. There are now dozens of books and several new journals on the subject, many definitions and perhaps a dozen "rough and ready" theories of consciousness, none of the latter with a convincing claim of believability. The field is waiting for its Newton to show the way. There are experts (a minority) who believe the problem is not solvable by humans, but for many others it is an exciting journey along what may be one of the last frontiers to be conquered. I believe, though, at this time most anything that is said about the nature of consciousness and its contents is either speculative or trivial.

A key issue is how it may be possible to objectively investigate phenomena that seem to be purely subjective and not end up in seemingly inexorable circularity, the escape route from which we have not discovered yet. What is running our conscious show and for whom? Among the millions of decisions my body makes every day I consciously make only a few hundred. On basis of what unconscious information am I called upon (by what?) to make these decisions and how is it decided which information is important enough to appear in my consciousness?

CONSCIOUSNESS AND COLOR

In the present discussion the question to be addressed is what color is and why for most of us color is a major and integral part of our visual experience. Why do certain animals have color experiences or, for that matter, any experiences? For autonomous moving organisms, including the species of humans, a key purpose in life is to pass genes on to the next generation. This requires being able to operate successfully in the world long enough to accomplish it. Critical issues are safely growing to reproductive maturity, food, shelter, security from predators, locating a suitable partner and raising offspring to a level where they can operate independently, and they need to be managed successfully. Acquiring information from the world around us is an essential necessity in this effort. Evolutionary processes, as is generally believed, have provided organisms with various kinds of sensors, responsive to different kinds of energy (or information) input. From these inputs the organism computes images of the world and strategies for reaching its goals. The sensors are operational all the time except in sleep and senses critical for immediate survival operate also during sleep. Type, number and position of sensors on the body presumably have been optimized by evolutionary processes. They produce a huge amount of information, most of which at any given time is of no immediate value to their owner. It has been determined that the input to the visual system of humans in awake, normal condition is approximately 10 million bits per second. Perhaps half of it is related to color vision. However, in consciousness we can process visual information only at a much reduced rate, approximately 40 bits per second (a ratio of 250,000:1).[1] More of the incoming visual information is used at the subconscious (instinctive) level, e.g., to make us feel sleepy or alert, or to evade with an instinctive movement the door that suddenly threatens to hit us in the face. The brain acts as a huge filtering device to screen out unneeded data, interpret the rest for purposes of body maintenance and emergency reactions, and pass a small amount into consciousness.

It seems indisputable that spectral power distributions entering our eyes are experienced in some manner by our subconscious that forms actions on their basis. The heavy load of operational computation and control of the body takes

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

place at the unconscious level. Another example for unconscious processing is our reaction to accidentally touching a hot plate: we move our hand before we consciously are aware of our pain and realize what has happened. Predigested information, somehow determined as relevant and important (how, by whom or what and for whom or what?), is then presented in compressed format in a meaningful symbolic form to consciousness for our contemplation (the contents of our conscious experiences).

One proposed reason for consciousness is that it allows us to plan for the future by being able to contemplate aspects of our past up to the near-present. Being able to contemplate the past requires having symbolic representations of some sort available for the experiences of the past since they cannot be experienced again in their original form (at least for now, until perfection of virtual experiences). The symbolic representations must in consciousness seamlessly connect past with present experiences. Over time the quantities of physical data absorbed by our sensors and passed on to consciousness are large and their storage and near-immediate access proved vital. The need for high efficiency resulted in a condensed symbolic representation of important data, elaborated in the form of qualia: what we consciously experience when looking at a colorful painting, smelling a rose, touching a lover, or what we take an aspirin for. That there is a common mechanism behind qualia can be inferred from the facts of synesthesia, including that it is in most cases outgrown during childhood. [7]

For the visual sense the solution that developed involves two fundamental symbolic entities, brightness and hue (including the lack of it, the achromatic experience). The former conveys essentially absolute changes in spectral power in the visible range, the latter relative changes. An image of the relative changes (in the form of reflectances) resulting in the 40 colors of the Munsell hue circle at equal value (6) and chroma (8) is shown in Fig. 1.

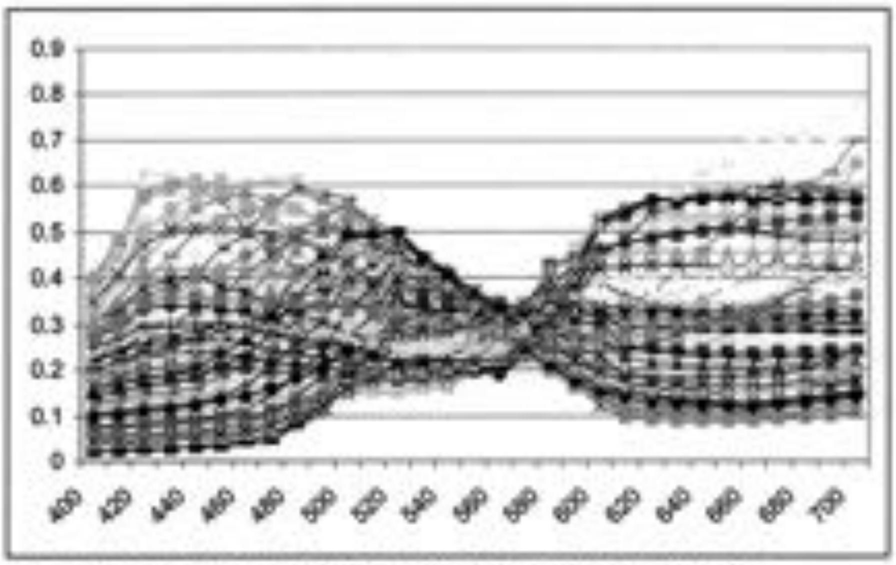


Fig. 1 Reflectance functions of the 40 Munsell hues at value 6 and chroma 8.

Five symbolic sub entities (Y, R, B, G, Gray) and their binary and ternary mixtures proved adequate to convey the relative changes at a given lightness value. As a result there are, as estimated by MacAdam, approximately 17,000 discernible colors in a constant lightness plane. The process can be summarized as follows: The information in the spectral power distribution arriving at the retina is compressed to the output of three cone types. It is then decompressed in the brain in a new format available for subconscious processing. People with blindsight presumably experience color stimuli in the subconscious format but cannot explain how they experience them. What seems to be missing for them is the next step: the translation (perhaps a 1:1 translation) from the unknown subconscious format to a format in form of color qualia that can be experienced in consciousness. We are told that the compression/decompression process for visual information is a very effective one in an information theoretic sense.[1]

Where does consciousness begin in the animal kingdom? We think a bee (with color vision) is not conscious. But already with hummingbirds the opinions of observers begin to differ. Do hummingbirds have qualia, or only macaques? If they do qualia cannot require a very complex process, given the brain size of hummingbirds. I would want to paraphrase Nagel's famous question: what is it like for a hummingbird to experience relative changes in spectral power?

The present outline implies that color experience is entirely subjective. The world out there is not colored. Colors are symbolic representations of localized spectral power structures in comparison to neighboring different spectral power structures. Colorants merely cause controlled absorption of light energy and thereby manipulate the spectral power distributions arriving at the eyes. There are, of course, many complications: adaptation, contrast effects, etc., which modify the simple picture presented above.

SOME PHILOSOPHICAL CONUNDRA

Some philosophers, a small minority, believe colors are out in the world and we experience them directly. Color is reflectance, in their view. There are many problems with this view, for example dealing with the fact that certain reflecting samples can look greenish in one white light and reddish in another. Other problems involve definition of "reflectance" of lights and light transmitting filters.

Another perennial philosophical issue is what philosophers describe as "spectrum inversion." The subjective nature of our color experiences makes it impossible to decide if you and I have in fact the same experience when looking at a given color sample. The fact that we both call it green does not address the problem. This matter has, to my best knowledge, been raised in print first by the French mathematician and philosopher Pierre Gassendi in 1624.[3] Since then philosophers have used a lot of ink over this question. Various scenarios are possible. But in the absence of full understanding of the mechanism of color vision all are hypothetical. A simple possibility is that the hookup of the cone outputs to opponent color cells might be miswired. Geneticists have now determined that there are only limited possibilities in this regard. There might be variability in translation from subconscious to conscious color experience. But, in my view, in order to have a sensible basis for discussion it is necessary to agree on certain minimal facts. For example: are fundamental object color hues connected to their lightnesses? In other words: is yellow always an intrinsically light color? (and so on for the other three unique hues). If not, that is, if the highest chroma object yellow can be relatively dark and the highest chroma blue relatively light one avenue of distinguishing them in a possible inversion is blocked. Recently it has become evident that the number of unit size hue differences between the four unique hues varies significantly.[4] The question arises if this involves intrinsic properties of the hue qualia (i.e., blue is phenomenologically farther away from red than from green) or if it is simply a matter of cone sensitivity properties. In the former case we could detect switched qualia experimentally, in the latter not. The extreme proponent of "spectrum inversion" cannot be disproved but the assumptions she makes are less and less believable. A moderate proponent can be convinced that "spectrum inversion," if it exists, can be detected by visual experiment and its causes presumably determined.

UNIQUE GREEN AND FOCAL GREEN

My favored theory of color vision explains the appearance of unique hue experiences as caused by stimuli that invoke response by one opponent-color system while the other one is neutral. Thus, the unique green hue is the unique output of the greenness-redness opponent-color system in one polarity if the yellowness-blueness system is neutral. With Churchland, Hardin and many others I believe that there is a direct relationship between opponent-color signals of some sort and the experience of unique hues. Thus, physiology is the basis of unique hue experience. I recently discovered, however, that for 40 of 40 observers their focal (ideal) green is significantly yellower than their unique green.[5] For the other three major hues there was close agreement between unique and focal hue. Many textbooks describe yellow as being the result of additive mixture of red and green. More accurately, yellow is the additive result of a yellowish (perhaps preferred) green and a yellowish (perhaps long wave spectral) red. The color of chlorophyll is a yellowish green and in spring most plant leaves begin with a chartreuse color and assume a bluer (but still yellowish) green hue only after a few weeks (presumably as more and more chlorophyll develops and covers the yellow pigments in the leaves). One could think of the focal green as caused by a cognitive overlay on the unique hue based on millennia of exposure to natural greens. The puzzling thing, however, is that for these 40 observers the focal green is as narrowly bounded on both sides as the unique green, raising the question of what neural mechanism is responsible for our judgment of focal green.

REAPPEARANCE OF RED AT THE SHORT WAVE END OF THE SPECTRUM

Another interesting question is: why does red reappear at the short end of the spectrum? Is it an accidental byproduct of neural wiring or is it the result of some necessity? Without reappearance of red in colors caused by short wave light we, presumably, would see unique blue at the short wave end of the spectrum. As a result there would be 4 Munsell 40 hue steps (or approximately 25 just noticeable differences) fewer in the range between unique green and the short wave end of the spectrum, compared to what we experience, a loss of some 30% in discriminability in the region from 400nm to 500nm.

Thus, it may well be that the reappearance of red was the result of a "cheap" neural solution implemented by evolution to improve discrimination in this spectral region because additional discrimination was aiding the survival of some early ancestors.

Have I explained what color is? Obviously not. I have come to accept that a meaningful answer will not appear anytime soon. But I would never say "Never." It is the kind of mountain that to me is more interesting to attempt to climb than Mt. Everest.

References:

1. M. Zimmermann. The nervous system in the context of information theory. In *Human Physiology*, 2nd ed., R.F. Schmidt and G. Thews, eds.Berlin: Springer Verlag, 1989.
2. K.T. Dann. *Bright colors falsely seen*. New Haven: Yale University Press, 1998.
3. C.B. Brush (transl. and ed.). *The selected works of Pierre Gassendi*. New York: Johnson Reprint, 1972.
4. R.G. Kuehni. Uniform color space is not homogeneous. *Proceedings COLOR 2001*.
5. R.G. Kuehni. Focal colors and unique hues. *Color Res. Appl.* **26** (2001) 171-172.

Author's address: 4112 Blaydes Court, Charlotte, NC 28226. rkuehni@carolina.rr.com.

Pre Congress E-mail Debate

Panelists' completed papers were circulated a few weeks before the Congress. This was so that all could have some early understanding of each other's points of view and so be well prepared for discussion during the symposium. In the event the debate began almost immediately by e-mail:

Kuehni
June 10, 2001

I understand that we are to get some discussion going among ourselves in advance of the forthcoming conference and I would like to make a contribution to this effort. Obviously, practical constraints make it impossible to present detailed arguments in each case.

My first challenge is to Lois Swirnoff and John Werner. In their own ways they both make the claim that color is form. Lois says explicitly: "no form is visible in nature in the absence of color." John and his co-author's paper is an extended argument on this subject. I believe it is first necessary to state what is meant by color. If color here includes all achromatic percepts then the argument is true but, as I see it, also becomes trivial. The argument then becomes: color is vision, or vice versa. It is clear that people with achromatic vision have perfectly normal form perception; people with achromatopsia generally also have good form perception. On the other hand, people with object agnosia have no problems seeing colors while being unable to recognize objects.

People like Zeki believe and have offered evidence that this is because there are two different pathways for form-related information: the magnocellular pathway that contains form related information together with motion information and the parvocellular pathway that contains form related information together with color related information. Zeki also offered evidence that in time color is processed first, followed by form (presumably because the information from the two pathways needs to be integrated) and motion last. One can then argue that there are three separate visual modules the information of which is integrated to form the conscious image.

The full-blown color vision system we have today is, based on work of geneticists, only about 20,000 years old. Rhodopsin, providing vision, is believed to be about 1.5 billion years old; the first cone type about 800 million years. The second cone type is believed to have developed about 200 million years ago. Does it mean that our forebears had no usable form recognition system until 200 million years ago, when a rudimentary color vision system may have developed, and maybe until 20,000 years ago?

On a practical level, again assuming that Lois and John do not mean color is vision, I would like to refer to colorless (chromatic) works of art (sculpture, engravings, etc.), informational objects: black and white photographic images, movies, etc., that convey a large amount of information about form in the absence of chromatic color and that contain as much emotional impact as any comparable images with color. For this reason, color during most of the Renaissance was largely used to express symbolic meanings (which meanings escape most of us today), harmony, and general esthetic beauty. Form (disegno and chiaroscuro) clearly had preeminence over colore. Only in impressionism and later low-representational art styles did color become important as a medium to express form relationships, particularly in fauvism.

I also have some questions and comments for Osvaldo da Pos:

In 1.1 you state that color, as shape, size, etc., is objective. At any given time I experience pleasure or pain, both or none. Does it mean pleasure and pain are objective as far as my body as an object is concerned?

In 3.1 you discuss sensation and perception. I would like you to define the two terms specifically in regard to color. What is sensed color and what is perceived color?

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

I do not agree with your comparison (in 3.2) of most of colorimetry with reduction screen vision. Colorimetry minimally compares two fields of color seen against a surround (in the color matching experiment). In most of its practical applications colorimetry tries, with more or less success, to represent more complex situations (color difference calculation, adaptation, color constancy, etc. While it is true that colorimetry and its applications deal with a simple, controlled world view, it is not at the level of reduction screen vision.

In 4.1 it is my view (perhaps in agreement with you) that all colors are pseudo colors since there is no objective truth to colors. If the leaves on the tree were red (as they sometimes are in Fall) it would change nothing about their objective truth.

In 4.2 you should be aware that the term Evans used is "fluorence", not fluorescence. The meaning of the two terms is much different. With fluorence Evans described the appearance of light or object colors if their luminance exceeded that of the surround in which they were viewed and the appearance therefore became self-luminous. Fluorescent object colors are usually fluorent because their luminance + emission typically exceeds the luminance of the surround. The definition of fluorescence is absorption of ultraviolet or visible energy and reemission of a portion in the visible spectrum. Special chemistry is required for fluorescence while most any light or object color can be made to look fluorent.

5.2: Here you state: color matching does not help us to understand how colors appear Why should it? Its expressed only purpose is to determine which spectral power distributions are found to be matching. Even though, based on color matching functions or cone response functions, we can build a fairly accurate geometrical model of, say, the Munsell Atlas, I believe most anybody understands that this says nothing about the phenomenal nature of the colors in the Munsell atlas. Multidimensional scaling doesn't either, nor does factor analysis. Such procedures, aside from being subject to a considerable number of assumptions and interpretations, derive a lot of their validity from the fact that colorimetry makes possible the definition of the samples involved in terms of objective measurable properties. Two different lightness scales (say, that by Ebbinghaus and that by Munsell) tell me little about their agreement and disagreement unless I can accurately compare them on basis of the photometry.

Da Pos
June 11, 2001

I am very glad to have the opportunity to exchange a few comments before the Conference, and I start by offering some answers to the questions posed by Kuehni.

1.1 "Shape, size, distance, and movement of the perceived objects are as objective as their colour": I think that the question by Kuehni "Does it mean pleasure and pain are objective as far as my body as an object is concerned?" is well posed, and the answer is "Yes". In fact a great deal of research is done in measuring human pain in order to control the effects of analgesic substances.

The general problem is the distinction between primary and secondary qualities (and the tertiary ones as well): it was believed that only the primary qualities are objective, while the others are subjective. But the concept of "objectivity" is questioned here: one diffuse idea is that something is objective if it is independent from the observer. Therefore everything which is happening inside the observer cannot be objective: from this point of view all perceptions, not only "shape, size, distance, and movement of perceived objects", but also colours and sounds are subjective; moreover emotions and pain, but also thoughts, concepts, and theoretical structures are subjective. The whole science would be subjective. The objection that the existence of physical objects does not depend on the subject who is declaring that existence, should be re-analysed: we can only assert the existence of some object or event on some perceptual basis, without which we have only hypotheses and not facts. On the contrary I think, like many others, that in science something is objective if it can be adequately described and successfully communicated.

3.1. Sensed colour and perceived colour: the first is the case of a colour seen "in the aperture mode of perception, in the special case of zero surround" (Boynton, - Human color vision - pag. 29). Notice that "zero surround" means absence of stimulation, absolute darkness. The second case is the colour perceived in a context. In the first case the dual code 'surface colour / illumination' (Mausfeld, "Color perception: from Grassmann codes to a dual code for object and illumination colors", in: W.G.K. Backhaus, R. Kliegel, J.S. Werner eds., "Color vision", W. de Gruyter, Berlin, 1998, 219-250) cannot be used by our visual system; surface colours and illumination can be perceived only in case of different stimulations in different retinal areas. Brightness is a correlate of the sensed colour (which directly depends on the luminance on a specific location of the retina) and lightness is a correlate of a perceived colour (it implies relations between different luminances, i.e. in a context).

About Colorimetry, the use of a "bipartite, or split, field" is a common methodology for deriving the basic colorimetric functions (colour mixture functions). I would agree with the distinction betewen "colorimetry vs its applications", or between "colorimetry vs colour appearance models". Moreover, the fact that often colour vision is studied in decontextualised situation is corroborated by Boynton when he writes: "I have decided not to deal with the very difficult topic of chromatic context in this book (Human color vision)" (pag. 21).

4.1. I am glad for the agreement on the idea that all colours are pseudocolours. Nevertheless I cannot understand the meaning of the expression "objective truth" in connection with colours. I would say: "physical entities are independent from the way I perceive colours", while the contrary does not hold ("the way I perceive colour actually depends (also, but not only) on the retinal stimulation, i.e. on the spatial/temporal distribution of the physical radiations").

4.2. No problem with the use of 'fluorence' to describe the perceptual characteristics of fluorescence. (See my paper about this topic).

5.2 Again we agree that colour matching (like colour detection and discrimination) does not help us to understand how colours appear. But why so large part of "colour" science is almost uniquely devoted to this topic? By reading many papers it seems that once you have clarified detection and discrimination problems, the essential part of colour science is performed. Details on colour appearance often look as optional. Boynton himself felt the need of affirming "the chromaticity diagram does not represent color appearance very well, and although there is really no reason why it should (see Chapter 8), it has been often used for this purpose." (pag. 19)

About multidimensional scaling and factor analysis: by themselves they say nothing about colour phenomenology, but they can be used to elaborate subjective estimates and descriptions of colours. Of course the field of psychometry is particularly difficult.

Kuehni
June 14, 2001

1.1 Subjective and objective: My dictionary definitions of s. and o. are as follows: S: existing in the mind, belonging to the thinking subject rather than to the object of thought. O: being or belonging to the object of perception or thought. It seems to me you are proposing entirely new definitions for s and o. It would require a more extended presentation of the theory behind your new definitions to be able to assess its merits. I do not think that because colors may be subjective it would mean that science also would be subjective.

3.1 Sensed and perceived color: It seems hardly worth to have a separate term for such a contrived viewing situation as you quote from Boynton where he describes aperture mode. Other people describe aperture color less exclusively as film color. Sensation and perception, of course have a rather tortuous history regarding their meaning. Another possible definition might be: s: colors that are seen, but not with conscious attention; p: colors seen with conscious attention.

I think it has been normal human endeavor to use a reductive approach in order to study phenomena. The process of heat was only understood once it was reduced to the degree of motion of atoms and molecules (notwithstanding a deeper quantum related definition). It makes sense to study color in simple situations. The changes that are taking place when gradually making the viewing and contextual situation more complex can then perhaps be explained in terms of additional processes. Color only exists in terms of contrast between at least two retinal fields. As the number and spectral complexity of images on retinal fields increases color changes, often dramatically. New ideas indicate that much of this may happen based on our personal past experiences.

5.2 Stimulus and response: Much of the impetus of color science (as distinct from vision science) has come from technology. Objective color control has been and continues to be an important project. Color management relies entirely on psychophysics to describe and control the stimulus that then, under controlled, simple viewing conditions, produces the expected response. Models that attempt to predict average response under increasingly complex viewing conditions are being proposed. Since we are unable to describe color experiences with words with any degree of precision people have learned to rely on stimulus description in controlled surrounds to do so.

There are now efforts (Indow) to describe color percepts from object stimuli (again, as seen in simple controlled conditions) by the content of unique hues and grayness. Individual results vary considerably. Average results are cumbersome to obtain and not of greater precision and repeatability than physics-based descriptions of the stimulus. The success of color technology clearly shows that this approach can work quite well. On the other hand, purely phenomenologically, I can have two indistinguishable white lights under which I look at colored objects. One that has a greenish appearance under one light can have a reddish appearance under the other. What does MDS and factor analysis do for me here? Physics helps me to begin to understand such phenomena.

There is no question that we are far away from accurate description of color percepts and a lot more psychophysical work is required. Our psychophysical models are primitive, in part because we have poor psychological data, in another because we do not understand as yet how color vision works, e.g., we do not know the neurophysiological processes behind hues and hue difference perception. Much remains to be done. But, in my view, only a psychophysical approach will allow us to make progress.

Da Pos
June 15, 2001

1.1 Subjective vs objective. The problem is not so simple that it can be solved by referring to a dictionary. As a matter of fact, the first definition for subjective would be "existing in the mind, belonging to the thinking subject" : from this point of view ideas, concepts, theories exist only in the mind. A number of scholars are debating the matter, and to give more space to this crucial point, I quote a "principle of objectivity" from Akins & Hahn (in: S. Davis ed., "Color perception : philosophical, phychological, artistic, and computational perspectives" New York, Oxford University Press, 2000):

> "Color is an objective property if and only if whenever an object appears to have a certain color, say, red, there is some distal property of that object which (i) normally causes it to appear red; (ii) is tracked by the appearance or redness; (iii) is mind-independent." (pag. 232).

The authors argue that this principle does not guarantee objectivity (their proposal refers to the apparent/reality distinction, where for reality they seem to mean the conclusion of a judgement as opposed to the simple perception); Evan Thompson does not consider colour as objective, while colour is an objective property of objects for F. Jackson and D.R. Hilbert (ibidem).

The trend I think to have grasped from many readings is that the qualities like redness, blueness, etc. are characteristics of the phenomenal world, which in turn is subjectively experienced and not reducible to physical correlates. The causal theory of perception seems not to have good grounds (Stephen E. Palmer - "Color, consciousness, and the isomorphism constraint" Behavioral and Brain Sciences, 1999, 22 : 923-989) and therefore it seems we have only correlations between the physical and the phenomenal world.

3.1 I often wonder what would be a good example of "film colour". One answer would be the sky, but it is impossible to see anything if only the clear sky is visible (we would be immersed in a Ganzfeld). Usually no other specification are added than: looking through an aperture. But it is quite obvious that a lot depends on where this "hole" is made, as "colour only exists in terms of contrast between at least two retinal fields". A white or grey or black holed surface would make a lot of difference! This is why I think that the simplest retinal contrast can be identified in the case of "zero surround", which would produce the most elementary perception of colour (hence my proposal of calling this "colour sensation").

5.2 Stimulus and response. Put simply, the leading title recalls a well known psychological theory, behaviourism, which, after contending the primacy with Gestalt theory, is thought to have given place, in the field of psychology, to cognitive science. It would be rather intricate to expound the pros and cons of the actual psychological theories. Although some modern versions of behaviourism (neo-behaviourism) are still present (paralleled by a form of neo-Gestalt which is more solidly characterised by quantitative structures and neuro-physiological correlates), ecological psychology seems one of those gaining more and more credit. Nevertheless few people question the importance of phenomenology in human life (for instance colour qualia seem important for conscious decision, efficient memory, and so on), which on the contrary would be the source of problems to be solved by other disciplines.

I would disagree with the statement "we are unable to describe color experiences with words with any degree of precision": this would mean that we are unable to describe anything by words, which contrasts with common experience and the vast literature of all kinds. We can more or less efficiently describe and communicate both the contents of our perception and of our thinking. The degree of precision is relative to all sciences. Linguistic tools are evolving as technological tools are, both for individuals and for society.

A question about "consciousness and color": The problem of consciousness is at the centre of a large debate (look for instance at the Tucson III, where many studies are dealing with colour). About the terminology used in the paper, I would need some clarification about the differences between unconscious and subconscious, and an indication if both are different from pre-conscious, which is a much more diffuse term in the field of visual perception.

The statement: "Colors are symbolic representations of localized spectral power structures", would entail that the phenomenal world would be a symbolic representation of the physical world. The concept of representation is probably not only ambiguous but perhaps also equivocal ('The world as its own representation', Edelmann S. - "Representation is representation of similarities", Behavioral and Brain Sciences, 2001). Is a represented object a mirrored thing which appears distorted as compared with the original? As agreed, pseudocolours have nothing to do with the physical entities they would "represent", except that some isomorphism exists between their structure and the structure of the physical world. In this sense colours can be thought of as symbols which are used to describe, in a very vivid way, abstract relationships.

Kuehni
June 16, 2001

1.1 Subjective and objective: My point here was mainly to get back to a plea you are making in your main presentation, that of using clear, well-defined terminology. I fully agree that this is essential. The historical definitions of terms are found in dictionaries, but language develops constantly and new definitions appear. Unless we have a common understanding and acceptance of a definition, or at least understand what is meant by a particular definition we will not be able to make progress. What is your accepted (by you) definition of subjective and objective?

3.1 "Zero surround": I agree that film color is not a widespread natural phenomenon, even though it occurs more often, I think, than aperture color as you define it. In my view "zero surround" can only mean Ganzfeld. Even a black surround without energy flux is a surround because there is signal activity in the cones exposed to it. Zero surround, in my view, means local blindness, either retinal or cortical.

5.2 Stimulus and response: These terms, by themselves, are innocent enough that they do not need to be appropriated by behaviorism forever. There is clearly a stimulus in vision and there is some kind of response (we experience color).

My statement "we are unable to describe color experiences with words with any degree of precision" I perhaps did not express myself fully and clearly. My meaning is: we cannot express the redness of red in words and we cannot, in common language, express the color of Munsell chip 5P4/12 with any degree of precision. It does not mean that we cannot express anything in language (but the only precise language is mathematics) only that there are particular problems with describing meaningfully experiences, including pleasure and pain. We may have the *Universal Color Language* but virtually nobody uses it and it does not mean anything without an atlas to show what is meant by the words.

1.1 Subjective: on the side of the subject, i.e. as far as something is produced or elaborated by the subject's activity. From this point of view colour is originated by the perceptual process of the subject; but also ideas, hypothesis, theories are created by our mind.

Objective: belonging to the object (i.e. the object/content of perceiving, of thinking, reasoning). So colours belong to the perceived objects.

Natural phenomena (gravity, for instance) are not subjective because they are not produced by the subject's activity, although they are "known" by the subjects. Colours on the contrary are subjective.

I oppose the view that subjective is what only the subject can experience or think, while objective would be what other people beyond the subject can observe, see and evaluate. What would be so objective in this sense that one does not need to "perceive", or to think?

As far as the content of perception and thinking can be verbally described, it becomes an object for the subject itself, and can be communicated to other people. My view is that verbal communication is not like an apple which is given to another person, but a set of signs which induces the receiver to trace the same contents of perception in his own experience, to formulate the same ideas, to identify the same feelings he already proved. Understanding is not only decoding but re-creating the contents of the communication.

The object can be quantified at different levels of precision by using both the "common language" and the more developed language of experts, poets, scientist, and so on: from large/small to very large/very small, to extremely large to extremely small, to 15 times bigger than ... and so on. Mathematics seems to be a language used to express the content of our knowledge, especially the relationships between objects. For some purpose, less precise linguistic tools are enough: I do not think there are separate languages, the scientific on the one side, the common ones on the other side. They lie along a continuum, and are endlessly evolving, mathematics included.

Questions and Comments

After the formal presentations at the symposium, Larry Hardin took the chair and invited members of the audience to make comments, raise objections and ask questions.

SUBJECTIVE AND OBJECTIVE

James King asked for clarification about the distinction between subjective and objective, citing the example of Harvey the rabbit. In the play the rabbit is supposed to be invisible to all the characters except one. If the rabbit is the figment of that character's imagination, is it an objective or a subjective rabbit?

DaPos
The object of our imagination is objective because we can express and we can also describe and we can also measure how big it is – large or small and so on. And we can see it as it were in front of us. It is produced by our mind so in this sense it is objective … because when we communicate through words other people understand only because they think again the same things. So objectivity is after our mind has produced something.

UNIQUE GREEN AND FOCAL GREEN

Leonhard Oberascher referred to the difference between unique green and focal green that had been reported by Kuehni. Oberascher described one of his own early research projects into color memory. When people were asked to choose the most 'typical' colors their choices had corresponded very closely with the unique hues. Oberascher had also investigated associations, asking people what words they associated with color samples. He had found no differences in the case of the 'primaries' (white, black, yellow, red, blue, and green), but significant differences for binary hues like violet and turquoise. He had concluded that the concept of a color and its visual presentation are quite different things except when they are prototypical colors.

John Werner then asked Kuehni if he had found that disparity between unique and focal colors for any colors other than green.

Kuehni
As I indicated I was surprised, or perhaps not, to find the very good agreement between the unique hues and the focal hues as determined by the World Color Survey from I don't know how many hundred thousand people. I was surprised to find this very significant difference for green. Of course I gave some thought as to where it might come from, and for example if you look at chlorophyll – chlorophyll is a greenish yellow – we have been in the past presumably extensively exposed to natural green up to now (not in the last 100, 200 years - some of us are not so much exposed any more to natural green). So we may be somehow imprinted with some kind of natural green. My only question is how come it seems to be so narrowly bounded. There must be some mechanism somewhere up there that decides that this is focal green and the mechanism is different from that which tells us what is unique green.

Karin Fridell Anter reported that she had made a survey of greenery in Sweden and found a very narrow range of hues - G40Y or G50Y in the NCS system – for the mature greenery of grass or trees.

Karin Topfer referred to her own studies of memory color and asked how the colors of natural foliage compared to unique and focal green.

Kuehni
I did not make any quantitative comparisons, but as you saw from the relatively poor reproduction, a unique green is what most people would consider a fairly bluish green, yet it is a green that is neither bluish nor yellowish.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

UNCONSCIOUS COLOR

Ulf Klaren asked about unconscious colors. He said that, for him, color is what we see and that there can be no color if you do not see it.

Kuehni

I'm very happy to put color in that term in quotation marks. Obviously conscious color may be what we are experiencing consciously while unconscious color is what our brain experiences with its owner not being consciously aware of it. On the other hand the physiologists are trying very hard to come up with signals in the brain they feel are very closely or directly related to our color experiences. Some philosophers believe that these signals in the brain are identical with colors, and therefore there is only one kind of color – it's the one we are experiencing and it's nothing but a particular brain state. Other philosophers disagree with this. We know that color is experienced without consciousness, known as blindsight. The idea is that people with blindsight experience color in the unconscious format. They cannot describe what they are seeing because it does not reach consciousness. That is where the idea of unconscious color in quotation marks comes from.

DaPos

Speaking about conscious and unconscious colors, I think that the difference is related to what Hardin mentioned before between robots and humans. Robots might do exactly the same thing without having the experience. So what is it that distinguishes between them is just the experience. There is an example: a physiologist who is colour blind is working in a lab, he has never seen color, and after studying the nervous system, can he understand what is color without having this experience? He knows all what happens inside the brain, inside the neurons, but this identity doesn't appear to him.

COLOR AS A BIOLOGICAL CODE

Swirnoff

I would like to reorient the discussion, which for the most part has been focussed on human perception. What led me to think of color as dimension, and to work three dimensionally on color models, was derived from nature. We are increasingly able to observe and understand the structures and strategies which produce natural coloration. The scales of fish, feathers of birds, cellular structures of iridescence are forms of microarchitecture, lavished by evolution in great variety, for the purpose of bending and refracting light, to produce color. Taking iridescence alone, as an example: for each iridescent incidence – from oil slick to mallard duck feathers – a unique cell has developed, to utilise the melanin source with efficiency to produce the array of spectral hues displayed by the viscous liquid, or the on again, off again oscillations on the duck's neck.

It seems to me that if color in the natural world were unimportant, as some have suggested, natural strategies would not have developed to the extent that they have. Adolf Portman (*Animal Forms and Patterns*, Shocken, 1952) asserts that apart from the issue of survival, for animals color's attributes may include an aesthetic dimension, to mark distinctiveness of individual animal forms made visible by their coloration or patterning. Hannah Arendt, in an essay *On Thinking*, explores the significance of surface appearance as such. Given the frequency of its incidence and variety of expression, color may turn out to be not mere decoration, but fundamentally, a biological code – perhaps even a pre-verbal message – worthy of study and investigation for its own sake.

COLOR DEFINES FORM

This comment by John Werner can be seen as a reply to Kuehni's challenge in his e-mail before the Congress:

Werner

Approximately 80% of the fibres in the optic nerve carrying signals and perhaps close to 100% of cells in the visual cortex carry information about color. Why? Evolution did not provide us with luxuries so that we can see pretty rainbows although that can be very enjoyable. Evolution provides us what we need for survival. And I think the reason we need color for survival is to distinguish the shapes of objects. And why can't you do that with achromatic vision? Well you can many times, but there are also times in which color carries information about large spatial features. When a directional light source casts a shadow or creates highlights and so forth an image can be somewhat ambiguous if seen achromatically, but we can perceive [the shadowed and highlight features] as parts of the same object if we see them as sharing a common color. So I go back to my main point that we have evolved color to recognise objects.

THE WATERCOLOR EFFECT

A question was asked about the watercolor effect which had been illustrated by John Werner.

Werner
This is a relatively new effect so a lot of conditions haven't been investigated. But we do know that there are some parameters which are critical for this kind of colour expression. For example the colour tends to spread from the low luminance curves that are adjacent. The higher luminance lines tend to block the expression. It works very well with chromatic stimuli. It's almost impossible to find with achromatic stimuli. So this color spreading seems to be a purely chromatic dimension and it's blocked by any border that is higher in chroma.

Harald Arnkil described his own encounter with this effect which he had experienced without knowing that it had been scientifically investigated or that it had a name. He is a painter and often lays masking tape round the edge of white paper to form a frame. He said he had noticed that the paper can take on something of the color of the masking tape, becoming a pale yellowish color.

RETINEX THEORY

Harald Arnkil then asked whether Edwin Land's Retinex theory was still relevant today. He said it was his understanding that it is the theory that corresponds most closely to the algorithms that are applied to robotic vision.

Swirnoff
In response to the question regarding Land's Retinex theory, indeed it is still relevant. Experiments that I've done with light and shadow on volumetric models show that the appearance of surfaces depend upon a ratio between light and dark, as perceived by the visual system, rather than surface measurements of light.

An experiment done at MIT's Artificial Intelligence Lab had attempted to replicate the appearance of a still-life, a la Cezanne. Painstaking measurements of reflected light were made of areas and surface planes in the array of fruits and objects on a table surface, and fed into the computer. The expected result was to have been an achromatic rendition of the composition. Instead, to the surprise of the experimenters, the computer image was nothing like it. Despite the accuracy of measurement, a descriptive perceptual pattern did not result by computer simulation.

Grays are the most adaptive aspects of color, changing readily in context- an observation made by Chevreul (simultaneous contrast) and Albers. In three dimensions, our models show a geometric discrepancy between measured and perceived contrast. The Retinex theory is basically a relational system, between retina and cortex, dependent upon proportional ratio-making in the visual system, and not replication of surface measurements of light and dark.

Some Concluding Thoughts

C.L. Hardin

So what does color do for the human animal? Jack Werner and Lois Swirnoff say that it helps delimit form. Rolf Kuehni disputes this, arguing that achromats are able to discern form, as are the rest of us when we view achromatic images. Closer examination shows that both are right. For the most part, achromatic contrasts suffice. But there are situations, particularly in the dappled environment of a forest floor, when the achromatic image is ambiguous, and color helps one to segment it: I see bits of lion behind that bush! In her "Dimensional Color" work, Lois makes a similar point by showing how different applications of color will disambiguate a figure in different ways. Rolf might well reply that the examples that Jack and Lois produce are minor as compared with the great variety of scenes for which achromatic contrast suffices to detect significant forms. Were these worth the evolutionary cost of innovating chromatic vision?

In evaluating all of this three things are worth bearing in mind. The first is that our modern world is not the one in which we evolved. Being able to distinguish edible from inedible food and detecting concealed predators have substantial survival advantages even though food and predators might be a statistically small portion of the total available forms in the environment. The second is that although human trichromatic vision may be, from an evolutionary point of view, relatively recent, dichromatic vision is much older, and presumably the advantages of chromatic vision that Jack and Lois have brought to our attention will hold for dichromats. The third point is that color vision has independently evolved in the animal kingdom countless times, and serves a variety of purposes, often for the same species. In our case, biological signals, such as are involved in distinguishing edible from inedible vegetation may have also helped to drive the further evolution of chromatic vision. Perhaps form detection promoted chromatic vision, and "vegetation reading" promoted the emergence of trichromacy. We as a species could get along without chromatic vision, but having it has improved our chances.

In an earlier version of his paper, Osvaldo da Pos stressed the importance of care in terminology. The field of color studies certainly suffers from a terminology problem, and it showed itself in the debate between Osvaldo and Rolf over the proper meanings of 'objective' and 'subjective'. I have often used these two terms for my own purposes, and found that this commonly causes confusion. Are colors objective or subjective? What about pains? Numbers? Science? Although on the surface Rolf and Osvaldo seem to disagree about the status of each of these, a closer look shows that this is not so. If 'objective' is construed as 'not dependent on human minds', pain and science and numerical systems and colors are not objective. If 'objective' is construed as 'susceptible to scientific evidence and validation,' then each of these is objective. Science itself can be studied scientifically, and although scientific theory and discourse depend upon human minds, their objects - the structures and processes of the material world - commonly do not. Even when the mind is the object of scientific study, the characteristics of mental events do not depend upon what we believe about them; not all opinions about such matters are of equal weight. (Cf. the philosopher-scientist C. S. Peirce: "Reality is that whose characters are independent of what we believe them to be.")

Sometimes 'objective' and 'subjective' are used to mark the distinction between fact and belief, and it is this that Lois seems to have had in mind when she insisted that colors are not subjective, but objective. Here she is, the heir of Albers, devoting her life to teaching some deep principles about the phenomenology of interaction of color, space, and light to generations of students who have taken it for granted that the use of color is mostly a matter of personal taste and opinion. "No! These color phenomena are not merely subjective, they are perfectly objective!" In this sense, she is of course right. In informal conversation she and I agreed that color phenomenology depends essentially on a cognitive and perceptual endowment that we human beings share. Color phenomenology is *intersubjective*.

All of the panelists seemed to find Osvaldo's analogy with pseudocolors to be a nice way of understanding the relationship between relative spectral power distributions and our mental coding of them as red, yellow, green, and blue. It is a curious sociological fact that people professionally involved with the study of color almost always concur with the panelists on this matter, whereas very many (not, as Rolf asserts, "a tiny minority" of) professional philosophers do not.

9th Congress of the International Colour Association, Proceedings
of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

It was Rolf who straightforwardly and elegantly addressed the relationship between consciousness and color that I had hoped would capture the attention of the other panelists and the members of the audience. His essential point is that consciousness seems to be required for high-level deliberation in preparation for action, but that the information-carrying capacity of consciousness is quite low. Most of the vast amount of wavelength information taken in by the receptors never appears at the conscious level. What does must be efficiently coded in a simple form: in the human case, by six elementary processes. This goes part of the way to understanding the importance of color experience.

Another part has to do with coming to terms with the affective or emotional dimensions of color experience, of color experience as intimately tied to action. This seemed to me to be a deep link between the concerns of visual science and the concerns of visual art. How might we get beyond the folklore of color affect into more interesting and secure ground? For this, alas, there were no takers among the panelists. Perhaps a reader of these words will take up this challenge.

Finally there was the little mystery to which Rolf drew our attention: the disparity between focal green and unique green, a disparity that does not exist for the other elementary colors. I find this interesting for two reasons. The first is that Rolf's attempt to account for this in terms of the appearance of vegetation suggests that we might try to understand color categorization by appealing to the distribution of chromaticities in the environment rather than, as is usual, to inbuilt perceptual and cognitive mechanisms. Later on, at the AIC meeting, Serguei Endrikhovski shared with me a draft of a paper of his in which he takes this very approach to color categories.

The second thing that intrigues me about this mystery is that it is yet another oddity involving green. One of the others is that in several studies, including one of Rolf's own, the variation in the distribution of loci for unique green is appreciably greater than the variation for the other unique hues. Another is that if one looks at languages with fewer than eleven basic color terms, one finds quite a few with a single basic term that includes both blue and green, but many fewer that have a basic term that includes both red and yellow. More remarkably, no language that has separate basic terms for blue and green has a common term for red and yellow, whereas many languages with separate terms for red and yellow have a common term for green and blue. So here we have three little mysteries about green. Might they be connected in some way?

The little green mysteries are as unlikely to receive concerted scientific attention as the problem of emotions and color. The same cannot be said of the interlinked problems of long-range color interactions and of approximate color constancy. Naïve appeals to colorimetry will invariably get the colors in natural scenes wrong, as Lois remarked in the question period. All the panelists would, I think, agree with this. Jack addressed the problems directly, and both Rolf and Osvaldo touched upon them. It was interesting to hear Edwin Land mentioned during the question period. Land was by no means the first either to discuss the problem or to suggest that the eye-brain must somehow calculate ratios across the visual scene. Furthermore, his own Retinex Theory breaks down when applied to simple displays and is in any case not physiologically supported. Nevertheless, Land's work was very influential. He made scientists outside of the visual science community as well as a general public aware of the problem of color constancy, and the Retinex Theory was one of the first robust algorithms in the then-new field of machine vision. It spawned a variety of computational approaches to color constancy. Like the Retinex original, none of them is without its drawbacks. This was to be expected, for the problem is for a host of reasons not easily solved; see, for example, what Osvaldo says about "natural reduction screens"; there can't be an algorithm for the perceiver's attitude! But then, as we all know, serious color study is not easy. Fortunately we also know is that it's fun.

Color Categories are not universal: New evidence from Traditional and Western cultures.

Debi Roberson*[a], Jules Davidoff[b], Ian Davies[c]
[a]University of Essex; [b]Goldsmiths College, University of London; [c]University of Surrey

ABSTRACT

Evidence presented supports the linguistic relativity of color categories in three different paradigms. Firstly, a series of cross-cultural investigations, which had set out to replicate the seminal work of Rosch Heider[1,2] with the Dani of New Guinea, failed to find evidence of a set of universal color categories. Instead, we found evidence of linguistic relativity in both populations tested. Neither participants from a Melanesian hunter-gatherer culture, nor those from an African pastoral tribe, whose languages both contain five color terms, showed a cognitive organization of color resembling that of English speakers. Further, Melanesian participants showed evidence of Categorical Perception, but only at their linguistic category boundaries. Secondly, in native English speakers verbal interference was found to selectively remove the defining features of Categorical Perception. Under verbal interference, the greater accuracy normally observed for cross-category judgments compared to within-category judgments disappeared. While both visual and verbal codes may be employed in the recognition memory of colors, participants only make use of verbal coding when demonstrating Categorical Perception. Thirdly, in a brain-damaged patient suffering from a naming disorder, the loss of labels radically impaired his ability to categorize colors. We conclude that language affects both the perception of and memory for colors.

I. INTRODUCTION

The linguistic relativity hypothesis, widely credited to Sapir's pupil Whorf,[3] suggests that the reason for choosing one particular set of cognitive categories over any other is largely one of cultural and linguistic agreement. The hypothesis was specifically applied to color[4] when a wide range of cultures had been reported to segment the range of visible colors in different, and apparently arbitrary, ways. The suggestion was reinforced by findings of correlations between linguistic factors (speed of naming, communication accuracy) and cognitive factors (memory)[5,6]. The view was famously challenged by Berlin and Kay[7], who highlighted the ease with which color terms translate between languages and proposed, instead, a restricted set of universal cognitive color categories that could be independent of (and orthogonal to) a culture's linguistic categories. Supporting evidence for this view came from Rosch's seminal cross-cultural investigations of color categories compared naming and memory for colors between an American English population and a stone-age agricultural population in Irian Jaya, whose language had only two basic color terms (the 'Dugum' Dani)[1,2].

It was further suggested[8] that the proposed set of universal color categories (those that are "basic" to the English language) derived directly from the opponent-process mechanism of neurons in the lateral geniculate nucleus. However, subsequent evidence showed that the wavelengths chosen to correspond, respectively, to the typical or unique colors of blue, yellow and green do not consistently match the predictions from neurophysiology[9]. In any case, no neurophysiological rather than linguistic conclusion could really be drawn by asking a person who already has the concept blue, yellow or green to indicate a color that is uniquely blue, yellow or green. In fact, the neurophysiological data show that neurons only respond selectively to particular wavelengths[10] or to combinations of wavelength and brightness[11]. Such selectivity is insufficient to conclude that the neurons act in a categorical fashion. Despite much investigation, there is no evidence that any neurons respond to all, and only all, of any of the four basic colors yet alone selectively to colors that we might call purple, brown etc.

Over the intervening years since Rosch's original studies, evidence of linguistic relativity has been found in a number of other areas of categorization, such as recognizing emotion from facial expression[12], number systems[13], spatial relations[14], modes of motion[15], and shape categories[16]. Furthermore, while taxonomies of natural kinds do appear to be similar across all cultures ([17],[18]), this universality is also reflected in language. So, if Universal cognitive color categories were to exist independently of linguistic categorization, this would constitute a unique case in human classification. This, together with a range of unresolved methodological problems concerning Rosch's original studies, led us to reexamine the case for color. Our work examined the categorization of color in three paradigms. The first considered the cross-cultural case, in an attempted replication of Rosch's studies with the Dugum Dani (henceforward called Dani).

* contact author: Dr. Debi Roberson, Dept. of Psychology, University of Essex, Wivenhoe Park, Colchester, Essex, CO4 3SQ, UK. Email robedd@essex.ac.uk. Tel: +44 (0)1206873710, fax: +44(0)1206873598.

2. CROSS-CULTURAL EXPERIMENTS

In the first of her seminal experiments, Rosch found that two populations with widely differing color vocabularies remembered colors in very similar ways that were not affected by differences in color naming[1]. In two further critical experiments[2] she also found that despite having only two color terms, the Dani found it easier to recognize and learn the 'foci' (best examples) of the eight basic chromatic categories of English. Thus, her cross-cultural research showed evidence of superior learning and memory for focal colors by subjects who did not code the categories linguistically. Yet some potentially serious flaws have been pointed out in both the design and interpretation of these studies. In the first experiment, two different measures, both based on multidimensional scaling of the same data set, gave conflicting results. A graphical representation supported the view that color categorization is universal while a statistical measure suggested that speakers of different languages organize their perceptual/cognitive categories in line with their different linguistic codings. The graphical result (that supporting the universalist view) was accepted but no proper explanation was given of why the statistical analysis of the data failed to support this interpretation. For the second and third studies, Rosch's interpretation is weakened by the extremely poor performance of Dani speakers on these tasks.

In light of the concerns about the interpretation of Rosch's data, we attempted to replicate those three experiments. No other culture has since been found to have as few as two basic color terms; indeed, Rosch[19] casts some doubt as to whether the Dani might have had as few as two basic terms. In the present investigation, native English speaking subjects were compared to monolingual Berinmo speakers from three villages in Papua New Guinea whose language contains five basic color terms[20]. We were unable to repeat her findings. Berinmo speakers' memory patterns followed their patterns of naming, they did not show superior memory for the best examples of English color categories, nor did they learn these categories more easily than others. These findings have now been replicated on the other side of the world, with African pastoral tribesmen, whose language also contains five basic color terms. Furthermore, new experiments, which took advantage of the phenomenon of categorical perception showed positive evidence of the effects of language on perceptual categorization in both populations.

Categorical Perception is the name given to the phenomenon observed when a continuous quantitative change in a perceivable stimulus, such as color or sound, comes to be perceived as a series of sharp, qualitative discontinuities. Stimuli from the center of categories come to be classified faster than those at the edges and consequently discrimination of stimuli is better across than within categories. Our results with Berinmo and English speakers demonstrated, in three tasks with different instructions, that Categorical Perception was consistently more closely aligned with the linguistic categories of each language than with underlying perceptual universals. Investigations are ongoing in Africa.

When making similarity judgments between a group of three stimuli, observers judged two stimuli from the same linguistic category to be more similar even though perceptual distances between each pair of stimuli were held equal. However, for those who made no linguistic distinction between these categories, no reliable tendencies were observable in similarity judgments. Thus, English speakers showed Categorical Perception for stimuli across the green-blue boundary but not for those across the nol-wor boundary, while the reverse was true for Berinmo speakers. Furthermore, in a learned categorization task, participants from the two populations again showed a dissociation between categories that they did or did not distinguish linguistically. For English speakers, the division between green and blue was easier to learn than an arbitrary division of the green category while the division between yellow and green was easier to learn than the division between the Berinmo categories nol and wor. For the Berinmo, there was no difference in difficulty between learning the green-blue division and learning the arbitrary green division; however, the nol-wor division was significantly easier to learn than the yellow-green division. Similar results for the blue-green versus the arbitrary green division have also been found for Himba tribesmen in Africa (see figure 1). Further investigations of their category boundaries are being undertaken at present.

Finally, in a recognition memory paradigm, English speakers showed significantly superior recognition for targets from cross-category pairs than for those from within-category pairs for the green-blue boundary but not for the nol-wor boundary. Berinmo speakers showed the opposite pattern. Put together, these three new cross-cultural studies suggest that Categorical Perception shows the influence of language on perception. Our results suggest that the structure of linguistic categories distorts perception by stretching perceptual distances at category boundaries[21,22]. The internal color space appears to be pliable; some distances within it are 'stretched' or 'distorted' by the influence of linguistic categories.

Figure 1. Mean errors to criterion for English, Berinmo and Himba speakers learning the blue vs green and green 1 vs green 2 category divisions, and for those learning the nol vs wor and yellow vs green divisions

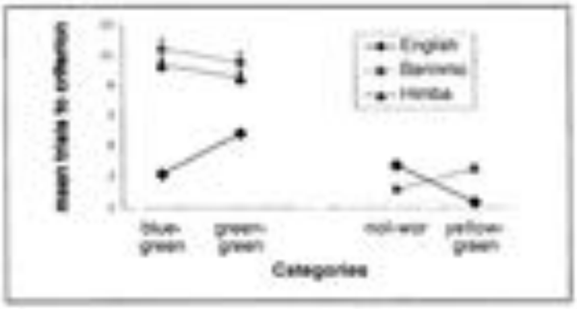
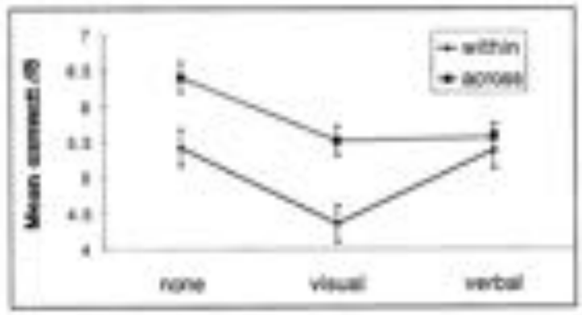


Figure 2. Mean correct identifications for cross- vs within-category pairs of colors with either an unfilled interval, or an interval filled with visual or verbal interference.



3. INTERFERENCE EXPERIMENTS

Within the constraints on experimental design required to work with Berinmo, experimental intervention was not possible to verify whether an essentially verbal code might underlie Categorical Perception. However, verbal suppression paradigms have been applied to native English speakers with results in accord with a verbal code[23]. In the study, the advantage for cross-category judgments was examined in the same recognition memory paradigm used with the Berinmo. In this case a short interval (5 seconds) was inserted between presentation of the target and test items. This interval was either unfilled, or filled with either visual or verbal interference. Without interference, there was no effect of a 5 sec. interval, and the superior recognition for pairs of stimuli that cross the category boundary was observed. In the visual interference condition, performance on both within and cross-category pairs of stimuli deteriorated significantly, but the advantage for cross-category discrimination remained. Only verbal interference removed the cross-category advantage (see figure 2). This suggests that, even for English speakers, the discriminatory peak at the category boundary, which is the hallmark of Categorical Perception, results from the verbal coding of stimuli and not, as has been suggested, from low level perceptual categorization.

4. NEUROPSYCHOLOGICAL EXPERIMENTS

Finally, language impairments have been shown to make perceptual categorization including color categorization very difficult in a patient (LEW) with normal color vision, who had no difficulty in recognizing and interacting with objects. LEW showed marked difficulties in naming colors (2/10), making some gross errors (blue called "red", red called "yellow") and comprehending color names, and experienced great difficulty in sorting colors into groups[24]. In the absence of color names it appeared that LEW was reduced to sorting colors by perceptual similarity in a pairwise fashion, which led him to form extremely large categories encompassing a number of basic categories (e.g. pink, yellow, pale green, pale blue and light purple all grouped together).

5. CONCULSIONS

These three lines of evidence, the cross-cultural findings, the neuropsychological case and the findings of verbal interference effects in normal English speakers converge on the conclusion that for color, as for other types of human categorization, language and cognition are inextricably linked. This does not imply that language must drive cognition, it may merely reflect it. What it does imply is that, for those cultures whose language contains fewer than eleven basic color terms, these genuinely reflect the cognitive categories of the speakers of that language. Nor does the argument for the linguistic and cultural relativity of color categories necessarily lead to an open-house. There are constraints on color categorization linked to the properties of the visual system. The most important of these constraints is that similar items (as defined by perceptual discrimination) are universally grouped together. Thus, no language would exhibit categories that include two areas of color space but excludes an area between them[17]. Grouping by similarity can explain (for example) why there is no language category that includes yellow and blue but excludes green. There is simply no associative chain of similarity that could connect yellow to blue without passing through green. Within these constraints, color categorization appears to be linguistically and culturally relative.

ACKNOWLEDGEMENTS

This work is supported by Economic and Social Research Council Grants R0002367-50 and R0002383-10.

REFERENCES

1. Heider, E.R. & Olivier, D.C. "The structure of the color space in naming and memory for two languages." *Cognitive Psychology* **3**, 337-354, 1972.
2. Heider, E.R. "Universals in color naming and memory." *Journal of Experimental Psychology* **93**, 10-20, 1972.
3. Whorf, B.L. "The relation of habitual thought and behavior to language." In *Language, Thought and Reality: Essays by B.L. Whorf*. J.B. Carroll (ed.) Cambridge: M.I.T. Press, 1956.
4. Ray, V.F. "Techniques and problems in the study of human color perception." *Southwestern Journal of Anthropology* **8**, 251-259, 1952.
5. Brown, R. & Lenneberg, E. "A study in language and cognition." *Journal of Abnormal and Social Psychology*, **49**, 454-462, 1954.
6. Lenneberg, E.H. & Roberts, J. "The language of experience: A study in methodology." *Memoir 13, Indiana University Publications in Anthropology and Linguistics*, Baltimore: Waverly Press, 1956.
7. Berlin, B. & Kay, P. "*Basic color terms: Their universality and evolution.*" Berkeley: University of California Press, 1969.
8. Kay, P. & Kempton, W. "What is the Sapir-Whorf hypothesis?" *American Anthropologist* **86**, 65-78, 1984.
9. Saunders, B.A.C. & van Brakel, J. "Are there non-trivial constraints on color categorization?" *Behavioral & Brain Sciences*, **20**, 167-178, 1997.
10. Zeki, S. "Color coding in the cerebral cortex: The reaction of cells in monkey visual cortex to wavelengths and colors." *Neuroscience* **9**, 741-765, 1983.
11. Yoshioka, T., Dow, B.M. & Vautin, R.G. "Neural mechanisms of color categorization in areas V1, V2 and V4 of macaque monkey cortex." *Behavioral Brain Research*, **76**, 51-70, 1996.
12. Russell, J.A. "Is there universal recognition of emotion from facial expression? A review of the cross-cultural studies." *Psychological Bulletin*, **115**, 102-141, 1994.
13. Gumperz, J.J. & Levinson, S.C. "Rethinking linguistic relativity." *Current Anthropology*, **32**, 613-623, 1997.
14. Levinson, S.C. "Language and space." *Annual review of Anthropology*, **25**, 353-382, 1996.
15. Gennari, S.P., Sloman, S, Malt, B. & Fitch, W.T. (2000) "Motion events in language and cognition." *Proceedings of Fourth International Conference on Thinking, Durham, UK*: British Psychological Society, Cognitive Section (2000).
16. Roberson, D., Davidoff, J. & Shapiro, L. "Squaring the circle: The cultural relativity of good shape" (submitted), 2001.
17. Atran, S. *Cognitive foundations of natural history*. New York: Cambridge University Press, 1990.
18. Berlin, B. "Ethnobiological classification." In E. Rosch & B.B. Lloyd (Eds.), *Cognition and categorization* (pp. 9-26) Hillsdale, NJ: Erlbaum, 1978.
19. Rosch, E.H. "Probabilities, sampling and ethnographic method: The case of Dani color names." *Man*, **7**, 448-466, 1972.
20. Roberson, D., Davies I. & Davidoff, J. "Color categories are not universal: Replications and new evidence from a Stone-Age Culture." *Journal of Experimental Psychology: General*, **129**, 369-398, 2000.
21. Goldstone, R. "Influences of categorization on perceptual discrimination." *Journal of Experimental Psychology (General)*, **123**, 178-200, 1994.
22. Goldstone, R.L. "Perceptual learning." *Annual Review of Psychology*, **49**, 585-612, 1998.
23. Roberson, D. & Davidoff, J. "The categorical perception of colors and facial expressions: The effect of verbal interference." *Memory & Cognition*, **28**, 977-986, 2000.
24. Roberson, D., Davidoff, J. & Braisby, N. "Similarity and categorization: Neuropsychological evidence for a dissociation in explicit categorization tasks." *Cognition* **71**, 1-42, 1999.
25. Kay, P., Berlin, B. & Merrifield, W.R. "Biocultural implications of systems of color naming." *Journal of Linguistic Anthropology*, **1**, 12-25, 1991.

The Russian Avant-Garde and Colour as Worldview

Margareta Tillberg, Stockholm University, Sweden
Department of Art History

Members of the Russian Avant-garde were initially eager to participate in the revolutionary reconstruction of a new socialist paradise. This Utopia was to be painted in bright colours. In their "Decree No. 1 - Making the Arts Democratic", Futurists among them such as Mayakovsky declared that the art should abandon the vaults and palaces and that - "Colours should pour through the streets and squares like multi-coloured rainbows, from house to house, and delight and dignify the eyes of passers-by."

What they felt was that you could use art to commence changing the world. The whole enormous country needed to be reconstructed. Terms like "new" and "fast" were the key-concepts. The old, odorous, decadent, bourgeois remnants were to be destroyed, and like the bird of Phoenix a New Socialist Brotherhood would rise up from the ashes. In order to rebuild after the czar's realm, a fruitful cooperation of art, craft and industry was to produce standardised and simple but beautiful everyday objects.

Based on the cubist economical expression of volume and space, Constructivism was developed at the newly founded institutes for art, theory and architecture in Moscow. Here the "Artist-Philosopher" formulated proposals for new designs, to be accomplished for the people by the "Artist-Engineer". Here, Wassily Kandinsky worked at the start of the twenties on his Art Synthesis, with colour as an important component, before he left to teach what was termed the "objective fundaments" of colour and form at the Workshop for Wall-Painting at Bauhaus in Germany between 1922 and 1933. Although his name was not further mentioned in his homeland, his ideas nevertheless continued to influence the colour debate in Soviet Russia. In this paper, however, I will be concentrating on Leningrad rather than Moscow.

In Leningrad in the 1920s intensive colour research was made at "The State Institute of Artistic Culture" - GINKhUK, led by Kazimir Malevich the originator of the abstract painting "Black Square". Here, a basis for a union of art, science and practical application was developed. In the "Department of Organic Culture", the so-called "Laboratories for Colour and Form" were supervised by the musician, composer, painter and colour theorist Mikhail Matiushin (1866-1934) who in 1932 achieved publication of *Zakonomernost' izmeniaemosti tsvetovykh sochetanii. Spravochnik po tsvetu.* ("The Laws Governing the Variability of Colour Combinations: A Reference Book on Colour"). [1]

Different worldviews produce different colour perception. In the preface to the Colour Handbook, having what is called a "worldview" is pointed out as fundamental to the understanding of any colour concept. Worldview is a translation from the German Weltanschauung, which figuratively indicates an individual's understanding of the world, and which determines that person's artistic production. Literally, it means the concrete way of looking at the world. So how did Matiushin look at the world?

From the Colour Handbook we learn that all observations which led to the
establishment of the colour charts were carried out with so-called "extended vision", a combination of foveal vision sensing colours and sharp contours in daylight, and peripheral vision of the retinal periphery sensing light, darkness and motion in dusk conditions. Today we would talk in terms of the parvo and magno systems.

Matiushin's expanded vision was however extended to cover a full circuit of 360°. To give his students practice, he used to take them to the embankments of the Neva River opening into the Gulf of Finland, where they sat with their backs towards the river while painting it, much to the astonishment of the passers-by.

Translated into colour-application, a panoramic radial vision was closer to suiting the real needs of colour-designers in particular than the use of tiny colour-samples. Other factors adding to the complexity of colour design, for example movement of the perceiving subject and the changing of light conditions, were problems that would be solved once "extended vision" was mastered.

---

[1] John Gage incorrectly places Matiushin in Moscow, see *Colour and Meaning*, Thames and Hudson, 2000 p. 248.

9th Congress of the International Colour Association, Proceedings
of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

In addition to money-saving practical applicability for industrial purposes, Matiushin's worldview did however have other aspects that were not mentioned in the Colour Handbook at all. But when his archives with unpublished material are studied, the colour philosophy appears in an altogether different light. In order to be able to produce a comprehensive picture of Matiushin's colour theory, or - as it may be called - colour philosophy, I have spent almost two years in Russian archives and libraries studying the original sources.

From Matiushin's unpublished texts we learn that the fundamental concepts of his worldview were called "Organic Culture" and "Spatial Realism", which were also the names of the workshops he supervised as a "red professor". Matiushin developed a training programme with different exercises, including yoga and meditation, designed - and I quote - "to create and develop the artist and the artist's new physical possibilities of perception", termed "extended", "amplified" or "expanded vision". This new kind of vision included not only the eyes, but was expanded to include hearing, tactility, and thinking. Bodily organs and senses should be cultivated and synchronised into an organic whole, comparable with a form of consciously developed synaesthesia. In the laboratory, experiments were made on the colourinteraction, colour and form, colour and sound, colour in motion and colour perception without using the eyes.

Those who mastered the "extended vision" could switch from one mode of perceiving reality to another; from "normal" to "extended". In this new spatial reality colours would appear more intensely than in our normal, physical world. The connections between the objects would become visible and as a consequence, the person seeing would become organically at one with the universe. This new "spatial realism" was also called the "fourth dimension" and expanded vision equals expanded consciousness.

Fuelled by the new technique of x-ray photography which made solid bodies look transparent, people began to realise that the universe was not necessarily made up of matter at all, but could be energy. The borders between what was perceived as static or dynamic, solid or fluid, and between the material and the immaterial dissolved.

When Maxwell discovered light to consist of electromagnetic rays, forces that earlier had seemed unconnected were now shown by the new physics to be "waves" or "vibrations": light-waves, radio-waves, sound-waves of music, radioactive waves, gamma waves and electromagnetic light-waves giving rise to the colour spectrum. This of course created a vivid image of the universe as a pulsating whole for numerous artists of the time, such as Kupka, Mondrian and Duchamp, many of whom gained inspiration from theosophical and anthroposophical mystics such as C.H. Hinton, P.D. Ouspensky and G.I. Gurdjieff.

Different vibrations gave the elements their different characteristics. By those who mastered expanded vision, and thus could perceive the highest dimensions, these different frequencies would be perceived as the one unified motion. They gained the ability to SEE all these waves moving with different frequency, to embrace all different speeds of motion simultaneously. With untrained eyes inorganic objects for example would seem 'dead', immobile, static. In the fourth dimension, however, it would be possible to see the low frequency waves of solid materials like stones and minerals. With cars at one speed, people at another, trees growing at yet a third speed, to the untrained eye the world appears scattered and fragmented.

Matiushin describes this in his still unpublished autobiography from 1934 - the year in which he died - as follows: "The task I put to my workshop was to create a new image of nature, as a flow of matter linked together, with degrees of volume, colour, growth, weight and form in constant flux. Nature does not allow nor give reason for static observation, and should not merely be used as an excuse for making crude deductions from torn off fragments of time and space. It is impossible to draw a person, an apple, a table, a tree, a street separately - everything is connected [...] Motion is life! [...] and we ourselves are vibrating instruments, finely tuned by nature itself to a degree of perception which responds to the visible forms. Our organism vibrates constantly [...] via our nerve system, and with new sensations, more and more complicated images are transmitted."

In Matiushin's expanded vision - the very flow of energy that passes between objects would unify the image of the world. Seen from the perspective of Matiushin as colour theorist, I interpret this vibrating energy as the appearance of complementary coloured after-images, emerging as the visible 'proof' of an existing 'adhesive' between the objects. Matiushin was interested in a higher reality of which he believed the afterimages to be the first indication, floating between the objects as visible vibrations.

What were the consequences for Matiushin of working in the Soviet Union of Stalin? From the 1920s onwards, research on colour was controversial in the Soviet Union. Why?

According to Dialectical Materialism, the Marxist-Leninist State Philosophy, "objective reality" exists whether we are aware of it or not. This meant that the class-struggle, which was described as an "inevitable" stage in the "objective historical evolution", would take place whether you or I were to take part in it or not. But within colour research this caused tremendous problems, because as we all know, colour exists only in the eye and the mind of the beholder. Mental processes, including consciousness, were not allowed to be anything more than a simple mirroring of the physical world. Thus, within officially-sanctioned materialism even the elementary transformation of a red stimulus into a luminous turquoise-green, illusory-like after image, was problematic. Firstly because it was the result of processes within the individual, thus "subjective" and therefore bad, and secondly, because it was not a material surface colour which - as was said - "belongs to the object" and was therefore not possible to explain as existent in the real external world. This paradoxically meant, that stimuli were politically accepted, but percepts not.

Matiushin's Colour Handbook was one of the last manifestos from the Russian Avant-garde. It passed censorship thanks to the omission of many controversial ideas - and a great deal of luck. Matiushin succeeded in publishing the Colour Handbook two years before his death, but it presented only a tiny part of the research on colour vision he produced during his lifetime. Four hundred copies were published in Moscow and Leningrad in 1932, the same year that the Central Committee of the Communist Party took measures to centralise all art organisations, which eventually led to Socialist Realism becoming the only prescriptive method in all fields of culture until the beginning of the 1990s.

After his death, Matiushin's findings were stored away in archives and were largely forgotten as a result of the political circumstances in which they were conceived. [2]

Matiushin was not however simply an outsider. For he believed that achieving the ability of expanded vision would cause anatomical changes, and these could be passed on to coming generations by heredity. With this belief he was very much part of the Great Communist Project to create a new human species - Homo Sovieticus. Colours were allowed to exist on the objects in the so-called 'real' world, and were given symbolic content stipulated from above and cheered on by the masses. Yet in the middle of the masses thronging amongst bright red flags blowing under the sunshine in the fresh communist wind, Matiushin's New Soviet Man was capable of perceiving their green counterpart. And such individualism in an era of compulsory collectivism was unthinkable, indeed, even criminal.

---

[2] In the doctoral dissertation I am currently writing at the Department of Art History, Stockholm University, Sweden, I position Matiushin in the context of the increasing ideological pressure of the 1920s, linking him to the reconstruction of all educational institutions within all fields of culture which took place after the Bolsheviks assumed power under the slogan "art unto the people". My inquiry deals with the debate on art, science, design, architecture, aesthetics and experimental psychology of the time, with perspectives on contemporary colour theories both inside and outside Soviet Stalinist Russia.

The Pluralist Framework for Colours

Barry Maund
Department of Philosophy, University of Western Australia

ABSTRACT

The visual world, the world we see, is a world populated by coloured objects. Central to any adequate theoretical account of colour is a theory of how these colours are experienced. The best theory of colour experience, I have argued previously, is an Illusion theory: objects are represented in colour experience as having colours that neither they nor any physical object actually has. We cannot, however, be content with this conclusion which comprises a negative thesis. We need to go on and ask how we should think of colours. For some purposes, e.g. for most practical purposes, the answer is that we should think of colours in the same way as we always did. For some purposes, e.g. theoretical and philosophical purposes, however, we need to develop a more comprehensive account. In principle, we should expect to develop a pluralist framework for colours, one that has room for a range of different, but related, colours.

Keywords: colour concepts, pluralist, dispositional concept, objectivist concept, appearance.

1. INTRODUCTION

The visual world, the world we see, is a world populated by coloured objects. Typically, we see the world as having a rich tapestry of colours _ of coloured forms _ fields, mountains, oceans, hairstyles, clothing, fruit, plants, animals, buildings, and so on. Despite the centrality of colour to the visual world, and despite much thought, however, by philosophers and scientists, over hundreds of years, we seem little closer now to an agreed account of colour than we ever were. The disagreement is reflected in the fact that some theorists believe colours to be dispositions or powers to induce experiences of a certain kind. Others take them to be objective, physical properties of objects: either physical microstructures, or as sui generis irreducible properties of physical bodies, or yet again, as dispositional properties to affect light, in various and complex ways. Others take colours are subjective qualities, intrinsic to our subjective experiences. Finally, there are even some who deny that there are colours in the world at all: there are none of the colours, it is claimed, that we naturally and normally and unreflectingly attribute to objects.

Is it possible that these different theorists are not talking about the same thing? Could it be that more than one of them is right? Leon Hurvich begins the second chapter of his *Colour Vision* by first asking 'What is color?' and then asking a series of questions: Is colour something that inheres in objects themselves? Is it related to the light falling on an object? Is it a photochemical event that occurs in the receptor layer of the eye? Is it a neural brain-excitation process? Is it a psychical event? Hurvich's answer is 'Colour is all these things.'[1] I don't know that I would wish to defend such an ecumenical view as that presented by Hurvich. Nevertheless, I think he is right in suggesting a pluralist framework for thinking about colour. It is possible, I shall argue, to construct a pluralist framework in which there is a place for a range of concepts of colour, concepts that are different but systematically related.

2. THE CENTRALITY OF THE NATURAL OR FOLK CONCEPT OF COLOUR

It is not just that they have a central role to play in our visual world that colours are significant. An important part of their significance lies in the purposes they serve, in our social and personal lives, through being a central part of that perceived world. Two roles stand out. First, colours are important as part of 'practical epistemology', i.e. as signs for the identification and re-identification of physical objects, serving both as natural signs and as social, conventional signs, e.g. as badges, uniforms, for ceremony etc. In addition, they may also be said to have a 'life of their own'. That is, they are used in social life to amuse, to entertain, to delight, to shock, to impress, to astound, to warn, to attract, to be enjoyed, and so on, in contexts having to do with pageantry, ceremonial, courtship, painting, lighting, plays, clothing, dining, drinking, and so on. Simplifying, we use colours as signs, natural and conventional; we use colours emotionally and aesthetically.

It is because we use colours for such a variety of purposes, that there has developed a flourishing colour vocabulary, and a set of conceptual practices, linguistic and non-linguistic, pertaining to colour. Accordingly, it is possible to identify what we might call 'the folk concept', or alternatively 'the natural concept', of colour, a concept embedded in the

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) · 0277-786X/02/$15.00

conceptual practices in which the folk, i.e. all of us, engage. The folk/natural concept is the concept of a certain kind of property: one that the perceiver's perceptual colour experiences represent objects as having, one that is captured by the colour language that natural language-users employ and so on. The centrality of the folk concept (natural concept) reflects an important point about colour. We the folk who employ the folk concept of colour are experts with colour. Colour experts are not just those who study colour in a scientific way, nor those who paint in colours, nor those who are industrial chemists.

3. THE ILLUSORY NATURE OF COLOUR EXPERIENCE

Our visual experiences are experiences which have a certain content: they represent objects such as fruit, lips, hair, oceans, skies, etc as having colours. The best theory of colour experience, as I have argued previously, is an illusion theory: that the colours objects are represented as having, are not actually possessed by the objects in question.[3] The argument for the illusory nature of colour experience is as follows. The content of our visual experience is given by means of the folk/natural concept of colour. That concept, on the face of it, identifies a certain property, or group of properties, possessed by physical objects in the world. Built into the concept, however, are certain constraints. Given those constraints, it turns out that there are no actual properties in the world that actually satisfy them.

According to this concept, colours are properties of a distinctive kind. They are, at a minimum, properties which satisfy the following constraints (principles):

1. Colours are intrinsic features of physical bodies, whose nature is manifest.
2. Colours are sensuous, intrinsic (i.e. non-relational), perceiver-independent properties of objects.
3. Colours have a causal role, vis-a-vis the perception and identification of specific objects as red, yellow, blue, and so on; and with their use as paradigm examples in teaching colour language;
4. Colours can be arranged systematically in ordered arrays. Colours are properties that as a group, form an internally-related 4+2 structure, built on the four unique, primary hues: green, red, blue and yellow, and related to the black/white pair. That is, a set of internal relationships hold between the range of colours.

Once we have specified the folk/natural concept in this way, however, an important consequence emerges. It turns out that there are no properties which satisfy these requirements. In particular, there are no colours that are intrinsic, non-relational, perceiver-independent properties and which are sensuous and satisfy the requirements of the three-dimensional colour solid. None that is, that allow us to make sense of the way in which we perceive and identify and recognise colours.

Colours, as conceptualised by the folk, are virtual properties, in the way that caloric and phlogiston were virtual natural kinds (or natural principles). This thesis may seem paradoxical in view of the fact that, as I have insisted, colour perception is an integral part of visual perception. The paradox is only apparent. The point about colour illusions is that they are not only beneficial, but are highly so. For most practical purposes, i.e. the practical-epistemological and social purposes mentioned above, it does not matter that colours are virtual properties. For even if physical objects do not have colours, they have significant dispositional properties: they have the disposition to appear in the way characteristic of colours. It is as if they have the colours. For most purposes, it is sufficient that objects appear to have the properties in question; they do not need to really have them. Moreover, given that our interests in colour are mainly tied up with their practical-epistemological and social uses, then even if colours were real, they way they would serve these purposes would be by appearing in their distinctive ways.

4. A PLURALIST FRAMEWORK

It is one thing to point out that the folk concept contains an illusory element. It is another to say how we should proceed in our future thinking about colour. We need, that is, to develop an account that prescribes how we should, in the future, think about colour, at least in general terms.

When someone perceives a coloured object as coloured, then there occurs a very complex process, whose details, at least in general terms, are well-known. The perceiver is causally affected by some physical object O, which has a physical texture (broadly understood), by virtue of which, either the object emits light, or the object interacts with incident light, modifying it in some way, either absorbing it, reflecting it, or transmitting it (differentially). The perceiver is affected in a variety of physiological means, e.g., retinal stimulation, neural activation, and in psychological ways, i.e., the object appears in a way characteristic of each colour. Summarising, there are the following distinctive aspects (concentring on surface colour) that are important for the perception of colour:

1. The physical texture;
2. The light pattern at surface of object O;
3. The light pattern at distance from O;
4. The retinal stimulation;
5. The neural activation pattern;
6. The appearance in way distinctive of colour.

In other words, a given physical texture is associated with a variety of different dispositional properties: causal powers which under the right conditions, are exercised in their various ways. (There are different types of dispositional properties, come more complex than others. Some are defined in terms of the object's relative contribution to the physical quantity, relative to some standard background.)

Given the range of aspects described above, there is no reason in principle and in the abstract why we should not have a range of colour concepts and properties corresponding to some or all of the aspects above. The situation might be such that the same colour term, 'red', 'blue', etc. can be used to apply to each aspect. That is to say, there might be a systematic ambiguity as there is with the property of size. One can, for example, speak of a rabbit's intrinsic size or its angular size, relative to the distance from which it is viewed. As far as angular size is concerned, we can also distinguish between two types: geometrical and optical, the first dealing with geometrical angles and the second with light rays. Mostly these angular sizes are the same, but they will be different in some situations, e.g., if light rays pass through a refracting medium.

Adopting Hurvich's suggestion (see Introduction), we might characterise these different types and properties (mostly dispositional properties) as types of colour, but if we do, what makes us call each of them (any of them) a type of *colour*? To help answer that question, let us consider the situation with standard scientific reductions. When scientists traditionally have employed scientific reductions, e.g., when they have identified a property such as temperature of a gas, with average kinetic energy, or light with electromagnetic radiation from a certain range of the spectrum, the reduction makes certain assumptions about the pre-existing concept, say of temperature:

1. It conceptualise temperature as a property that is associated with a certain range of causal powers;
2. It takes temperature to be identical with that property that is the causal basis of those causal powers (usually a microstructural basis).

Both assumptions may involve replacing the pre-existing concept with a new concept, in terms of which the reduction proceeds. The justification of this process rests on whether or not important causal powers are being ignored. The scientific reduction, in other words, assumes a certain model for how the concept operates. There are, however, other possible models. Take solidity, for example, which is associated with such powers and capacities as relative impenetrability, stability of a certain kind, capacities to resist, and so on. There are different models for how the concept might work. On the model above, solidity would be conceptualised as 'that property which is the causal basis for the causal powers.' There are, however, other models available. One is that the property, e.g., solidity, is a mixed dispositional property, either the property of having *some* intrinsic structure whereby the object has the relevant capacities and powers, or alternatively, the property of having *a certain* intrinsic structure whereby the object has the capacities and powers. We may compare the three models as follows:

1. solidity = that intrinsic structure, whatever it is, that is the categorical base for the causal capacities and powers: relative impenetrability, stability of a certain kind, capacities to resist, and so on.
2. solidity = the property of having *some* intrinsic structure whereby the object has the capacities and powers.
3. solidity = the property of having *a certain* intrinsic structure whereby the object has the capacities and powers (where what the structure is may be further specified).

Only with the first model do the standard reductions work. It may be that, for some properties and natural kinds, this model is appropriate, but for many properties the second model seems the right one: solidity, solubility, elasticity.

In the case of colours, adopting the first model would commit us to saying that the reductionist account of colour requires identifying colour with the corresponding physical texture. However, if there is a wide range of causal powers associated with colour, there may be value in dividing up that range of causal powers and associating some of them with certain physical dispositions, and others with other dispositions. Take colour constancy, the phenomenon that that surface colours appear the same under a wide variety of illumination constancy. That phenomenon seems allied to reflectance profiles. But while certain features of colours can be accommodated in that way, others cannot. For example, the fact that colours as a collective group, can be ordered into a 4+2 systematically ordered array, characteristic of the various colour systems, e.g., NCS, is not explained on the reflectance model. To accommodate such features we need to concentrate on other dispositions, e.g., the disposition to affect the perceiver's opponent-process channels in the right way, or better, the disposition to appear in characteristic ways.

To argue in this way for the place of a number of concepts of colour, and for the possibility of an objectivist concept, to supplement other concepts of colour, is to argue for a pluralist framework for colours. This framework has the advantage of allowing a place for an objectivist concept of colour, proposed by F. Jackson (1998: Ch.4), while not making it mandatory.[3] Likewise, it allows a place for the ecological concept of E.Thompson (1995: Ch. 5).[4] But if we do characterise these different types and properties (mostly dispositional properties) as types of colour, what makes us call each of them (any of them) a type of colour? What reason is there for identifying each of them as a type of colour? In part it is the inter-connection between the causal powers and the causal basis. In important part, however, it is because of the central role of one concept: a dispositional property which is tied to the *appearance* of colour, i.e., a psychological concept.

There are two reasons why the disposition defined in terms of appearance is important. The first is that while there are certain causal powers and causal relationships that colours enter into, the most significant features of colour are tied up with the way colours appear, i.e., with the dispositions objects have to *look* blue, or *look* yellow, or *look* red, and so on. It is because of the way colours appear that they are important to us both biologically and socially. It is because colours have a characteristic appearance that: the colours can be ordered systematically in colour arrays; they have emotional effects; principles of harmony and contrast apply; there are principles governing phenomena of colour contrast. It is true that physical features both of physical objects and of retinal cells contribute causally to these phenomena, but central to all of these colour principles is the way colour appears. There is an additional reason for requiring dispositional colour that is tied to appearances. Physical surfaces, in the main, have distinctive ways of appearing, ways differing from those for volumes and films and light sources, and so on. Nevertheless they are all modes of appearing for colour. What makes them all examples of colour can only be understood in terms of them as being related to appearances. The account that makes most sense of these modes of appearance is the dispositional account, one that unites these ways of appearing into dispositions to appear.

The underlying point here is that the way colours appear is central to any account of what colours are. An account of colour that takes us away from how things appear to competent observers is an account of something else. Thus, without the dispositional concept tied to the colour appearances, the Pluralist Framework dissolves.

The dispositional concept, it should be noted carries with it several other concepts, but in different ways. Blue$_D$ objects (objects that are blue in the dispositional sense) are objects that have some feature by virtue of which they look as if they are blue, i.e. blue in the intrinsic sense, i.e. blue in the virtual-colour sense. The content of the dispositional concept thus presupposes the folk concept (or natural concept) of colour. This means that there is point in retaining this concept, even when we come to know that no objects have the property. The fact that I do not believe that this property of intrinsic blueness is ever instantiated does not mean that I should give up the concept, any more than disbelievers in Satan should give up the concept of satanic. We need a further concept, to explain how it is that the natural concept takes the form that it does, and in particular how it conceptualises colour as sensuous qualitative features of physical objects. This set of features is important since it contains the basis for the structure that underpins the various colour systems for ordering colours. To explain why the folk concept has this character, we need to introduce a phenomenal concept of colour, i.e., a concept of colour as subjective, qualitative feature of one's experience. In this way we can explain the illusory nature of colour experience.

5. CONCLUSION:

It has been argued in this paper that we should develop a pluralist framework for colours, one that has room for a range of different, but related, colours. It has also been argued that a certain psychological concept, the disposition to appear, is central to the pluralist framework. Within this framework there is room, in principle, for objectivist concepts of colour. Whether we have objectivist concepts or not, we need to provide an account of how colours appear.

REFERENCES:

1. L. Hurvich (1981), *Colour Vision*, Sunderland: Sinauer.
2. B.Maund (1995), *Colours: their Nature and Representation*, Cambridge: Cambridge Univ. Press.
3. F. Jackson (1998), *From Metaphysics to Ethics*, Oxford: Clarendon.
4. E. Thompson (1995), *Colour Vision*, London & New York: Routledge..

Semantics of color in chromatism

Nikolai V. Serov, Dept. of Psychophysiology, State Institute of Psychology, Saint-Petersburg, Russia*

ABSTRACT

The aim of this investigation is to describe the semantics of color in chromatism (from the ancient Greek triune notion of «chroma»: 1. color as ideal *(Id-plan)*, psychic; 2. tint as physical, verbal; material *(M-plan)*, physiological, syntonic *(S-plan)*, and 3. emotion as their informative-energetic correlation). Being a new field of science, chromatism links humanitarian and natural subjects by means of interdiscipline investigation of a real (f-m) man living in a real (color) surrounding environment[1]. According to the definition for «chroma», color may be considered to be the most universal notion, permitting to assume the unity of both a man and an environment. Due to this assumption, we may give models of human intellect.

Keywords: Color model of intellect, canons, gender , color codes, dimension

1. INTRODUCTION

Intellect is thought to be the complex of conscious and unconscious psychic and psychophysiological functions. So, it is a notion linked with a personality, with psychic in psychology and consciousness in philosophy. In chromatism these notions were combined in a single triad. Its existence is supposed to be based on description of a human spirit during long history of thousand years. Intellect functions are designated as a triad of plans which enable us to formalize intellect and gender in order to develop a quantitative model of natural intellect (Table 1).

Table 1. Chromatic division of intellect

Intellect functions	Unconsciousness	Subconsciousness	Consciousness
Intellect plans (MIdS)	S-plan	Id-plan	M-plan
Etymology of plans	ευγγενες – relationship	ιδεα – idea	μαθημα – knowledge
Predicates of intellect being a system open to outer environment (OE)	natural, basically organic, biological	cultural, figuratively logic, creatively human	social, formally logic, socially conditioned
Thinking (from sensation to thought)	intuition, temporary insanity, sensation	emotion, feelings, perception birth of ideas	shape, notion, realization of ideas in objects
Structural dynamic localization of functions	cerebral trunks and subcortex	right hemisphere and subcortex of the brain	left hemisphere and cortex of the brain
Gender dominants	Δ f (S > Id < M)	Δ m (S < Id > M)	Δ f (S > Id < M)
Information coding	spectra OE ⇒ metamers	⇒ aperture color-code⇒	cognitive code of society
Coding results	color sensation	color perception	color designation

2. COLOR CODES

Thus, the principles of transforming color information considered above, enable us to give three principally different codes of generalization. On the one hand, it is often assumed by scientists to interpret realized formally logical unity of «homogenous» objects as a verbalized abstraction on the conceptional level, that is not always representative (colorless). On the other hand, it is the color image that shows the unity of individual-specific (aperture color is concrete, because it shows the color of certain objects, being completely «unlinked» with them) and generalized (aperture color is not concrete, because it contains color characteristics of plenty of objects and their functions are subject not to abstraction by consciousness, but to chromatic generalization, i.e. to sublimation by subconsciousness).

This two-dimensional description of the world may be considered to be first approximation to a real mechanism of information treatment performed by neurons. At the stage, the development of a computer language seems to be quite

 9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) · 0277-786X/02/$15.00

possible. Such language could classify every object using three parameters of generalization simultaneously: achromatic axis of abstraction and volume of color space for sublimates. Visual examples of such codes are given in Table 2.

Table 2. The relationship between abstract and sublimate

Abstract ↓ \ Sublimate→	Red	Yellow	Green	Blue
Fruits	apple	lemon	kiwi	plum
Temperament	choleric	sanguine	phlegmatic	melancholic
Preferable colors *)	m	f	m	m + f
Emotion, sense	passion	merriment	tranquillity	anxiety

*) Preferable colors, dependent of gender, i.e. colors, preferred by women (f) and men (m).

We are speaking exactly about «sublimation», because metamer of unconsciousness is transferred to a more appropriate for chrome-plans aperture code in conformity with libido, being transformed to creative activity. Metamerization of information about environment occurs on unconsciousness level and, as it follows from our experience, it doesn't need any proof. In other words, from the very beginning a mechanism of relationship (between realized transparent and unrealized contests) appeared and was developing in the intellect, that had practically all attributes of a knowledge representation system and could define actual contribution of each of the intellect components in homeostatic processes (Table 3).

Table 3. Color codes in environment-intellect system

Object color	Generalization		Color percepted by intellect (level of generalization)			
Stimulus (kind)	(process)	Percept	Code (concept)		Carrier (result)	Plan*)
red, yellow...	abstraction	color	abstract		color name (term)	M-
blood, fire, berries...	sublimation	red	archetype	sublimate	aperture color	Id-
spectrum of Sun, fire...	metamerization	yellow		metamer	metameric color	S-

*) Formalization of Intellect Model in chrome-plans, see Table 1.

3. CANONIZATION OF COLOR SEMANTICS

According to psycholinguistics data, color designation status is similar to family terminology status. This enables us to suppose systemic-functional relationship between them. In other words, color concepts may contain value, archetypical (very significant, linked with species' survival and gender reproduction) characteristics of a man, nature and society.

Consequently, the development of a family relations' system, that are primary relations in any society, is first and foremost based on a reproductive function. One of the most important conditions of realizing this function is physical and psychic health of future infants and succeeding possibility of their education and socialization. Evidently, this condition may be completely implemented only in case of an adequate choice by themselves of future husband or wife, and this supposes «love» as the interaction of, at least, three components (S-, Id-, M-) in each of their intellects. Their choice is probably empathetically dependent on color (preference, etc.), because it is the archetypically fixed concept, which simulates basic intellect components for them in order to achieve tight connection, i.e. mutually dependent survival of individuals (recreation, etc.) and species reproduction (healthy generation).

According to Plato («State», 617 c), the Gods divided time into the past, present and future. In such a case, the present is associated with the right arm, while the future is associated with the left arm. Practically all traditional cultures associate «right» with something that is correct (true, just et c.), while «left» is something unknown, incorrect, unintelligible, frightening, because unknown future seems frightening and unintelligible for a man, similar to «black» and «left». Actually, the dark of the night often scares a man not less than the dark of the future, while in the past (as in the right hand of the Goddess or in the white color) everything was clear, definite, real. Apropos of this, Fromm [3] wrote that clearness is associated with the past only, while about the future we only know that some day will come, bringing us death. When comparing above mentioned relation between time periods and color sublimates, we may come to the final conclusion; future = black, present = grey, past = white.

Semantics of color turned to be related with gender, cultural-sexual dimorphism of a man [3]. Thus, chromatic analysis of green and purple, that are very differently interpreted by the researchers, showed that green defines archetypical features of male selfconsciousness (Osiris, YAN), while purple is the characteristic of female superconsciousness (Sophia, Virgin Maria) [3] (Table 4).

Table 4. Canonization of color semantics in world culture

Color	Canons (gender-sex, time)	Traditional Cultures	Intellect	MIdS*)
white	female, IN: tradition, the past	Ancient Egypt, China, India	Consciousness	ΔM
grey	male (red+green): creative work	Ancient Egypt, China, Iran	Subconsciousness	ΔId
black	female, IN: birth, the future	Ancient Egypt, China, India	Unconsciousness	ΔS
red	male body (Gods), YAN	Ancient Egypt, Greece, China	Male unconsciousness	ΔS(m)
yellow	female body (Goddesses), IN	Ancient Egypt, Greece, China	Female unconsciousness	ΔS(f)
green	male, Osiris, YAN, seed	Ancient Egypt, China, Israel	Male selfconsciousness	ΔM(m)
azure	female, IN, «Virgins' hearts»	Ancient Egypt, China, Inkis	Female subconsciousness	ΔId(f)
violet	male, Vishnu, Lel	Ancient Egypt, India, Russia	Male subconsciousness	ΔId(m)
purple	female, Sophia, Mother's virtue	Ancient Israel, Bysantia, Russia	Female superconsciousness	ΔM(f)

*) Functional-dynamic model of Intellect MIdS and gender MIdS(f-m); Δg(f, m) are gender dominants of components in intellect, when living conditions are normal (not extreme).

4. SEMANTIC UNIVERSALS OF COLOR

On the other hand, according to A. Wierzbicka [4], it is the objective natural phenomena (red - fire, yellow - sun, etc.) that must be thought to be basic color universals or, in other words, universal denotata of color designation. Such disregard of subjective (psychophysiological) factors appeared to be based on absolutization of such concepts as ideal and material. To illustrate this, «external» and «internal» color universals, obtained by the author, are given in Table 5.

Table 5. Semantic universals of color (UC)

UC	External according to A. Wierzbicka		Internal according to N. Serov	
Color	Light, time, season	Objects	Color, time-periods, space*	Subjects (time f-m)**
white	daytime, winter	light, clouds	«bygone days», the past, top	M-plan (f)
grey	late evening, twilight	mist, sky	«imperceptible», the present, centre	Id-plan (m)
black	night	earth, water	«frightening», the future, bottom	S-plan (f)
red	fire in the night	sun, blood	«night guard», active ⇒ S(m)	forestall
orange	sunset, autumn	moon	left, S(m) + S(f) = S(n)	less ↑
yellow	fire in the afternoon	sun, yolk of egg	female «the warmth of the day» ⇒ S(f)	the least ↑
green	summer	verdure	near, «now», «I-conception» ⇒ M(m)	adequate
azure	sky in the spring	sky in the North	«lady's novel», passive ⇒ Id(f)	is late ↑
blue	sky in the evening	sky in the South	right, Id(f) + Id(m) = Id(n)	less ↑
violet	sky in the night	storm	elite, stars ⇒ Id(m)	the least ↑
purple	sky in the morning	dawn, berries	far, Homeric Eos (Goddesses) ⇒ M(f)	adequate

*) Orientation in color space (color solid).

**) Letters f and m signify dominant character of «female» and «male» gender properties, simulated by the color, given in the line. Simultaneously, this color manifests these properties (mentioned in the text) in time.

Indeed, generally adopted parameters, essential for survival (for both species and an individual), were consolidated philogenetically. Taking into account correlation between designation of family relations and color, we may assume that color concepts (including internal and external colors of «prototypes») are fixed in intellect for adequate homeostasis. The latter are probably defined by Goethe's Harmony Law (principle of complementarity for color components): to achieve harmony or, in other words, a stable system, partners unconsciously tend to possess each other and/or their complementary «colors» in differently termed components of intellects, and/or identical «colors» in components of the same name.

Our conception helps to understand better the sense of known B. Russell's paradox [5] («logic incompatibility of red and blue colors»). And, indeed, as it follows from Table 5, concept of red color, first of all, simulates «physiologically male sexual» unconscious component of intellect, that is really hard to be matched with «blue union» (f + m = n) of male and female subconsciousness in their «love for the God». Probably, it was necessary to have for analysis axiological aspects, rather than logical ones. This testifies precisely to the internal archetypical characteristics of color, because the use of external «universals» would exclude any paradox: red «sun» in the morning, mist, etc. is quite compatible with blue sky.

5. LIT-DIMENSIONAL SYSTEM IN COLOR SPACE

LIT-dimensional system must be used for actual comparison of chrome-plans in different systems. Here, dimensions *[L]* and *[T]* traditionally describe generalized knowledge about space and time, while *[I]* includes in itself generalized knowledge about information. Sense of *[I]* is defined by the system of analysis, e.g. in outer environment: by mass in mechanics, specific heat capacity in thermodynamics, by a charge in electromagnetism, etc., staying invariant for all branches of knowledge, including humanitarian ones [3], as it is shown in Table 6.

Table 6. Chromatic modeling of complex systems

Dimensions *[LIT]*						Chroma		
Space *[L]*			Information *[I]*		Time *[T]*	Plan	Color	Tint
top (White)	far (Purple)	left (Red)	Consciousness (thesaurus)	Mass m	The past	M	White	con- ti-
center (Grey)			Subconsciousness (percept)	Heat capacity C_v	The present	Id	Grey	nui- ty
bottom (Black)	near (Green)	right (Blue)	Unconsciousness (stimulus environment)	Charge e	The future	S	Black	
Color space			Intellect	Environment	Achromatic axis of color space			

From here it follows that formalization of certain ideas is based on natural property of intellect (MIdS) to treat information automatically (see levels in Table 3-5). This condition is thought to be necessary and enough to derive algorithms for complex developing systems as chrome-plans according to true sense criteria LIT. The lowest line in Table 6 shows that using color space, the systems under investigation (that include humanitarian notion also) can be formalized in codes LIT, MIdS by means of color alphabet percepted automatically.

CONCLUSION

Tint included in triune notion of «chroma» enables to solve problems of continuous character, e.g. quantitative modeling of time by means of certain plans and colors. On this grounds, we can say that dimension *[I]* together with chrome-plans characterize peculiarity of both environment and intellect. Due to this, it's possible to introduce units of measurement for color and intellect common with environment.

Thus, it is shown that both types of description (LIT and MIdS) turned to be mutually complementary, but not convertible contexts. In both types of generalization there are differences in power of contextually dependent versions of language. So, LIT dimensional system enabled us to systematize knowledge among date bases because information distribution in lines and columns, generally speaking, characterizes the components of database management systems.

In conclusion, color space appeared to be a very versatile (chromatic, i.e. interdiscipline) model, that may define properties of outer environment, time periods, gender, and intellect according to the aspects of analysis. Obviously, all said above, explains known polysemantics of color.

REFERENCES

1. N. Serov, *Aesthetics of Color. Methodological Aspects in Chromatism*, (in Russian), Biont, St. Petersburg, 1997.
2. E. Fromm *The Art of Loving*. Sec.1, First Harper Colophon edition published, 1962.
3. N.V. Serov, *Semantics of color in traditional culture*. Thesis D. Cult.(in Russian), Saint-Petersburg State Univ., 1998.
4. A. Wierzbicka "The meaning of color terms: semantics, culture, and cognition", *Cogn. lingv.* **1**, 1, pp. 99-150, 1990.
5. B. Russell *An inquiry into meaning and truth*, p.78, Penguin, Harmondsworth, 1973.

* Correspondence: nv_serov@mail.ru; ul. Shevchenko 3 «B» -11, St Petersburg, 199106, Russia.

What is Color for?

"To inform about objects and their qualities, and to decorate."

David Wright

Color styling in fashion, cosmetics home furnishings and automobiles, color design, color in art, color in architecture, environmental color design, graphic arts, color coding, color in culture

<u>Symposium:</u> What is Color For?

Walch, The aesthetics and commercial value of color*
Stein, Color in home furnishings (Abstract Only)*
Smedal, Color as a language in architecture*
Kinlock, Color and the World Wide Web*

<u>Symposium:</u> Environmental Color Design

Caivano, Oberascher, Report of activities of the ECD study group
Hårleman, Colour appearance in rooms lit by daylight: observation of hue shifts in different compass orientations
Hutchings, Colour contrasts in advertising: facade colours of food and drink consumption venues
Arrarte-Grau, Climate and coloured walls: in search of visual comfort
Anter, What colour is the red house? An invitation for multicultural research on colour and architecture
Habib, Çetinturk, Paint or color? Bursa example
Oberascher, Oberascher, Black: meaning and connotation in Europe and Africa

ECD/Architecture

<u>Oral Session</u>

Herneoja, Use of colour at home during Finland's post-war reconstruction period
Smith, RED or READ: the built environment is coloured
Inagaki, A study on evaluation of exterior colors of foreground buildings
Rizzo, Works on color design installed in an urban environment
Avila, Colour and urban image at the beginning of 21st century

<u>Poster Papers</u>:

Onishi, Ishida, Katsuya, Influence of outdoor advertisement colors on psychological evaluation of townscape in Kyoto
Takahasi, Fujibayashi, Shimonaka, Sato, Analysis of colors used on outdoor advertising in urban landscape: a case study in Osaka City

**** denotes invited papers***

Architecture

Oral Sessions:

Billger d'Élia, Colour appearance in virtual reality: a comparison between a full-scale room and a virtual reality simulation

Toda, Ishida, How does our visual system interpret the color of light filled in a three-dimensional space?

Oberascher, Luminos 3: a new tool to explore colour and light in 3-D

Metcalfe, gender, colour and the domestic sphere in Western Australia 1890–1914

Schindler, Color in present culture of European architecture

Cler,, Colour words in chromatic urbanscape

Minah, Color constellations in the Seattle cityscape

Poster Papers:

Akita, Nara, Increasing use of yellow colors in Kyoto

Karman, Exterior colours of the traditional Northern Hungarian country houses

Lee, Kim, Yim, Lee, Measurement of area effect by the color panel size

Newton, Colour-form meanings: inter-connections between perception, association, and symbolism

del Rio, Rainero, Rosario, a grey city

Sakahara, An exterior expression of the houses on the CG and a color assessment on the method of pair comparison

Art & Design

Oral Sessions:

Lazaro, Renaissance: the color between the ideals of beauty and reasons of freedom

Carrabot, Lewis, Piehl, A method of simulating paint mixing on computer monitors

Albert-Vanel, Optical fusions and proportional syntheses

Melita, Applications of the Three Color Zone System: a cinematographer's tool to understand color

Charnay, Colour, light, and altruistic creation

MacDonald, Effective colour design for displays

Guan, A study of color harmony relating with area ratio

McGinley, The development of a large colour range for a paint company

Sakamoto, How can we find and handle colors with the same undertone? A proposal of method to specify and quantify undertone

Martinson, Waldron, Color in graphic design: an analysis of meanings and trends

Cheng, Xin, Taylor, Colour planner for designers based on colour emotions

Poster Papers:

Charnay, Colours fallen from heaven

Golob, Strafela, Golob, Color management in creating of fabric season collection

Gonçalves, Pereira, Neves, Chromatic harmonization concepts applied to indoor environments using computer simulation

Ligory, Line, space, and color

Morton , The multidimensional effects of color on the World Wide Web

Peña , Díaz, García, Casado de Amezúa, Romero, Lerma, Cano, Cubillo, The treatment of light with matter

Tosca, The contribution of the contemporary use of colour and light to the evolution of mankind: a designer's viewpoint

Symposium: The Future Role of Color in the Three Dimensional World

Caan, The future role of color in the three-dimensional world*

Gregory, Painting with light: enlightening your architecture with color*

Bromberg, Color in the design of the workplace: a provocation (Presentation Only)

**** denotes invited papers***

The Aesthetic and Commercial Value of Color

Margaret Walch
Director of the Color Association of the United States (CAUS)
Reported by Veronica Piselli ISCC June 2001 Color Club FIT

Margaret Walch, Director of the Color Association of the United States (CAUS) and writer on historic color palettes proposed that color functions to bring aesthetic values and delight into our lives. The aesthetic and commercial values of color go hand in hand affecting the marketplace

We learned it was Queen Victoria, who when she wore the newly discovered "mauve" (1856), popularized and created a demand for the color, ushering in the beginnings of the synthetic dye industry in Europe. Another famous woman, former First Lady Jacqueline Kennedy strongly impacted the art and fashion world. Her beautifully elegant wardrobe when exhibited at the Metropolitan Museum of Art was attended by reported record breaking numbers of viewers. Not since King Tutankhamen have color aesthetic become so powerful.

What is color in the 21st Century? Color will be clever and play tricks for us Ms. Walch responds. In her slide presentation, Ms. Walch discussed the colors the Association's Interior Forecasting Committee predicts will be popular in 2003, and she combined this with an examination of four palettes that related to these colors.

Forecasted colors for 2003 include environmental greens and blues; assortments of warm reddish shades, sunny yellows, hot pinks and violets. Presently in fabric and furniture, appearance and surface of mixed materials are very important rather than color, only a minimum of henna and indigo with many glass effects present. Color, as we understand it in its transparent mode is the direction in which we are headed.

Metallic is strong and gaining strength with patina-ed gold, hammered silver, copper and bronze important in the future; polyester fabric treated with powdered stainless steel is here. Damask, an old fabric with two-tone effects is returning with all color effects and important in the very high-end price marketplace.

Golden and glazed paints make the case for yellow, especially in bathrooms. Warm color is where we are at, with reds and yellows. She suggested a connection between color and climate.

Architecture gives us models for color as light and transparency. In New York City, reflective color is important.

Inspiration for color comes from several sources and among them not to be overlooked are Spas, such as Elizabeth Arden with the use of metallic and shiny surfaces.

So in summary she sees us moving off silver tones and blues and moving towards a warmer palette. Color has softened dramatically since the early 1990's, with brown replacing black says the fashion industry. Oranges and yellows will replace reds. Color softens as changing light. We may see a return to "mauve" as we reach 2004!

As we go forward into the 21st century we will understand color as glass; color as light. Ms. Walch used Tiffany's glass colors to illustrate the direction of special effects and the use of light to alter pigment colors. She shared that colored glass (Depression glass) is presently enjoying a revival. (The Blue Room in the White House with its light, colorful glass effects of Tiffany glass has been restored through computer renditions, which was originally smashed by Theodore Roosevelt who claimed it was too feminine a room.)

Sources for color ideas come from restaurants also. The Rockwell Group in Aspen, Colorado uses silver and orange for the kitchen. Another Rockwell Group restaurant in Kansas City, MO. employs colored light passing through glass and surfaces. Multicolored, highly theatrical effects are evident and maybe Las Vegas is a symbol of recreating color experiential reality. She suggests going to Vegas to see for yourself!

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

Frank Lloyd Wright's Taliesen West was referenced for a warm natural palette of reddish oranges. People wanted it for reflection. Wright collected many ideas from Asia, which are right in style today.

Vermeer's paintings of 17th century Delft homey interiors drew large crowds at the Metropolitan Museum of Art. This would indicate that his palette of soft blues, substantial browns and vibrant yellows is desirable, comforting and has wide appeal to a diverse audience. We will see this comforting realism of warm palettes with touches of cooler ones, suggesting that economic changes bring about color changes in fashion, signs of which she sees reflected in the color forecasts.

Her final palette of new color is found in new materials such as resins that present "hyper or nervous" color. Here she sees patterned color in resins and in computer art. The most pervasive look in color (shown in computer art, virtual reality,) is not pigment, nor dye, but light. Color is important as it provides an experiential quality to our lives.

Color in Home Furnishings

Catherine Stein
Director of The Color Council for the Home Furnishings Industries
Reported by Veronica Piselli ISCC June 2001 Color Club FIT

Ms. Stein, President and Creative Director of The Color Council took us through a fast paced international tour via slide presentations of the latest furnishings, fabrics, lighting, gifts and accessories for the home.

She explained that color events and predictions occur simultaneously with no time lag in spreading color news throughout industries, perhaps due to technology and the Internet.

She noted a global network for distinctive pockets of color wherein little difference of color exists between Europe and New York. For instance at the French Pavilion in Frankfort, a house of turquoise blue with red interior displaying huge proportions of color establishes intense chroma and huge proportions in style and design for the home furnishings industry in the United States.

In Belgium, in1999 the 2nd largest fabric fair looked like an opera with so much passion; everyone said "red" and word of mouth set "red" into motion followed by red and gold introduced as the new color in High Point, North Carolina.

We are moving from the cool tones of silvers, nickel and aluminum of the past ten years to the brushed bronzes, brasses and warmer tones.

A new color to enter the United States is orange; popular in women's, men's, children's wear, sportswear and the automotive industry. The orange is more to the pumpkin, leading to saffron. Influenced by tint or shade, there is more melon color to the new orange.

Yellows of the last decade influenced the color palette, followed by photo prints and large flowers in bedding and wall decor.

Green, a color phenomenon since 1990 with teal blanketing American interiors, it remains a mainstay in the construction industry. But green becomes yellow/green in the 90's, but not only as an accent color but as a chic color, due to a change of belief from a "sickly, bile color" to a "chic" color. As more people became aware of Ecology and the environment, there is more green, deep forest green and the new "kelly green" as seen in Paris which has power going for it!

Lavender is another color selling well. Larry Laslo for John Widdcomb takes "livable" lavender to large areas

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

including walls, not just for accent. At the French Fair, lilac tones, periwinkle blue with pink and magenta were featured for a new color range. Even in floor coverings we have magenta and lavender. The new hot pinks and oranges are really the late 60's pop art colors.

Ms. Stein stated that it takes the American market a couple of seasons to see a color and become familiar enough with it to gain confidence to wear it. It takes the manufacturer 18 months lag time from the Trade Fair showing before a color is shown at a "Target" store.

Sheer wall paneling and transparency will be a presence in the working environment replacing opaque structures.

Ralph Lauren's response to the new color palette was a 180 degrees turn around to the use of primary color.

Stripes in handbags and stripes in water-bottle sweaters will probably be in the Gap stores for Christmas.

Color as a language in Architecture

Grete Smedal, Kunsthøgskolen i Bergen (National College of Art and Design;Bergen)

ABSTRACT

This paper takes into consideration the role of color as a non-verbal language between human beings and the environment. The communication is based on the function of the colour vision to separate and identify. A language about color can be based on the same. The concept behind the Natural Colour System is color differentiation and color identification, which I find very useful both in color education of design students and in environmental color design work. A commission to plan the exterior use of color for a whole mining town on 78° North in Longyearbyen, Spitsbergen, will illustrate my ideas. This will serve as an example of how these different "languages" can work together. After a twenty years ongoing process this work is now almost fulfilled and the result will be shown in the presentation.

Keywords: color education, Natural Color system, environmental color design

INTRODUCTION

"What is color for" to me really is the basic question!

Why on earth did the creator get the marvelous idea to let human beings be capable to see things both chromatic and a-chromatic, and separate all these colors by millions! What was the real purpose?

I remember well when Anders Hård, the Swedish color researcher behind the Natural Color System (NCS), raised this question on a color conference and quoted W.D.Wright for the answer:

«Color is

- to inform about the existence of objects
- to give information about the quality of these objects
- to decorate»

The two first points are dealing with form and content: the capacity we are given by our color vision to separate objects and to understand our environments. The last one is a more"luxurious" part of the game: To beautify our surroundings.

This attitude, or understanding of color, has led me to investigate the possibilities of our color vision both in my educational work and in my environmental color design work.

From the understanding of color as a belonging to everyone, ever existent and inevitable,
I firmly believe that every person with open, seeing eyes, can expand their color-world both with deeper knowledge of the phenomenon, but also by being confronted with unexpected, even provocative color, use and combination.

No doubt most people have a spontaneous reaction of discomfort or attraction when a color designer change their surroundings, in interior space or in the outer environment.
Working with architecture we are well used to the fact that as long as it is dealing with the three-dimensional design or the shape itself. most people are willing to give the responsibility to the designer without too much involvement. Most people do not get very personal involved, even if they like or dislike the the result. They more or less consider it to be the work of experts.

Quite the opposite with color! As soon as the painter opens the bucket people are curious engaged and involved. The designer immediately is the target for inevitable exchange of views.
For many years I have been involved with color design in a smaller or bigger scale. I am used to meeting people in discussions of ideas and proposals often commissioned by the board of the settlement or the joint ownership of one-family houses.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

I have a deep respect for the welfare of every inhabitant, but I know that it is impossible to meet everyone's need, or taste.

If the colourisation shall be more than a question of decorating - which surely will lead to endless discussions of "Ugly and beautiful" it must have a deeper idea behind it. The purpose of the color should be «to inform about the objects» and «to give information», or identification.

Color education

To deal with these questions quite a lot of knowledge of color is needed. To understand how color works and how people react, to be able to foresee a result from a given idea, and to communicate the ideas to the public in a way that makes them understand why the proposal looks the way is does. All this is needed to see color design as a profession above personal preferences. It is to me a crucial educational question how this knowledge can be developed and integrated in the designstudies.

Both in my professional work as a color designer, and as Ass. Prof at the National Institute of Art and design in Bergen, I need to communicate.
So I need a color-language that is reasonable understood, and builds on the color vision itself.
Color differentiation and color identification are the basic concept behind the Swedish NCS color system as I see it, so it early appealed to me as a possibility to enhance my color work, and coherent with my own understanding of "What color is for" .It can easily be shown and understood in this simple illustration of the NCS color system, which is based on the fact that we can separate color differences in hue and nuance and also identify color groups from their similarity to the six elementary colours RBGYSW.

With this as a sort of common language - both verbally by defined ideas and graphic symbols like shown, the students work with form and content question of color in surface, three dimensions and space. The different variables of color are more or less systematically investigated to see how it influences the result. This training emphasizes color as a tool for expression, and we can discuss results and gained experiences in a common understood language. The fact, e.g, that the final result of a colourisation can be very far from the impression one can have from small color samples, due to light, size, distance and surface conditions is well know to experienced designers. But how to build up real knowledge of the dimensions of this important variable of color? (OBS Karin)

Words can be thresholds for understanding if they have different, undefined meanings. This fairly unambiguous way to communicate new and old knowledge about color, and to make discoveries to conscious experiences, seems to me very useful in education.

Acolor language in design

But even more I need this color language in my work as a Color designer. I must find a way to discuss with myself, organize my own thoughts and verbalize and visualize my concepts.
In many of my design commissions I have to present ideas to bigger groups of people, that will be involved. To illustrate my ideas I need different tools, like sketches, colourmaps etc. It can also be very useful to show the logic behind, or the more abstract concept, in the graphic symbols, which are now fairly well known in Scandinavia, and if unknown are explained in five minutes!

CASE STUDY

I intend to show you an example of this - how I structured my own work, how I conceptualized my ideas; and at last how I convinced the commissioners that my ideas were worth putting into life.

As you will see, the NCS color system was a great help to me. Let me however here emphasize the fact that no color system in the world can do the job for the Colour Designer. All the decisions taken will in the end be influenced by personal feelings or "taste». Finally the solution should build on knowledge and professional understanding combined with artistic ability.
What a color system can do is to provide the process, abstract and with colour samples so that the idea can see the daylight.

This work started almost twenty years ago, and I am still involved as the Color Designer.
We go to the northernmost settlement in the world - and a part of Norway as well, Spitzbergen, 78° North.

In the beginning of the eighties the responsible Company for this coal-mining town commissioned a color plan for all buildings and installations in the town. I was lucky to get the responsibility for this plan, which in the beginning was meant to cover a ten years period, but should expand to grow and continue until today.

The processes I will show you are still not ended. My latest visit to the islands in March pointed out new areas to be involved in the color plan for the coming years.

At this latitude the light plays a dominant role in the perception of color.
Three months of absolute darkness, six months of "normal" day and night, and three months of full midnight sun, makes this extreme. Snow covers the ground for most of the year, and very limited vegetation, mostly gravel makes a grayish/blackish surrounding for the snow less part of the year.

In environmental color design one of the main decisions will be whether to mimic the nature or to contrast it.
My first analysis was to look at the different color categories exposed to the extremes of the surroundings, black and white. It was obvious that it would be impossible to merge the manmade installations with the nature around in all parts of the year. Quite the opposite we decided to let the buildings stand out and speak for themselves in a powerful dialogue with the surroundings.

My analysis of the existing color used, showed mainly brownish and very dark colors, with a few red and yellow houses spread.

The town is situated along the Longyear Vale in distinct different groups (shows on map. My intention from the beginning was to separate and characterize these different parts of the town by color.
From my basic understanding this would separate houses and areas, and identify them differently. The small family houses distinct different from the "heavier" administrative part, town center from harbor area, the old miners barrack area different from the new lodging area, etcetera.

This was a color category thinking that I started out with, first in small collages, and then closer to an illustration of an over all color plan,

To illustrate this for the commissioner and the inhabitants, I made small sketches from the different areas, connected to samples of the facade colour for each building.
From this, the board of the mining company took the decision to put the whole thing to work (Just imagine - in principle one decision for the whole project - the formal owner of almost every building in the town).

Even though the inhabitants was, as I thought, well informed by my illustrations, it shall not be denied that it was lively reactions when the first seven houses in Lia was painted in 1984! They signaled to me through the process that they wanted, and needed color, but this was really too much! The contrast to the used colors and their traditional thinking of facade colours, was a real shock to many at that time.

But as the houses were painted during the following years the vigorous reactions slacked down. From few, provoking colors, in intolerable contrast to the existing, the color groups and the wholeness of the plan gradually became visible. And even more: the varieties of light, weather, time of the year etc. became an ever-changing experience and attracted more and more attention.

This was indeed an exciting new experience to me. A feeling of anticipation was created, and also a considerable widened appreciations of what people not only are ready to put up with, but positively enjoy.

CONCLUSION

A tour will show you what has happened from the first beginning, until today where new buildings and house groups have been added. The first overall plan has made it possible to keep the goal in sight, even though the variety has become quite wide as new activities (University and tourism,) gradually change the mining society.

I have by this example tried to show you how color really can separate and identify, and from my basic philosophy this is really «what color is for». My intention was not to "decorate", but as painting is not needed to preserve wood in this dry and cold climate, I certainly have tried to use color to beautify the build up area.

The landscape itself has shape and color scale that can stand by itself and establish a strong contrast to this very small part of the islandgroups.

Once you leave the valley and Longyearbyen, Spitzbergen remains what is has always been: Silent, untouched and endlessly beautiful.

Color and the World Wide Web

Ray Kinlock
Fashion Institute of Technology, New York. USA

Guide lines to publishing and transmitting color via the Internet.
An introduction to how individuals can cope with color issues using off the shelf package solutions and a glimpse to what there is on the development frontier.

Topics to be discussed include:

1. Optimizing your files for transfer via the net with an off the shelf software package.
2. Embedded color management packages in some off the shelf packages
3. Mac and Window differences
4. A look at compression pros and cons
5. An introduction to some of the high end color calibration systems and equipment

"For color to be reproduced in a predictable manner across different devices and materials, it has to be described in a way that is independent of the specific behavior of the mechanisms and materials used to produce it. For instance, color CRTs and color printers use very different mechanisms for producing color. To address this issue, current methods require that color be described using device independent color coordinates, which are translated into device dependent color coordinates for each device."

http://www.color.org/sRGB.html

When working with color on the web, we are in a dependent world rather than an independent one, in which we would control the world of our color rather than the developers.

The above quote appeared on a website named color.org but, actually came from a spokesman of a committee that had members form Adobe, Kodak, Microsoft, Hewlet Packard, and other outstanding members of the color world.
Notice the use of the word **INDEPENDENT.**

The usual way an idea becomes adopted into a standard:

- The individual develops an idea into a research project
- The research results are delivered at a prestigious conference like the International Color Association
- Committees adopt the research into a standards environment.

In other words, **WE ARE DEPENDENT ON STANDARDS COMMITTEES.**
And as long as we are dependent, there are going to have to be standards that we must be limited to in our choices. We are not working in a one same computer; one operating system and all have the same release computer world.
If we are to become **TRULY INDEPENDENT** than we, the end user, must direct the standards. Today the standards evolve from hardware and software giants and committees. They in turn decipher it for us and put it into ease of use format for our home and business computing environments.

The quote also mentions current methods; it does not look at the future.

By the FUTURE I mean the total evolution into a truly digital world, where all dependent and independent devices will and can leverage the standards of the past and the new and more truly digital frontier.

An example of the Digital Frontier would be true digital broadcast network television. There will have to be new and additional standards for one of the largest industries in America. Digital standards were not quite in place when the Recording of Feature Films digitally started and there is controversy over how and what standards should be used.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

Not on a committee? Don't think you have any clout or say in the standards for the way color is managed or delivered? Well **you do, if you have a personal computer**!

One way we have all decided what standards and when they get used is by logging onto the Internet. The internet has become powerful and demanding when it comes to the true electronic representation of color, and how it might relate to the devices that we will and already have connected to our computers.

COLOR CAN BE APPRECIATED AND EFFECTIVE ONLY IF IT IS SEEN THE WAY THE ARTIST WANTS IT TO BE SEEN.

How do color and the WWW relate?

On the World Wide Web, color is a result of Photons being bounced at the back of a Cathode Ray Tube, a.k.a., the monitor with three guns. The resulting impact of the ions is the color we perceive. Each Monitor like all other color input / output devices has it's own color fingerprint, meaning that no two appliances will receive or transmit color the exact same way.
We can logically and mathematically break this color information down further with software and prepare the image to be used in a four- color environment.
Browsers

- These are the programs that allow us to see the information on the internet in a graphical fashion.
- The most common ones would be Netscape, MS Explorer, and AOL as a browser.
- Others like Eudora and other free browsers are also included.
- There are differences in the releases of the browsers and how color is and was used.

Operating Systems

- The set of instructions that determines how the information in your computer will be directed and stored.
- The most common Operating Systems used today are MS Windows, Apple's MAC OS, and the variations of Unix Operating System.

We have come a long way since DOS.

Compression and File Formats

- Compression is a way to make existing files smaller and easier to be handled.
- Some forms of compression can change the original file structure with differing and sometimes unwanted results.
- File formats are extensions that show up at the end of the file and can determine what file type and storage criteria.
- Different file formats work better in native formats than others and some file formats are transferable across operating systems while other formats are not as easily transferred.
- Newly developed extensions that usually evolve from some new proprietary structure get adopted into products because the customer usually see a need for them and they are therefore market driven.

Things can have a SHORT history in the electronic world of color.

In a WEB Safe Color Palette that Lynda Weinman did for Adobe Photoshop just over four years ago, there are RGB values as well as printer codes for the colors. There were 216 web safe colors.

In order for me to project a slide I would have to first of all:
•Have a computer with a color monitor and board that understood color

•Have an operating system
•Have a software package to open the image that understood color
•Then put it into a presentation package
•Project it through another software package
•And finally you get to see it
•Now, if you want to see it on your computer you have to add into the mix your hardware and software equipement.

Now let's complicate things a little.
There are many PC users.
Many verisons of Windows: 95, 98, ME, NT and 2000.
There are many MAC users.
Who can use Apple OS8, OS9 or OSX.
Others use a UNIX OS, Red HAT, Berkley, ATT, SUN, or IBM.

There can be many permutations of color. This is not going to go away soon.

With all of the new Processors, amounts of color available to us can we really depend on the colors being something we can all live with.

I know that as a college professor, the first disappointment I get is when my students print out for the first time without any lecture on color management.
The first thing out of their mouths is **YUCK! That's not the color on the screen!**

So if it is not good on the paper how can we correct it?
New strides in affordable color management are in the vendor showcases and in the technical papers being delivered.

If the 216 WEB SAFE colors are the only true web safe what will the WWW end up looking like? Very green! It may be more appealing to go back to a black and white monitor.

Windows Operating System needs 40 color cells to be used in the operating system. The MAC has all 256-color cells available while the Windows does not. This means that MAC and Windows are NOT CREATED EQUAL when color is concerned.

Some observations up to now:
All of these statements are a little ambivalent, but this is how the WEB sees and handles color.
I bring this to you attention because the WEB is just like my students.
Just when is the WEB going to say YUCK!!!!

The Unix operating system uses MAILCAPS to manage its color information.
PC and Apple use TAB Oriented structures to manage theirs.
But given their different safe color palettes they immediately become UNEQUAL!

The ICC and color congresses like the International Color Association try to make colors on cross platforms perform better.
This is done through sharing technologies and information.

I have included the names here of the founding of ICC to show you they come from large corporations who have and continue to put design and research dollars into this area.

They have a lot to make in profit if their standards or the ones they support are the first to be implemented and adhered to.
Since the WEB is being seen as the Gorilla of the development cycle for so many companies, color and color related issues on the web will become big business.

Remember that we were going to address compression well here is a simplified version with some key facts to keep in mind.

Lossy, the first four letters say it all LOSS.
You loose information. This information can not be re-manufactured for the most part although there are some companies that are trying to have the loss be undetectable.

Loss Less I wish it did not even have the LOSS word in it but it does not throw away information.

There are many versions of both types of compression on the market.

Here are just a few suggestions if you need to know more about these types run a search on the web and have some fun.

The web safe solution for mixing colors.

The hexadecimal form of a color is considered a safe way of mixing colors for the web but again it is not guaranteed across platforms and the permutations of releases and equipment.

DISCLAIMER:
I am not in any way promoting products nor do companies named in this presentation compensate me. I do this because it makes the presentation more understandable to the audience.

There are many companies besides the ones I have mentioned, so please do your homework before you take what I have presented as the "be all" solution.
I am always looking for the newest and share-ware solutions that some of you might be working with.

The Hex mixer I found on the net and it lets you see the Web safe colors as they appear on top of each other.
I would prefer a medium gray background instead of white but that is the WEB!

A few tips to help you with colors on the web.
As you know it just isn't what you put on the web it is how it looks on the web.

I have at home four computers, four different operating systems and four different versions of browsers so; I can do a reasonable web page and web development.
Not may of you can afford that luxury of room and clutter.

Here are few tip though that I think will help you in the World of Color on the WEB!
•CROP, CROP, CROP keep the amount of the picture you want to use to a minimum, less color conflict.
•Minimize the number of colors, Close colors can sometimes be seen as on. Choose you colors from a non dithering color palette, there are plenty on free downloads on the web and will fit right into your color look up table program folders.
• Use lais san serif fonts like Geneva or Chicago. The word fonts are really important and Anti-alaising will kill an ordinarily nice looking font because it will break apart on the web.
• Use flat, horizontal areas of color. Stay away from the sexy graduations of color. They will break apart under certain computing environments.
•Be WEB savvy prepare you file by reducing the resolution to 72 dpi before you publish to the WEB.
•Try to use only one Color Look Up Table for all of you graphics.

Good luck with you adventures on the web and remember you can always draw inside the line or go out where the results can be exciting.

These are some of the WEB sites I encourage you to visit and some of the information that I have used today is from some of these great sites.

Also try typing color management into your favorite search engine on a rainy day and see what is new and that you can use in the evolving world of color on the WEB.

http://help.netscape.com/kb/consumer/19960513-14.html

http://www.adobe.com/newsfeatures/palette/main.html

http://the-light.com/netcol.html

http://www.cyber-hawaii.com/hc/webmasters/netscape.colors.html

http://hotwired.lycos.com/webmonkey

Report of activities of the Environmental Color Design Study Group

Jose Luis Caivano* and Leonhard Oberascher**

The AIC Study Group on Environmental Color Design (ECD) is an international community of scientists, designers, architects, artists and other professionals with a specific interest in color as a means of environmental design and its effects on human emotion, cognition and behavior. The general aims are: the exchange of knowledge and experience among its members; the stimulation of research and teaching, meetings and exhibitions; the propagation of knowledge and experiences through congresses, seminars, workshops, publications and exhibitions.

At the Study Group Meeting in the AIC Congress 1997, in Kyoto, Japan, it was proposed to follow two steps to meet some of the mentioned aims: 1) to establish an internet site for the Study Group, and 2) to create a e-mail list for discussion. The first aspect would include a home page with general information about the ECD Study Group, the list of members with their postal and e-mail addresses (in order to facilitate the knowledge of each other and the exchange of information), links to other web sites (a call is made to provide information about sites related to environmental color design), and a section where contributed papers on environmental color design could be published. The second aspect —the e-mail list— would allow more informal discussion on topics related to color design, posting news and information of interest to subscribers.

At present, the internet home page was set up, at least in its first aspects (www/fadu.uba.ar/sicyt/color/ecd.htm), and the e-mail list is running, with more than 160 subscribers from 27 countries (the list is constantly growing). It still remains to arrange the publication of papers on the web. The idea is to establish an editorial committee and a referral system in order to evaluate the articles before publication.

The e-mail list allowed a continuous connection among ECD members and other interested people, exchange of abstracts presented to AIC meetings 1999, 2000, and 2001, more or less informal documents and images produced by subscribers, call for papers and programs of meetings, etc. Subscription to the list is free and unrestricted, that is, every interested person can subscribe, not only ECD members. However, it has been arranged as a closed list, so that only subscribers can send messages to it. This is to avoid the list being saturated with commercial or non pertinent messages. A communication from a subscriber is automatically received by all subscribers; in case a non-subscriber intends to send a message to the list, it arrives only to the moderator, and he decides on the pertinence or not of forwarding it to the list. The address of the list is <color@fadu.uba.ar>.

The list is automatically handled by the program Majordomo, with a server at the School of Architecture, Design and Urbanism of Buenos Aires University. In order to be included, it is only necessary to send the message "subscribe color <email address>" (just this line in the body of the message —without quotation marks, and with the address of the subscriber—, no subject, no signature) to <majordomo@fadu.uba.ar>. Participation is voluntary. Subscribers have no obligation to answer messages or get involved in a discussion. They may just use the list to receive information and read what the others discuss about.

ECD membership is also free, and is available for every person or organization dealing with color as a means of environmental design, contributing to the realization of the aims mentioned above or wanting to support the Study Group. The only requisites for being incorporated as a new member of the ECD Study Group are: a) to subscribe and participate in the e-mail list; b) to have presented a paper or poster at an AIC meeting (as a matter of fact, new members are incorporated at AIC meetings).

The purpose of this report is to briefly introduce the Symposium on Environmental Color Design at AIC 2001 in Rochester, where papers on different specific aspects of this subject will be presented.

* jcaivano@fadu.uba.ar; tel/fax 54-11 4702-6009, www.fadu.uba.ar/sicyt/color/ecd.htm; SICyT-FADU-UBA, Ciudad Universit. Pab. 3 piso 4, 1428 Buenos Aires, Argentina; ** leonecolor@salzburg.co.at; fax 43-662 628-459-50, Kaltnergasse 8, A-5020 Salzburg, Austria

COLOUR APPEARANCE IN INTERIOR DAYLIGHT
Observations of hue shifts in different compass orientations

Maud Hårleman, Interior architect, Ph.D. student
School of Architecture, Royal Institute of Technology

ABSTRACT

In this paper problems, aims, and preliminary results from an investigation of colour appearance in north- and south- facing rooms are presented. This first part of the project includes an experimental study of six colours in two nuances of chromaticness, altogether twelve colours. Several methods for assessment and description have been used. Hue shifts are in focus together with chromaticness and room character. Colour appearance was compared between rooms in different compass orientations and found to be clearly different. In the south facing room yellow colours tended towards elementary yellow, while greenish blue tended towards green. All colours increased in chromaticness. Colours in the north- facing room, on the other hand, tended to go in the opposite direction; greenish blue tended towards elementary blue and elementary blue increased its cromaticness most of all. Reddish blue colours showed no distinct tendency. Colour variations due to reflexes, patches of light, shade and, shadow were important in assessing the identity colour. The identity colour is discussed together with the elasticity concept that has been developed to describe the range of different colour appearances of an inherent colour inside the room.
Keywords: Colour appearance, room studies, interior daylight, hue shifts, room character, identity colour, elasticity.

1. INTRODUCTION

This research project deals with differences in colour appearance caused by variations in natural daylight. Interior colours will shift in hue depending upon which light enters the room. As this affect colour design it needs to be mapped out for better colour education and colour control in architecture and design. Despite colour constancy we still notice differences in coloured material and the colour of light. Divergent compass orientations in interior daylight result in different colour appearances. [1], [2] In the visual system, these differences from dissimilar spectral composition, light distribution, and light level, are enhanced or reduced by way of comparing differences. [3]

My research is based on an investigation made in full- scale interiors in the northern hemisphere in Stockholm, Sweden. The overall research objective is to describe what happens with colour appearance and room character in north- and south facing rooms. Full- scale studies in rooms are important, as colour appearance differs between a flat surface and an enclosed space. Billger concluded that reflexions inside the room can also enhance or reduce contrast effects and chromaticness. [4] Equally painted walls were illuminated alternatively, with sunlight and natural daylight from the sky, and the effects were evaluated by several methods to describe colour appearances and differences between the rooms. [1], [2] There are three aims: the main aim is to evaluate and map out hue shifts with regard to compass orientations. The second is to examine and discuss different ways to approach various lighting conditions in colour design, in order to enhance or reduce the light character. The third is to evaluate and describe how these specific colours and compass orientations affect the character of the room. This question concerns weather the room seems to be warm or cool, open or secluded, indistinct or legible, and if it has such emotional tones as light or heavy, pushy or restrained. This aim was less studied than the other two, but still deserves to be mentioned. Parts of this research, concerning experiences of light and colour, are now being left out and instead presented more extensive in Nordic Journal of Architectural Research. [2] In this paper I concentrate on the first question concerning hue shifts: overall hue shifts, colour variations, elasticity, identity colour and a displacement effect. This project is made in close relation to Billger, whose research also concernes colour appearance in enclosed spaces though illuminated by artificial light. She has developed the main concepts and methods that I was able to use.

Terminology

I use the terminology of the NCS (Natural Colour System) for notations and descriptions. I use the term SKY- LIGHT as a referent for natural daylight from the north sky in the northern hemisphere. Daylight is defined by CIE by standardised relative distributions normalised to the zenith values. The term sky- light is meant to clarify a distinction between 1. light from the sky as opposed to sunlight, 2. interior daylight through vertical windows, as opposed to sky- light windows, and 3.

9th Congress of the International Colour Association, Proceedings
of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

day- light from the northern sky in the north hemisphere, containing its specific spectral composition, luminance- and spatial distribution, as opposed to diffused light with spectral- and luminance distribution values similar to CIE's daylight or diffused light from any other orientation. Sky- light is a visual concept to express visual experiences as opposed to physical data. Billger defines IDENTITY COLOUR as the main colour impression of surfaces or parts of the room that are perceived as being uniformly coloured. [4] COLOUR VARIATIONS are the local colour appearances of the identity colour. These differences might depend upon light distribution, reflections from other surfaces or contrast effects. [4] INHERENT COLOUR is used as Fridell Anter has defined it: "the colour that the coloured object would have, if it was observed under the standardised viewing conditions that are a prerequisite for the NCS colour samples to coincide with their specifications." [6] Fridell Anter remarks "this means that the inherent colour is a constant quality of the object and does not depend on external conditions (apart from bleaching, pollution, and other physical changes of the object itself)." ELASTICITY. Billger has defined it as: "the way a specific coloured material can vary in appearance under different specified conditions in a room." [5] I use it in a as "the way a specific coloured material can vary in appearance under different periodical *variations due to daylight conditions in a room.*" [1] [2] ADAPTATION refers to conditions for colour constancy; the visual system has to adapt to the illuminations intensity and spectral composition for colour constancy.

2. EXPERIMENTAL DESIGN

This research is based on empirical observations of experimental character made with comparative methods in north- and south facing rooms. The investigation is qualitative, with a perspective based on perception and phenomenology. The designers perspective is taken as a starting point. Shifts in hue and nuance differeng from the inherent colour are in focus together with colour gestalt and room character. The questions involved have two perspectives; one is the colour perspective and the other is the room perspective – that is, what does the colour look like in the room and what does the room look like in a certain colour? Comparisons were made between the same inherent colour under likely comparable weather conditions in north- and south orientation. Observations are made mainly on clear days, yet studies in all sorts of weather were made.

The room models were used in the introductory phase. The experimental full-scale room had a north- and a south-facing window where monochrome painted walls were illuminated by one window alternately. Six qualified observers were used for assessments, two ordinary, and four complementary observers. They made 43 observations of room models and 83 full-scale studies in twelve inherent colours. From an hour-long session of visual assessments, the observers gave comments of various aspects of the colour appearance, including impressions of change caused by atmospheric conditions. Three yellowish and three bluish colours in two nuances of chromaticness were used: S-1010 and S-1030, thus six pale colours and six with stronger chromaticness. The hues were NCS -G80Y, -Y, -Y20R, -B30G, -B and -R80. Identity colour and colour variations were assessed and compared between the north- and south facing rooms and different lighting conditions.

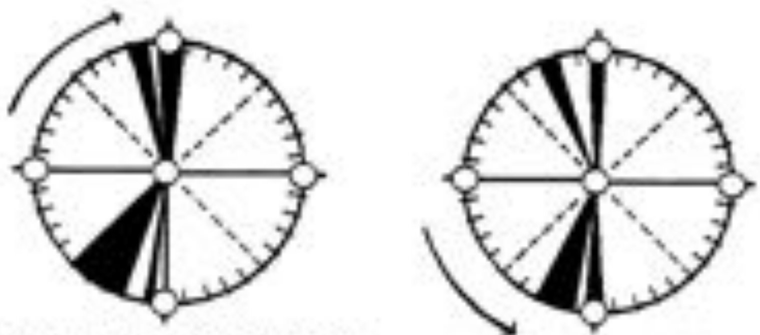
Six different methods for description of colour appearance and room character were used. Basic ground for observation and description are PSYCHOPHYSICAL and PHENOMENOLOGICAL methods, containing other methods for description. METHOD for VISUAL EVALUATION was used for the evaluation of light and room. [7] This method specify both physical and visual aspects of the light situation and establish connections between them in terms of of seven factors: light level, light distribution, shadows, sun patches, glare, reflections, colour of light and colours in the room.
The COLOUR REFERENCE BOX METHOD was used to evaluate colours according to NCS colour notations. [4],[5] This method includes a Colour Reference Box, a light booth, used as a standard situation where NCS colour samples were illuminated by a standard source, in this investigation artificial daylight named D55, and compared with the perceived colour of certain patches in the room.
The ASSOCIATIVE, REFLECTIVE METHOD is inspired of phenomenological theory in approaching colours as phenomena. [1], [2] The method consists of verbal descriptions of both room and colours, and it originates from a will to work with a designers special work procedure; being attentive to appearances and express them as images or characters.
RULED SEMANTIC SCALES, in three steps were used in describing the room character.
MEMORY COLOUR was used as a memory-match to compare data from different methods, as an analyse.
COLOUR SCHEME was used to understand the situation when data seemed misleading. It proved to be different sizes in area of distribution between some of the colour variations. [8]

Observers started with a verbal description of visual impression of the colour with the Associative, Reflective method. 2. They then used the method for Visual Evaluation. **3.**The colour was evaluated with colour matching by Colour Reference Box Method. 4. A psychometric method with ruled semantic alternatives was used in describing the colour gestalt from the room's perspective. 5. The atmosphere of the room was noted in semantic scales. 6. *Watercolour paintings* of the colours in the room were made as a part in the description and documentation.

The data was noted and arranged in tables for analysis. Data from the verbal descriptions and semantic scales was collecte and compared with data from the Colour Reference Box Method. In some cases data from different methods seemed contradictory. In those cases memory colour and a colour scheme together with the watercolour paintings were good tools for analyse. Put together the colour scheme provided the missing link, that in most cases proved to consist of different sizes in extension of colour variations. Using the Colour Reference Box Method, it is found that there is an adaptation effect between the room light and the light situation in the Colour Reference Box. [3] [7] Adaptation tests were made and it was concluded that adaptation effects could be controlled.

3. DISCUSSION and RESULTS

As main result, this investigation show a distinct and settled hue shift between the rooms, depending upon their compass orientation. Only in overcast weather, had the rooms similar colour appearances. On top of these structural variations, there were occasional colour variations in nuance and hue. Most significant was an overall hue shift in identity colour. If his overall hue can be approximately estimated, colour appearance will still shift contiously, within a certain range, with atmospheric conditions.



Hue shifts in the south facing room tend towards yellow

Hue shifts in the north facing room tend towards blue

In sunlight all colours shifted in hue, become warmer and tended towards elementary yellow. Greenish blue and elementary blue shifted towards green. In the south facing room all colours increased in chromaticness. In sky- light, the inherent pale yellow colour in most cases appeared as less yellow, with either more blackness or whiteness, and tending towards greenish. The blue and greenish- blue colours tended towards elementary blue Bluish colours increased in chromaticness. Reddish-blue colours varied, as by chance, both in sunlight and sky- light. Often the inherent reddish- blue colour appeared as more reddish in sunlight, although in all cases the same hue was found in sky- light data as in sunlight. It was experienced as a distinct hue shift, although we still found the colour sample among the samples picked out for the north- facing room. Also small hue tendencies as 5 – 10 steps in the NCS- scale, were noticed as distinctly different hues. Hue shifts due to different compass orientations can be described according to the figure above.

Colour variations were shown to be important for the identity colour, in some cases a hue shift could derive as a general impression from occasional colour variations even when it did not show in the identity colour A hue shift dependent on occational colour variatioms, could be evoked and affected by several mechanisms: • Elasticity. Changes in daylight conditions influence colour constancy and can cause a Bezold- Brücke effect. • Displacement Effect. Room conditions in themselves gave rise to colour phenomenas, this phenomena is missing and ought to be found between contrast and assimilation effects.

• Elasticity. Some shifts in colour variations appeared with sudden changes in the light situation, as when sunlight flickered also, without obvious reasons, and inherent colours could gain or loose specific colour qualities. As daylight varies continuously, such variations were found to be important aspects in evaluating colour. From mutual experience in research, Billger and myself started to define the new term elasticity. It was used in a few of my studies to describe how an inherent colour can shift in colour appearance in different illumination. In my studies it is restricted to a room in a certain daylight situation. Elasticity is a visual concept describing how we experience colours in a room. As the visual system needs time to adapt to keep colour constancy, these changes are obvious and also essential qualities in experiencing interior colours. It may depend on a slow colour visual function that these changes occur to opposing colours. As the inherent yellow colour in the south- facing room was illuminated by increasing light level, shadows tended towards reddish yellow, while instead a decreasing light level made shadows tend towards greenish yellow. Such changes are essential for colour experience in daylight interiors.

• Displacement effect as a colour phenomena. I found no fitting term for this, influential and yet probably well-known colour phenomena, that was frequently seen in the studies. I believe that it belongs somewhere in between contrast effect and assimilation effect. As the walls were monochromely painted, there were no simultaneous contrast effects between them; yet there was a certain contrasting effect, separating the coloured surfaces from each other by a more or less strong contrast in hue tendency. That resulted in a room with a wide range of colour variations. Assimilation effect work in the opposite direction as it seems to blend or mix colours in pattern or small details. In the investigation we saw colour variations too obvious to blend as in assimilation, as they were singular big. In experiencing the room together with colours and light, these colour variations were included in the general impression. *They established a displacement effect*, moving colour appearance towards this active colour variation. Shadows showed to play an important role in this, as they differed from nearby areas not only in nuance but also in hue, and also had a greater extension than the well illuminated areas. Reflections and light patches also took part in this displacement effect.

4. CONCLUSIONS and FURTHER STUDY

To increase design knowledge, it is important to study colour appearance in full-scale experiments. Colour appearance depends on several factors and seems to emerge on different levels. In evaluating what the colour looked like it was significant that light, shadow and shade contain layers of deep symbolic nature as does the concept warm and cool colours. Colour variations by shadows and light patches, are important in assessing the identity colour. Studies remain to clarify how this works. The elasticity concept can be useful for designers and users in understanding the outcome of a colour choice. An area of expected elasticity in a certain compass orientation would offer a better colour conception for daylight conditions than a single colour code of an inherent colour; as it will hardly ever be in full concordance between the outcome of colour colour sample and colour appearance. The identity colour concept is indispensable for evaluating colour appearance in interiors. However, an adjusted identity colour for situations with a wide range in colour variations seems to be called for and will be worked out and tested. The next step in this investigation is to use green and red colours in similar experiments. Furthermore, it is my intention to make studies on possible methodological problem with the colour reference box. Room characteristics will be further investigated for a better understanding of not just WHAT, but also HOW, we experience a certain colour in a defined light situation.

ACKNOWLEDGEMENTS

This work has been supported by a grant from the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning, together with the Swedish Association of Painting Contractors, and the Swedish Painters Union. It has also been supported by Alcro - Beckers.

REFERENCES

[1] Hårleman, M. Färg i norr- och södervettande rum. Royal Institute of Technology, KTH Stockholm 2000.
[2] Hårleman, M. Colour appearance in different compass orientations. Nordic Journal of Architecture Research, 2/2001
[3] Liljefors 1996. Lighting and Colour Terminology. Visually- physically. AIC Gothenburg 1996
[4] Billger, M. Colour in Enclosed Space. Chalmers, Gothenburg 1999.
[5] Billger, M. The Identification of Colour in Spacial Situations. Chalmers, Gothenburg 1996.
[6] Fridell Anter, K. What colour is the red house? Percieved colour of painted facades. KTH, Stockholm 2000.
[7] Liljefors, A. Seende och ljusstrålning. Baskompendium. ALV Belysningslära, KTH Stockholm 1997.
[8] Perez – Carpinell Joaquin, Baldovi Rosa, de Fez M. Dolores and Castro José. Color Memory Matching: Time Effect and other Factors. Color Research and Application 1998/ 23.

Colour contrasts in advertising – facade colours of food and drink consumption venues

John Hutchings*,
food colour and appearance consultant

ABSTRACT

The building facade has a visually defined impact and there are numerous forces driving the choice of colours used. Commercial premises such as pubs, restaurants and bars are normally but not always clearly marked as such. Although we human beings can have the option of free choice in the colours we use around the home there are numerous positive driving forces dictating those we use in business life. Many of these factors have been identified. They depend on the type of population these venues serve, their geography and their traditions.

Keywords: advertising, impact colours, building exteriors, food and drink venues

1. INTRODUCTION

Colour and appearance of food play a vital part in the enjoyment of a meal[1]. Similarly, the decor and exterior of the building in which we eat form part of the total meal experience. The effectiveness of the building exterior and facade as an advertisement depends to a large extent upon impact colour contrast, in many cases on large colour differences. Different colour combinations are used as appropriate to the type of advertisement. Hence the cacophony of colour noise that can occur within the street environment. This study concerns colour contrasts announcing the presence of a restaurant, café or bar, that is, anywhere where food or drink can be purchased for consumption.

We require only a brief moment to observe the exterior of a restaurant to conclude the type of food served there. That is, there is a typicality of, say individual fast-food outlets that prompts their instant recognition as such. Examples of relevant cues may include the presence of a brightly coloured sign perhaps complete with a brand mark, large windows, clean exteriors and glass doors. The accuracy with which we correctly identify the outlet depends on the perceived typicality compared with the typicality catalogued during our learning process. What part does colour play in recognition of eating venues, and how may this typicality vary from place to place?

The facade and/or seating external to the venue provide the impact colours that announce to the potential customer the presence of the restaurant or store. Is there any pattern to the colours used, or, do they just occur at the whim of the proprietor? As might be expected there are in fact driving forces governing the choice of many of the colour contrasts declaring the site of the hostelry. Examples have been taken from towns and cities around the world.

2. THE STUDY

During the year 2000 opportunities arose to record the exterior colours of random samples of restaurants, cafes and bars in the cities of Stockholm, Sweden, Mendoza, Argentina, the Art Deco area of Miami, USA, the old city of San Juan, Puerto Rico, Palermo, Italy and Bedford, England. Colours were recorded while travelling around town on foot, on the bus or in the taxi. That is, the colours recorded were those as seen by the potential customer looking for somewhere to eat or drink. In the real life of the exterior advertisement colours tend not to be the more subtle shades that occur in the interior. They may consist of bold impact colours.

Estimates were made in terms of the mix of chromatic colours, whether they had added black, white or grey, levels of brown, pale colours that would only provide a dark contrast to white itself, and achromatic white, black and three shades of grey. Records were made of the colours as they existed, whether brand new, faded by the sun, covered in dirt or wet from rain. Thus, precise recording was not relevant and not attempted

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

The problem arose of how to express the results of the study simply in terms of an illustration of the actual impact colours used in the advertisement and their relationship to each other. A conventional colour order system might be used but this requires the use of two separate diagrams. Kobayashi's single colour image scale diagram[2] also might have been used. However, because colours are related to the emotion produced by the image, small differences in colour can be a large distance apart on the diagram and dissimilar colours can occur close together. Hence, little feeling of the impact nature of the combination is gained. However, Paul Green-Armytage's new, two-dimensional, colour tutorial diagram[3] is an efficient and effective method of illustrating colour contrasts, particularly those that have not been recorded precisely. This can be used to illustrate the results of environment impact studies.

3. THE RESULTS

Facade colours of many restaurants are, of course, individually selected by their owners. However, for very many food and drink venues the colours selected are subject to a number of specific driving forces. Examples are given of driving forces found to be at work in the towns and cities included in the study. They are discussed within the frameworks of population type and building tradition.

3.1 Population type

There are a number of factors at work that are sensitive to the type of population comprising the community. These include the number of inhabitants that live within the specific catchment area, their expectations, income and origins. Specific driving forces include brand colours, the number of young people living on restricted budgets and ethnicity of food venue owners.

Brand colours

Throughout the world customers patronise large fast food outlets and brand colours of, for example, McDonald's and Burger King are imprinted on many town centre streets. Similarly, company sponsorship of restaurants and bars accounts for a good proportion of eating venue facade colours. For example, commercial sponsorship provided the driving force in 17 of the 61 observations made in downtown Mendoza, Argentina. Of these, 11 are dominated by the brand colours of Pepsi (red, white and blue), and four by the red and white of Coca-Cola. The facade either followed the logo colours directly or the impact was derived from appropriately coloured chairs and tables on the pavement outside. In addition, brand impact colours provide the traveller with a sense of stability in that venues serving familiar dishes can be easily recognised.

Student power

Competition and the need for visibility determine the extent to which a high impact facade is necessary. Bedford, for example, has a large population of college and university students. To cater for these many low cost restaurants and food take-away businesses have opened in the town. Fierce competition on the street has resulted in the use of high impact saturated reds and yellows with black and white. On the other hand, the far fewer more expensive restaurants advertise their presence more subtly. Their clients tend to know where the venue is sited as well as what quality of food to expect. They are driven away by fierce, high chroma and expect quieter, more sophisticated colours inside as well as out.

Ethnicity

Colours may be linked with ethnicity of the eatery owner. Examples are the exotic impact colours on the facades of some Indian and Chinese restaurants. Saturated colours here indicate the need of the business to be noticed and clearly advertise the availability of different cuisines.

3.2 Building tradition

Availability of local building materials, as well as tradition and design style are included in this class of driving force for facade impact colours.

Geology

In places where a great proportion of the building is constructed of exposed and unpainted local stone, it is this that can provide one part of the facade colour contrast. An example is Stockholm where the stone is grey, often subtly shaded. Here one third of observed venues possess stone as one of the significant contrast colours. Reddish, brownish and greenish colours are the most popular dark contrasts to the stone, while paleish, yellowish and whitish colours the most common light contrasts.

Other locally available materials

Absence of local stone results in the use of brick or other locally available building material. These contribute in a major way to traditional facades. Two examples are recorded, one concerning building tradition, the other, design style. At various times in British history timber-framed buildings have been fashionable. Many of these consist of black, mostly vertical, stripes derived from painted wooded support timbers and a whitened mud or plaster fill. Concentrations of the 1920's revival of this medieval to Tudor period style can be found in cities such as Chester, England. However as the fashion waxed and waned many examples of original, converted and revival Tudor can be found in British towns and villages. In such food venues it is this black and white contrast that usually overwhelms signage to provide the impact.

The heritage industry

Old San Juan, Puerto Rico and the Art Deco district of Miami provide contrasting examples of cities where what has been interpreted as past colour glories are being resurrected. The clean colour quality tends to be the same in both areas but Art Deco colours tend to contain more white than those that appear to have been used in the days of the Old Spanish Empire. Similarly, the Dutch past is being recreated in the Caribbean Islands of Curacao and Aruba.

In Old San Juan a total of 35 observations were made, 31 of which have white as a light contrast. Dark contrasts are mainly, in order of use, greenish, brownish, greyish, yellowish, orangeish, bluish and reddish. The wide range of dark contrasts also includes yellowish brown, purplish and pinkish hues. Eleven observations were made in the Art Deco District of Miami. Ten of these have light contrasts that are paleish and yellowish. In contrast, no palish and yellowish colours were seen in Old San Juan. The most popular dark contrasts in Miami are bluish and greenish.

Function

Some cafés are situated within shops selling bread and pastries. Such premises may have brown facades and window blinds. This is an example where colours are linked with function, other examples being green blinds for greengrocers and butchers. An added advantage of the latter is that the green possibly accentuates the complementary red of fresh beef.

Design Style

Italy is famed for its beautiful design style, particularly of dresses, clothes and cars. In many modern urban areas architectural style is undistinguished, but layout and design of restaurant signboards displays an echo of a favourable industrial style. In Palermo there is no blatant screaming of competing facades, but a gentle reminder of the presence of a place where inner persons can have their culinary desires satisfied.

Traditions of the people

In Mediterranean countries many facades are white, as were numerous cottages and churches in the English countryside. This colour is easily obtained from chalk and limestone from which it is traditionally prepared by mixing the powder with milk or size. Whitewash is hygienic as well as psychologically clean, it transforms appearance and reflects heat. In parts of Greece white inside and out was said to keep the plague away and even cracks between paving slabs were painted[4]. In Britain lime was used as a fire retardant and walls and thatch were painted. Here white lines painted around all entrances to buildings were once designed to keep the witches away. This tradition has been preserved in a few English pubs.

4. CONCLUSIONS

Colour usage by an unregulated population cannot be fully predicted because human beings have evolved to be able to make choices. However, the approach used to understand human colour choices through driving forces is the same as that used to understand colour in biological nature[5] and the use of colour in our tradition and folklore[6]. Driving forces for colour use in advertising within the eating and drinking environment are clearly identifiable. Their number and variety contribute significantly to the differences in environmental impact we experience when visiting different parts of the world.

REFERENCES

1. John Hutchings, *Food color and appearance,* 2nd edition, Gaithersburg, MD, Aspen Publishers, 1999
2. Shigenobu Kobayashi, *Color image scale*, English translation, Tokyo: Kodansha International, 1998
3. Paul Green-Armytage, Colour zones, connecting colour order and everyday language, see the proceedings of this conference
4. Michael Lancaster, *Colourscape*, London, Academy Group, 1996
5. John Hutchings, Living colour - appearance in nature, in *Color for science, art and technology*, Kurt Nassau (ed), Amsterdam: Elsevier, 1997, 222-246
6. John Hutchings, Colour in oral tradition. In *Proceedings of the conference Colour between art and science*, Oslo, October 1998, invited paper, 23-31

* john.hutchings@physics.org; phone +44 1234 376768; 6 Queens Road, Colmworth, Bedford, England MK44 2LA

Climate and coloured walls, in search of visual comfort

Malvina Arrarte-Grau*, Study Group on Environmental Colour Design

ABSTRACT

The quality of natural light, the landscape surrounds and the techniques of construction are important factors in the selection of architectural colours. Observation of exterior walls in differentiated climates allows the recognition of particularities in the use of colour which satisfy the need for visual comfort. At a distance of 2000 kilometers along the coast of Perú, Lima and Mancora at 12°S and 4°S respectively, are well defined for their climatic characteristics: in Mancora sunlight causes high reflection, in Lima overcast sky and high humidity cause glare. The study of building colour effects at these locations serves to illustrate that colour values may be controlled in order to achieve visual comfort and contribute to colour identity.

Keywords: coloured walls, visual comfort, glare, colour identity, colour designer, colour temperature, synaesthesia, scales of perception, visual adaptation

1. INTRODUCTION

In Perú, where architectural colour regulations are rare, façades reflect people's preferences. A historian from Lima wrote in the 80's: "The colour of a city is the result of its climate and of its history"[1]. Nowadays the importance of natural factors seems diminished by the variety of stimuli in the outdoor environment. The unlimited possibilities for building colours offered by paint manufacturers, added to the fashion and novelty transmitted through the media influence aesthetic values and ideas for the image of buildings, not necessarily with appreciation of architecture or its impact on the context. Colours may be replaced easily causing places to change their appearance in no time.[2]

The designer should take advantage of the possibilities of paint and architectural materials after analysing the variables that influence colour perception and the importance each deserves. According to Professor Werner Spillmann at the preliminary project stage "The designer asks himself what general design measures can answer to human needs, can favour desirable behaviour or compensate for inconvenient factors in the given conditions. The consequences which he draws from the problem analysis concern the whole spectrum of design means, one of which is colour..."[3]. In selecting colours for walls the scales of perception play a major role: the geographical scale determined by climate and landscape characteristics, the intermediate scale which phocuses on architecture as an object, and the detail scale of textures and constituent materials. The complexity of building colour design demands going back and forth from the outermost to the inner levels, giving shape to colours and adjusting their dimensions. The three scales interact with each other in the aspect of colour and, with time become part of the *genius loci* or spirit of the place.[2]

2. BACKGROUND

Architectural colour perception depends on three variables: the lighting conditions, the characteristics of the object and the observer. The factors which affect natural lighting are closely related to the climate. Colour temperature, measured in Kelvins, determines the emission of coloured light-waves and varies according to air quality, characteristics of the sky, time of day and year. Fluctuations in colour temperature produce distinct tonal and shadow effects on architecture, as were recorded by Monet. Sky colour and clouds also intervene in architectural colour compositions as part of the background. Images appear sharp, diffuse or whitish for the presence of particles in the air. Humidity in particular affects visibility making colours appear less saturated, while mist prevents the perception of shapes and distances [1]. The psychological sensations of heat and cold are associated to temperature through synaesthesia [4], but not to a physical thermal experience [5].

It is not by chance that artistic preferences tend to coincide with the principles of physics and optics. Although value judgements on colour depend on non-sensorial data from cultural, social and personal aspects, the perception of colour is primarily conditioned by physical disposition. The climate and the surroundings have direct influence in the perception of

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

building colours as our visual system becomes predisposed to sunlight, mist and darkness, adapting to light changes. The sensitivity of human vision is tested when pictures taken at midday in summer show an overall blue-violet tone, for the film is not able to adjust in the way the human eye does. While in daylight adaptation is immediate, in darkness the process of recognizing shapes takes time, as the activity of the fovea depends on light levels: when light is stronger, our vision makes less effort in reading the surroundings, by consequence, we see less detail. As light levels diminish, for example, when clouds passing by interrupt the brightness of the sky, the sharpness of our perception increases, improving three-dimensionality and precision. In the case of difuse light, comparable to fluorescent light, objects appear shadowless, with a tendency towards blue and violet when high colour temperatures are produced.[4]

Visual comfort is related to processes in the eye and the brain, implicating comprehension of what is perceived. The effectiveness of colour greatly depends on the function of a space, for example, in a driveway or a parking area a single colour may cause disorientation or detraction from important signs, whereas varied colour sequences work in situations of long permanence [7]. The number of colours is a an important factor in the organization of images, but it is mainly for contrasts in brightness that hierarchies within the visual field are defined: the lightest object draws the attention of the eye [8]. The effects of simultaneous contrast between an object and its background are intensified by colour luminosity and the time of observation, leading to fatigue [5]. In the case of white, high levels of illumination produce glare, compromising sight precision and producing eye strain in the process of adjusting to lightness [9].

3. CASE STUDIES

Mancora and Lima will be described briefly in the aspects of climate, landscape, architecture and colour. By comparing the colours of buildings set in both locations the importance of colour selection according to visual comfort will be pointed out. Exterior walls rather than façades serve as colour support in the examples, the elements which affect the perception of wall colours will be commented without emphasizing on style or value, as it may be impair. For the analysis colours have been grouped as paint colours: acromatic, luminous, saturated and earthy, and exposed materials for walls, details and roofing.

Mancora used to be a fishing village, now it is attractive to surfers and tourists from around the world. Due to distances, it has kept a genuine character. Talara, the closest city is one hour away, Lima, at fifteen hours by bus, while the border with Ecuador, at less than three hours. The actual popullation of 9,000 inhabitants works mainly in fishing, the oil industry, commerce and tourism. Mancora belongs to the dry woodland region, it combines sandy beaches and plateaus cut by river beds, usually dry. The climate brings a well defined palette of clear sky with pink and purple clouds at sunset time, a dry soil, low mountains of marine origin with textures emphasized by shadows, dusty trees, desert vegetation, and the changing Cenia[a] of the ocean. Because of its proximity to the Equator the duration of days in summer and winter is very similar. Seasons are slightly differentiated during the year by summer rain and changes in the wind from July to November. Sunlight is strong all year long, the average temperatures are 22.3°C and 28.6°C, humidity oscilates between 50% and 55%. The rising of oceanic temperatures during El Niño phenomenom, recurrent every six to fifteen years, causes heavy rainfall. The last was in 1998.[10]

In Mancora dwellings occupy elongated plots, with a corridor to the side and a yard at the back. Isolated buildings appear as icons around the valleys and along an old highway where a few architects have intervened with individual projects. The climate is a major consideration in architectural design in this dry equatorial site. Sloping roofs, eaves, sun-porches, patios and shutters are common features in vernacular constructions, interiors result fresh and shaded by the use of small windows and high ceilings. Even though water in not abundant trees and plants are used to adorn and refresh, the native *algarrobo (Prosopis juliflora)* provides shade, nourishment and material for construction. *Tabique* is the traditional construction technique in the region: on a structure of *hualtaco* (native tree) chips of the same hardwood are bound together by a horizontal cane, then rendered with a mixture of mud and *algarrobo* leaves called *puño*, an additional layer of mud and cement may be applied on top and finished with paint. Since timber extraction is restricted, old structures are bought for recycling, recent constructions also being made of stone and concrete, with cane or brick walls rendered in cement, natural materials are left for details. The original palm roofing has widely been replaced by corrugated sheets (metal or cement with synthetic fibers), palm leaves are used as a cover. The nature of constructions is mainly organic, tabique walls are smooth, rough and uneven, these were traditionally left unpainted, in fishermen's huts only doors used to have colour. Chalk-based paint in light colours was used for building exteriors until the 90s. Though luminous colours are still the most used, the three stores that sell latex paint in the district also offer nuances as ochre, terracotta and olive green, more saturated ones, available on request from paint catalogues, have been used for restaurant and hostel façades.

The city of Lima is located at 12°S. The duration of night and day between seasons varies in thirty minutes. Temperatures oscilate between 14°C and 29°C from winter to summer. Its proximity to a relatively cold sea, due to the Humboldt stream, changes the climate that would correspond to its geographical location from tropical to humid. The overcast sky of Lima is its main characteristic, from May to November low and dense stratus clouds cover 7/8 of the sky. Only light drizzles occur during this period, so dust remains in the air. Mist is common in January and it dissipates from February to April. Humidity levels vary from 71% to 99%, allowing introduced plant species to thrive with little watering. The geomorphology of the area is mainly flat, though the foothills of the central Andes reach the coast at some points. The predominant colors of the natural landscape, defined by cloudy skies and bare soil, appear luminous and close to neutral. [1]

Climatic conditions in Lima allow flat roofs, plain façades and a wide choice of materials. Colonial and early Republican buildings were made of adobe rendered in plaster. Different styles and eclectic mixtures were built in brick and *quincha*, a technique which employs cane, mud and plaster, before the arrival of concrete. Brick and concrete rendered in cement mortar and painted predominate in modern and contemporary architecture. In Lima constructions have been coloured since Prehispanic times. At the arrival of the Spaniards imported pigments were used almost pure for decoration and for preventing glare. In the 1920s French influences arrived by means of an edict from the president which converted the city into the fashionable cream colours of that time, combined with brown and gray doors. In the 1950s paint in light colours was brough in from the United States and then produced locally. In the 1980s the assortment was poor, with a tendency to green, light blue and terracotta. [1] Though white and off-whites remain the most used, competition amongst the paint makers has resulted in a vast range of colours, making the selection a complicated task. The city presents a variety of combinations, a superimposition of colour periods may still be seen in the impoverished areas showing how architectural variety is reinforced by colour diversity. The relatively recent colour experiences have developed a colour culture.. [2]

4. RESULTS

The results presented in the following table are based on the observation of building colour evolution since 1986 in Lima and since 1995 in Máncora, on my experience as colour designer and on data from paint shops and users.

Colour	Use in Mancora		Effect	Use in Lima		Effect
Acromatic	White	Used	Glare if unshaded. Cold sensation.	White and variations	Common	Glare. Blend with sky. Demand complement
	Gray	Seldom used	Unnatural against the soil. Cold sensation.	Gray and variations	Used	Blend with sky. Monotonous or interesting
	Black	Not used	——	Black	Seldom used	Attracts attention
Luminous	Cream, green, light-blue, salmon, pink	Common	Blend with sky, contrast with natural materials. Cold sensation.	Cream, green, light-blue, salmon, pink	Common	Glare proportional to content of white. Blend with sky.
Medium-saturated	Ochre, olive, terracotta	Used	Blend with landscape and natural materials.	Ochre, terracotta, green, blue, red	Common	Moderate contrast with sky. Add definition.
Saturated	Yellow, blue, red	Seldom used	Unnatural. Attract attention. Hot sensation.	Various	Used	High contrast with sky and among buildings.
Exposed wall materials	*Palo* and *tabique*	More than 50%	Blend with landscape. Cold sensation. Ventilation.	Brick and concrete	Common, often left unfinished indefinitely	Add texture. If unfinished appear dull and monotonous.
Details and rendering	*Tabique*, cane, palm, stone	Common	Blend with landscape. Cold sensation.	Brick, concrete and others	Used	Add texture, variety and ornament to architecture.
Sloping roof materials	Corrugated sheets, palm	More than 80%	High reflection, unnatural if not covered by palm	Ceramic tiles, others	Seldom used	Add texture, variety and ornament to architecture.

Table 1: The use and effect of building colours in Máncora and Lima.

5. SUMMARY

In Mancora and in Lima colour decisions often result from tradition and practical issues such as availability, cost and maintenance. In Máncora most exteriors remain unpainted as at least an additional layer of material is necessary before applying a paint coating. In the case of Lima, despite the glaring effect, conservative white is the most used paint, luminous colours follow for their efficiency. Nevertheless, at both locations paint colours acquire an essential value when used for visual comfort, making it a substantial motivation in contributing to place identity. In Máncora a tendency to use luminous colours for mitigating high reflection is observed. In Lima non-luminous colours, grayish and earthy, are efficacious at controlling glare, in compensating the lack of shadows on walls and the monotony of the landscape.

Though the prevailing colour temperature of light at both locations is stable, the suitability of tonal values for exterior walls greatly depends on values of luminosity and saturation and on the particularities of each case. In Mancora landscape colours and natural materials delimit the range of nuances for exteriors, exact context is relevant in colour selection as the backdrop changes from mountains to sea and sky. For the hot climate colour-temperature synaesthesia is evident, luminous nuances produce a compensating cold sensation, while saturated colours appear unnatural. In Lima the urban background incentives varied harmonious combinations among adjacent buildings, with consideration to style and function, medium-saturated nuances are used for contrast with the overcast sky.

Surfaces determine the final aspect of architectural colour. In Lima, painted colours make-up building exteriors, paint is used for resisting humidity and repelling dust, in addition to its visual properties. In the rustic architecture of Mancora weathering creates a physical and chemical bond between surfaces and the natural context. The wide use and positive effect of natural elements in the architecture of Mancora denote the importance of texture and material quality in relation to the climate.

6. FURTHER STUDY

It would be valuable to assess levels of visual comfort and colour-temperature synaesthesia by experimenting with the perception of coloured walls in different climatic conditions. The application of this approach in places with differentiated seasons is another subject to be developed.

REFERENCES

1. M. Arrarte-Grau and B.Ludmir, "Lima actual: el color de la vivienda", architecture thesis, U. Ricardo Palma, Lima, 1987
2. M. Arrarte-Grau, "El color que los edificios quieren", proceedings from Perucolor I Congreso Peruano del Color, pp. 5-8, Interiores, Lima, 1999
3. W. Spillmann, "Colour order systems and environmental colour design", invited main lecture in the Forsius Symposium on Colour Order Systems, Sweden , 1983
4. J.C. Sanz, *El Libro del Color*, Alianza Editorial, Madrid, 1993
5. M. Déribéré, *El Color en las Actividades Humanas*, Madrid, Editorial Tecnos, Madrid, 1964
6. H. Varley, H. Armstrong & P. Morgan, *El Gran Libro del Color*, Editorial Blume, Barcelona, 1982
7. H.M. Proshansky & Col., *Psicologia Ambiental*, Editorial Trillas, México, 1978
8. K. Sagawa and Y. Shimizu, "Visual comfort of a colored image evaluated by chroma and categorical color", Colour Report F50 from AIC Interim Meeting 96 in Gothenburg, pp. 47-48, Färginstitutet, Stockholm, 1997
9. J.L. Caivano, "Semiotics and Costa: the meanings of the spatial distribution of light", pp. 161-163, Färginstitutet, Stockholm, 1997
10. G. Petersen Gaulke, *Historia Maritima del Perú*, Tomo I, Vol I, Editorial Ausonia-Talleres Gráficos, Perú, 1972

A. Liljefors, "Lighting and colour terminology", Colour Report, pp. 230-234, Färginstitutet, Stockholm, 1997
J.P. Lenclos and D. Lenclos, *Les Couleurs de la France*, Editions du Moniteur, Paris, 1990
K. Fridell-Anter, *Nature's Colour Palette*, Scandinavian Colour Institute, Stockholm, 1996

*Correspondence: e-mail colorarq@gnet.com.pe; tel 5114 36-8263 (Lima) , 5174 85-8326 (Mancora); fax 5114 41-0532; postal address Av. Jorge Basadre 971, San Isidro, Lima 27-Perú.

What colour is the red house?
An invitation for multicultural research on colour and architecture

Karin Fridell Anter*, School of Architecture, Royal Institute of Technology, Stockholm

ABSTRACT

This paper is an invitation for international research co-operation in the field of colour and architecture. It present a thesis work starting from an experience shared by many architects and others who have at some time chosen facade colours: *The house is not the colour I thought it would be!* 3600 observations of painted timber and rendered facades showed consistent variation patterns for differences between the "approximate perceived colours" and the inherent colours, involving both hue and nuance. These results were achieved in Swedish light conditions, nature and colour traditions. Comparisons with similar surveys in other parts of the world could help the understanding of the found variation patterns and their causes.

Keywords: Colour, architecture, perception, facade, exterior, research co-operation.

1. INTRODUCTION

This paper is based upon my doctoral dissertation *What colour is the red house*, which was presented in November 2000. Here I will give a short summary of some of its methods and results and, more important, discuss possibilities for new research starting from where my thesis ended. Thus, this is above all an invitation and a suggestion for further international research co-operation in the field of colour and architecture. I do hope that some of you will find my suggestions fruitful – and then we'll see what we can achieve together!

2. STARTING POINTS AND BASIC CONCEPTS

My theses work started from an experience shared by many architects and others who have at some time chosen facade colours: *The house is not the colour I thought it would be!* More specifically this means that there is a difference between the colour that we see on a colour sample and the colour that we see on a facade painted according to that sample. There is also another related experience, that the colour of a facade is not constant but changes with the observation situation, the distance, the weather and the season.

The basic concepts of my work are the following:
Perceived colour means the colour that is seen in the specific situation, by the specific observer. This means that the perceived colour of an object is likely to vary with factors such as light and viewing distance. It also means that there can be differences between the colours that different people perceive in a seemingly unaltered situation. I have, however, found means of identifying the "approximate perceived colour" irrespective of observer and, within specified limits, irrespective of viewing situation. Future references to *perceived colour* will mean this "approximate perceived colour" if nothing else is specified.

Inherent colour means the colour that the colour object would have, if it was observed under the standardised viewing conditions that are a prerequisite for the NCS colour samples to coincide with their specification. But to observe facades under such conditions is in practice impossible. One simply cannot place the house inside a lightbooth! Therefore the definition has been supplemented with an operational method of determination, in which the inherent colour is determined through visual comparison with NCS samples places directly towards the facade surface. (Fig.1)

3. MAIN QUESTIONS AND METHODS

The thesis work dealt with three main sets of questions:

1. Is it possible to survey and map out what colours people perceive on facades observed under different conditions? If so, what methods can be used and to what extent is it possible to obtain results of wider application?

* Correspondence: karinfa@arch.kth.se; phone +070 769 4017; Karin Fridell Anter, Noreens väg 71, S-752 63 UPPSALA.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

2. How does the perceived colour of a facade vary with changing observation conditions? What is the impact of factors such as light conditions, viewing distance and surrounding colours?
3. How does the perceived colour of the facade, in different situations, differ from the inherent colour of the same facade? Are there any recurring tendencies or perhaps even consistent variation patterns that can be presented in a practically useful way?

Starting from these questions I have made a broad explorative survey of the colours of painted facades seen in daylight. I combined six psychometric methods, which all were based on the basic understanding that the colour that a person sees in a specific situation cannot be determined in any other way than to ask her what she actually sees. The problem was to interpret the answers in a way that could convey the individual experience to other people and make it available for statistical processing and for comparisons between different persons and situations. In one of the methods the observer – a trained colour architect or research colleague – stands in front of the house and looks in the NCS atlas for a sample which in this specific situation look the same colour as the facade. (Fig. 2) I also used the method of marking the perceived colour in NCS symbols without access to any reference samples.

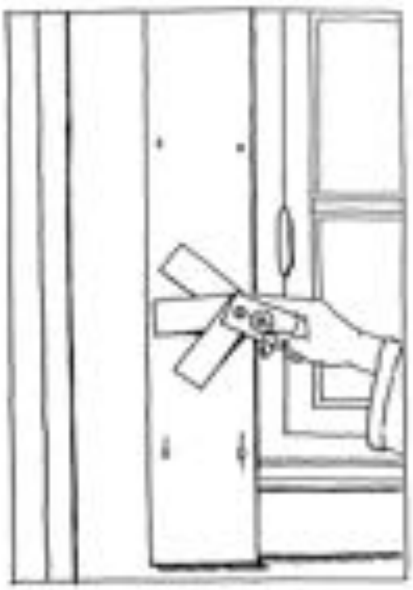


Figure 1: The method for determining inherent colour.

Figure 2: Determination of perceived colour using the NCS atlas.

In other methods "naïve" school students were asked to name the house colour with their own words, to chose between given colour words or to mark its colour attributes on given scales. The total survey included about 100 houses with different colours, 400 observers and a total of 3600 observations. In the analysis the NCS was used as a colour language and as a tool for categorising and quantifying different aspects of the relationships between colours.

4. RESULTS

The observations resulted in a vast information about perceived colour in different situations, and for each facade this was compared to the inherent colour. The method evaluation and the detailed results are presented in my thesis. Here I will only illustrate some of my findings, and after that proceed to my suggestions about further research.

The comparison between the "approximate perceived colours" and the inherent colours of the observed facades showed consistent variation patterns for differences in both hue and nuance. The most obvious and consistent tendency was that the perceived colour always had less blackness than the inherent colour. This was true for all observed facades. The typical nuance differences between inherent and perceived colours are shown in Figure 3.

Also the hue differences between inherent and perceived colour showed a consistent variation, as is shown in Figure 4. Using the NCS colour circle the most important recurring tendencies can be described as follows:

- Inherent colours in the reddish yellow octant, the green/yellow quadrant and the blue/green quadrant would tend to give perceived colours which shifted anticlockwise in the circle, aiming towards a breaking point where inherent and perceived colour would seem to coincide, near the hue of the blue elementary colour.
- Inherent colours in the yellowish red octant and most of the red/blue quadrant would on the contrary tend to shift clockwise aiming towards the same breaking point.
- Neutral grey inherent colours would tend to get an added chromaticness and a hue near blue.

In a slightly simplified manner, this could be summarised as a *hue shift from yellow towards blue*.

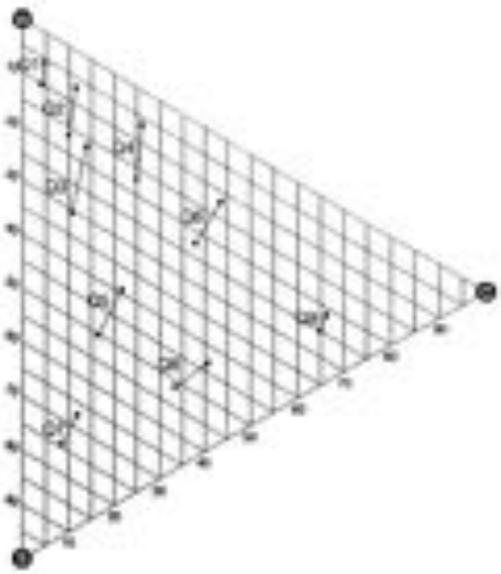


Figure 3 Nuance differences between inherent (●) and perceived (▲) colour for a number of typical timber facades shown in NCS triangle.

Figure 4 Recurring tendencies for hue shift from inherent to perceived colour, shown in NCS circle. Arrows indicate directions, not sizes of shifts.

5. SUGGESTIONS OF JOINT RESEARCH

One of my three sets of initial questions included the issue of wider applicability. My studies were all made in mid-Sweden, that is in Swedish light and against the background of Swedish nature and building tradition. So my results are scientifically validated only under these circumstances and not for any other part of the world. I have, however, reason to believe that at least the major variation patterns are valid also elsewhere – this assumption I base upon my presentations on conferences in Sydney 1999 and in Savannah 2000, where other participants confirmed that they recognised the patterns I showed.

It would, however, be very valuable to be able to carry out similar surveys in other countries. This could throw light on the question of applicability – are the patterns showed in my thesis specifically Swedish, or are they valid more universally? I therefore hope that some other researchers would be interested to carry out investigations parallel to mine, with the important difference that the light conditions, the natural colour scheme and the traditions of facade colours would differ from those in Sweden. Such a multi-geografic and multi-cultural comparison could also help to answer the question that always comes as step two when my results are presented: What is the explanation behind the found variation patterns? Why do such colour shifts occur?

In my research I aimed at surveying, mapping and describing the differences between inherent colour and perceived colour on facades, rather than explaining the causes of these variation patterns. My results have already been presented at seminars and published in magazines, with the intention of supplying a useful tool for architects and other colour designers, and I hope to be able to present them in a book with this specific scope. But, of course, as a scientist one is also curious to understand the mechanisms behind what is found. In my thesis I have discussed some possible explanations, and several of these could be clarified through cross-national comparisons.

1. Light seems to play a very important rule for the difference between inherent and perceived colour. There is a difference in both intensity and spectral composition between the standard light in which the inherent colour is defined, and the natural daylight of the outdoor situation. Other possible explanations are connected to the altitude of the sun and the relative dampness or pollution of the air, which might cause different patterns of changes in the energy spectrum of the sunlight. This set of possible explanations could fruitfully be explored if surveys parallel to mine were undertaken in parts of the world with light conditions specifically different from those in Sweden.

2. The second set of possible explanations depend on the coloristic context in which the house is seen. My results preliminarily imply that simple simultaneous contrast effects between the house and its surroundings are not decisive for the colour perceived on the house. There are, however, more sophisticated context effects that would need further investigation. One possibility is the *acquired successive contrast*. This hypothesis implies that we tend to disregard colour qualities that are overall existing in a special type of situation, and then react when we meet objects that lack this overall quality. In Swedish nature and in Swedish building tradition practically everything has an inherent yellowness, and my hypothesis is that we disregard this yellowness when we are moving around in the outdoor world. Then, when we meet an object with no or only a little inherent yellowness we would tend to perceive blueness – an idea that agrees well with my findings of hue differences between perceived and inherent colour. This hypothesis could be tested through comparisons with other countries, where the colour scheme of soil, rocks and vegetation is different from that in Sweden and where there is also a difference in traditional building materials.

3. A third set of possible explanations deals with the observer's attitude, references and expectations. Many signs indicate that our perception of house colours is based on our specific experiences of how just *houses* usually look. The traditional hue-scale of Swedish houses is mainly yellow-red, whereas bluish colours hardly exist at all. When people in Sweden see houses that differ from this scale we might tend to enlarge the difference – which for houses with some tinge of blue would make us perceive a larger blueness than what there is in the inherent colour. This would mean that colour perception in this respect is culture dependent – a hypothesis that could be adequately tested only trough comparisons with cultures that have different colour traditions and references than those of Sweden.

Thus I have found at least three possible starting points for cross-national comparisons of the relationship between inherent and perceived colour:

- What is the importance of regional light differences?
- What is the importance of the colours of the surrounding nature?
- What is the importance of cultural differences in colour traditions and expectations?

The primary problem behind my study was: *The house is not the colour I thought it would be!* Even if my results may not be applicable outside Sweden, I am sure that the problem as such is close to universal. Comparative studies made in different conditions would help finding a more widely applicable solution of this problem, to the benefit of colour designers throughout the world. They would also bring us closer to understanding the mechanisms behind the difference between inherent and perceived colour, and thus add more general knowledge to the field of colour science.

I am certain that many of the problems dealt with by the congress participants or the readers of the proceedings would similarly benefit from international co-operation. Therefore I hope that some of you will consider my suggestion on joint research starting from my ideas presented here or from questions raised by your own research.

ACKNOWLEDGEMENTS

The thesis work was carried out at the Department of Architectural Forms, Royal Institute of Technology, Stockholm. Principal supervisor was Professor Jadwiga Krupinska. The work was financed by research grants from the Swedish Council of Building Research, the Swedish Federation of Painting Contractors and the Swedish Painters Union.

REFERENCES

1 K. Fridell Anter, *What colour is the red house? Perceived colour of painted facades*, Royal Institute of Technology, Stockholm, 2000.

Paint or *Color*? Bursa example

Susan Habib*, Nihal Çetinturk*
Ph.D. Student in Architecture, Lecturer in Architectural History

ABSTRACT

While traditional/vernacular color scheme of a city in historical regions should be protected, changes in life style reflect on cityscapes in all ways, in which the role of new materials, paints, etc can not be denied. Lack of architectural and urban design studies in this field added to existing countless opportunities of new technology, with the strong desire to *trying* those by building owners, users and contractors have caused a chaotic situation in the use of color in cities; Bursa with its historical colorful background is no exception. All these form a *trial and error* phase, with painted or materials applied on surfaces without a sensitive touch to transform them to *color*. This must be taken in mind that color with its inherent power can bind past, present and future of the city and create an urban sense of place.

Keywords: Sense of place, vernacular/traditional architecture, color, Bursa.

1. SENSE OF PLACE AND COLOR

Sense of place implies an interaction or response to place. In spite of differences in perception of different individuals, if the relationships in a designed space are perceived with similar meanings, then one can talk about a sense of place; a consciousness towards it, not totally dependent of the physical environment, yet comprehensive of life, soul and pattern of all events experienced in the place. In sum, it is our sense of time, habits, experiences that in the long term, creates our sense of place. Color has an important role in creating this sense and giving identity to the built environment. Juliet Albany proposes to explore the role of five contextual elements: climate, color, community, and conjuncture as contributing factors of urban design and planning in creating localness and an authentic sense of place. She defines color as "the language of place" and adds: "It is the manifestation of these elements in the physical and social environments, that provides the context for an urban Sense of Place." (1)

2. SOMETHING TO TELL WITH COLOR

Vernacular/traditional architectures always have some stories to tell about the communities they belong to, their creatures' lives, beliefs, myths, rituals, traditions, history, life conditions of their times, interact or response to the place, the environment and climate nourishing them. They use color as a powerful tool of communication, for narrations bridging the past and present.

Fernand Léger addressed to the architects in 1925: "From an artistic standpoint a bare wall is perfect, but from a social one it fails. And to think, gentlemen of the architectural profession, that we might have come to some agreement about these walls. You didn't want to believe that colors are there to destroy lifeless surfaces, to make them habitable, to take away their absolute, architectonic status..."(2)

A famous theory advanced by Swedish art historian Erik Lundberg is about the deep red color of the log-houses, in contrast to their green surroundings, in rural districts in Norway and Sweden: "It started in imitation of the much grander and more durable red brick manor houses. The idea arose that a real house *had to be* red." (3) The wall paintings in some towns at the foot of southern Germany's Alp Mountains tell much about the religious beliefs of the residents. (4) The joyful peach and parrot green walls of a house painted by a Greek mother to express her pride and happiness from her daughter's homecoming from America, tells us about expressions of some powerful inner feelings of the owner. In another island in Greece, gray doors and windows indicate mourning period of a widow living in the house. However the actual cause for these paintings is protecting the local porous stone walls by plaster and paint from humidity. (5) In Burano Island in Italy, where women frequently work in front of their houses watching their husbands fish a few meters away, similar colors of boats and houses facilitates spotting each other easier. With this we learn something about the everyday life in Burano Island. (6) *Bango* is a small, one-room dwelling decorated and lived in by young boys on the Indian Ocean island of Mayotte. From the age of 11 or 12 years old, boys are encouraged to construct their *bangos* outside the family compound, in order to avoid gender promiscuity. Although women of houses continue to care for the young boys' needs, the *bango* becomes their own private space, highly individual expressive of their tastes, desires, fantasies, ideals. By signs, emblems and colors in their wall paintings, the exterior walls of *bangos* assert differing claims to identity, both personal and

9th Congress of the International Colour Association, Proceedings
of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

collective, telling much about their passage from youth into manhood. (7) The story of colors on facades of Afro-Brazilian Mosques in West Africa is another astonishing one: "In the 17th and 18th centuries, Bahia was a major export town of sugar and tobacco, grown on numerous slave plantations where majority of the slaves were from the same stretch of West African coast, Benin to Lagos. What the Portuguese-Brazilian plantation owners did not know, and were to discover only later after nearly being overthrown by the slaves, was that many of them were devout Muslims. Number of those was literate in Arabic, and had been respected participants in the militant reformist *Jihad* in the north of Nigeria from 1804 to 1815. The slaves' faith in Islam and language were kept private. ...As they bided their time, they also helped to build the city of Bahia. The architectural landscape of the old city center, since then, is a collage of soft pastels. As time passed ornamentation became more elaborate. Bahian houses also were transformed by decoration. Exterior walls were painted in every shade of the city's distinctive pastels and liberally decorated with bas-relief floral motifs. ...Between 1807 and 1835 there were a dozen organized revolts by the slaves, all directed by African Muslims. ...The Bahian colonists found it increasingly difficult to be at ease in the company of their own slaves. Then they found the strange documents and scraps of paper, at first thought to be written in Hebrew or Egyptian hieroglyphics. When the script was identified as Arabic, and the catalyst behind the revolts as Islam, a resolution was hastily taken to deport all 'dangerous Africans' back to their home continent. ... Previously slaves, Muslim artisans who had carried their skills back, initially found little demand for their services. ... Only when they established themselves economically were they able to build houses and mosques suited to their own taste. These still stand in a number of Beninoise and Nigerian 'coastal' cities. ...One decorative element that has increased in importance and has become much more complex is color. While the churches of Bahia were sparing in its exterior use, the Afro-Brazilian mosques affirm the use of numerous complementary colors, usually pastels, to create and reinforce the architectural elements." (8)

"The construction of *bangas* in Mayotte is a cultural phenomenon which has been dying out recently. In order to try to reinvigorate the custom, a competition was held in spring 1987 to determine the most beautiful *bangas* on the whole island." (9) These words were written in 1987. We don't know whether this cultural phenomenon continues today or not, but the fact is that we are faced with some positive and negative rapid changes in our life conditions. Abandonment of vernacular/traditional architectural colors can take place among the negative ones.

A research in Kirkkonaklar, a squatter region in Ankara*, sought the reasons and preferences of the residents about their use of color in interior and exterior of their houses. It ended: "You have painted your house with nice colors. What if you move to an apartment house? Which color do you prefer for the building or the exterior and interior walls of your flat?" Almost 90% of answers were "white". And the answer of "Why white?" was: "because white is more conspicuous", or "because white shows the house more beautiful." But almost none of the current apartment houses built in the region are white. Their facades are highlighted with odd and garish paints, selected from samples given by paint producers following the international fashion, by individual tastes of the contractors or architects. (10) The case is not different in most of the cities with rich heritage of vernacular/traditional architecture. We still can see some existing examples, but most of them are in bad situations, some are restored or renovated but with almost no attention to the original vernacular colors. Some are painted in white or in some colors more or less similar to the traditional ones, which might be done with good intention, but at the same time, they could be dangerous, since the similarities are limited by the use of, for example a yellowish paint, commercially produced rather than one of the yellow ocher tones, originally used in traditional/vernacular houses.

3. A SHORT LOOK TO OUR SITUATION

Historian Marc Bloch asserted: "Human beings are children of their time more than they are their fathers' children". (11) We are living in the Communication Age, which speed is one of its most evident characteristics. It looks impossible to prevent globalization. What we should not overlook is that there is only one *humanity* and one of the facts of universalism should be respecting and valuing the *local*. While new communication means bring us closer together rapidly, they also reflect in our awareness about differences among us, and suggest being more conscious about our common fate. This may support the idea that new evolution may bring a new approach to the concept of *identity*. "An identity that will be perceived as a sum of all of our conceptual belongings^. In this new perception there is more place for belongings to the community of

* These houses were built without acquiring the land rights 25 or 30 years ago, by immigrants from different parts of Turkey, following similar rules of Turkish vernacular/traditional houses of the regions they came from and continued their lives with colorful facades in their green gardens, cultivated by themselves. Now almost all of them are destroyed and high-rise apartment buildings are arisen instead. The owners had the right to half or have free flats in case of selling their lands to contractors. Therefore, they preferred to cut the trees, use them as firewood for heating during the last winter they lived in their houses, before their second migration to apartment life.

^ appartenance (French)

humanity, without obliterating our multidimensional private belongings. An identity that finally, one day in future, will become our main belonging." (12)

Human beings previously did not share this much common knowledge, references, means, ideas, images and fate, which obliges us to emphasize our differences as well. Differences are always required as balancing factors, but these should be as peacefully, humane and environmentalistic as possible. Researching local/vernacular/traditional architectures, learning from them and finding bonds with the future can be mentioned among them.

4. WHAT TRNSFORMS *PAINT* TO *COLOR* IN BURSA

Some cities in the world are known for their peculiar historical and traditional/vernacular color schemes. Turin, Bologna, Burano, Seville, Prague, Vienna are some of those, and we propose Bursa (a city in the Marmara Region of Turkey) to be regarded as one of them: A city with an original and still vibrant historical/traditional color scheme, famous for its colorful silken textiles and high-quality, colorful ceramics (İznik). We believe that dealing with silk and ceramics of Bursa has enriched the sensitivity of people towards color combinations in living environment, reflected in architecture, either interior or exterior, monumental or civil.[*] Today, however, Bursa is an important industrial center of Turkey. Many factories have been built around the city and inevitably the fruit orchards and greenness, which nicknamed Bursa "Green", are gradually disappearing. While the restoration applications must be done simultaneously with color restorations, according to color maps and guidelines -what has been overlooked till now- new buildings and districts must be designed and colored consciously in order to achieve continuity and be helpful to preserve the colorful characteristic of Bursa. All designs, selections among new availabilities, materials and paints, and applications should be for creating a sense of place, universal with local colors, which occult the dynamism of life.

Most of the houses of Bursa remaining from the 18^{th} or 19^{th} century, are generally two stories. The first floor facades are coated with various tones of indigo blue (çivit mavisi), yellow and red ochre (aşı boyası), white, green and black. Usually, stones are used for basements, ground floor and the walls of courtyards. Nowadays, however, these stones are covered, usually, by red ocher or black paint to prevent humidity. A timber beam divides ground and first floors. Originally timber beams, doors, windows and buttresses remain with their natural colors (with the slivery brown color of the timber patina), but recently, in order to prevent deterioration and aging, these were painted by oil paint close to the natural color of timber. Only two other colors are seen on doors and windows: light green and light blue. Also some imitations of these, by oil paint, are seen on more recent painted windows and doors. Some believe that the green color shows that the owner of the house has completed the pilgrimage to Mecca, and the blue one may have some relations with the believe of being protected by the *evil eye*. Although number of façade colors is not as much as those in Burano Island, but these three colors, and mainly the original wood color, have the role that white has there to achieve a harmonious impression to the colorful streets. (13)

Luis Swirnoff talks about the existence of a "vernacular eye" and compares traditional/vernacular colors with languages, local and specific to place, which arise in a particular environment, repeat over time and become a part of the public memory and express a human response to that environment. (14) This "vernacular eye" is a universal concept and language with different accents in different parts of the world. While the privacy of interiors brings other factors to follow, and they are mostly dependent to the user or owners' preferences and priorities, the exteriors belong to the public, embracing both natural and cultural circumstances. They have some worries, some cares to share with neighbors, other residents and passengers. Color in urban space is seen in four different scales: the scale of architectural details, their surface colors and textures and their relations to each other; the scale of individual building; the scale of the street, square and close environment, relationships with colors of surroundings whether natural or man-made, and finally in the scale of city or district in a wider point of view. Color design in urban space has to be considered in these scales. Meanwhile, we determined some factors in color combinations in Bursa vernacular/traditional architecture, which we accept as both universal and local, similar in other vernacular/traditional architectures we know about, and we think that taking those in mind, in design and application phases, can be helpful to create an urban sense of:[**]

- Being responsive to both natural and built environment, establishing relations with them either by contrasting or by adaptation and harmony,
- Being responsive to local climate and light conditions,
- Reflecting or establish relations with faith and beliefs, traditions, time or historical phase, or in sum social/cultural values

---

[*] More information about architectural color combinations in Bursa vernacular/traditional architecture is available in our previous studies presented in AIC meetings in Warsaw (1999) and Seoul (2000).

[**] Please find visual materials in our poster.

of the community,
- Reflecting life conditions and affiliation of the owner or user,
- Participation of users or others who have been familiar with the life in the region or in similar natural and cultural context, like building masters,
- Improvisation, finding quick solutions to unexpected problems in construction and later revisions,
- Using natural paints and pigments, which at the same time provide a better and natural image during aging,
- Being responsive to the kind of activities, which take place in the space,
- Balanced proportions, ratios among different surfaces either painted or with natural colors are as important as hues,
- Repetition of some colors, either symbolic or not, in some specific architectonic elements,
- Continuity, not in using same colors on same buildings but continuity of same or similar colors in time, which can be interpreted as similar behaviors forming the "soul" of place and opening the way for the "memory" of place.

These are lessons we drive by experiencing Bursa vernacular/traditional architecture as a part of what Amin Maalouf calls our "vertical heritage", which comes from our ancestors, traditions. He asserts our "horizontal heritage" coming from our period and contemporaries is characteristic than the vertical one. (15) What should be done is making a synthesis of those, which is responsive to both physical and psychological human requirements. In another words, forming a whole with a "unique expression of time and circumstances"(16). Whole which is always more and different than the sum of the parts; like one that contemporary Turkish Poet, Edip Cansever describes in his poem, *Hope*:

When you touch your finger to the apple,
You understand its color.
When you see the apple with your eyes,
You hear its voice.
If you hear it,
The roundness stays with you.
There is a new meaning in each beginning. (17)

ACKNOWLEDGMENT

This study, partially presented in this congress, is supported by the Gazi University Research Fund. We wish to extend deep gratitude to Prof. Seçil Karal Akgün for her wise suggestions, and to Karıncayuvası for their assistance in preparation of our posters.

REFERENCES

1. Albany,J., "The Five Contextual Values Of Urban Design That Can Facilitate Sense Of Place", *Habitus 2000, A Sense Of Place*, Perth, Australia, (2000)
2. Dutmann,M., *Color In Townscape*, Architectural Press, London, p.25, (1980).
3. Rasmussen,S.E., *Experiencing Architecture*, The M.I.T.Press, Massachusetts Institute of Technology, Cambridge, pp.216-217, (1968).
4. Sato,M., *Community Design, Elements of Modern Environmental Landscape and Signage*, Graphic-Sha,Tokyo, Japan,pp.18-19, (1992).
5. Becom, J., *Mediterranean Color*, Abbeville Press Publishers, New York, p.152, (1990).
6. Ibid. p.26.
7. Lignon,C., "Bangas, Self-Built Houses in Mayotte", *MIMAR 26*, Dec, Concept Media Pte Ltd, Singapore, pp.12-19, (1987).
8. Hallen,B., "Afro-Brazilian Mosques in West Africa", *MIMAR 29*, Sept., Concept Media Pte Ltd, Singapore, pp.16-23,(1988).
9. Lignon,C., "Bangas, Self-Built Houses in Mayotte", *MIMAR 26*, Dec, Concept Media Pte Ltd, Singapore, p.14, (1987).
10. Habib,S., Irkh,D.,"A Color Research in Kirkkonaklar Squatter Quarter",*ADA Kentliyim*,No.16, Yayınevi, Ankara,pp.86-90, (1998).
11. Maalouf,A., *Les Identités Meurtrières*, Editions Grasset & Fasquelle, (1998), (*Ölümcül Kimlikler*, Turkish translation by Bora, A., YKY, Istanbul, p.p.86), (2000).
12. Ibid. p.85.
13. Lancaster, M., *Colourscape*, Academy Editions, London, p. 26, (1996)
14. Swirnoff, L., *The Color of Cities, an International Perspective*, McGraw-Hill, USA, p.1-5, (2000).
15. Maalouf,A., pp.86-87.
16. Coomaraswamy,A., quoted by Alexander, C. in http://www.math.utsa.edu/sphere/salingar/Chris.furniture.html
17. Yenitürkü, *Fira Fira*, Göksoy Yayıncılık, Istanbul, (1990) (Audio cassette)

---

* Correspondence:
Susan Habib 6. Sokak 47/8 06500 Bahcelievler Ankara Turkey
Phone: +90 312 212 05 31 Fax: +90 312 230 84 34 or +98 21 200 69 06 E-mail: lapismaple@hotmail.com

Nihal Cetinturk Gazi University Faculty of Engineering and Architecture Dept. of Architecture Celal Bayar Bulvarı 06570 Maltepe Ankara Turkey
Phone: +90 312 231 74 00/2712 Fax: +90 312 230 84 34 E-mail: nihal@mikasa.mmf.gazi.edu.tr

Black - Meaning and Connotation in Europe and Africa

Leonhard Oberascher* and Fatumata Oberascher*

ABSTRACT

The two fundamental questions of this study are: 1) Do the concept of black and the colour black evoke the same associations? 2) Do all cultures (and all social groups) in fact rate the colour black mainly negatively? The first part of our investigation deals with the colour associations of a particular professional group within the (endemic) society of Austria, the second part with people who, by reason of their skin colour and origins, have a very personal association with black. So far, 51 architects, designers and students of design have been questioned about their associations with black and other colours / colour combinations (presented as a concept and as a colour sample). No significant differences were found (similarly for the other elementary colours W, Y, R, B, G). By contrast, clear differences from the connotations of black reported in European literature were demonstrated by 40 (dark-skinned) persons (37 from various parts of Africa, 2 Caribbean and 1 Colombian), questioned about their associations with black, the term(s) used for black, the significance and the use of black within their culture or tribe, and about the significance of their own skin colour, both to them personally and to their own culture.

Keywords: black, skin colour, Africa, associations, semantic valency, ambivalence, male/female, erotic love, dark energy

1. INTRODUCTION

Hardly any other colour is so mysterious and exerts such fascination as black. Despite its consistent popularity in the world of designers, architects and fashion, the colour black is associated in Europe and in European-influenced cultures almost exclusively with negative concepts. Thus in his meticulously constructed comprehensive phenomenological study of the central semantic valency[*] of black, Ecker[1] reaches the conclusion that for all its ambivalence, predominantly negative associations are ascribed to black. Quoting Kranz, he writes (p 151) that such features common to the symbolism of various races, countries and periods, are more numerous and important than the differences – which we shall examine more closely in the context of our survey amongst dark-skinned people.

These results are to a large extent confirmed by those from the studies done by Hackl-Grümm[2] (Austria), Riedel[3] (Germany) and Heller[4] (Germany) on free or aided associations with black in their respective native countries.

All the connotations reported in these studies and the semantic aspects deducible from them can be classified in Ecker's (ibid. p 208) schematic representation of the valence of black, abstracted and synthesised from various spheres of experience. He characterises the stable semantic core – the final result of an increasingly abstract hermeneutic semantic distillation – as a "manifest nothingness / source of being as an objectless unity / idea of nothingness as an entity and counterpole of what exists". From this – inversely to the direction of abstraction, a first step towards semantic concretisation (finally arriving at the individual perception, the everyday/cultic use or valuation of black) – he deduces 5 forms, each with infinite additional concretisable effects: 1. essential quality (reinforcement, visible invisibility, competence); 2. exorbitance (particularity versus generality, excellence and spirituality, abnormality and strangeness); 3. immanence (repression and introversion, reduction and regression, negation and latency); 4. transcendence (the world beyond and the supernatural, cosmos and mysticism, infinity and God); 5. the ouroboros-Janus principle (life and chthonian origin, death and end, assertion – positive: as being, claim to power; negative: as nothing, powerlessness). This characterisation shows clearly the typical ambivalence of black. The concrete use of this model can be illustrated by clinical psychopathological experience; in related diagnostic procedures, it is frequently patients suffering from, for instance, depression, who show a conspicuous affinity for the colour black (see form 5: inner void ⇒ nothingness)...

Amongst the most frequent negative semantic connotations mentioned by all the previously quoted sources (including our own study of 51 subjects) are: night (dark, sombre, gloomy, shade), death/dying/end, burnt/charred/atrophied, burial (cemetery), mourning (dress), fear (eerie, threatening, dangerous), power, dirt, amongst the most frequent positive associations: dignity, solemnity, elegance/fashion, status.

* Ecker (ibid.) uses the concept of "valency" to denote the totality of the meaning attributed to a phenomenon (here the colour black) deduced phenomenologically from its most diverse manifestations (etymology, cultural history, psychology...) and despite its heterogeneity and versatility, integrated into a meaningfully structured whole – i.e. arriving at the essential quality.

The negative valence of black was also documented by two further studies on the basis of procedures other than (free or aided) association: Biasi and Bonaiuto[3] showed that amongst a wide variety of available colours, the majority of people choose black mainly or exclusively for drawing recollections of stressful experiences. The Japanese study by Ohno and Nakano[6] used retrospective methods to demonstrate black as the colour associated by their subjects with immediate experience of the 1995 Kobe earthquake; initially, during and immediately after the catastrophe, the emotional colour images of those affected were predominantly black, but also grey and white; a week later, black clearly decreased in these images, and only after 3 months do the colours become brighter. The authors deduce that "fear produced black and grey" (p 70).

On the other hand – here ambiguity as a basic dimension of its valence – in specific contexts, black can assume a definitely positive role. Paradoxically enough, this is often due to the primarily negative connotation – as reported by Hutchings[7], for instance, in his article on Colour in Folklore: "Anyone or anything looking perfect or beautiful is trying to copy and hence blaspheme God, therefore man-made beauty must be spoiled with black (or dirt). In this way the wrath of God or the Evil Eye is avoided and black symbolises good. Chimney-sweeps can be hired in Britain to bring good luck at a wedding by touching and spoiling the appearance of the bride's dress." (Taking Ecker's valence analysis / psychogram of black, here semantic aspects become operative which in other contexts assume a sombre or threatening character: associated with the 3rd form (immanence), negation – in this case of a claim to perfection or to being God-like; with the 5th form (ouroboros-Janus principle), reflection on death, finiteness, being earth-bound).

Languages are also an inexhaustible if gloomy source of connotations for black. The Romans, for instance, had two words for black: *niger* and *ater*, each of which also means dark, sad, ominous, dreadful, malicious. The Latin word *sordere* (to be dirty) can be followed through various modifications down to the German *schwarz* (black; originally: dark, dirt-coloured), while the English *black* is ascribed to a root meaning "burnt, scorched". Even if this connection is no longer so apparent in modern European languages, there are a great many idiomatic expressions in which black stands as a synonym for negative aspects. In Brewer's Dictionary of Phrase and Fable[8], for instance, there are no less than 81 expressions using the word "black"; of these 47 may be taken as having clearly negative connotations, only 4 positive and 30 neutral.

These findings on the valence of black, apparently largely consistent over time and distance, should not obscure the fact that, like all other colours, black has undergone a change in at least some aspects of its (social) significance. In my paper "The role of color in the 21st century"[9] I presented a "model of how our relation to color has changed in the course of history. The important thing is that earlier stages of development are not replaced, but overlaid by the succeeding ones. Thus archaic experiences as well as those specific to cultures, social levels, groups and individuals, determine our present relation to color. This is, however, not static, but is constantly altering as a result of social change." Moreover, the growing possibilities of intercultural exchange, due to increasingly efficient communication and information technology (mass media, Internet, etc.) are rapidly accelerating this process of change. "A particularly important role is played here by the spread of religion, irrespective of culture, as well as the increasing intensification of trade relations. The worldwide expansion of large trade organisations and the global marketing of particular brands or products started a process of global homogenisation, which has also had a lasting effect on people's relation to color" (ibid.). Indeed, today we encounter black widely as a favourite colour in fashion, design and architecture. This may be due to the fact that on the one hand black, more than almost any other colour, has the effect of being elegant, exclusive, impressive (see Ecker's 2nd fundamental valence form: exorbitance), and on the other, it is a very practical colour, which can be combined to advantage with other colours – as Coco Chanel said, black stands up to anything. It may be assumed that the current success story of black in various fields of (external) modes of living is based not least in the need for differentiation and individuality that is the dialectic accompaniment to global homogenisation. This phenomenon demands the counter-tendency to "local, cultural separation (diversification)...", one result of which is "that group-specific colours within individual cultures are being classified to a greater extent and are becoming more unconventional" (Oberascher[10], p 7), black with its exclusive qualities as well as negation and internalisation (see Ecker) seems ideally suited to this.

In her reflections on the "archetyp of black in our time", the theologian and Jungian psychotherapist Riedel (ibid., pp. 169ff) sees further (depth-psychological) reasons for our current relation to black. She maintains that "an immensely destructive trait permeates our age", in which sadism, torture and (political) violence have assumed extreme dimensions (SS uniforms); even in the field of eroticism, this circumstance finds expression in the black of sado-masochistic acts. On the other hand, she detects a change in the image of God: the rejection of the Manichaean duality of Good and Evil, in favour of a divinity with an integral dark side (cf. also Ecker's ouroboros valence), both in theological debate and in the (individual, but also, increasingly, collective) unconscious of many religious people of our time. And at last, "attention is also being turned to the representation of the female principle in the image of God" (ibid.). Furthermore, so-called "black theology", based on resistance against repression of the black population in the USA, is focusing on the efforts towards emancipation, in the name of a God "who stands by the underprivileged, the poor, the 'black' on this earth" (ibid.).

The popularity of black, particularly in fashion, design and architecture, shows this colour clearly as trend-setting, and thus as the result of a collective desire for a change of colour. Trend colours are a symbolic expression of predominant taste orientation, and serve basically to demonstrate that one belongs to a reference group (idealised in the media) which represents the spirit of the age (cf. Oberascher[10], p 6).

The phenomenon of a colour's change in significance is shown with particular clarity in purple. "Since 1987 [until 1994/95] there has been a continuous rise in the proportion of purple colors [nuances with focal points at NCS 3050-R50B and NCS 3050-R60B] or color combinations with purple [...], not confined to certain types of products" (Oberascher[11], p 66f). Thus purple gradually became one of those trend colours that suddenly take over whole areas of production, from underwear to bicycle saddles. Purple – the "in" colour – often combined with turquoise, was used to express modernity, fashion and trend awareness – despite the fact that it "had always been regarded negatively in literature on color psychology (tension, reluctance, disquiet, renunciation, etc.) [...]" (ibid.).

For black, too, this development into a fashionable colour is well documented historically (cf. Heller[4], p 97ff). Black made great headway in the late 15th century, when Spain became a world power and established the Inquisition. "There began a century of sombre piety. Black was the appropriate colour" (cf. Ecker's forms of valence, e. g. exorbitance: peculiarity, excellence, spirituality; immanence: repression, negation; transcendence: ouroboros-Janus principle; claim to power...). Appropriate also to dress fashion – "demure as none before or after" – with the characteristic requisite of the increasingly starched ruff. At the end of the 16th century, the Netherlands gained political and cultural influence. Dress, especially the ruff, became less stiff, but black remained, also as the colour of the Protestants, since the Reformation had taken a firm hold in the Netherlands. Martin Luther was convinced that all people, including priests, are equal before God. Luther preached in black, and his black robe, adopted by all the bourgeois authorities, is still the basis of ceremonial mayoral dress and judges' robes. Black was also important as the (dress) colour of Sartre's existentialists; black individualises, sets apart, endows with seriousness, remains in the background to allow focus on the wearer's face as the centre of his individuality – a basic theme of existentialist thinking. More generally, "black clothes are popular with all groups that wish to see themselves as apart from the mass, as untouched by conformist values" (Heller[4], p 101).
In modern (high-tech) design, with the motto "form follows function", black is "the absolute colour" (Heller[4], p 109). Together with white, grey, and the natural colours of preferred materials such as glass, mirror, metal or chromium, black is appropriate to the deliberate avoidance of what is superfluous, in favour of functionalism: "the severity of self-sufficient technology" (ibid).

2. COLOUR CONCEPT – COLOUR SAMPLE: DIFFERENT ASSOCIATIONS?

We have used empirical studies to examine the question of the significance and the effects of the connotations of black, in the context of a more comprehensive study of the semantic domains of 12 individual colours and 3 colour combinations. On the one hand we gave the verbal concept, on the other a direct optical representation in the form of NCS samples. Thus we obtained associations from a total of 33 persons, primarily from the fields of design and architecture, with the colour concepts (in this order): 1. RED 2. BLACK 3. WHITE 4. GREY 5. YELLOW 6. BLUE 7. GREEN 8. ORANGE 9. PURPLE 10. TURQUOISE 11. BROWN 12. PINK 13. BLACK & RED 14. BLUE & WHITE 15. YELLOW & GREEN, as well as with the NCS colour samples: 1. 1090-R, 2. 9500-N, 3. 0500-N, 4. 5000-N, 5. 0080-Y, 6. 2070-B, 7. 2070-G, 8. 0080-Y50R, 9. 3060-R60B, 10. 1050-B50G, 11. 7020-Y70R, 12. 1040-Y90R, 13. 9000-N & 1090-Y90R, 14. 1060-B & 0500-N, 15. 0070-G90B & 2070-G10Y.

Of these 33 persons, a group of 17 (group 1) was given first (in the above order) the concepts and then the samples for (written) association; a second group of 16 (group 2) was given first the samples and then the concepts.

This produced considerable differences in the number of associations stated for any one colour concept, differences both between the individual persons and between the various colour concepts: *(RED: total 147 associations, BLACK: 132, YELLOW: 128, WHITE: 123, BLUE: 116, GREY: 107, GREEN: 103, BROWN: 101, ORANGE: 81, PINK: 78, TURQUOISE: 69, PURPLE: 67)*. The different associations with the colour concepts and samples do not come from different persons; we have taken several (thematically related) associations of a single person with one colour concept or sample (e.g. with BLACK: "mourning, sadness, depression" – associations of a single person).
As the analysis showed, for the elementary colours BLACK, WHITE, YELLOW, RED, BLUE, GREEN there emerged no striking differences between the associations with the concept and those with the sample, in either the first (1. concept 2. sample) or the reverse sequence. Apparently for BLACK and the other elementary colours, the colour sample we chose turned out to be prototypical for the concept. This may be because there exists a close, almost definite relationship between the (verbal) concept and its mental representation, and thus its visual concretisation. The binary hues (or compound colours)

such as PURPLE** show a different result: here the associations with both colour concept and sample vary, sometimes considerably. Particularly in the sequence 1. concept 2. sample, there emerges a semantic restriction and alteration (usually in a negative direction). The associations with the sample are fewer; it often seems "inauthentic, artificial", leading to more concrete associations, "disappointing" the mental representation corresponding to the concept ("but I imagined this colour quite differently!"). Thus from the viewpoint of this kind of empirical comparison between conceptual and concrete visual perception, the elementary colour black appears largely more uniform and unambiguous, even if in its valence it is a more differentiated component of the sum of our collective experience.

3. BLACK IN AFRICA (FOR DARK-SKINNED PERSONS)

In order to test out assumption that non-European, dark-skinned persons attach to the archetype black a (partly, at least) different significance and social function, we interviewed 37 persons of African origin, 2 Caribbean and 1 Colombian, about terms and expressions for "black", the significance of "black" and the use of black colour in their culture of origin, and finally the significance of their own skin colour, on the one hand in their culture of origin and on the other for their individual selves. These detailed interviews – which went beyond the frequently discussed universal semantic aspects of black – showed particular personal and cultural emphases:

1) Citing of positive attributes of black is substantially higher than that shown in European studies (e.g. Hackl-Grümm, Riedel). Amongst the personal associations, the highest incidence (well over half) is of concepts such as (combined with sheen and depth, "perfect") "beauty", valuable, attractive, elegant.
2) It is striking how often the predominantly positive attributions refer directly to their own skin-colour, or are derived from it. Most of those interviewed have lived in Europe for many years, and only though their dealings with a white majority have they developed a particular consciousness of their own skin-colour. Thus when looking at another dark-skinned person, they feel "pleasure, sympathy, nostalgia". Black people are usually regarded as "having strength and stamina", "erotic, attractive, " "likeable, vivacious". Negative associations with their own skin-colour stem – as on might expect – exclusively from historical and current experience of discrimination. Many account for "pride" and "satisfaction" with their own skin-colour by pointing out its practical and aesthetic advantages: age and emotion are not easily detectable, in contrast to light-skinned people, whose skin/face "shows age sooner" or betrays emotion through various nuances of yellow, red or blue.
3) Both in the verbal expressions and the personal associations, there is frequently a connection between beauty, femininity and fertility ("My wife has black eyes" = she is pregnant).
4) In cult and ritual, black fulfils not only its (better-known) role in the context of death and mourning, jurisdiction and punishment, but also serves, in the form of tattoos, to enhance a woman's beauty, or through the pigmenting of parts of the body or objects (amulets, etc.) to fend off or drive out evil, or to shut out the dead (if, for instance, they occur persistently in the dreams of tribal members).
5) Some simply associate black with their native country of Africa, or even with "the origin of the human race".

The individual and cultural specificity of the significance of black that emerges from this study demonstrates that a person's own relation to a colour – as here, on the basis of skin-colour – has a definite influence on its valuation and use, in the sense of a selective emphasis on individual aspects of valence. In the next section, two of these will be examined more closely:
1) black between male and female; 2) black and erotic love.

4. BLACK BETWEEN MALE AND FEMALE

In contrast to the (spontaneous) association of black with female beauty and fertility, made by some of our dark-skinned interviewees, in our previously shown study of the associations made by light-skinned Europeans with colour concepts and samples there was no direct gender classification. The 1986 Hackl-Grümm[3] study found a "gender definition" of black only in given concepts. Amongst 480 Austrians questioned on 12 colour concepts, "male" was attributed by 26% to black, 18%

** In our colour courses over a period of several years, we have collected data on individual denotation of the terms violet and brown, from a total of 175 participants. Each participant was asked to choose from the NCS Atlas the nuance most typical of the term. Analysis showed that the German concept "violet" covers a colour range from NCS 5040-R30B to 3070-R70B. Two focal areas can be established: one towards red, around NCS 3050-, 3060-, 4050-R50B, and one towards blue, around NCS 3050-, 3060-R60B – the boundaries towards red being considerably more blurred than those towards blue. In their study *Color naming: a mapping in the NCS of common color terms* (Scandinavian Journal of Psycology, 1994, 35 ,144-164), Sivik and Taft arrive at similar results, although in Swedish the term "lilac" is more widely used than "violet" or "purple". Sivik and Taft point out that a literal translation of these terms between English and Swedish often leads to misunderstandings.

to brown and 16% to blue, "female" by only 4% to black, 23% to pink and 19% to red (cf. p 69). Sivik[12] also found a clear connection between the concept "male" and the colour black, or the perceptual colour dimension of blackness. Here, too, black as such did not elicit the association, but when the concepts "male/female" and "masculine/feminine" were given, it was clearly classified under "male". This applies both for isolated colour samples and for the colour of a product. It seems, as we stated earlier[13] (p 139) "that the general connotations of colour as such are indeed crucial for the collective assessment and evaluation of coloured objects, its qualities and value" (irrespective of whether the object *per se* – in this case – seems more male or more female). This connection was also demonstrated in several of our studies about colour and industrial design (cf. Green-Armitage[14]) by having subjects evaluate colour samples and correspondingly coloured products on the basis of semantic differentials.
Heller's[8] study shows that within gender polarity, black is associated predominantly with "male" (masculine). The concepts with a high proportion of attributions to black (also as a concept) include egoism, hard, angular, brutality, callousness, infidelity, heavy, functionality, strength, power, large – concepts which in our cultural area are often – at least traditionally – associated with masculinity (in positive and negative senses).

On the other hand, the "feminine side" of black, which is not expressed in these studies, is based on archaic and spiritual ideas of fertility and earth-mother, in the archetypes of the dark (yet protective, nurturing, life-giving) womb and its chthonic counterpart (cf. Ecker's ouroboros principle), fertile black soil. In ancient Egypt, black Isis, the great mother goddess, was assigned the fertile mud of the Nile, as well as night and death. Painted as mother of death on the inside of a coffin, she receives the mortal remains with open arms; as mother of life, she reconstitutes the dismembered body of her husband-brother Osiris, to bring him back to life and conceive Horus with him. In Christianity, there are black Madonnas (such as the famous Madonna of Czestochowa) in the tradition of black female divinities.
Our dark-skinned interviewees' frequent association of black with (beautiful) femininity and (female and chthonic) fertility is probably – apart from the high degree of positive connotation of black as linked with their own skin-colour – due to the fact that, almost without exception, they grew up in traditional African tribes, close to nature, where rituals concerning the wonderful dark secret of fertility play an important role.

5. BLACK AND EROTIC LOVE

Also in "clothing" and accessories in the field of erotic love and sexuality, the many aspects of the valence of black come into effect. In traditionally patriarchal Christian cultures – such as that in Portugal, Spain, (southern) Italy, Yugoslavia or Greece – the black clothes of the women serve (reinforced in Islam by the yashmak) to cover, indeed to suppress female beauty and eroticism (and thus of course freedom). In our culture, however, it is often preferred in puberty, signalling on the one hand what is also a repressive intention "to block the rising sexual impulse, symbolised by red"[3] (p 159f), yet on the other hand "the precise opposite: the acceptance of, and emphasis on, budding eroticism. For black is also a colour of erotic love." This is shown with particular clarity in the preference for black in s-m erotic performances. Here black – according to "taste" or intention – becomes a metaphor for weirdness, for " complexly obscured" violent sexual impulses which "demand 'release'" (ibid). A particularly dark aspect of the fascination exerted by black in aggressive symbolically military variants of s-m scenes may be furnished by its association with the insignia of sadistic, fascist violence (e.g. black SS uniforms) – an expressive potential of black which (according to Ecker's analysis) is to be classified along with exorbitance, repression, negation, death and (brutally subjugating) power.
Freud's description of female (psycho-)sexuality also expresses the unfathomable darkness of (female) eroticism as a "black continent" – a characteristic term for Africa, seen as dark (perhaps more so at that time), because unknown and thus uncanny. In his day, at the dawn of "scientific" psychologisation of sexuality, it was in particular "the nuances in the sexuality of women" – also according to the contemporary biologist Marañon – that appeared as "a part of the whole, which is inaccessible to the researcher"[17] (p 625). (Have we today gained more insight?)

6. SUBSTANTIVE INTERIOR AND EXTERIOR VIEW OF THE PHENOMENON "BLACK": PHYSIOLOGY AND COSMOLOGY OF PERCEPTION

The phenomenology of the mysterious depth of the colour black can be rounded off by looking at the physiology of the perception of black – an interior view, so to speak – and by a cosmological view of unfathomable darkness.
The physiology of visual perception common to all (healthy) people forms a universal basis for the intercultural and intersubjective connotation of black – similar in essentials, apart from personally motivated valuations due to skin-colour or professional interest. We have to realise that to see black does not mean "not to see", nor yet "to see nothing". Seeing black is an act of perception. One prerequisite is cerebral activity (of the calcarine cortex), which is subliminal in relation to the demands of the secondary visual centre and space sense. This subliminality can be due to insufficient light stimuli (intensity

too low, or wavelengths under 400 and over 760 nm), damage to retina, optic nerve or lateral geniculate nucleus. In this sense, blind people also "see" black, if the calcarine cortex is functioning (only its failure leads to non-sight). The "black" perceived under these conditions is, however, more of a dark grey ("subjective visual grey" [Ecker[1]] or "self-grey" [after Hering, see Fischer[16], p 13ff]). The perception of a deep black, on the other hand, demands a further condition, manifesting a paradox of visual perception: this black requires at least a partial light stimulus of the retina – light enters the eye precisely at the black part, the pupil – thus, "due to a complementary contrast effect" (simultaneous or successive), as "contrast black" (Ecker[1], p 140). This phenomenon is also described by Hurvich[18] (p 62): "The blackness response *cannot* be produced by direct light stimulation applied on a given retinal locus. Blackness responses are obtained indirectly [....] One way to produce a black response in a given part of the visual field is to stimulate a neighboring region with a stimulus that looks white. Another way is to stimulate the eye with the white-appearing stimulus and then remove it or block it out". Analogously to red/green and yellow/blue vision, Hering[17] also – rightly – postulates antagonistic processes of corresponding opposing receptors. Thus black appears blackest in contrast to white, apparently deriving its strength from its contrast with light, from negation – a fundamental aspect on the semantic level.
Over and above the paradox of physiological perception, the latest cosmological findings on black as the colour of night and the immeasurable depth of the universe seem positively uncanny, if not completely beyond our imagination. (Seen in terms of physics, the universe itself, of course, is multicoloured, since it is filled with rays of all wavelengths, though below the level of visual perception.) Within the orbit of hypothetical constructs such as "black holes", cosmological views on the infinite expanse of the universe give rise to the assumption, for instance, that "the universe is made mostly of dark matter and dark energy"[19] which could be the basis of the opposition of the self-attraction of matter and the accelerated expansion of the universe. The extent of this sinister cosmic invisible dark matter, already termed "quintessence"[19] – a further confirmation of the deep significance of black resulting from Ecker's valence analysis – might be many times the total mass of the universe. Even if the physicist Svec[20] found this "unobservable dark matter in a completely transparent universe [...] a very unsatisfying idea", we should not worry too much about it, but rather engross ourselves, bright-eyed, in the richly faceted, multi-hued panopticon of the meanings and manifestations of the phenomenon "black".

REFERENCES

1. H. Ecker, *Versuch einer psychologischen Phänomenologie der Unbuntfarben* (Dissertation), Salzburg, 1980.
2. S. Hackl-Grümm, *Farbstudie 1986*, Psychotechnisches Institut Wien, Wien, 1986.
3. I. Riedel, *Farben*, Kreuz Verlag, Stuttgart, 1989 (7th ed.).
4. E. Heller, *Wie Farben wirken*, Rowohlt, Reinbeck/Hamburg, 1989.
5. V. Biasi, P. Bonaiuto, "Colour and the experimental representation of stress and comfort", *Colour Report, Colour and Psychology F 50*, Lars Sivik, pp. 59-65, Scandinavian Colour Institute AB, Göteborg, 1997.
6. H. Ohno, Y. Nakano, "Study of the Color Image and the Eearthquake Experience in Kobe, Japan", *Colour Report, Colour and Psychology F 50*, Lars Sivik, pp. 68-70, Scandinavian Colour Institute AB, Göteborg, 1997.
7. J. Hutchings, "Colour in Folklore", *Colour Report, Colour and Psychology F 50*, Lars Sivik, pp. 182-186, Scandinavian Colour Institute AB, Göteborg, 1997.
8. E. C. Brewer, *Dictionary of Phrase and Fable*, Cassell and Company, Ltd., London, 1900.
9. L. Oberascher, "The role of color in the 21st century. Color culture between homogenization and diversification", *AIC-COLOR 97, Proceedings of the 8th Congress of the International Colour Association*, pp. 83-89, Color Science Association of Japan, Kyoto/Japan, 1997.
10. L. Oberascher, "Colour trends – colour changes in collective and group specific colour preferences", *In Print*, pp. 4-7, Interprint Rotationsdruck GmbH & CO KG, Arnsberg, 1997.
11. L. Oberascher, "Cyclic Recurrence of Collective Colour Preferences", *Color Forecasting. A Survey of International Color Marketing*, H. Linton, pp. 66-77, Van Nostrand Reinhold, New York, 1994.
12. L. Sivik, "Color meaning and perceptual color dimensions: A study of color samples", *Göteborg Psychological Reports* **4/1**, pp.1-21, 1974.
13. L. Oberascher, "The language of colour", *AIC - COLOR 93, Proceedings of the 7th Congress of the International Colour Association*, A. Nemcsis and J. Schanda, (Ed.), Volume A, pp. 137-140, Technical University of Budapest, Budapest, 1993.
14. P. Green-Armitage, "Synopsis of round table discussion on environmental colour design", *AIC - COLOR 93, Proceedings of the 7th Congress of the International Colour Association*, A. Nemcsis and J. Schanda, (Ed.), Volume A, pp. 175-184, Technical University of Budapest, Budapest, 1993.
15. *Moderne Enzyklopädie der Erotik* **Volume 2 (M-Z)**, Verlag Kurt Desch GmbH, München, 1963.
16. E. P. Fischer, "Die Farbe der Nacht als Farbe der Welt", *Die Farben Schwarz*, T. Zaunschirm (Ed.), pp. 11-15, Springer, Wien, 1999.
17. E. Hering, *Grundzüge vom Lichtsinn*, Verlag von Julius Springer, Berlin, 1920.
18. L. M. Hurvich, *Color Vision*, Sinauer Associates Inc., Sunderland/MA, 1981.
19. Dark Energy Fills the Cosmos, National Laboratory (http://www.lbl.gov).
20. Dark Energy in Deep Space, http://spacer.com/news/darkmatter-99a.html.

* Correspondence: leoncolor@salzburg.co.at; phone +43 662 628458; fax +43 662 628458-50; ÖKO-PSY, http://www.grappa-design-approach.com; Kaltnergasse 8, A 5020 Salzburg, Austria

Use of colour at home during Finland's post-war reconstruction period

Aulikki Herneoja*, University of Oulu, Department of Architecture, Finland

ABSTRACT

This study concerning the use of colour among architects and public in Finland during the post-war reconstruction period is part of my forthcoming doctoral thesis. Due to cultural comparison, the study shows that a unique silent agreement among public and professional tastes concerning colour did exist. This is welcome feature in the way understanding the confusing situation between architecture and everyday life.

Keywords: architecture, everyday life, post-war reconstruction period, pragmatist aesthetics, taste, use of colour

1. INTRODUCTION

The post-war reconstruction period, from the late 1940's to the late 1950's, is widely considered to be one of the best periods in Finnish architecture. Finnish housing construction took nature into consideration and also received international fame. The essential qualities of construction were scale, which took into consideration both human and environmental elements, and a plain, controlled artistic approach. Soft colours and skilled use of natural materials as a part of interior colouring were typical of the architecture of that period.

Arkkitehti (Architect) magazine is purely a professional magazine, representing the contemporary architecture in Finland. During the post-war time colour was used very skilfully, but talking about colour didn't seem to be part of architectural discourse. At the same time *Kaunis koti* (Beautiful Home) magazine, which was founded in 1948, was first the Finnish interior decorating magazine. Its purpose was to influence public taste. In spite of its role, it is also possible to picture interior decorating of everyday life in *Kaunis koti* magazine. Colour had a central position both in influencing public taste and the public's own way of decorating interiors. Especially in the late 1940's, *Kaunis Koti* magazine reflected the shortage of resources of the post-war period. The word colour was given a positive meaning and almost without exception the articles connected it to happiness.

At the end of the 1940's and into the 1950's *Arkkitehti* magazine concentrated on presenting reconstruction projects, where priority was given to numeric quantities and texts describing the buildings' structures. Black-and-white photographs and their captions rarely mentioned colour or gave tips about the use of colour in interior decoration. *Kaunis koti* and *Arkkitehti* magazine quite often published the same projects, but *Kaunis koti* magazine viewed them more softly than the professional journal, also with regard to colour. This confusing difference in attitudes toward colour between professionals and the public leads me to further search the background of these matters.

2. COLOUR AND MODERN ARCHITECTURE

In architecture colour is accompanied by a dichotomous basic arrangement: on one hand colour is thought of as an object of scientific observation, and on the other hand it is considered a tool of artistic interpretation. From the beginning of modernism the position of architecture among other arts was argued. Because of its material nature, the philosopher Hegel in the 1820's gave architecture the lowest position in the hierarchy of arts. The situation didn't raise a bigger conflict between architecture and art philosophy, but from the viewpoint of aesthetic discourse, architecture was set aside. When the possibilities of architecture were defined within the prevailing opinion of art, the only choice that was left inside modernism was modernisation and enlightenment. At that time in architecture a consolidation process began between romantic and rational modernism. The ideal of romantic modernism was to bring art and life closer together, to embellish everyday life. Rational modernism was more interested in rules and their cumulative rational development. During that time colour education in the Deutche Werkbund and in the Bauhaus school was searching for its position between the objectivistic and subjectivistic attitudes towards colour in architecture.

The dispute between rational and romantic modernism in a way ended in the 1920s, when the pioneers of architectural modernism paved the way for the beginning of a new architecture that united art and technology. The contrary positions of art and technology were abandoned and the aim was to unite the two voluntarily. In practice, fusing art with technology on

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

the terms of technology made it possible to pass over the romantic movement, which had been awkward for rational modernism. One ideal of rational modernism was the belief in the possibility of objective methods. Because colour by its basic character is qualitative, flickering and continuously changing, a clearly objective study of colour in the context of built architecture is difficult. In rational modernism, colour was considered insignificant or meaningless. The relationship between colour and architecture remained undefined. In theoretical studies colour was transferred outside of architecture. The pioneers of continental architectural modernism also lead architecture to differentiated development, where architecture retired into itself and made inner criticism of modernisation difficult. The unification of art and technology eliminated all boundaries, but also a lot of possibilities. The presence of this rational modernism has always been seen in a very strong way in Finnish modernism.

3. CULTURAL COMPARISON

When one looks at the colours of home by comparing the articles of *Arkkitehti* magazine and the articles of *Kaunis koti* magazine it inevitably leads to cultural comparisons. I will be looking at the legitimate viewpoint of architects and architecture in parallel with lived architecture or architectural practices, and the works and practices of intellectual and especially artistic activity, which in the area of architecture refers to self-making and generally to traditional vernacular building. In parallel, the traditionally understood architecture and the less appreciated popular architecture of everyday life will then also be compared. High and low art or culture is more generally connected with institutional activity and functions. According to Herbert J. Gans, architects were professional imperialists who expressed the contemporary culture and philosophy of their society through their buildings. Architecture's professional expertise involved aesthetics that lead to a debate over the merits of high culture and popular culture. Gans points out that the architectural elite were generally on the side of high culture, having disdain for popular culture and popular vernacular building. In the field of architecture the maintenance of internal control was very clear and purposeful. The power-holding core in Finland was solid and unanimous, being mostly on the side of rational modernism.

The concept of taste is in a very central way connected to the debates about the differences and similarities in high and popular cultures. French sociologist Pierre Bourdieu has studied the concept of taste in an advanced way in his work, *Distinction. A Social Critique of the Judgement of Taste*. According to him, taste classifies, and it classifies the classifier. Social subjects are classified by their classifications. They distinguish themselves by the distinctions they make. One of Bourdieu's main arguments is that cultural distinctions are used to support class distinctions. According to Gronow, Bourdieu claims that the taste of the ruling class is always the legitimate taste of society, but it is not genuine good taste: in fact, there could not possibly be any genuine good taste. Legitimate taste pretends to be the universally valid and disinterested good taste, whereas in reality it is nothing more than the taste of one particular class, the ruling class. One crucial difference between popular and high cultural taste concerns presentation and things presented. According to Bourdieu the popular taste has tendency to reduce the things of art to the things of life. In the field of interior colour it would mean that popular taste looks at colours only as such and intellectual taste, in this case architects, look at colours as representing something in architecture. But because the position of colour was so undefined, it was difficult to talk about it. Still the tacit knowledge of how to use colour in an architectural way was quietly developed.

Richard Shusterman argues about high culture from the viewpoint of pragmatist aesthetics. He has three arguments. The first one concerns the consolidating development of autonomic aesthetics, where 'aesthetic' and 'spiritual values' were lifted above the things of everyday life, which is still present when defining high culture. Because of its nature, architecture has never been utterly disengaged from practical and material interests of life, nor has it ever reached the tightest autonomic aesthetic mode of art's ideology. In the architectural field, challenge may be seen in Shusterman's spirit as a process where the tight, self-defining core of architecture voluntarily opens and starts to discuss on equal level using non-architectural language together with the surrounding world.

Shusterman's second argument refers to high art as an oppressive social evil, because it provides a devastating strategy by which the socio-cultural elite asserts its proud claim to intrinsic superiority. For our high art, tradition is unfamiliar and insufficiently accessible to the culturally underprivileged. According to Bourdieu, the logic of what is sometimes called in typical 'pedantic' language the 'reading' of a work of art offers an objective basis for this opposition. Bourdieu argues that one can say that the capacity to see is a function of the knowledge, or the concepts, meaning the words that are available to name the visible things are programmers for perception. A work of art has meaning and interest only for someone who possesses the cultural competence, that is, the code into which it is encoded. Without a doubt the language of architecture belongs to this high art tradition that is difficult to unfold. It is very common that among architects and the enlightened elite, opinions about the quality of a certain building were in conflict with the liking of the public. With the cultural elite and architects there were also draught about architectural propositions, although architects as a professional group are outwardly quite loyal. Despite these contradictions between high and popular culture, one presupposition of my forthcoming thesis is that especially during the post-war reconstruction period, architects' and the public's liking were quite close to each other.

Shusterman names the third and last argument against high culture, which is its escapist nature. Enchantment with art's glorious products gives the lie to the miserable and sinful material conditions in which they are generated and admired. It is not possible to turn all these accusations against architecture, because the ideas aiming towards social good have from time to time tried to carry this out by architectural means. For example, especially the housing architecture of the Finnish post-war reconstruction period has produced many successful and lasting solutions and realisations. The escapist nature that Shusterman above described can easily be found in the relationship between heroic architecture and the housing architecture of many architectural periods. Prominent public buildings and their architects are usually raised more easily than buildings that are smaller and more modest, but often important in everyday life.

4. COLOUR IN FINNISH ARCHITECTURE

During the post-war reconstruction period there was a romantic phase in Finnish architecture, when the popular taste and the intellectual taste of architecture did meet each other. This period was quite strong but very short in length. Planners and designers began to speak about the aesthetics of utility, which was considered to be a carrying idea, for example, by *Kaunis Koti* magazine, which advocated aesthetics and concepts of beauty during that period. Asymmetrical colouring was typical in post-war reconstruction period interiors. The uniform furnishing of the living-room and the dining-room were replaced by combinations of pieces of furniture representing different styles and collected from various places. Mixing the old and the new was permissible.

Colour is often perceived as a synonym with paint or a painted surface. I extend the examination to also include the use of the colours of natural materials, such as wooden and stone materials, and the use of red brick, which was very typical at that time. During the post-war reconstruction period the skilful use of natural materials as part of the fixed interiors was very typical. For this reason the colourings of natural materials are in a central position, especially when picturing the entire colour scheme of the post-war time. A fine example of using cut red-hearted pine as a surface material on a cabinet wall can be found in the master bedroom of architect Aarne Ervi's private residence. Veneers cut from very old almost thoroughly heartwood red-hearted pine as vertical thickly-striped columns create an image of a glowing trunk forest. Wallpaper with a pattern of large leaves on the wall next to the cabinet supports the strong analogy with nature in the room.

In the interior natural stone material was often situated in the fireplace or the wall surrounding the fireplace. A common material was grey slate stone, which was used to cover the whole fireplace or it was combined with white roughcast plastering. This theme often continued outside, where the chimney, terrace and foundation were also covered with grey slate stone. Cleanly laid red brick on fireplaces and the surrounding walls was even more common than slate stone coverings. In these cases red brick was used almost without exception in cleanly laid chimneys, too. In some cases even without a fireplace the red brick facade was extended into the interior as a roughly warm colour theme

During the post-war reconstruction period it was also very typical to use authentic natural green tones in interior colourings. It was almost a rule to have a "flower window" in one's apartment and especially in one's living room. The flower window usually was rich in indoor plant species, of which at least one was a climbing plant situated to frame the window, where it smoothen the outlines of the window opening and in many cases also replaces the curtains. The generality of flower windows in *Arkkitehti* magazine could only be read from the pictures because they were not written about. They were not only the property of homes, they were also used to frame the windows of public spaces. The reason to use indoor plants as part of the interior was the need to unite the living spirit with the dead surroundings: walls, ceilings, furniture and textiles. Indoor plants were felt to convey outdoor nature inside. This nature's greenness brought inside formed a reference point for defining interior colour schemes. For example, the strong green colour of the plants determined the upholstery of chairs close to the flower window. Both magazines, *Kaunis koti* and *Arkkitehti*, show that the flower windows of living rooms were in a pervious way the property of the strata of population from the luxurious residence to the modest working class city flat. Interior decoration at home was quite modest. In addition to the flower window, climbing plants or groups of plants on one side of a doorway or as a partition in a room in the inner parts of the flat were also typical. The climbing plant was often supported by a rattan frame or a stretched string partition. Even a little tree trunk from the woods was suggested as a supporting structure. In addition to indoor plants, strongly leaf-patterned green one-sided curtains on one side were used as pictorial motifs of a real plants. Nature's green presence was very concrete in homes during the post-war reconstruction period.

5. CONCLUSIONS

Arkkitehti magazine published only a couple of colour pictures and a few textual remarks concerning colour under some black-and-white photographs while *Kaunis koti* magazine published many, at that time still rare, colour pictures and numerous articles concerning interior. This situation is confusing. The early consolidating process between rational and romantic modernism and the confusing situation regarding the position of colour in architecture especially in the Bauhaus school led to Finnish rational modernistic architecture being not very talkative about colour. The different viewpoint on the meaning of colour in architecture led architects and the public apart from each other. For the public, colour as such was easier to talk about than colour in architecture, which for architects did not exist as such, but had meaning in the presentation. The position of architecture among the arts led it easily apart from common people. The codes of architectural language and the presentations of architectural colour were difficult to for non-professionals to unfold. In spite of all these borders and obstacles during the post-war reconstruction period, there did exist a unique silent agreement among public and professional tastes concerning colour that makes this period especially interesting to study. The mostly black-and-white photographed architecture of the post-war reconstruction period needs to be put back into colour, and the unbalanced situation of using but not talking about colour is worth further research in the direction of unfolding the tacit paths of architecture and everyday life.

REFERENCES

1. *Arkkitehti* 2/1952, pp. 53-54; 9-10/1952, pp. 151-154; 11-12/1952, pp. 145-162; 4-5/1953, pp.77-80; 1-2 1955, p. 13.
2. Bonsdorff, Pauline von, *Arkkitehtuurin määrittely Suomessa 1940-1989* (Defininf architecture in Finland 1940-1989), Valtion teknillinen tutkimuskeskus, Tutkimuksia 752, Valtion teknillinen tutkimuskeskus, Espoo, 1991.
3. Bourdieu, Pierre. *Distinction. A Social Critique of the Judgement of Taste* (1984). Translation from French *La Distinction. Critique social du judgement* (1979) by Richard Nice. Routledge & Kegan Paul, London, 2000.
4. Gans, Herbert J. "Towards a Human Architecture: A Sociologist view of the profession" in Judith Blau, Mark La Gory and John S. Pipkin (eds.), *Professionals and Urban Form.* State University of New York Press, 1983.
5. Gronow, Jukka. *The Sosiology of Taste.* Routledge, London and New York, 1997.
6. Herneoja, Aulikki, *Värin käsitteestä arkkitehtuurissa. Näkökulma kulttuurisesti elettyyn väriin* (About concept of colour in architecture. A viewpoint to culturally lived colour), Oulun yliopiston Arkkitehtuurin osasto, julkaisu A 25, 1998.
7. Herneoja, Aulikki, "Colour of Home. About the use of colours during Finland's post-war reconstruction period." *Nordisk Arkitekturforskning*, 2/2001.
8. Kahri, Esko; Hannu Pyykönen, *Asuntoarkkitehtuuri ja –suunnittelu*, Rakennustieto Oy, Helsinki, 1994.
9. *Kaunis Koti* 3/1948, pp.18-19; 2/1954, p.24.
10. Pesonen, Riitta, "A Personal Work of Art", *Rooms for Everyone. Perspectives on Finnish Interior Design 1949-1999*, Minna Srantola-Weiss, ed., Otava, pp. 194-205, 1999.
11. Saarikangas, Kirsi, "The dignity of the everyday" –housing architecture in the 1950s. *Heroism and the everyday – Building Finland in the 1950s*, Riitta Nikula, ed., Museum of Finnish architecture, pp.133-154, 1994.
12. Sarantola-Weiss, Minna, "Det sköna hemmet. Heminredning som en samhällsfråga i Finland under 1900-talet", *Kultur och konsumtion i norden 1750-1950*, Johan Söderberg ja Lars Magnusson, toim., Historiallinen Arkisto 110:2, Suomen Historiallinen Seura, Helsinki, 1997.
13. Storey, John. *An Introductory Guide to Cultural Theory and Popular Culture.* Harvester Wheatsheaf, New York, London, Toronto, Sydney, Tokyo, Singapore, 1993.
14. Shusterman, Richard. *Pragmatist Aesthetics. Living Beauty, Rethinking Art* (1992). Blackwell, Oxford UK, Cambridge USA, 1993.
15. Turunen, Risto in Koistinen, Tero; Sevänen, Erkki ja Turunen, Risto (eds.), *Musta Lammas. Kirjoituksia populaari ja massakulttuurista.* Kirjallisuuden ja kulttuurin tutkimuksia – Studies in Literature and Culture, Joensuun yliopisto, Humanistinen tiedekunta, University of Joensuu, Faculty of Arts, nco 8, 1995.
16. Williams, Raymond. *Keywords.* A vocabulary of culture and society. Flamingo, Fontana Paperbacks (1976) 1981.

aulikki.herneoja@na.netppl.fi; phone +358 40 5787018; fax +358 8 3118911; Department of Architecture, PL 4100, 90014 University of Oulu, Finland

RED or READ — The Built Environment is Coloured

Dianne Smith
School of Design and Built Environment, Queensland University of Technology,
Brisbane, Australia 4000

ABSTRACT

How important is colour in the design of our built environment? Prototypes and massing models for designs are often presented in white or monochromatic combinations, irrespective of the materials incorporated and the colours that may be applied in the final constructed building, interior or object. Therefore, it is of interest to identify the way colour is positioned by designers in how they go about the business of making environments. The built environment is understood by the designers and design researchers generally in one of four fields—as object, as product, as communicator, or as social domain[1]. In addition, Franz[2] identified four conceptions of designing held by designers—the experiential conception, the structural conception, the production conception and the retail conception. Fashion and style are often associated with colour in a local context and may simply be applied to the physical environment because it is in fashion, rather than because of what it communicates more broadly. It is assumed that the integration of colour in the built environment is influenced by these understandings. In order to address colour's position in the design process and the importance of colour in relation to space, form, and the experience of place, a selection of Queensland architects and interior designers were surveyed. The study is not conclusive, however, it does identify differences and commonalities between the participants that are of interest in light of the above issues. Explorations into environmental meaning, in addition to colour theory and decorative applications, are hypothesised to be important sources of information for designers involved in the colouration of the built environment.

Key Words: colour, conceptions, signification, design process, design practice

1. INTRODUCTION

By drawing initially upon a theoretical understanding of interpretation, I sought to understand how designers integrate colour into their design process and into the creation of 'place'. In conjunction, insight into the relationship between colouration and design concepts was sought. From my experience as a practitioner—both interior and architect—I proposed that designers tended to use colour in an ad hoc fashion with little theoretical knowledge. Fashion or trends and/or the materials, samples and/or paint company colour systems that were readily available often influenced their selections. In addition, little consideration to the integration of the design concept or to colour theory appeared to be given. Therefore, through a questionnaire distributed to a variety of interior designers and architects in Brisbane, I sought to gain insights into what was the position of colour as part of the design process in practice. Explorations into environmental meaning, in addition to colour theory and decorative applications, are hypothesised to be important sources of information for designers involved in the colouration of the built environment. Consideration of the built environment in terms of signification and experience may broaden practitioners' understandings of the role that colour plays in place formation. Therefore, a theoretical framework will be described that may assist in understanding colouration as part of a design process before I discuss the study's findings.

2. THEORETICAL FRAMEWORK

Although not necessarily exclusive, there are four aspects which may inform an understanding of the practice of design in regard to the question 'How does colour shape the environment?' or 'Is colour an integral part of the design process?' These aspects are conceptions of designing, understandings of the nature of the built environment, 'place' formation and the architectural experience; and style, fashion and the everyday-discourse of environmental colouration. Each will be discussed in turn.

Smith[1] identified four ways that the built environment is commonly understood. These *environmental understandings* identify the built environment as an object, product, communicator and/or social domain. Depending on the particular framework, the relationship between the person and the environment shifts and, in association, the way the designer may approach the design task. For example, the environment as object is seen as a 'thing' to be created that is an entity in its own

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

Figure 1.0: Colour and design practice

right or a form of self-expression. It may be removed from cultural norms or accepted societal expectations. In contrast, as a product, the environment is understood through the discourse of economics, and its creators may strive to satisfy market trends or demands, or may aim to lead the market in some way to achieve an economic advantage. As communicator, the environment is believed to represent societal standards or to signify for the interpreter particular meanings. The object is not understood in isolation but in relationship with the person. The fourth framework, the social domain has two dimensions. Firstly, as backdrop to activities that are influenced by hegemonies and ideologies, and secondly, as an extension of the self through an interdependent relationship. How do these understandings influence the interpretation of environmental colour? Simplistically we could describe the outcome as an activity that embraces the environment as one of these 'types of things'. As an object, it is 'something' to be coloured as an expression of the designer; as a product, an entity is coloured in keeping with perceived market demands or norms; as a communicator, the colouration of the entity acts as sign in the construction of meaning, and therefore, meaning-making is part of the process; and/or as a social domain, the environment is understood as integral to contextualised person-environment relationships and that colour is an integrated part of that phenomenon.

The four *conceptions of designing* proposed by Franz[2] are the experiential conception, the structural conception, the production conception and the retail conception. The designer's conception of what it is *to design* in general is related to the manner in which *they design* in practice. To briefly summarise, the experiential conception portrays design as 'the development of a framework incorporating both people and their environments' and that designing is 'a way of being-in-the-world for the designer'. In contrast, the structural conception refers to design as the 'generation of an environment for supporting interaction within that environment' and 'the need for the environment to meet the demands of the designers, clients and primary users'. The production conception refers to design as predominantly a business or job (within the context of the design professions) where the prime concern are 'the clients' espoused requirements and their accommodation' by the building. The outcome is an aggregate of discrete parts. In contrast, the outcome of the retail conception is an object or environment for accommodating specific functions. This design practice focuses making a living, rather than, the project, and the activity is not concerned with the broader professional context. What do these conceptions imply about colouring the environment? It was assumed that the integration of colour as part of the built environment would also be an extension of these by these understandings—from the exploration of the phenomenon to the expedient application.

So far I have raised the conceptions of the activity, designing, and the understandings of the environment that are the result of this activity, as two dimensions of what-it-is-to-practice. In association is a third, *'place' formation and the architectural experience*. Smith[3] describes the architectural experience as a composition of viewpoints that is the integration of various forms of the person-environment relationships. Place, therefore, is seen to exist through the shifting state of these relationships. Colour plays a role in the way people engage with and withdraw from these relationships with the environment and/or with other people. Place as a *semiotic reality*[3]—a state that comes into being through the relationship of the person with the environment—involves colour as a dimension. The interconnectedness with place occurs through an interpretive framework—albeit through varying frameworks. This is the basis of the experience and sense of place.

The context of our design decisions, and of the client and user expectations or responses, includes the concepts of *style, fashion and the everyday discourse of environmental colouration*. Therefore we may ask; how does the 'everydayness' of colouration influence environmental meaning? Crook[4] states that since the disintegration of the classical traditions in architecture that designers are faced with choices in image, codes, systems of design and styles which he has termed *the dilemma of style*. Style is defined by Stuart Ewan[5]as information (or dis-information) and he states that the power of style is its influence in closing the universe of discourse, and as style has become increasing ubiquitous, other ways of knowing, alternative ways of seeing have become scarce. A style originally is generated 'out of difference' and Hebdige's work concerning subcultures demonstrated how subcultural groups construct or appropriate styles as a representation of identity and values[6].

> The struggle between different subcultures, different definitions and meanings within ideology is therefore always, at the same time, a struggle of signification: a struggle for possession of the sign which extends to even the most mundane areas of everyday life...p19

Over time, styles can be adopted to become the mundane because that style is adopted into the everyday of the general populus or a wider subgroup. In fact Ewan[5] states that styles are facades that are ever-changing, are often incoherent, are something to be used up, and in fact, part of its significance in a contemporary world, is that it will loose significance. Style, fashion or design-trends may lead to pressure for designers to conform; or induce laziness by 'following' an external norm rather than the integrating the design concept. Consequently, environmental sameness may result or an environmental context may arise that does not address issues which are any deeper than the surface appearance of the entity.

By marrying these concepts together, what could they tell us about the practice of design in relation to colour? An entity comes to have meaning for someone through a process of signification[7]. The interpreter's field of interpretation is merged with the potential of an environmental situation 'to produce' a particular understanding within that particular context. In a discussion concerning design, this involves the field of aesthetics. That is, the environment is experienced by the occupant or viewer, not simply as visual interpretation, but as a bodily experience (which does incorporate each of the senses to a greater or lesser degree) and this involves the environment as a trigger for interpretation.

The designer, however, is predicting what that meaning could be—or should be—as part of the design. The design therefore, could be described as *constructed meaning*. The four dimensions identified would therefore be aspects of the generation of such a 'construction'. These issues are juxtaposed with the understandings of a select group of practitioners.

3. THE STUDY

The objective of the investigation was to ascertain practicing designers' impressions of the perceived need for designers to be educated in colour prior to joining design practice, the integration of colour work into the design practice, and the way in which it is used in an individual designer's work. The study involved a cross section of interior design and architectural firms selected from the telephone book. These were selected on reputation—that is, they were known 'around town' for their work. The companies were contacted and the name of the key interior designer and key design-architect (if they existed) were obtained if they were not already known. Each was sent a questionnaire. Of the 26 sent 16 were returned. Of these six were from architects, eight were from interior designers, and two who labelled themselves as both. The questionnaire was divided into three sections—educational relevance, organisational practice, and personal practice.

The key findings include:
Process: Colour is generally discussed at the sketch design stage and/or design development stages.
Integration:

- Although, there was also some variation in the importance of colour in regard to particular aspects of the built environment, most designers listed colour as being relevant to highly relevant.
- There was division in regard to the importance of colour for particular building types. Only eight designers indicated that equal consideration should be given to all types. Those designers who differentiated between building types focused largely on health care with some reference to institutional or public buildings.

Outcomes

- There was some variation between the description of the organisational colour usage and the personal colour usage (however, not in all cases).
- Both organisational and personal practices were listed as being context-sensitive in most cases. In addition, for organisational practice, adjectives that were not selected from a list of given descriptors, by any of the interior designers or architects, were *avant-garde; flamboyant; and conservative.*. The highest-ranking adjective was *context-sensitive* 12/16 while the number of responses for each of the remaining adjectives totalled <6/16 responses. In contrast, for the designer's personal practice, those adjectives that were **not** identified by any of the interior designers or architects were *predictable; safe; well trialed; driven by available samples; in organisational style; flamboyant;* and *conservative*. The highest-ranking adjectives were *Innovative* 8/13[16]; *context sensitive* 11/13[16]; and *thoughtful* 10/13 [16].The rest of the responses for the adjectives totalled <6/16 responses

Colourist

- Designers should be educated in colour
- Colour work is seen to be a task that 'junior designers' or new graduates can undertake and, in some instances, was stated to be the aspect where they could have a freedom to express themselves.

- Although most of the respondent-designers designed 'in colour', most did not visualise the colours clearly.

The finished work

- The finished projects were discussed in terms of colour usage, the selection process and the selection of colour, and practices. Little attention was given to the experience of the user or the concept of place.

We can describe to some degree how colour is incorporated into the designed environment. Colour is integrated into the early stages of designing. Although it was considered that designers should be educated for colour-work, the task is considered appropriate for junior staff. It was also noted that this was a chance for them to 'express themselves'. This may imply that colour, although considered relevant, is not necessarily believed to be important. In contrast, colour was seen to be relevant to highly relevant in safety coding, perception of space, building form, way-finding, ambience, and image. Interestingly, it was seen to be of the least relevance for decoration. Culture, comfort and stimulation were each added by a different designer to the list of aspects for which colour is relevant.

From the respondents' replies, most designers had had some training or education in colour; they were not overtly receptive to fashion or trends; and, rather than being limited to the materials that were available, they strove to integrate colours in association with materials in a reciprocal manner. In this study, colour was seen as relevant to the perception of space and form but the relationship to the design-concept was not clear. Only five respondents noted their work or their organisation's work as theoretical. The experience of place was similarly omitted as a major concern. To address this deficiency an exploration into environmental meaning, in addition to colour theory and decorative applications, *are hypothesised* to be important sources of information for designers involved in the colouration of the built environment.

1. PROVISIONAL PROPOSITIONS

The question that is of relevance to this study is; how is colour integrated into the process, rather than, what is its potential role. Indirectly the answer is an indicator of how colour is understood as a design tool. From the data to date, I would propose that *the practice of colouration* is part of the design process for the built environment. In summary, colour is believed to be relevant to the design of the built environment; colouration is not considered to be a difficult task requiring experience. Designing-with-colour seems to be separate to, although connected with, the design development and resolution. The activity was often "farmed-out" to those more expert or to young graduates or interior designers to resolve and then be approved by senior designers or design-architects. However, the conceptions of the individual designers can only be identified through closer scrutiny such as interviews. It would also seem, for many, to be difficult to accurately visualise the colouration of the building or interior while designing; and, in regard to the finished work, it is spoken about—as if—colour is an indicator of a variety of environmental variables such as theme, function, built form, location and direction. From the responses of the designers who participated in the study, it would seem that they are not driven by style or fashion per se. Of the designers' organisations and within their own personal practices combined (32 responses), only two were listed as being in-fashion, six of an organisational-style and eight as a reflection of personal-taste in total.

In order to reflect on these findings, I will now return to the theoretical model discussed earlier that depicted four dimensions of practice—the nature of the built environment, conceptions of designing and style, and formation of place. The theoretical description of practice provided above, depicted practice as an integrating process where the four dimensions may merge and by which a 'constructed meaning' comes into being. In light of these findings, how could colour be integrated into the process with more insight? The built environment is discussed as a communicator; something that is coloured to communicate a meaning to the users. Those aspects drawn from the data include the expression of a 'theme', demarcation of zones and associated uses, corporate identity, elements within the space or the broader context, linkages between elements and/or ideas, and an appropriate image. All of these imply a predetermined attitude to the resultant environmental meaning. However, it is through thought that we experience the built environment. People live their lives in thought[7]; or through interpretation. An environment including the way it is coloured, is the brute object that provides endless possibilities for interpretation and yet simultaneously potentiates a field of interpretations in relationship with a person—the interpreter.

How the environment is experienced involves the integration of the signification process—the process by which an understanding or interpretant evolves. This involves the interpreters striving toward a point of provisional belief or a point from which they will act based on that understanding. *Semeiosis* is the term Peirce[8] introduced to describe this propositional sequence. Why is this concept important in light of the data from this initial study? In the descriptions of projects, and in response to the questions posed, the designers only mentioned experience once and mood or ambience twice. This implies that the significance given to the colouration lies with communicating 'something' and not with environmental experience. It is essential to understand that these two aspects are not separate components that may or may not be brought together. Instead, they are interwoven as dimensions of the same thing and it is how we—as interpreters— live in the world. It may be beneficial for designers to understand the link between how designers conceive the nature of the built environment and the formation of place (or more generally how people experience the environment). Consequently, their integration could be developed more purposefully.

In summary, practice as an integrating process combines the four dimensions in some way. Practice is a process by which a constructed meaning [intention] comes into being through projection. The environment is part of *the everyday*. People construct 'meaning' through colour-in-context, and never alone. Because we experience our world through semiosis and 'in thought' then it is the basis of the interpretation. Colouration therefore, can be seen to be an integral dimension within this context. The consequences or implications of this study for future research may include investigations in the following areas.

- The importance of colour work in relation to the least experienced members of staff entrusted to carry out the work
- The ability of people to visualise designs 'in colour' rather than to conceptualise a colour design in principle and how these processes may influence the design resolution. This may also have implications for colour-design education.
- As most of the designers who replied were interior designers, these findings may indicate a different understanding of colouration to that for design-architects. It would be of interest to investigate what is said indirectly by not participating. Some of the responses included implied that some architects approach colouration in relation to the design process differently to interior designers; and/or,
- What is the concept of the design or the overall philosophical design-intent, and how are colours integrated into the physical manifestation of this understanding?

REFERENCES

1. D. Smith, *Architectural Experience: A composition of viewpoints*, PhD dissertation Queensland University of Technology, Australia, 2000.
2. J. Franz, A phenomenographic study of design in the interior context, PhD dissertation Queensland University of Technology, Australia, 1997.
3. G. Shank, & D.J. Cunningham, 'Modeling the six modes of Peircean abduction for education purposes', 1996, retrieved 17 Aug. 1999 from the World Wide Web: http://www.cs.indiana.edu/event/maics96/proceedings/shank.html.
4. J. Mordant Crook, 'Style in architecture the historical origins of the dilemma' in *The question of style in philosophy and the art*, edited by Caroline van Eck, James McAllister, Renee van de Val, Cambridge, Cambridge University Press, 1995.
5. S.Ewen, *All Consuming images. The politics of style in contemporary culture*, New York : Basic Books, 1988
6. D.Hebdige, *Subculture: the meaning of style*, London, Routledge, 1979.
7. C.S. Peirce, 'How to make our ideas clear' in *Chance, Love, and Logic: Philosophical Essays*, edited by, M.R., CohenLincoln and London, University of Nebraska Press, 1998, pp.32-60.
8. C.S. Peirce, *The Essential Peirce: Selected Philosophical Writings*, Volume 2, Bloomington and Indianapolis, IN: Indiana University Press, 1893–1913, pp. 477-491.

A study on evaluation of exterior colors of buildings with effects of colors of foreground buildings

Takuzo Inagaki*, Daido Institute of Technology

ABSTRACT

The experiments were carried out to confirm how the evaluation on an exterior color of building was influenced from the colors of the foreground buildings. Main results are as follows. Contrast acts on the evaluation of conspicuousness, and assimilation acts on the evaluation of harmony and the necessity of the restriction oppositely. As for striking building, it is not easy to harmonize with the surroundings and the necessity of the restriction is also high. The buildings stands out well, is not harmonized easily by the color difference with the foreground buildings large, and the necessity of the restriction rises further.

Keywords: exterior color of building, color evaluation, scale-model experiment, color difference

1. INTRODUCTION

The author once showed the range on acceptable chroma of the townscape elements [1]. The ranges are considerably influenced by hue and value. It was clarified that color evaluation of buildings was influenced by colors of adjacent buildings using the experiment results with the image processor.
The purpose of this study is to confirm how the evaluation on an exterior color of building was influenced from the colors of the adjacent buildings.

2. EXPERIMENT

The scale-model was made on the assumption that it expressed a typical example of the housing complex located in outskirts of metropolitan in Japan. The five buildings were arranged like "5" of about dice, and the center of them was to be evaluated (Figure 1.). The scale-model was lit by xenon lamp, and fluorescent lamps (AAA; 6,500K, Ra=98, 40W) were adopted as supplement light sources. Thus horizontal illuminance at the ground level in the model was secured at high level; more than 9,000~10,000lx.

Colors of exterior walls were selected from, 5R~10Y, 10GY and 10B in hue, value of chosen colors was set up 5 and 8. Chroma of colors was chosen 3 steps; from 1 at minimum. 50 colors were chosen as evaluate objects, and 20 colors were also chosen as the foreground (Table 1.). The color of the background, however, was fixed for N8. Consequently 1,000 stimuli were to be evaluated by subjects, and these colored papers were made precisely by a proper institute.

Figure 1. Samples of stimuli

Table 1. List of colors used in the experiment

Evaluation objects			Foreground buildings		
Hue	Value:8	Value:5	Hue	Value:8	Value:5
5R	8/1, 8/3, 8/5	5/1, 5/4, 5/7	5R		
10R	8/1, 8/3, 8/5	5/1, 5/6, 5/9	10R		
5YR	8/1, 8/3, 8/6	5/1, 5/4, 5/8	5YR	8/1, 8/3, 8/6	5/1, 5/4, 5/8
10YR	8/1, 8/5, 8/10	5/1, 5/3, 5/6	10YR		
5Y	8/1, 8/3, 8/6	5/1, 5/3, 5/6	5Y	8/1, 8/3, 8/6	5/1, 5/3, 5/6
10Y	8/1, 8/6, 8/9	5/1, 5/3, 5/5	10Y		
10GY	8/1, 8/2, 8/4	5/1, 5/3, 5/5	10GY		
10B	8/1, 8/2, 8/4	5/1, 5/3, 5/5	10B	8/1, 8/2, 8/4	5/1, 5/3, 5/5
N	N8	N5	N	N8	N5

As to 3 scales; activity, conspicuousness and harmony, subjects were requested to answer color evaluation of buildings on each semantic scale of the adjectives. Subjects were (8 males, 4 females) architecture majors.

3. DATA ANALYSIS

Obtained data except of 'necessity of regulation' were processed with a method of successive categories, and the result of 'necessity of regulation' was processed with ratio of regulate necessity (values which were gained by dividing the number of subjects who returned necessity of regulation by total subjects number-12). By choosing colors of the foreground buildings for horizontal axis, scaling value for vertical axis, the influence of colors of the foreground buildings was examined. Furthermore data were investigated by quantitative analysis.

A significant difference based on sex was not noticed.

As shown in Figure 2., the difference by colors of foreground buildings was extremely small, so it can be concluded that subjects evaluated concerning activity only according to colors to be evaluated, in other words, colors of foreground buildings had little effect on the evaluation objects.

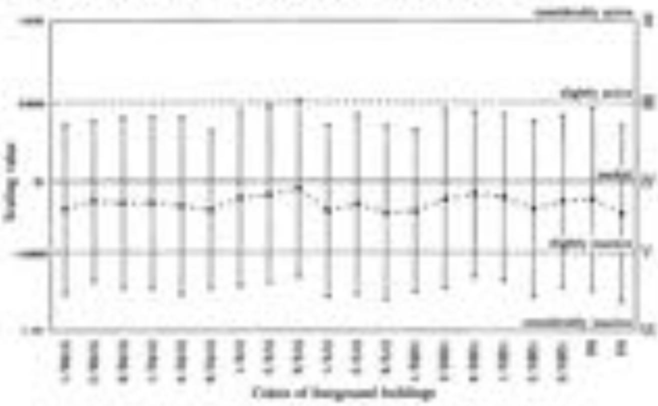


Figure 2. Mean and $\pm\sigma$ of 'Activity'

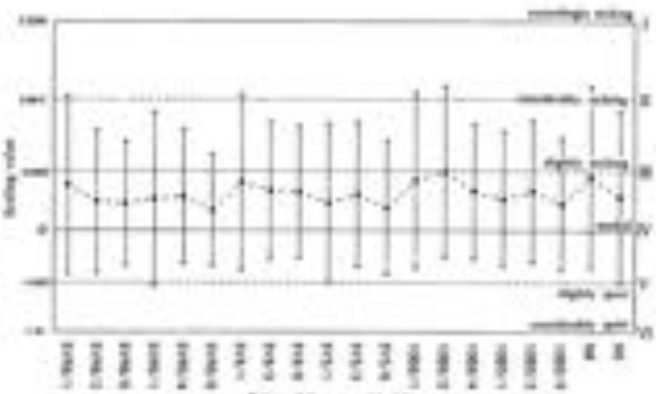


Figure 3. Mean and $\pm\sigma$ of 'Conspicuousness'

Table 2. Analysis of variance on 'Conspicuousness'

	10B 8/1	10B 8/2	N8
5YR 8/6		*	
5YR 5/8	*	*	*
5Y 5/1		*	
5Y 5/6		*	
10B 5/3		*	*

Table 3. Analysis of variance on 'Harmony'

	5YR 8/1	5YR 5/1	5Y 8/1	5Y 8/3	N8
5YR 5/8			*		
5Y 5/6	*	*	* *	*	*
10B 5/3			*		
10B 5/5			*		

* : level of significance=5%, * * : level of significance=1%

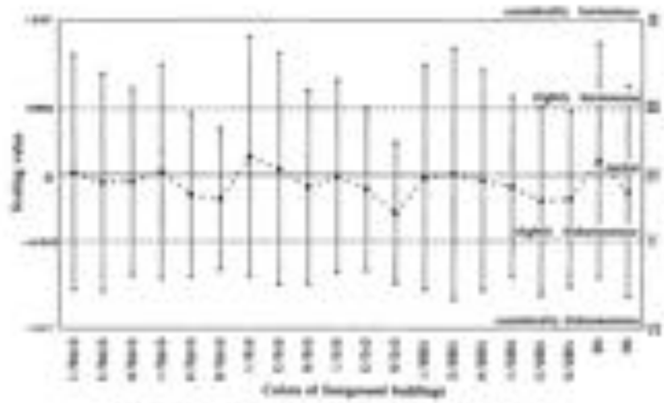


Figure 4. Mean and ± σ of 'Harmony'

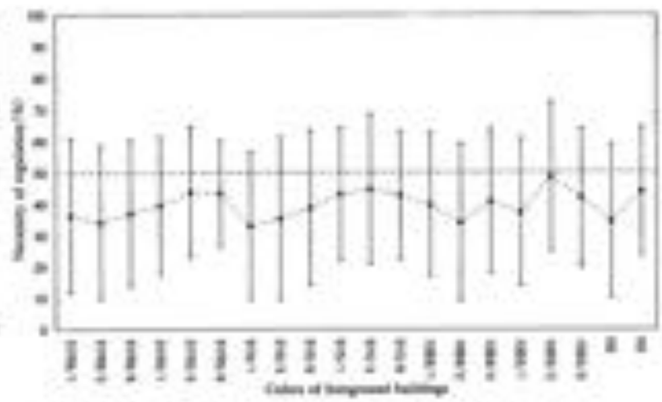


Figure 5. Mean and ± σ of 'Necessity of regulation'

Table 4. Analysis of variance on "Necessity of regulation"

	5YR 8/1	5YR 8/3	5YR 8/6	5YR 5/1	5Y 8/1	5Y 8/3	5Y 8/6	10B 8/2	10B 5/1	N8
5YR 5/4		**			**			**		**
5YR 5/8		**			**			**		
5Y 5/1					**					
5Y 5/3		**			**	**		**		**
5Y 5/6					**					
10B 5/3	** **	** **	**	**	** **	** **	**	** **	**	** **
N5		**			**			**		**

Also as shown in Figure 3., the colors of the foreground which are not noticeable make the evaluation objects stand out, and the foreground with striking color makes the objects not stand out. The fact that the foreground colors harmonize individually is reflected in the evaluation on objects. The restriction necessity rate lowers in case colors of foreground are warm, high in value and low in chroma. Colors of the foreground influenced the evaluation scales except activity. That is, the evaluation of colors of the foreground is reflected easily in the evaluation objects, and a phenomenon like assimilation is confirmed. The correlation between four evaluation scales were examined (Table 5.) As a result, only activity has low the correlation coefficients with the other three scales. Therefore, activity is regarded as an concept differed from the other three evaluation scales. As for buildings with the color which are striking in an average townscape, if a frank expression is done, it is not easy to harmonize, and the necessity of the regulation is also high.

Table 5. Correlation coefficients between 4 evaluation scales

	Activity	Conspic.	Harmony	N.of R.
Activity		0.2994	− 0.0692	0.1088
Conspic.			**− 0.8973**	**0.8524**
Harmony				**− 0.9043**
N.of R.				

Conspic.: Conspicuousness, N.of R.: Necessity of regulation

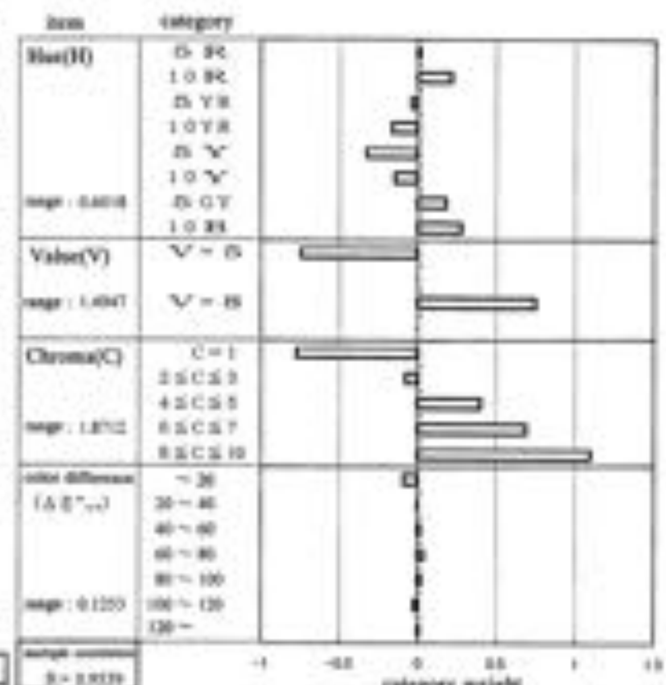


Figure 6. The result of 'Activity'

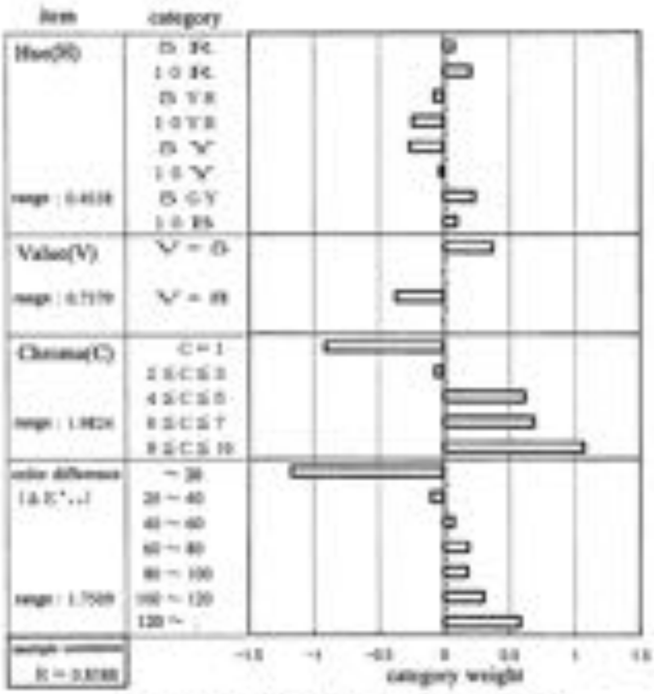


Figure 7. The result of 'Conspicuousness'

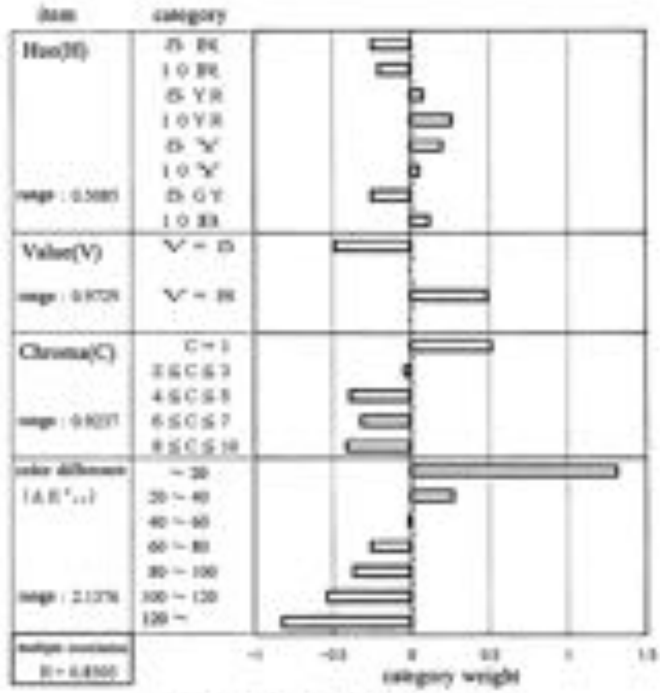


Figure 8. The result of 'Harmony'

Finally, the author examined the color difference between the evaluation object and the foreground. The color difference does not participate in activity at all (Figure 6.). Moreover, the larger the color difference and the higher the chroma of the evaluation object is, the better standing out the evaluation object is (Figure 7.). The larger the color difference is, the more it is uneasy to harmonize (Figure 8.). Furthermore the larger the color difference and the higher the chroma of the evaluation object and the lower the value is, the higher the restriction necessity is (Figure 9.). As for the evaluation scales except activity, the weight of the color difference is assumed to be large.

4. SUMMARY

Summarizing the above, the larger the color difference with the foreground is, the better standing out, not harmonizing easily, and rising the necessity of the restriction is.

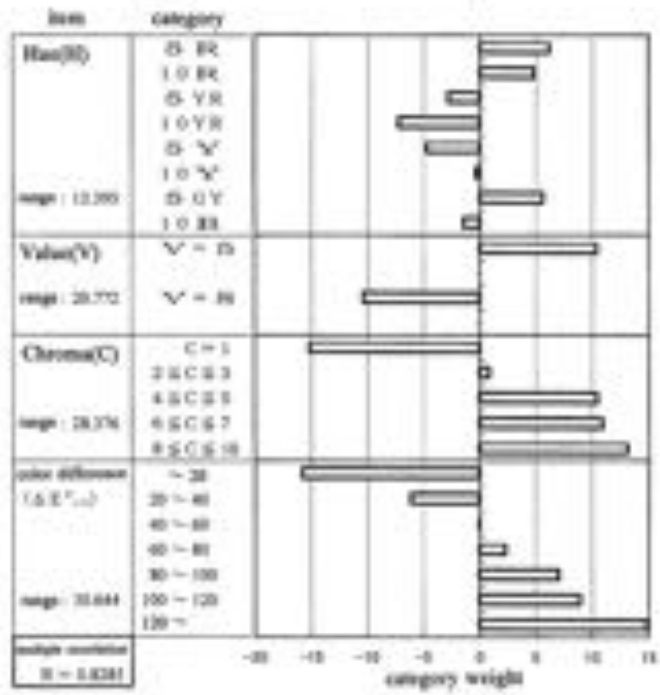


Figure 9. The result of 'Necessity of regulation'

REFERENCE

1. Inagaki, T., An experimental study on color evaluation of townscape elements. Proceedings of the 8th Congress of the International Colour association Volume Ⅱ, pp.900–904

* Correspondence: ina@daido-it.ac.jp; phone +81-(0) 52-612-5571; fax +81-(0) 52-612-5953; Dept. of Architecture, Faculty of Engineering, Daido Institute of Technology, 40 Hakusui-cho, Minami-ku, Nagoya 457-8532, JAPAN

Works on Color Design Installed in an Urban Environment

Silvia Rizzo
Liceo Artistico N. Barabino, Genoa Italy

ABSTRACT

This project is about color-design paintings with evident chromatic contents to be located in several parts of the city.
This project aims to make a two-dimension work alive in the three-dimension urban environment thus provoking a global vision of color and at the same time establishing a relation between both dimensions of the surrounding environment. Each work, which consists of a big colorful canvas, invites people to accept color as an active and aesthetic element to be experimented also in those areas that are normally without color. The project of color has been created and diversified considering the differences among various parts of the city. It is a confluence-comparison relationship between color and architecture. This project is part of a wide-research on "re-education to color", helping people to enjoy the positive vital message of color. Re-appropriation of color is therefore an element of cultural evolution for a more harmonious and sensitive relationship with the environment. Hence, it is the responsibility of scientists and aesthetic operators to investigate and communicate new suggestions in the exciting field of color.
Aesthetic operators along with scientists may contribute to a richer exploration in the use of color under innovative circumstances, in order to stimulate sensitivity to colors.

Keywords: color, bi-dimensional, re-education to color

1. INTRODUCTION

In this research, characterizing typologies for new perception experiences through color are the starting point. Color is considered as an active and dynamic subject in a new dialogue with the habitat, namely through the exploration of perceptive communication in a play of associations between the bi-dimensional nature of color and the three-dimensional nature of architectural or environmental space.
During the various historical periods, 'form-color' has either been cancelled from or included in the aesthetics of different types of architectural styles. Today's architectural works are often supports for visual, information or advertising messages. In general, confused perceptions are experienced. Our sensitivity is at a loss and biased.
This research and its meaning has originated from the above considerations. In other words, the intention was to radicalize research to basic morphologic features. The objective is thus to organize points of visual attraction in order to create new dynamic environmental patterns using (conceptual, intellectual) color as a 'revolutionary' means for man-environment communication. Actually, most cities and their own inhabitants fear colors.

2. METHODS AND CONTENTS

The idea expressed in the project is implemented by means of large canvasses with different color patterns to be placed in several areas of the city.
The objective is to give life to this bi-dimensional work in the city three-dimensional environment, thus creating a collective vision of color.
The project is also the confluence-comparison between painting and architecture. It differs according to city patterns and architectural spaces: e.g. historical, contemporary, suburban, etc. Colors, according to variegated shapes and compositions with their different qualitative expression meanings can be organized into large-sized color-design compositions, thus becoming visual attractions.
Regarding the actual project implementation applied to the city, it was not a case or by chance that such an experiment was developed in Genoa. This city indeed has followed an important tradition of frescoed facades up until the 16th century. So much so that historians used to define Genoa as a polychrome city overlooking the sea. This tradition was later lost. Some restoration has been carried out and the intention is to continue with this work, such as in the case of Ripa Maris, a long series of colorful ancient buildings (ca. 1200) arranged along an arch on the seafront. My project therefore intends to refer to the tradition of Genoa on a cultural level.

2.1 General Remarks for project development

The choice of colors is based on their external location and it is linked to the environment.
It can be referred to:
surrounding architecture, chromatic perception as a whole, exposure to sun light, or less illuminated areas.
Still with reference to the environment, we can consider the possibility to have a 'slow fruition' (e.g. in squares), quick circulation (on main thoroughfares), distances, as well as morphologic differences of historical, contemporary, and suburban places.
In particular, colors start from orthogonal patterns that can vary as follows:
color areas can be expressions of stylistic reference, becoming the projection of an architectural image (historical places), or they can give further stress to vertical or horizontal arrangement or formal equilibrium.
Composition can either be synthetic or fragmentary, in order to obtain the most effective result and for best color fruition. Depending on the distance, on the features of surrounding spaces, on contrast of color timber-tones, their intensity can be inversely proportional to natural light. Variations may occur depending on the weather and the time.
'Three-dimensionality' is undoubtedly the third morphological dimension of the meaning of space. It also means multiple problems linked to the space experienced and to be experienced with a view to developing and expanding concepts.

2.2 The Choice of Color

The emotional communication of chromatic choices is another very important element in project implementation. Thus, more 'humane' rather than cold codified colors. For this reason, in the selection of colors, I followed the suggestion of Shigenobu Kobayashi who matches chromatic scale codification with psychological aspects and the different emotions a color or a whole set of colors are likely to raise.
However, color selection also has to match its optical-sensitive, psychological, and intellectual-symbolic properties.
I give here below some examples of real locations in Genoa suitable for placing my colorful canvasses:

1) La Commenda (historical 13th century building)
2) Via XX Settembre (main street in Genoa for both pedestrians and cars)
3) Palazzo Ducale (also with a view from far away)
4) Internal courtyard of the School of Architecture, Genoa University
5) Piazza Lavagna - Historical Centre
6) Via d'Annunzio (modern buildings)
7) Piazza Fontane Marose (square with frescoed facades)

3. OBJECTIVES

The works located in several areas of the city are an actual route where color becomes a guiding thread in the maize of city spaces, acting as a signal in the surrounding environment. It can be considered as an event, a reference, for a better recognition of places, an invitation to experience space and establish a contact with the external environment, with city life, to communicate with the ancient history of places or to connote spaces without connotation.
The objective of this research is to devise the project as a new type of 'street furniture', without its usual employment features and industrial productivity, but with a mental and spiritual role enriching our own perception which is normally distracted and accustomed to anonymity and highly indifferent to the environment. An unexpected visual symbol that can enrich our lives and our cities.

4. CONCLUSIONS

Apart from the subject chosen for my project, I think that one of the most important elements is the 'collective vision of color'. From this point of view; we can also get close to the connotation of art, a form of art becoming a 'work of art' to be 'met' also by those who just happen to approach it.
It is a suggestion in order to get used to experiencing the topicality of color again, not only as a need of our senses, but also in full awareness of its ethical role for a greater attention to life and to the environment, starting from the very aesthetic project.
Visual examples will be provided during the presentation of the paper at the conference.
Furthermore, once again, this project develops the research on 're-education to color' and color contribution to the quality of life. I have expanded this research rationale also at other times to education, playgrounds and environments for children, as well as in my artistic research.

Re-education to color is indeed one of the several routes that can be followed in order to develop a more humane existence, which is more aware of the surrounding world. Re-appropriation of color is therefore an element of cultural evolution for a more harmonious and sensitive relationship with the environment. Hence, it is the responsibility of scientists and industry members to investigate and communicate new directions for research towards wider perception spaces, in order to identify what is still unexpressed, suggestive, and exciting in the field of color.
Aesthetic operators side by side with scientists may contribute to a richer exploration in the use of color in innovative circumstances, in order to stimulate sensitivity to colors.

These suggestions are useful in order to get used again to appreciating the topical features of color, not only as a need of our senses, but also in the awareness of its ethical result in terms of care for life and the environment, by starting from its aesthetic design.

REFERENCES

1. Jonathan M. Woodham, Twentieth Century Design, Publ. Oxford University Press, Oxford, New York, 1997
2. Silvia Rizzo, Colour Signals in the City, 1st Price for Didactics, in Documentation, Catalogue, 3rd International Colour Design Prize, 1986/87, Publ. Farb Design, International E.V., Stuttgard, 1987
3. Shigenobu Kobayashi, Color Image Scale, Nippon Color and Design Research Institute, publ. Kodansha, Ltd. 1991, Tokio, Inc
4. Various Authors, Landscape and the zero degree of architectural language, International meeting , The Architecture, No. 503, 2000, Publ. Istituto Poligrafico dello Stato, Rome

AUTHOR'S ADDRESS
Silvia Rizzo
Liceo Artistico Barabino, Genova
Via Mogadiscio 2A/7
16141 Genova, Italy
phone: +0039-010-8362185
fax: +0039-010-5305169
e-mail: gsonnewa@tin.it

Colour and urban image at the beginning of 21st century

Maria Mercedes Avila
Institute of Colour, School of Architecture Town Planning and Design

ABSTRACT

The urban shape is understood as the sensitive expression of an idea of city. The emergent aspects, at present involved in the development of technologies of information and communication, have modified the idea of city and, consequently, its shape, which expresses in its appearance the different aspects of this change. This is regarding the physical component, which is strongly engaged with its chromatic expression. As regards the human factor, the construction of the image is considered as a determining aspect of the process of knowledge, which is at present immersed in other dimensions of time and space where speed, simultaneity and alteration constitute parameters of new mechanisms of syntax and construction of the urban image. The challenge consists in interpreting how the urban shape expresses that idea of city and shows the changes in its appearance, in knowing how man builds his image considering this computerised era as well as discovering which the role of colour is in this discussion.

Keywords: Colour, urban image, technologies of information and communication, identity

1. INTRODUCTION

The rapid economic, technological and cultural changes pose a problem which affects man's habitat, in which some fundamental parameters such as space, identity, means of communication and consumption are some of its constitutive aspects. In addition, colour, present in every activity of life, is a tool of expression and communication which requires, on the part of designers, an updated knowledge of its scope of action. It is necessary, therefore, to understand the problems involved in the city of the end of the century, which will enable us to fully exploit its communicative and expressive potential.

Nowadays, the action of colour seems to be dominated by inner and external forces of this end of the century society with the complacency of its operators. "In the perceptual plane as well as in the level of icons, colour is a basic element of a progressive structuring of the suggestion of the physical surroundings, by means of which the inhabitant realises the environment around him"[1]. This double interpretation of the role of colour and the responsibility of its action as a tool of design in the construction of the city leads to think about certain considerations as regards the changing panorama of the present city.

The urban phenomenon of the last decades has suffered changes due to the development of technologies of communication and information. In the contemporary city, the technological innovations exert an important influence on social transformations, and therefore on spatial ones.

There is a process of emergence of a new space of communication and flow of information that goes beyond the boundaries and frontiers of territorial space. The informational city is defined "as a new way of social organisation made up of technology, cultural information, social information and their interrelations."[2] While facilitating this virtual elimination of territorial frontiers, technologies of communication and information also leave a transforming imprint on the urban landscape: the new urban fragmentation overlaps with the fragments of the pre-computer age.
The city becomes a huge producer of consumption of objects, information and images. Simultaneously, its spatial and symbolic configuration is involved in the growth of multi-cultural crossings and the invisible nets of communication technologies which blur any possible local identity and tend to turn the physical space into a metaphoric concept. More and more contrasts seem to characterise different settings: contrasts between historic centres and obscure agglomerations, between luxury and poverty, between the rashness of street violence and the quietness of preserved enclaves, being public spaces the places where the paradox between the local and the global, the phenomenon of globalisation and the impact of computer networks take place in full measure. These changes influence the way man perceives, relates to and communicates with his urban scenario, in which the action of colour is involved in the process of construction of his image.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

2. THE APPEARANCE OF THE CITY AND THE ROLE OF COLOUR

We can not separate the external shape from the real urban form or internal shape, since the latter is the essential content that gives rise to that appearance. That is why the expression in general and the chromatic aspect in particular express this end of the century city, full of fragments and contrasts, in which everything is unlimited exposed and seen, in which the over-action of colour and cesias[3] are present everywhere, shown in the character of architecture and in the environment design. Everything shows that hardly anything has been able to escape from the compulsion of *design-show*.

But this new end of the century, which lacks vanguard, does not appear to be visionary: this impact of design suggests a general trend which, tries to re-formulate every graphic sign and attempts at invading the urban spaces from graphics and notices to architecture itself. This phenomenon cannot be explained just by the advances of multinational corporations and the need for a constant growth in the market; it really leads the changes in the imaginary which makes the visual a competitive arena for a ferocious fight for distinctness. Indeed, in this capitalist post-modernism, the market has put emphasis on its symbolic condition: what is sold is not the product but a model of life, styles and images; which tend to configure identity.

2.1 The city, the colour and their imagery

Neither the city nor its imagery can elude this tendency. The city takes part in this mechanism and its image is built between the tension of what it is physically and the compulsion to position it in the regional or global context by means of advertising visual strategies. The city, like commercial products, is being advertised by means of *trade mark images* that make up the frame of *strategies of distinctness*. The city is being made *visible* so that it regains its meaning by turning to visibility operations of mediatic type which would help us find a meaning by insisting on the competitive appearance of urban scenarios. In this way, the structuring of the urban image is related with the contemporary iconic creation which has been progressively affected and conquered, in multiple and simultaneous ways, by means of communication and the development of technologies of information. There is a change in the perception of time and space as well as a progressive sophistication of iconosyntactic and symbolic resources, which is seen, among others, in an icon verbality and a convergence between connotation and denotation.[4]

The importance of lighting is evident in these iconolinguistic forms, the chromatism of which depends on the luminous source being used, and obviously, on the purpose of its use. These resources re a tool that the urban designer must handle with efficiency and clear objectives.

Because of all this, the action of the numberless components of the urban language strongly powered by colour must be studied in these iconolinguistic forms, the chromatism of which carries subliminal messages and is a means of the construction of image.[5] Since sight is a psycho-physical phenomenon, the iconic communication a social phenomenon and colour is a psychic one, the role of colour is essential in these strategies of the visible, because the action of the city with its images constitutes metaphors, associative operations and symbolic images which make the observer build his territoriality based on this imagology.

What is under discussion by means of this mediatic-festive territoriality is the imagibility of the city[1], that is to say, that by affecting the external form of the city, its legibility is developed. A city with strong legibility is distinguished from others by the increasing attention of urban receptors. This imagibility meets the need of identity and structure of modern cities through the constitutive elements of its language, of urban order and, primarily, of the idea of city that is supported. In this sense, the role of colour in the expression of urban façades and in each of the components of its language is decisive. Colour, by establishing chromatic syntax, behaves as a real morphogenetic agent that may destroy or reinforce the shape and meaning of urban spatial situations.

So now, how can we integrate aspects of the technologies of information and communication, such as simultaneity, speed, the overlapping of images and the immediacy with Lynch's three categories[1]: identification of an object, spatial relation between the object and the observer and meaning to provide the inhabitant with legible surroundings? The streets and squares, once the places for recurrent and orderly social events, have been changed through the media into ephemeral, mobile events with neither historic value nor social content due to the different ways to develop activities in the computerised age.

How can we match the basic human needs of orientation and sense of place when these places are under the mediatic manipulation of images, using colour as a tool, considering types and formats that do not belong to urban design? How can we act responsibly as regards colour without worshipping the image or neglecting the essence of objects? The above mentioned provokes the re-statement of the meaning, construction and appearance of public places, posing a new challenge to the role of colour.

3. THE PRESENT ENVIRONMENTAL IMAGE

The environmental image is the result of a bilateral process between the observer and the environment where three basic levels of communication must be considered: the perceptive-sensorial, the mental-cognitive and the evaluative-affective. These are the levels in which the inhabitant seizes his urban environment, considering the three qualitative aspects of image: identity, structuring and signification[3] where colour plays a predominant role.

The recognition of the urban components at different levels of approximation is an unavoidable fact to identify places or parts of them. The complete urban image used to be built with coherent surroundings and elements in contrast according to the legibility criterion, whereas the present image is fragmentary and disconnected as the consequence of the fracture of the city and the society that inhabits it, of the models of settlement and management that govern urban interventions.

So then, the above mentioned development of technologies of information and communication has modified the way of perception of reality, thus of urban reality. The perceptual mechanism has not changed; however, the way in which activities are developed and the way of seizing spaces in general and urban spaces in particular have been modified. There have been substantial changes in key notions such as the perception of time and space since the user seems to have a greater capacity and an attitude to admit and understand this fragmentation.

The understanding of the city is a process that normally takes place simultaneously with using or living in it, exploring it at different speeds, being the walker's one the most enriching. When this knowledge is acquired through the media or by surfing the cyber space without the commitment or enjoyment of having lived through it, with the ease and speed of interactive supports of virtual space, the experience will be involved with the contingency and the ephemeral that the computer supports provide and new imagery will be built: momentaneous, personal, fortuitous, of immediate history and fragmentary in concept and essence. This does not seem to apply only to the utilitarian realm, as part of the instruments to develop present life, but it also implies the manifestation of new rituals. In the same way that the environmental image has the function of allowing mobility with an aim, these new courses allow fast orientation in a virtual space with a different pleasure from the one obtained through immediate experience, without the fear of getting lost, but with the impossibility to genuinely transfer and share the experience with others.

Consequently, finding the way, original function of the environmental image and the base upon which its emotive associations might have been founded, is definitely not transferable, probably unique and ephemeral. The constructed landscape is an image that does not seem to have a social function since it does not provide shared material to remember or common symbols that allow communication among their members, so it stops acting as a mnemonic system for the retention of history and collective ideals. The symbolic organisation of this virtual urban landscape does not seem to help establish a safe emotional relation between human beings and their complete environment; in fact, it isolates it, creating a sort of elite among the specialists or followers.

The substitution of the immediate experience eludes the role of cognitive maps and memory, the "know how" to find the way home. New parameters take part in creating a sense of orientation. The city, at certain times, pretends to look like a dialogue box, with an iconography overloaded with messages and signals that pollute the environment or, according to the view, expose the mediatic and festive character of the new urban interventions, anticipating in time and/or in space what finally does not exist or has not been materialised yet, but has already been established in the imagery.

The present shape of the city, appearance of the idea of computerised city, of capitalism of over-modernism, is the one that exposes the fragmentation and disconnection as daily achievements. The user goes on building his image without paying attention to syntax or legibility, once important issues. His social actions tend to be segregated from the centre of the pre-computerised city and there are new stages to perform and new behaviours that aim at configuring a public landscape, based on the activities and mediatic communication, separated from or replacing the public space; on the other hand, there is not just a user-reader-spectator but a multimediator one, that is to say, a user who can read a text, see an image and interact with mobile situations in a simultaneous way.

4. FORESEEING THE FUTURE

The image of city that is being built with these strategies of appearance and the impact of technologies of information and communication seem to assimilate the city with a permanent metaphor. In addition, if this growing process of fragmentation is assumed as an irreversible condition, and we want to understand the city as a whole, we need to consider the relationship of fragments among themselves and the inherent qualities of such fragments. In an attempt to build a structure to help cognition, colour should be used, as form and sign, to re-construct the dispersion of fragments with their own identity, developing a new identity for the city as a whole.

Besides, we should not forget that the city has a social and historical past, a patrimonial identity and that the city is an experience that takes place mainly as the relation between an objective space and a subjective duration: the sensitive relation that integrates the inhabitant with his city and implies a long emotional appropriation, even if his space has been chosen as support of mediatic communication.

Therefore, we have to admit that the science of colour is a science of information with a psychological focus which has gained ground and has given back to colour its principal function, a referential function in its surroundings. The above mentioned encourages the consideration of the problem of colour in the city and establishes its action in the construction of its image taking into account some questions: Should colour be for man's living space in the city? or Should it be a vehicle of subliminal images that substitute a real urban physiognomy? Must colour identify a city? or Should it increase its potential for orientation and perception? Is colour to achieve a global mimesis? or Does it confirm an identity based on patrimonial testimony?

What has been stated before suggests that, in a commitment with the social, the aesthetic and the ideological it is necessary to act by thinking critically about colour from the open perspective of the Science of Colour avoiding complacency in the immediate and supporting the irreplaceable character of memory, essential to build the future.

ACKNOWLEDGMENTS

I wish to express my sincere appreciation to the following institutions for giving economic resources to the Institute of Colour: Secretaria de Ciencia y Técnica (SECyT) and Agencia Córdoba Ciencia ex CONICOR. Without their support, the project of investigation " The construction of the city at the beginning of third millennium", could not have done.

REFERENCES

1. J. C. Sanz, *El Libro del Color*, Alianza, Madrid, 1993.
2. M. Castells, *La Ciudad Informacional*, Alianza, Madrid, 1995.
3. J. L. Caivano, "Cesia: A system of visual signs complementing color", *Color Research and Application*, **16** (4), pp. 258-268, 1991.
4. J.C. Sanz, *El Libro de la Imagen*, Alianza, Madrid, 1996.
5. K. Lynch, *The Image of the City*, MIT Press, Cambridge, 1970.

* Correspondence: avilam@onenet.com.ar phone/fax 54 3543 421781; School of Architecture, Town Planning an Design, National University of Córdoba, P. Ferrer 6324, (5147) Granja de Funes, Córdoba, Argentina

Influence of outdoor advertisement colors on psychological evaluation of townscape in Kyoto

Ayumi ONISHI*, Taiichiro ISHIDA* and Yoshiko KATSUYA**

*Dept. of Architecture and Environmental Design, Graduate School of Engineering, Kyoto Univ.

**Currently with City Planning Bureau, Kyoto City Government

ABSTRACT

Outdoor advertisements must be one of the major factors that affect our psychological impression for townscapes. They often conflict with proper color environments in cities particularly in historic cities like Kyoto. In this study we investigated how outdoor advertisements influenced our visual evaluation of townscapes in Kyoto. In recent years, a new regulation for outdoor advertisements came into operation in Kyoto and some of the advertisements have been replaced or removed gradually. We examined psychological evaluation for the townscapes before and after thier changes. In the experiment, subjects evaluated "visual harmony", "visual busyness", "visual comfort" and "suitability to Kyoto" of townscapes projected on a screen. The results indicated that the evaluation of "visual busyness" significantly decreased with the amount of the advertisements. The relations between the advertisements and the psychological evaluation of the townscape are discussed.

Keywords: outdoor advertisement, visual evaluation, townscap

1. INTRODUCTION

Choice of colors is often regarded as a matter of personal preferences. But at the same time colors have significant effects on our living environment. In order to make it more comfortable, we must pay more attention on use of colors in public spaces. Outdoor advertisements may be one of the important items that we must think about.[1] Some buildings have commercial advertisements that designed and colored just to catch our attention. They sometimes disturb the order or tradition of townscapes. This problem appears typically in Kyoto, the old capital of JAPAN. While Kyoto has many traditional buildings and rows of houses to preserve, it also has the role of a regional center of economical and commercial activities. In recent years, a new regulation for outdoor advertisements came into operation in Kyoto, and accordingly some of the advertisements have been replaced or removed. In this study we examined how outdoor advertisements effect our psychological evaluation of the townscapes using photo slides taken before and after changes in the advertisements.

2. EXPERIMENT 1: PSYCHOLOGICAL EVALUATION OF TOWNSCAPES

2.1 METHODS

Figure.1 An example of a pair of two photos ; in 1998 on the left and in 2000 on the right at the same spot.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

The aim of experiment 1 was to investigate how outdoor advertisements influence our visual evaluation of townscapes using pairs of two slides taken with an interval of 2 years. We prepared many pairs of photo slides taken at the same place in Kyoto in 1998 and 2000. Figure 1 presents an example of a pair of two photos. During the two years, there are noticeable changes in outdoor advertisements in some pairs of the slides due to the regulation, while other elements of the townscape such as buildings remain almost the same. Thus we considered that effects of the advertisements could be examined by comparing these pairs of the townscapes.

The slides of the townscapes were projected on a screen one by one for 10 seconds and subjects evaluated "visual harmony (*chowa*)", "visual busyness (*nigiyakasa*)", "visual comfort (*yasuragi*)", and "suitability to Kyoto (*kyoto rashisa*)" of townscapes with 9 steps from 1(most negative) to 9(most affirmative). In actual, the subjects evaluated visual impressions of townscape based on Japanese language shown in the parenthesis. The evaluation factors, "visual harmony", "visual busyness" and "visual comfort" were chosen by referring to major factors typically extracted in the previous studies[2] on psychological evaluation of townscapes. We also added "suitability to Kyoto" in order to explore some unique characteristics of Kyoto.

Subjects observed a projected image 86 cm long and 129 cm wide from a distance of 210 cm in a dark room. After 10 seconds observation, subjects filled up an answer sheet. Twenty two subjects, 21-26 years old, took part in the experiment. They were students from various faculties at Kyoto University. Before starting the experiment they evaluated 10 slides for practice in order to get used to how to scale their impression of the townscapes. We selected 45 pairs of photo slides for the experiment that were taken at various areas from commercial areas to traditional residential areas. We divided 90 slides from 45 pairs into two groups so that each group had the equal number of slides taken in 1998 and 2000 and did not include two slides from the same pair. Each group of the slides was allocated to one experimental session. Two sessions were conducted for a subject on another day.

2.2 RESULTS

Figure 2 shows the changes in subject's evaluation of the townscapes in 1998 and 2000. The horizontal axis indicates the slide number of 45 pairs: each number corresponds to each of 45 places. The vertical axis indicates the difference between the average values of evaluation for 1998-slides and 2000-slides(the average of 2000-slide minus that of 1998-slide). As shown in this figure, absolute differences in the evaluation of two slides are not so large; the largest difference stayed 1.18 out of 9 steps. However the differences with an asterisk(*) in the

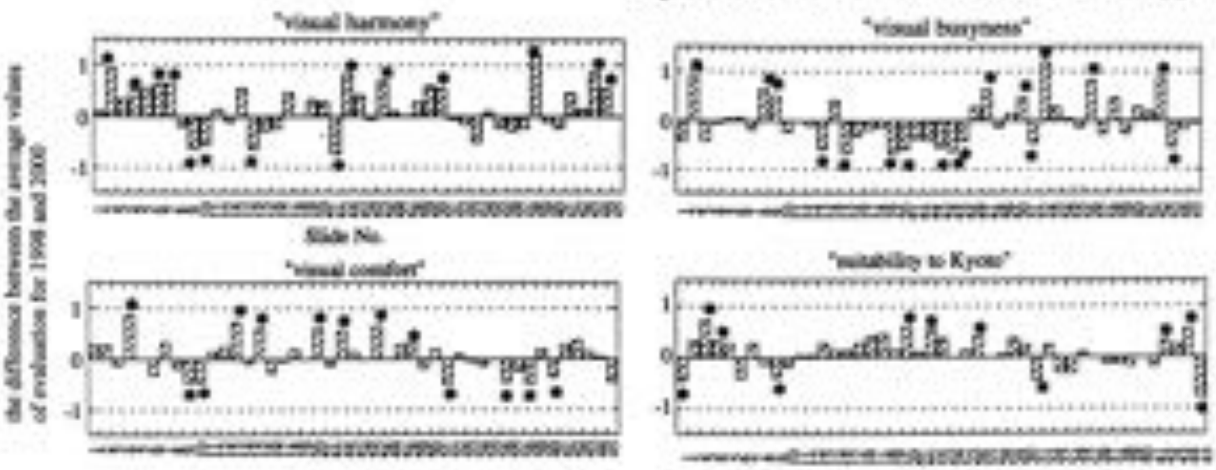


Figure.2 The changes in subject's evaluation of the townscapes in 1998 and 2000
The horizontal axis indicates the slide number of 45 pairs: each number corresponds to each of 45 places. The vertical axis indicates the difference between the average values of evaluation for 1998-slides and 2000-slides (the average of 2000-slide minus that of 1998-slide).

graph were statistically significant(paired t-test, α<0.1). It is evident that changes in the two slides give significant effects on subject's impression of the townscapes. Since two slides involved various temporal changes other than advertisements such as cars, people and weather, it is uncertain whether the differences in evaluation of the townscapes were really caused by changes in outdoor advertisements. We must know to what extent subjects were aware of changes in the advertisements in the pairs of the slides, and examine how they effects psychological evaluation obtained in the experiment 1.

3. EXPERIMENT 2: CHANGES IN OUTDOOR ADVERTISEMENTS

3.1 METHODS

The aim of the experiment 2 was to examine to what extent subjects noticed the changes in the advertisements. In experiment 2, a pair of two slides taken in 1998 and 2000 was projected on the screen one at a time in randomized order. The presentation time was 5 seconds a slide. Subjects observed two slides in order and judge changes in the advertisements. They gave a number between -2 to 2 according to the changes in the quantity of the advertisements in the latter slide comparing with the former using 5 steps: -2 (decrease), -1 (decrease a little), 0 (almost no change), 1 (increase a little), 2 (increase). All pairs of the slides used in the experiment 1 were examined. The configuration of the slide projection was identical with that in the experiment 1. Nine subjects who experienced the experiment 1 participated in the experiment 2. They evaluated five pairs of the slides for practice before starting the experiment 2. We analyzed the data from 45 pairs of the slides.

3.2 RESULTS

Figure 3 shows subject's judgment on changes in the quantity of the advertisements. The horizontal axis indicates the slide number of 45 pairs and the vertical axis indicates the average value of changes in the

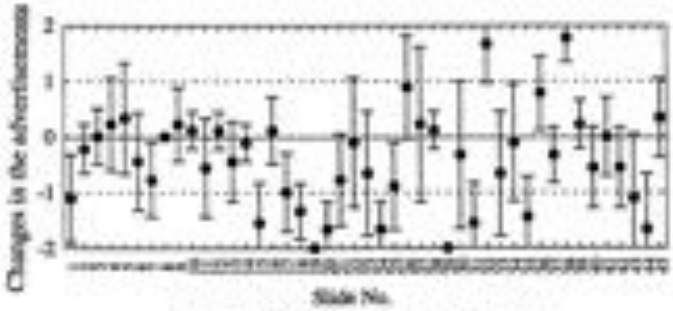


Figure.3 Subject's judgment on changes in the quantity of the advertisements

The horizontal axis indicates the slide number of 45 pairs and the vertical axis indicates the average value of changes in the advertisements: positive value shows that the subjects judged there are more advertisements in the 2000-slide than in the 1998-slide.

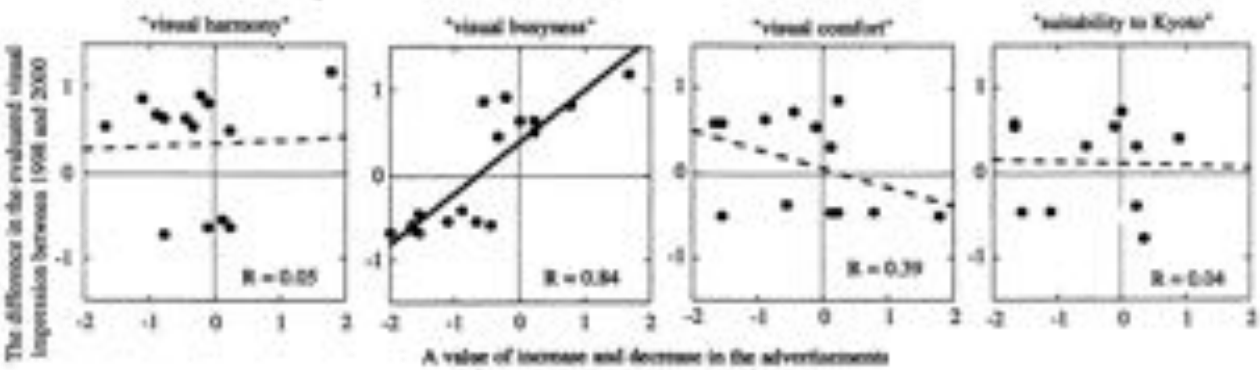


Figure.4 The relation between changes in the advertisements and changes in the evaluation of the townscapes (only significant differences)

The horizontal axis indicates a value of increase and decrease in the advertisements of 2000-slides compared with the 1998-slides and the vertical axis indicates the difference in the evaluated visual impression between 1998-slides and 2000-slides. Only the results of the pairs that showed significant differences in the experiment 1 are plotted in the graph.

advertisements: positive value shows that the subjects judged there are more advertisements in the 2000-slide than in the 1998-slide. As we can see from this figure, most pair of the slides was judged negative or nearly zero, indicating that they noticed that the quantity of the advertisements decreased or unchanged in many pairs of slides. This tendency may agree with the operation of the regulation for outdoor advertisements.

4. DISCUSSION

Figure 4 illustrates the relation between changes in the advertisements and changes in the evaluation of the townscapes. The horizontal axis indicates a value of increase and decrease in the advertisements of 2000-slides compared with the 1998-slides and the vertical axis indicates the difference in the evaluated visual impression between 1998-slides and 2000-slides. Only the results of the pairs that showed significant differences in the experiment 1 are plotted in the graph. We can see that judgment of the quantity of the advertisements strongly correlates with evaluation of "visual busyness"; the decrease in the outdoor advertisements caused decrease in busyness of the townscape. However the changes in the advertisements does not correlate with that of "visual harmony", "visual comfort" and "suitability of Kyoto". Some pairs of the slides contained noticeable changes in temporal elements such as weather, people and cars. These changes might influence subjects' psychological evaluation of the townscapes.

In summary, the present changes in the advertisements according to the regulation operated in Kyoto have limited effects on our overall impression of the townscape. In particular, "visual harmony", "visual comfort" and "suitability of Kyoto" are not 1400influenced by the changes. However the results of the present study indicate that decreases in the advertisements surely decreased visual busyness of townscapes. We consider that it is possible to improve quality of the townscape by making some proper regulation on outdoor advertisements. In addition, it must be important to consider synthetically every elements involved in the townscape such as forms, materials and colors to realize comfortable and suitable town environments.

REFERENCES

1)Y.KATSUYA,T.ISHIDA: "The Effects of Outdoor Advertisements on Visual Impressions of Townscape-The Outdoor Advertisements Controlled Area in Kyoto-", *Summaries of technical papers of annual meeting architectural institute of Japan*, **D-1**, 455-456, 1999

2)M. KIDA et al.: "STRUCTURE OF EVALUATION ON COLOR IN CITYSCAPE", *J. Architec Plan. Env. Engng.*, **502**, 147-154, 1997

Correspondence : hm.onishi@archi.kyoto-u.ac.jp, ishida@archi.kyoto-u.ac.jp ; fax +81-75-753-4766 ; Kyoto Univ. Architecture & Environ. Design, Yoshida-Honmachi, Sakyo-ku, Kyoto 606-8501 JAPAN

Analysis of Colors used on Outdoor Advertising in Urban Landscape
A Case Study in Osaka City

Mika Takahashi*, Kazumi Fujibayashi*, Tomomi Shimonaka*, Masako Sato*, Kazuhiro Sawa**
*Osaka City University, **Japan Color Technology Institute

ABSTRACT

This is a case study for practical survey and assessment of urban landscapes containing outdoor advertisements in Osaka City, Japan.

We practically surveyed and analyzed the colors used on the outdoor advertisements in the three urban areas: the business area along the main street, the amusement area along the shopping street, and the station plaza in front of the railroad terminal.

Further by the laboratory experiments, we examined the interrelation between the atmosphere of the area and the impression arising from the outdoor advertisements using the pictures of street scenes on video monitor. In this experiment, eye movements of each subject observing the scene were analyzed by eye point recorder.

1. In general, vivid red, yellow, green and blue, and white and black were frequently used on the outdoor advertisements in every area.
2. The character of each area was respectively found out by analysis of the following factors: the type of advertisement, the size of each advertisement, and the arrangement of the advertisements.
3. Vivid colors on the outdoor advertisements could be clearly perceived even from a distance. Then, our eyes would be attracted by vivid colors of them.
4. The atmosphere of the area would be affected by favorable or unfavorable impression from the outdoor advertisements. For instance, on the main street, the advertisements would impress us favorably if they are in harmony with each other and create an orderly and elegant streetscape. On the shopping street, various advertisements would impress us favorably if they create a lively and cheerful streetscape.

Keywords: urban landscape, outdoor advertising and advertisement, sign, color, case study

1. INTRODUCTION

The purpose of this study is to investigate how outdoor advertising would take part in urban landscape, and how various landscapes containing outdoor advertisements would be assessed, on the basis of the recent state in Osaka City, Japan.

In this study, outdoor advertising is used as the general term for various types of outdoor advertisement. The illustration of each type of advertisement is shown in Figure1.

Now, in most urban areas, more than one or many outdoor advertisements can be seen together along the street.

However, the important issues, namely the interrelations between advertisements, the effects of individual advertisements on the landscape, and the influences of advertisements on the atmosphere of the street and its surrounding area, haven't been discussed enough.

We practically examined the color and type distribution of outdoor advertisements in the three urban areas: the business area along the main street, the amusement area along the shopping street, and the station plaza in front of the railroad

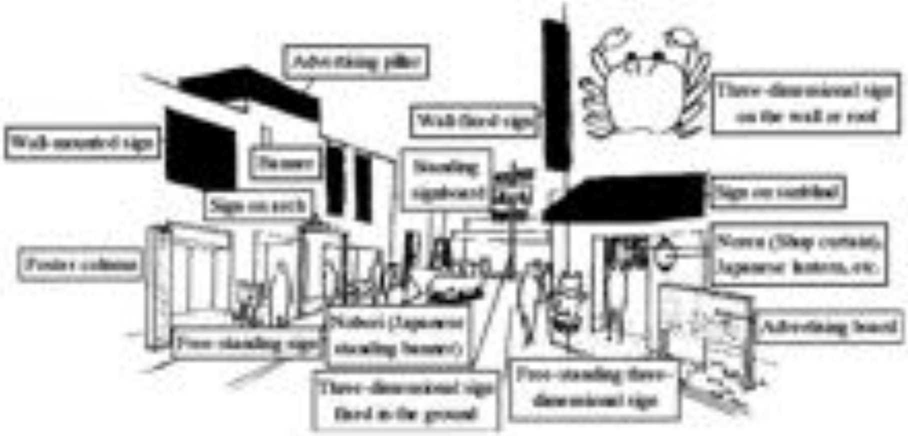


Figure 1. The types of outdoor advertisement

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

terminal. Various colors perceived on advertisements might affect the characteristic atmosphere of the street and its surrounding area by their artificial accent colors.

Then, we also examined by the laboratory experiments about the interrelation between the atmosphere of the area and the impression arising from the outdoor advertisements using the pictures of street scenes on video monitor. In this experiment, eye movements of each subject observing the scene were analyzed by eye point recorder.

2. METHODS

2.1. Outline of the three areas

We surveyed on the state of outdoor advertising in the central districts (Shinsaibashi District, Dotonbori District and Namba District) of Osaka City. The following three areas were picked up for examinations.

1) The business area along the main street: Midosuji Avenue

Many high-rise or large-scale office buildings and store buildings are lining on the both sides of the avenue running through three districts (from Shinsaibashi District to Namba District). This Avenue is lined with big maidenhair trees, and they are the symbols of this area. The architecture including outdoor advertising along the avenue is controlled more strictly than other areas, under the administrative guidance for creating the unity and the continuity throughout the avenue.

2) The amusement area along the shopping street: Dotonboridori Street

Various restaurants and amusement facilities are lined up along the shopping street. This street is the pedestrian precinct. Some advertisements are known as the symbols of this area, and they function as the tourist attractions. The municipal authorities encourage making good use of outdoor advertising in this area, and ease the restriction of advertisement (for example its size, shape and others) for creating amusing landscapes freely and positively.

3) The station plaza in front of the railroad terminal: Namba Station

The building of Namba Station is standing at the end of Midosuji Avenue. The open space in front of this building has a function of the station plaza. The movie theater and store buildings are standing across the street from the station building. The location of this area is also at the entrances of some shopping arcades: Ebisubashisuji Shopping Street leading to Dotonbori District, and others.

2.2. Survey on the color and type of outdoor advertising

We performed the field survey on the three areas, in summer of 1998. We selected the observation points on the street of each area in advance. Then, from each observation point, we measured visually the attributes (HV/C) of colors appeared on major landscape elements including outdoor advertisements in the daytime. The Book of JIS Colour Standards (Glossy Edition) was used as a measure of visual comparison. At that time, the types of advertisement were also recorded (see Figure1).

2.3. Experiments for assessment of the typical landscapes

We performed the laboratory experiments to examine the interrelation between the atmosphere of the area and the impression arising from the outdoor advertisements using eighteen pictures of street scenes on video monitor.

Eye movements of each subject observing the scene were analyzed by eye point recorder in advance. Then, two questionnaires were performed to the subjects.

At first, each subject was asked to assess the atmosphere of each scene using nineteen pairs of adjectives for the scales, that is the semantic differential method.

Next, the subject was asked to assess the impression of outdoor advertisements in each scene, then asked to choose the reasons for favorable or unfavorable impression from given choices as many as he/she wants.

3. RESULTS

3.1. Color Distribution of Outdoor Advertising

We analyzed the color distribution range of outdoor advertisements in each area respectively. The color distribution range of each type of advertisement was also analyzed respectively. Then, it turned out that there was no particular different among areas or types of advertisement. In addition, the analysis concerning other main landscape elements (such as the wall of building, the pavement, and so on) showed no particular difference among areas, either. Therefore, it turned out that the color distributions of major landscape elements in the three areas were almost the same.

Accordingly, the general trend of outdoor advertising color was analyzed using all data (N=979) deriving from advertisements in the three areas. We converted Munsell notations of these colors into the hue-tone notations by JIS Z 8102:

Names of Non-Luminous Object Colours.

The results are shown in Figure 2(a) and Figure 2(b) as the relative frequency distribution in hue and tone respectively.

In practical usage, white and black of achromatic colors, and chromatic colors with both high-chroma and primary hue (except purple) were frequently used on outdoor advertisements. The high frequencies of these colors resulted from the wide usage in both the figure (text, character, logotype, and so on) color of advertisement and the background color of it. The combination of white and red (or other hue) or black was the typical pattern of advertisement in this survey.

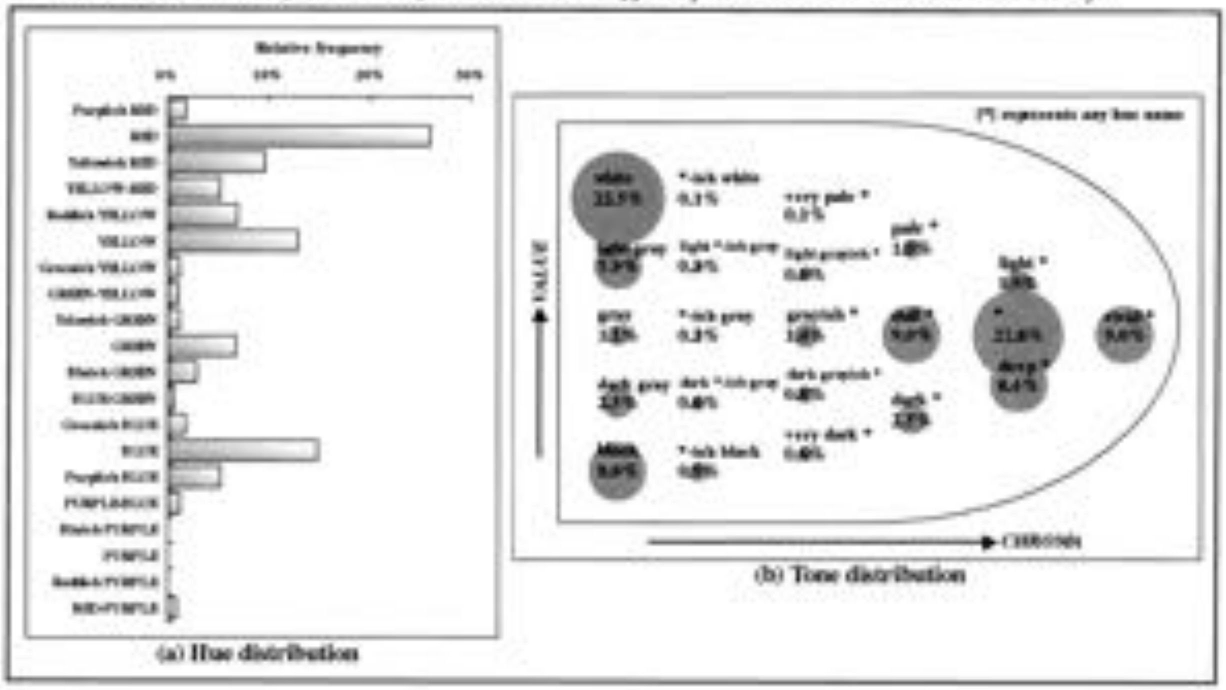


Figure 2. The color distribution of outdoor advertising. (a) shows hue distribution, and (b) shows tone distribution.

3.2. Characteristics of the three areas

The character of each area was respectively found out by analysis of the following factors: the type of advertisement, the size of each advertisement, and the arrangement of the advertisements.

In the business area (see Figure 3), outdoor advertising had minor but moderate influence on the landscape. The streetscape was mainly characterized by the low-chroma colors (off-white or gray, beige, brown, cream and others) or achromatic colors on the wall of each building and the pavement. The colors of advertisements could be seen in orderly manner as the guides or landmarks of individual buildings, and these colors were also perceived as the moderate accent on the streetscape.

On the other hand, in the amusement area (see Figure 4), outdoor advertising had major influence on the landscape. Along the shopping street, a great many and various types of advertisements could be seen continuously. Then, they filled the streetscape with their colorfulness. Accordingly, this area was plainly characterized by the various and colorful advertisements.

(a) (b)

Figure 3. The pictures of the business area

(a) (b)

Figure 4. The pictures of the amusement area

In the station plaza (see Figure 5), a series of advertisements could be looked over along the buildings standing in front of the railroad station. Among these advertisements, there was the group of large billboards (wall-mounted advertisements) around the entrance of the shopping arcade. This group of billboards gave a strong impact on the plaza-scape (Figure 5(b)). Then, this area was characterized mainly by this concentration of advertisements and the contrast between advertisements.

(a) (b)

Figure 5. The pictures of the station plaza

3.3. The results of laboratory experiments

1) Effects of outdoor advertising on eye movements

The analysis of eye movements showed that the eyes of observers could be attracted by vivid colors on outdoor advertisements even if they had no intention of searching for any advertisement. Moreover, the arrangement of advertisements and the size of each advertisement in the scene could affect eye movements to a certain extent. For instance, in case of the streetscape dotted with the small-scale advertisements, the eye point of observer tended to keep on moving slowly without staying long on one advertisement. On the other hand, in case of that including the group of advertisements or the large-scale advertisements, the eye point stayed long on them. These results indicate that individual advertisements might affect the way of looking at the landscape.

2) The interrelation between the atmosphere of the area and the impression from outdoor advertising

The principal component analysis showed that the atmosphere of the street scenery was assessed with the three principal components: the first component "the activity of the lively streetscape", the second component "the beauty of the orderly streetscape" and the third component "the powerfulness of the artificial streetscape".

Then, it turned out that the atmosphere of the scene and the favorable or unfavorable impression from the outdoor advertisements could affect each other. Consequently, the reason for the favorable or unfavorable impression from the advertisements differed according to the characteristic atmospheres of the areas. For instance, on the main street in the business area, the advertisements would impress subjects favorably if the advertisements were in harmony with each other and created an orderly and elegant streetscape. On the other hand, on the shopping street in the amusement area, many and various advertisements would impress subjects favorably if the advertisements created a lively and cheerful streetscape. These results indicate that the important criterion for the assessment of the streetscape would be whether the advertisements cooperate to create the desirable and suitable streetscape for each area or not.

REFERENCES

1. K.Fujibayashi et al.; Color of Outdoor Advertising in Urban Landscape in Shinsaibashi and Namba, Proceedings of the meeting of the Color Science Association of Japan in the Kansai region, 6-7, 1999
2. M.Takahashi et al.; Color of Outdoor Advertising in Urban Landscape in Shinsaibashi and Namba (Part II), Journal of the Color Science Association of Japan, 23, 64-65, 1999
3. M.Taniguchi and K.Sawa : The Study of Color on Signs –The Research into Trends of Display in Each Area, Journal of the Color Science Association of Japan, 23, 62-63, 1999

Contact author: Mika Takahashi (d98h203@ex.media.osaka-cu.ac.jp or mika-t@std2.life.osaka-cu.ac.jp)

*Graduate School of Human Life Science, Osaka City University
3-3-138, Sugimoto, Sumiyoshi-ku, Osaka, 558-8585, Japan
Telephone: +81-6-6605-2824 or +81-6-6605-2825, Fax: +81-6-6605-2824

** Japan Color Technology Institute
2-7-13-502, Minamisemba, Chuo-ku, Osaka, 542-0081, Japan
Telephone: +81-6-6265-3211, Fax: +81-6-6265-3631

Colour appearance in virtual reality: a comparison between a full-scale room and a virtual reality simulation

Monica Billger* and Stefano d'Élia, Department of Visualisation and Modeling,
School of Architecture, Chalmers, Sweden

ABSTRACT

The main goal of our project is to make VR applications usable for the planning of light and colour. To enable reliable simulations, we both need to develop better rendering methods and carefully study the appearance of light and colour in real rooms and in virtual environments. Assessments of real rooms are compared to simulations of the same rooms in immersive Virtual Reality (3D-cube). In this paper, we will present the outcome of a pilot study and discuss specific problems associated with the prospect of comparing reality to Virtual Reality. We will account for the experience of the room and go into details on the experience and perception of light. Indeed, the problems of getting enough light in the 3D-cube and of simulating the light situation of a real room affect colour appearance.

Keywords: Virtual Reality, VR, 3D-cube, colour appearance, light perception, room experience, visual assessments, simulations

1. INTRODUCTION

At Chalmers, the School of Architecture and the Department of Computer Engineering have started a project on simulation of light and colour in buildings. The main goal is to make VR applications usable for the planning of light and colour, and thereby solve problems connected to the difficulties to visualize and comprehend colour appearance. To enable reliable simulations, we both need to solve technical problems to develop better rendering methods and to study human perception of colour and light. Assessments of real rooms are compared to simulations in immersive Virtual Reality (3D-cube). The project is expected to contribute to the development of VR as a design tool, by giving us knowledge on colour perception and developed technical methods.

2. THE POTENTIAL OF USING VR AS A DESIGN TOOL

There is very little published concerning *colour appearance* in real rooms compared to virtual rooms. Comparative studies between real and virtual environments and different kinds of virtual environments have focused on other aspects such as, perception of distances, behaviour and social relations, the perception of presence, and the relation between task performance and presence. Concerning VR-studies in Architectural research, two focuses dominate the field: one is on functional and ergonomical studies from a user perspective, and the other on visualization of Architecture regarding aspects as spaciousness [1]. Our project enters the field of Virtual Reality from the perspective of architectural colour research. Factors as illumination, colour combinations and textures affect the appearance of coloured surfaces in rooms. The problem of informing about colour phenomena in rooms is obvious. Words are abstract and lack precision; to understand colour one has to see colour. Oberascher [2] points out the difficulty of predicting colour appearance in completed architectural space and he emphasizes the importance of full-scale studies. From experiments involving architecture students, he has reached the conclusion that full-scale modeling is the best means of exploring, assessing and communicating colour appearance. However, to carry out full-scale real room simulations during a planning process would be expensive and extremely time- and space consuming. Virtual Reality may reduce errors due to abstract representation (such as plans and perspectives) [3] and it enables presence [4] in another world than the real, which can be of great advantage during a planning process. VR simulations have potential to solve communication problems in the design process that has to do with the difficulty to visualize and comprehend the appearance of light and colour.

*corresondens to: billger@arch.chalmers.se; phone +46 31 772 23 83; fax +46 31 772 23 83; Dep. of Visualization and Modeling, Architecture, Chalmers, S-412 96 Göteborg, Sweden.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

However, the simulations of colour and light we can make today with existing software are of poor quality. Most important of all: even with a speeding technological development, we need to investigate how reliable these simulations are, *i.e* how well they agree with human's experience of real rooms.

3. PILOT STUDY OF A REAL ROOM AND ITS VR MODEL

3.1. Problems and aims

This project deals with two crucial sides of the problem of making usable simulations of light and colour in Virtual Environments. On one hand, the ways colours are perceived in real rooms; the reliability of the simulations is delimited by our lack of knowledge about how humans perceive spatial colour phenomena. On the other hand, we deal with the computer technical problem of creating realistic images at high enough speed.

In order to try out the various assessment methods and establish the procedure, we first carried out the pilot study discussed below. In this, we emphasize on methodology and on pointing out differences or similarities between the real room and the virtual room. This preliminary study have the aims to: (1) map out problems of creating simulations that show the same lighting effects and colour phenomena as in real rooms, (2) try various methods for assessing the appearance of light and colour in the virtual environment, (3) get a better understanding of the way we perceive light and colour in virtual environments compared to real ones.

3.2. Experimental design

The *real room studies* are carried out in a multicoloured experimental 12-m2 room equipped with a few chairs. The room has been studied in 4 different kinds of illumination: simulated daylight (Philips TLD 96[?], 6500 K, CRI 97), incandescent light, and a mix of each of these two lights in combination with real daylight from three small windows facing west. Only one of these light situations is included in the pilot study: simulated daylight. The *virtual room studies* are carried out in an immersive space laboratory. In this 3D-cube (3x3x3m), one carries VR-goggles and walks around in a room with projections on the walls and on the floor. There is no projection on the top of the cube, i.e. the observer can only see the ceiling of the simulated room when projected on the sides of the 3D-cube.

We are investigating the appearance of light and colours, as well as the observers' total impression of the room. The comparison between real and virtual rooms is carried out in two ways: by comparison of the visual assessments of each situation and by memory matching. The following assessment methods are used: (i) Semantic differential scaling, (ii) Interview, in which the observer freely can express himself or herself. (iii) Visual Evaluation of the light situation [5]. (iv) Semantic description using everyday language and the NCS-terminology, (v) Magnitude estimation (vi) Colour matching with *the Colour Reference Box method* [6,7]. All these methods were used in the real room study. 10 observers evaluated this room, which took a full day for each of them [7]. Up to now, 6 observers have evaluated the virtual room in an hour long session. They did not do any magnitude estimation or colour matching in this session. In addition, 3 other observers had a shorter session in the 3D-cube and only took part in the memory matching, and 1 tested to use the colour reference box.

Note, that the real room study was finished long before the VR-model was made and this part of the study had started. Only one of the observers in the VR-study had been an observer in the real room.

Figure 1.One observer studies the room model in the 3D-cube.

3.3. General impressions of the two spaces

Naturally, there is a big difference between experiencing a real room and a model of the same room projected in a 3D-cube. When entering a small real room like the one in this study, we get a grasp of it immediately. When moving around in the room, we know what is behind us and we believe that the part of the room we have turned our back to is still there. In our study it was not as easy to understand the virtual room. First of all, it took time for the observers to get acquainted with the new media. The procedure was that they first had time to understand how to use the control and to look upon the model from different angles. Thereafter, they placed themselves inside the model, standing on the floor, and placed one of the room model walls upon a side of the 3D-cube. Then they were asked to tell the size of the room and describe where they were and what they saw. They observers said rather quickly that they understood the room, however, from their descriptions we realized that they made mistakes. *E.g.*, one observer saw the window niches as boxes standing out into the room instead of the opposite. Another observer took one wall for an opening. All discovered their mistakes, but it could last until the end of the session, when they once again took time to walk in and out of the room to look at it from different distances. The observers found it easiest to grasp the room when looking at it on a distance through a wall. When standing inside the room, the best way to grasp it was by standing in the middle and slowly rotate the room around. In this way the illusion became stronger and the observer did not confuse the sides of the 3D-cube with the room surfaces.

After spending one hour in the 3D-cube, the observer walked directly to the real room. It took one minute to get from one room to the other. The spontaneous reaction from the observers was that the real room was distinctly smaller, that the light was clearer and much stronger and that the colours were more saturated. Coloured areas that had been equal in the virtual room were found to be distinctly different in the real one. They also pointed out that the light distribution and the shadowing differed between the two spaces.

3.4. What light? There is no light in here!

The method of Visual Evaluation by Liljefors and Eijhed [2] was used for evaluating the light. The light situation was evaluated according to 6 factors: *lightness level, light distribution, shadows, glare, reflexes, colour of light*. The method worked out well in the both kind of rooms with high agreement among the observers. However, to evaluate the light in the simulated room required much consideration and took more time. The *light level* in the real room was estimated rather high, it was light enough to read a book easily. The light was perceived as even. The room was "rounded off" with diffuse *shadows* in the corners; a smooth gradient went from the lighter, middle part of the walls towards the corners. Shadows were also noted on the ceiling and on the upper part of the walls. For most of the observers *glare* was only experienced when looking directly towards the armatures, however a few of them pointed out that they were slightly disturbed by glare all the time and that this disturbance contributed to the unpleasant light situation. There were very few *reflexes* from the light sources, only a few spots on the upper part of the walls. The *perceived colour of light* was described as cold and diffuse, it was white but not as transparent as daylight.

The first observer in the VR room said spontaneously: - What light should we discuss; there is no light in this room! With this he meant that there was light on the walls and the floor, but the space between was not illuminated. When preparing the VR model we aimed at getting as close as possible to the light situation in the real room, however, we had technical problems to get it light enough. The observers estimated *the light level* around medium light; some stated that it was significantly more to the dark, others that it was more to the light. From their reasoning we understood it as the difference came from the way they made their interpretation of the situation. One observer expressed it like this: "The colours on the walls tell me that this is a well illuminated room, however the illumination tells me that it is dark. It seels as we have forgotten to turn on the light." *The light distribution* was evaluated as very even. The room was almost without any *shadows*; the few that were found were very soft. The corners were not in shadow as in the real room; instead, one of the walls was darker than the others. There were no *reflexes* from light sources and absolutely no *glare* was experienced. The *perceived colour of light* was described as white or grayish. The most expressed quality was that it was very dim; it was like mist in the room.

All the observers where asked to describe what kind of light source was used and where they were placed. One said that it seemed as something like daylight, the other said that it seemed as dirty, fluorescent light. The light was described as extremely even, diffuse and indirectly reflected. The observers found it very hard to tell from where the light came; the illumination seemed contradictory. However, most observers suggested correctly that the light source was placed on the ceiling, and that it spread the light very diffusely. One of the observers came with an informative description: she said that it feels as we are inside in a room where the curtains are drawn, and that the light from outside comes pouring in through these curtains. The odd thing, she said, is that it is so evenly spread out.

1+2+3 = NCS S 2030-G30Y
4+5 = NCS S 2020-R50B
6 = NCS S 3000-N
7 = NCS S 5000-N
8 = NCS S 0500-N

Figure 2. The room seen from above.

3.5. Colour Appearance

In this phase, we focused on the relations between the equally painted areas in the real room compared to the virtual room. We have compared descriptions of *local appearances* of the green, violet, grey and white areas. The relations between the equally painted green areas were not the same in the VR-room as in the real room. The green on the grey-green wall (area 1, see Fig. 2) were perceived as equal to the green on the violet-green wall (area 2). In the real room the chromaticness was higher for the whole green corner than for the green half-wall, and the walls in the corner were more yellowish. The walls in the grey corner did not have the same relations either; in the real room one was slightly reddish and one slightly yellowish. One observer pointed out that in the VR-room the grey walls could be taken for white walls in shadow, however in the real room they appeared to be painted grey and white, respectively. The violet areas, however, differed from each other in the same way in the real room and the VR-model: the violet on the window-wall was greyer and bluer.

4. CONCLUDING THOUGHTS

So far, this study has taught us more about the usage and experience of being inside the 3D-cube than about simulating colour appearance in a virtual environment. The evaluation of the light was most valuable for our continuing study. To make this medium really interesting for presentations to colour appearance in rooms, we need to be able to simulate light better.

ACKNOWLEDGMENTS

This work was supported by grants from the Swedish Research Council, The Swedish Research Council for Environment, Agriculture and Spatial Planning, the Swedish Association of Painting Contractors and the Swedish Painters Union.

REFERENCES

1. **Nilsson, Alexander,** VR-forskning i Sverige, Dagsläge och framtida riktlinjer, Report for The Swedish Transport and Communications Research Board (KFB), Chalmers; Göteborg; 2000.
2. **Oberascher, Leonard,** Environmental Colour Design: Simulating real world complexity, In: Sivik Lars, Ed:Proceedings of the AIC Interim meeting Colour and Psychology in Göteborg 1995, , Colour report 50, Stockholm: Scandinavian Colour Institute; 1996, pp.49-55.
3. **Dorta, Tomas and Lanlande, Philippe,** The impact of Virtual Reality on the Design process, In: Seebohm T. *Ed*: Proceedings of ACADIA 98, pp.138-163 (October 1998, Quebec City, Canada)
4. **Riva Guiseppe,** From Technology to Communication: Psycho-social Issues in Developing Virtual Environments. Journal of Visual Languages and computing; 10:p.87-97;1999
5. **Liljefors, Anders**, Lighting and Colour Terminology, Visually – Physically, In: Sivik Lars, Ed: *Proceedings of the AIC Interim meeting Colour and Psychology in Göteborg 1995*, , Colour report 50, Stockholm: Scandinavian Colour Institute; 1996, pp. 230-234.
6. **Billger Monica**, Evaluation of a Colour Reference Box as an Aid for Identification of Colour Appearance in Rooms. *Colour Research and Application; no 3; p. 214-225; 2000*
7. **Billger Monica,** Assessing Colour Appearance In a Real Room Using Magnitude Estimation and Colour Matching Techniques. In: Conference proceedings for Colour and Visual Scales 2000, 3-5 April 2000; National Physical laboratory, Teddington, UK; 2000.

How does our visual system interpret the color of light filled in a three-dimensional space?

Naohiro TODA, Taiichiro ISHIDA
Dept. of Architecture and Environmental Design, Graduate School of Engineering, Kyoto Univ.

ABSTRACT

Light filled in a room consists of direct and mutual reflected components. Thus the color of light shifts physically to that of an interior of a room when the interior is colored. However, it is not understand how we interpret this color shift caused by the mutual reflection. In this study, we examined how we interpret the color of light filled in a room by using a light source color matching method. The test box had the chromatic interior and those of the matching box achromatic. The results indicated that subjects perceived the color shift produced by the mutual reflection as belonging to the light source.

Keywords: visual environment, lighting recognition, color of lighting, mutual reflection

1. INTRODUCTION

We can identify color of a surface regardless of considerable change in illuminant in a practical situation. This phenomenon is called color constancy.[1] This ability may require both recognition of characteristics of illuminants (e.g. spectral power distribution) and that of surfaces (e.g. spectral reflectance). The recognition of them might provide useful environmental information to us. For example, the recognition of illuminant provides clues to the weather and the time of day, and that of surfaces serves as clues to identification of objects. There remain, however, unsolved questions about the nature of color constancy. In particular, we must consider various factors to understand how we perceive the color of lighting and surfaces in an actual situation, because surfaces and objects are constructed three-dimensionally there.[2-4] The light filled in a room consists not only of a direct component from light sources but of indirect one produced by mutual reflection. The mutual reflection affects remarkably to quantity and color of lighting in a room because high reflectance materials are often used for the interior such as walls or ceiling. If they are colored, the color of the mutual reflected light would shift to the color of them from that of the original light source.

Our main concern here is to know how we interpret these two color components and recognize the color of light in a three-dimensional space. This question is important not only from the aspect of understanding human color perception but also practical architectural lighting design. In this study, we examined how we interpret the color of light filled in a room by using a light source color matching method.

2. EXPERIMENT 1

2.1 Method

In the experiment 1, we examined how subjects interpret the color of light in a colored box using a light source color matching method. The experiment was performed by using two model boxes; the one is a test box with chromatic colored interior, and the another is a matching box with achromatic interior. Subjects observed the inside of the test box illuminated by a certain color of a light source, and adjusted color of a light source in the matching box so that perceived color of the light source would be the same as that of the test box. Between the trials, subjects saw the inside of the matching box whose lighting condition keep constant: correlated color temperature 4000 K, horizontal illuminance on the floor 600 lx.

The apparatus used in the experiment is shown in Fig. 1, and the experimental condition appears in Table 1. The size of the boxes was 30 [W] x 45 [D] x 30 [H] cm. A white acrylic sheet was set up as ceiling in each box to diffuse light from the light source, but subjects could not see the ceiling directly. The floor and walls were painted, and their

Table. 1 Experimental conditions

	Test Box	Matching Box
Size	30 [W] x 45 [D] x 30 [H] cm	
Colors of the interior	N 7.4, 8.3Y 7.4/2.7, 46,6.7B 7.5/2.3, 9.8B 7/7.34, 7.4Y 7.4/6	N 7.4
Colors of the solids	N 6, 5R 6/3, 5Y 7/2, 10G 6/2, 10PB 6/2,10B 5.5/3	
Tc of the light source	3200 or 3800 or 4800 K	2400～7400 K, between the trial, 4000 K
Horizontal illuminance at the floor	600 lx	between the trial, 600 lx

reflectances were about 0.5. The inner surface of the matching box was neutral gray (N7.4). In the test box, plates of walls and a floor were changeable and were selected from among 5 color variations: N7.4, 8.3Y7.4/2.7, 6.7B7.5/2.3, 9.8B7/7.3 or 7.4Y7.4/6. Each box was illuminated by two kinds of light sources (yellowish and bluish), and the color of light could be adjusted by changing mixing ratio of the two types of lamps. The mixed lighting chromaticity was measured at the point denoted by X in the Fig. 1 by the colorimeter (MINOLTA CL-100). The one of the light sources was a fluorescent lamp of incandescent color type (Tc = 2700 K, Ra = 95) with a yellow filter of an acrylic sheet, and the another was a fluorescent lamp of white type (4500 K, Ra = 91) with a blue filter. The lighting conditions of each box are shown on the chromaticity diagram in Fig. 2. We can see from this plot that they fall on a line nearby the Planckian locus. Three lighting conditions were employed for the test box. Their correlated color temperatures were about 4800, 3800 and 3200 K, while their horizontal illuminance on the floor was kept about 600 lx. In the matching box, correlated color temperature of the lighting could be linearly changed from about 7400 to 2700 K. Several solids covered by color patches were put inside the boxes as references: their colors, N6, 5R6/3, 5Y7/2, 10G6/2, 10PB6/2, 10B5.5/3.

All of the floor and walls of the test box in the experiment 1 was set to the same color for a trial. Therefore, the number of conditions of the test box was 15: 5 (colors of the interior) x 3 (lighting conditions). One session consisted of these 15 trials, and one subject performed three sessions. Three subjects from author's laboratory took part in the experiment. They all had normal color vision.

2.2 Results and Discussion

Chromaticities of the indirect components of the light on each surface could conventionally be calculated using

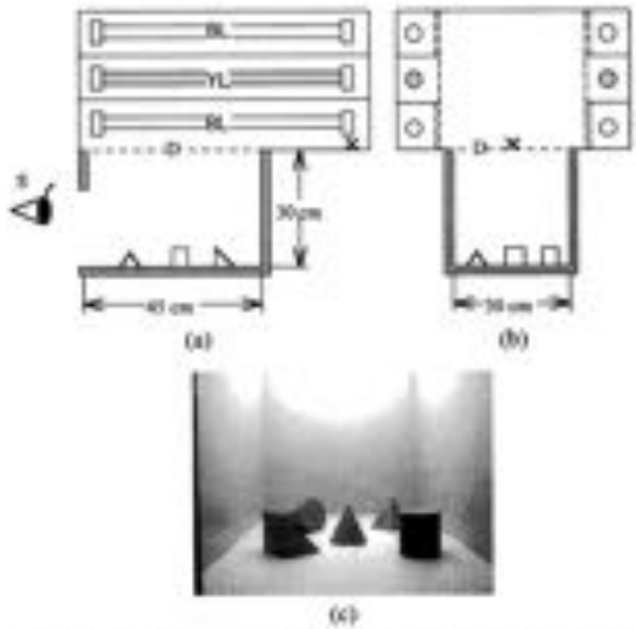


Fig. 1 Apparatus of the matching box. The test box is the same as this and they are constructed side by side. (a) side section view; (b) front section view; (c) picture of the front view. S, subject; BL, white type fluorescent lamp with blue filter; YL incandescent color type fluorescent lamp with yellow filter; x, measurement point of the chromaticity of the light; D, white acrylic sheet to diffuse light from light source.

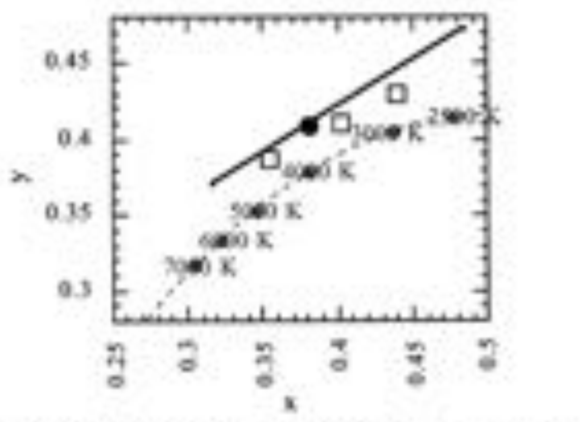


Fig. 2 Chromaticity coordinates of lighting conditions in each box. The grey curve in a diagram is Prankian locus, and labels on the curve are the correlated color temperatures at the point. Black straight line is the range of lighting in the matching box. Filled circle is the condition subject observed between trials. Open squares are lighting conditions in the test box.

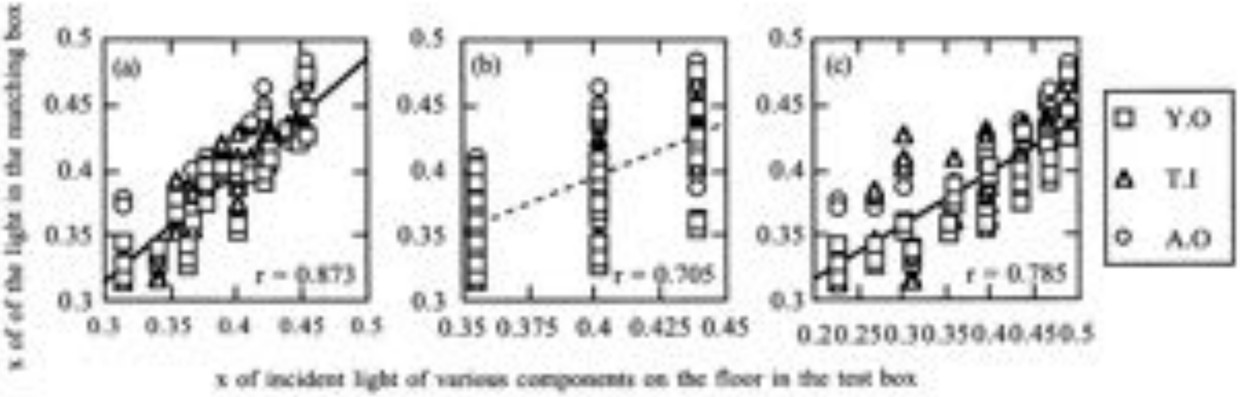


Fig. 3 Results of the experiment 1. Each symbol represents the results of the subjects. The ordinates, the color of the light in the matching box which represents the subject's perception of the light source color in the test box. The abscissa, the color of the light in the test box is shown in three ways: (a) sum of the direct and mutual reflected light components, (b) the direct light component, (c) the mutual reflected component.

spectral power distribution of the light source, spectral reflectances of each surfaces, and form factors decided by the configuration of the boxes.[9] The x-coordinate calculated by this method will be used in the following results and discussion. Figure 3 shows the results of experiment 1 for all subjects. The ordinates of Fig. 3 (a) - (c) shows the color of the light in the matching box which represents the subject's perception of the light source color in the test box. On the abscissa the color of the light in the test box is shown in three ways: (a) sum of the direct and mutual reflected light components, (b) the direct light component, (c) the mutual reflected component. That is, abscissa of Fig. 3 (a) corresponds to the color of actual incident light on the inner surface of the test box, that of Fig. 3 (b) to the light source color, and that of Fig. 3 (c) to the color of the calculated indirect light. The main interest of the experiment 1 is which component of the light corresponds to the subject's matching color of the light source. It is clearly shown in Fig. 3 (a) that the color of the light in the matching box strongly correlates with the sum of the direct and mutual reflected components of the light in the test box. The subject's perception of the light source color does not coincide with that of the actual light source (Fig. 3 (b)). That is, the results suggest that the subjects perceived the sum of the direct and indirect light as the light source of the test box. It is possible, however, that they simply adjusted the color of the light in the matching box by referring color of the interior of the test box. This possibility will be considered in the next experiment.

3. EXPERIMENT 2

3.1 Method

In the experiment 1, we found that subjects perceived the color of the light source in the colored room as shifting toward that of the interior from that of the actual light source. Since we used a single color on the interior of the test box in the experiment 1, we could not determine whether this shift was attributed to the subject's perception of the color of lighting or simply that of the interior surface color. Thus, in the experiment 2, we used several different colors on the surface of the interior to distinguish the color of the light and that of the interior. The experimental procedure was the same as in the experiment 1 except for the colors of the wall and the floor in the test box. The colors of the sidewalls, back wall, and floor were determined independently from 5 colors used in the experiment 1. Therefore, the number of combination of the interior color of the test box was 125: 5 (colors of the floor) x 5 (colors of the side walls) x 5 (colors of the back wall). Also we set 3 lighting conditions as in the experiment 1, producing 375 conditions in total. These were allocated to 25 sessions at random, and one subject performed 5 sessions of the 25 sessions. Five subjects participated in the experiment 2, and all had normal color vision. Three of them also took part in the experiment 1 and two of them were naive.

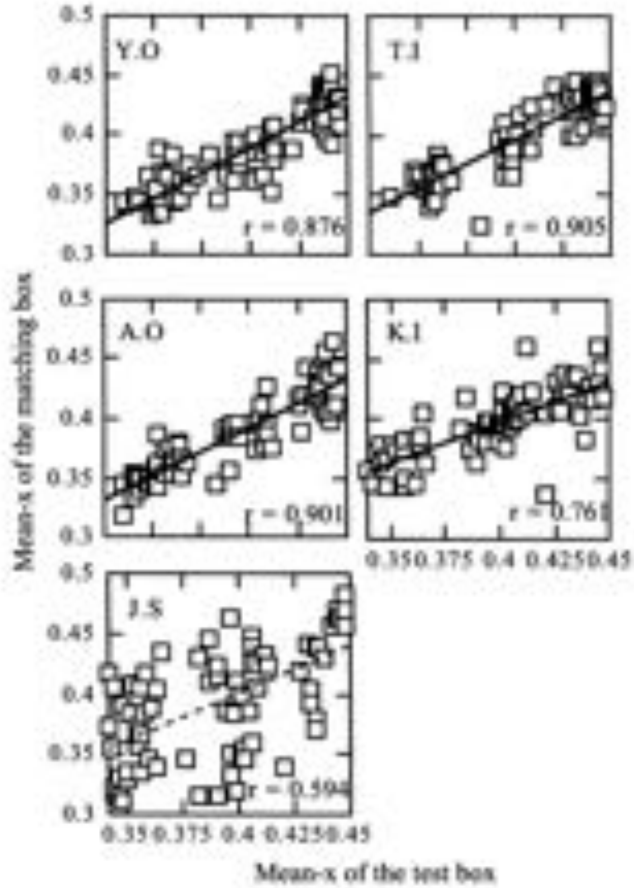


Fig. 4 The results of each of the five subjects in the experiment 2. Mean-x of the test box are plotted against that of the matching box.

3.2 Results and Discussion

In the experiment 2, color of the incident light on each of the surfaces in the test box was slightly different because we selected different colors to each of the inner surfaces, which produced different mutual reflections. Thus we prepared an index called *Mean-x* and expressed overall color of the light filled in a room using this index. The mean-x is defined as follows:

$$Mean - x = \frac{\Sigma Y_i a_i x_i}{\Sigma Y_i a_i}$$

Where Y_i refers to calculated tristimulus value Y of each incident light on each surface, a_i is the ratio of the area that each surfaces occupied in the visual field, and x_i is the calculated x-coordinate of each incident light on each of the surfaces.

Fig. 4 shows the results of each of the five subjects in the experiment 2. Mean-x of the test box are plotted against that of the matching box. We clearly see from Fig. 4 that the subject's adjustment of the color in the matching box closely correlate with the mean-x in the test box for all subjects except subject J. S. These results indicate that most of the subjects perceived the color of the sum of the direct and mutual reflection components of light as the light source color in the test box. We do not have definite evidence why subject J. S gave different results and what determined his judgments on the color of the light source. It remains as a matter to be examined further.

4. CONCLUSION

In conclusion, it was shown in the experiment 1 that subjects perceived the color of the light source in a colored room as shifting to that of the interior. The results of the experiment 2 indicated that most subjects interpreted the color of the sum of the direct and indirect components as the light source color, indicating that we perceive the lighting component produced by the mutual reflection as belonging to the original light source. Moreover the results obtained here suggest that we can predict recognized color of lighting in a room using physical variables about spectral power distribution of the light source, spectral reflectance of the interior, and configuration of the room.

REFERENCES

1) E. H. Land and J. J. McCann: "Lightness and retinex theory", *J. Opt. Soc. Am (A)*, **61**, 1-11, 1971.
2) Naohiro TODA, Taiichiro ISHIDA: "Assessment of Visual Harmony of a Room: Effect of Colors of Lighting and the Interior", *AIC Midterm Meeting in Seoul, Proc.*, 247-250, 2000
3) Yuko MIZOKAMI, Mitsuo IKEDA and Hiroyuki SHINODA: "Color Property of Recognized Visual Space of Illumination Controlled by Interior Color as the Initial Visual Information", *Optical Review*, 7, 358-363, 2000.
4) Monica Billger: "Color Combination Effects in Experimental Rooms", *Color Res. Appl.*, **24**, 230-242, 1999.
5) *IES LIGHTING HANDBOOK 1984 Reference Volume*, chap. 9, Illuminating Engineering Society of North America, 1984

Correspondence : hm.toda@archi.kyoto-u.ac.jp, ishida@archi.kyoto-u.ac.jp ; phone/Fax +81-75-753-4766 ; Kyoto Univ. Architecture & Environ. Design; Yoshida-Honmachi, Sakyo-Ku, Kyoto 606-8501 JAPAN

"Luminos 3" – a new tool to explore colour and light in 3D

Leonhard Oberascher*, Öko-PSY, 2000

ABSTRACT

Colour in architecture is not a simple perceptual entity, but is perceived relatively to space and time, material and form, light and surface, as well as movement, action and characteristics of the user. The actual colour image is a constant flux of changing and overlapping scenes, which are the result of the compound effects of various factors. According to our experience in simulating light and colour at the Department of Spatial Simulation at the Vienna University of Technology we may conclude that this complex interplay can not be studied adequately other than by means of full-scale modelling[1,2]. 1998 we developed a full-scale model of an interactive colour space. 1999 Melanie Yonge set up a similar model in New Zealand, which we used for workshops. 2000 we built "Luminos 3" – The Colour Light Labyrinth: a mobile and interactive installation offering a unique opportunity to develop and explore, teach and research colour design concepts in the context of space, movement and time. "Luminos 3" is a step further to bridge the gap between theory and practical application, imagination and reality. This presentation reports our experiences with it and discusses its potential for exploring and assessing colour and light in 3D.

1. INTRODUCTION

In her article in the catalogue for the exhibition on "Virtual Color", the curator Shashi Caan[3] refers to an observation which has for years been one of my major concerns, and which was an important motivation in pursuing the phenomenon of colour on the basis of a complex concept such as "Luminos 3": "Considering the visual significance and dominance of color it is always rather surprising how little substantial research and exploration of the different phenomena of color has been conducted, particularly where it concerns the third dimension." In the course of my theoretical, practical and educational study of the use of colour in architecture, I have had the opportunity of questioning architects and students on their primary interests regarding this topic. The information they volunteered (the complex effect of light, color and material on perception of and movement within a space; examination of ecopsychological hypotheses; shaping of our environment by "soft" rather than architectural measures...) indicate clearly the advisability, indeed the necessity of appropriate 1:1 3D research.
In one of my workshops at the Department of Spatial Simulation at the Vienna University of Technology[4], in 1998, I sought an answer to these concerns by developing, with the help of the students, a full-scale model of an interactive colour space.

2. "LUMINOS 3" – CONSTRUCTION OF THE "COLOUR-LIGHT LABYRINTH"

This is a variable installation set up to enable the experimental exploration of the various combined effects of material, light and colour in the context of space and time. The variable arrangement of the spatial components causes the user/visitor to take an active part in shaping his immediate surroundings. Our aim was also to deduce, from the countless statically and dynamically feasible spatial situations, general statements for an optimised person-environment compatibility. The basic construction consists of 16 cells, the walls of which are formed by 40 swivel-frames of aluminium and wood measuring 150 x 225 cm. The total enclosed volume is about 600 x 600 x 350 cm. Any number of swivel-doors may be positioned as required, and for the surfaces any colours and materials may be used (textiles, net, acrylic glass, panels 0.2 - 1 mm thick). Also available are 7 translucent panels which may be variably regulated by BUS-connected technology (Luxmate Lightning Management System by Zumtobl).

3. IMPORTANT RELEVANT RESEARCH OF COLLEGUES

One example of an approach I would like to continue with my "Luminos 3" concept is that of Lois Swirnoff[5]. An influential teacher and model for many of us, she learned much from her long study of the natural complexity of the phenomenon of colour: "Complexity and richness in the environment is a consequence of the interplay of color, light, and shadow. While conceptually a distinction is made between form and color, there is no such distinction in nature. The visible universe is colored; color forms, defines, and re-forms the environment. Primary definitions, the blueness of sky, green of grass, include

9th Congress of the International Colour Association, Proceedings
of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

the chromatic sensation within the spatial context. The integration of color in the built environment, however, remains at present more often a possibility or aspiration rather than an achievement." For her educational work in colour design, she deduces from this two kinds of methodological conclusions: on the one hand, she carries out empirical experiments with 3D colour models and examines colour (correspondingly as "dimensional colour") with regard to the interaction with and influence on the perception of attributes such as estimates of size, shape, distance, placement or locality, extent of boundary (cf. loc. cit.). On the other hand, she points to nature itself as an inexhaustible source of significant coloration (for instance, of organisms in their ecological context), and regrets that "[h]umans have hardly begun to observe, much less be influenced by, natural models" (ibid.). Findings from this kind of observation can be introduced into architecture, perhaps in the form of ecological (natural or nature-simulating) surface structure (cf. my own writings on "visual ecology"[6,7]), which take into account the interaction of (sun)light and microstructure. Essentially, Lois Swirnoff considers "form, color and light as inseparable", and colour as "a constituent of form", so that "color can be considered a dimension" (v. Timothy B. McDonald's[8] report on her book *Dimensional Color*, 1989) of architectural or, more generally, spatial design. "Luminos 3" can be understood partly as a conceptual and practical continuation of this theoretical approach.

4. THE CONCEPTUAL AND PRACTICAL SPECIFICITY OF "LUMINOS 3"

In contrast to Lois Swirnoff's approach, however, "Luminos 3" – which goes beyond the diverse and complex manipulation and corresponding studies of visual environmental features such as light, shade, colour, texture, angle of vision, reflection, etc. – includes the independent movement and activity (swivelling panels, etc.) of the observer, as well as aspects such as length of time spent (and possible effects of adaptation) in this multidimensionality, in order to do justice to the total colour appearance (v. Oberascher[1] about John Hutchings, Paul Green-Armitage and José Caivano). Corresponding to such a complex simulation of the visual environment are also diverse possibilities of collecting data on the reactions of the observer. We refer here to Craik's[9] *Environmental Assessment* – "a general conceptual and methodological framework for describing and predicting how attributes of places relate to a wide range of cognitive, affective, and behavioural responses". The realisation of the concept as a Light Labyrinth (e.g. with Melanie Yonge in New Zealand) "revealed that the true colour of a panel was continually altered by the colour of the light, the intensity of the light and the reflections remitted by its surrounding environment. Thus colour proved to be a virtual property, a complex and dynamic element of design communicated by simple and often inadequate semantics"[10]. This goes to show how indispensable this kind of laboratory is for innovative, progressive research in design, since the perceptual (e.g. documentation of changes of the room-layout and of behaviours by means of mounted time-lapse cameras), cognitive (e.g. data from cognitive maps), emotional (e.g. evaluation of spatial combinations by means of assigning different uses) and behavioural (e.g. establishing the movement of the visitor/observer within the installation by non-reactive hodological processes) qualities of this 1:1 simulation cannot be replaced by any scale model or digitally achieved virtual reality.

5. THE 3 POSSIBLE USES OF "LUMINOS 3"

Our mobile, modular laboratory can be used for three main purposes:

- as a field of experiment for research into practical questions of the visual effect of colour/light/material/surface/texture/form/space;
- as an educational method of training purposes
- as an installation for artistic (ideological) purposes

My own particular concern in using "Luminos 3" is its enormous potential for the development of new methods of research into creative and especially environmental design. Various architectural projects (Chirurgie-West/Salzburg Hospital Complex, Fondachhof, Krischanitz building) have already afforded me concrete experience in the use of "Luminos 3"

6. CONCLUSION

Thanks to the brilliant organisation by Grete Smedal and her colleagues in Bergen in the spring of 2000, we were able to hold a seminar on "Research and Education in the field of Form and Colour"[11]. The aim of this was:

- to produce a differentiated picture of educational and research programmes in an international perspective;
- to identify areas in which there is little or only casual knowledge;
- to define new research and development projects for further work and exploration;
- to establish a dedicated network for the regular and ongoing exchange of ideas and experiences.

My own main interest was to develop tools that will allow us to observe, investigate and analyse different (and new) possibilities of how colour and light, material, surface and form can influence each other (perceptually) in the context of space and time; to observe and describe the appearance of colour and light caused by size and orientation of spatial elements, movement of spatial elements and of the observer, distance, angle and duration of observation, changes of light/illumination (intensity, spectral composition, angle, duration), and finally to systematise these observations and look for general explanations/rules. "Luminos 3" is my contribution – with the help of my students, my wife Fatumata, Melanie Yonge, Markus Schlegel, and the Caparol Design Studio – to achieving this aim.

ACKNOWLEDGEMENTS

We wish to express our thanks for their generous support to the following companies: SURVEY, Gesellschaft für Markt- und Produktanalysen mbH, Peter H. Meyer (D-33615 Bielefeld). CAPAROL, Farben Lacke Bautenschutz GmbH & Co Vertriebs KG (D-64372 Ober-Ramstadt, ZUMTOBEL STAFF GmbH, Lichtsysteme (A-6850 Dornbirn).

REFERENCES

1. L. Oberascher, "Environmental Colour Design - Simulating Real-world Complexity", *Colour Report, Colour and Psychology F 50*, Lars Sivik (Ed.), pp. 49-55, Scandinavian Colour Institute AB, Göteborg, 1997.
2. L. Oberascher, "Simulating Real-World Complexity", *Color in Architecture. Design Methods for Buildings, Interiors, and Urban Spaces*, H. Linton (Ed.), pp. 192-212, McGraw-Hill, New York, 1999.
3. S. Caan, "Why virtual color", *Virtual Color – Light, Hue & Form integrated*, pp. 5-6, N. Y. School of Interior Design, N. Y., 1997.
4. http://info.tuwien.ac.at/raumsim/LVA-Katalog.html#cfg
5. L. Swirnoff, "Dimensional color", *Virtual Color – Light, Hue & Form integrated*, pp. 13-14, N. Y. School of Interior Design, 1997.
6. L. Oberascher, "Adventurous furniture design through visual-ecological surface design", *In Print*, Interprint, Arnsberg, 1997.
7. L. Oberascher, "An ecological approach in environmental colour design: The work of Paul Meyer-Speer", *Colour in environmental design. Proceedings of the AIC Symposium 1988*, W. Spillmann (Ed.), Winterthur Polytechnic/Switzerland, Winterthur, 1988.
8. T.B. McDonald, "Landmark Research in Relating Color and Form", *Architecture*, pp. 105-109, July 1989.
9. K.H. Craik & N.R. Feimer, "Environmental Assessment", *Handbook of Environmental Psychology*, D. Stokols & I. Altman (Ed.), pp. 891-918, J. Wiley & Sons, New York, 1989.
10. M. Yonge, "The Light Labyrinth exhibition…at Auckland's Fisher Gallery…", *Urbis*, p. 84, Summer 1999.
11. *Research and Education in the field of Form And Colour*, Centre of Form and Colour, Bergen, 1999.

*Correspondence: leoncolor@salzburg.co.at; phone +43 662 628458; fax +43 662 628458-50; ÖKO-PSY, http://www.grappa-design-approach.com; Kaltnergasse 8, A 5020 Salzburg, Austria

Gender, Colour and the Domestic Sphere in Western Australia 1890-1914

Priya Metcalfe, School of Architecture, Construction and Planning, Curtin University of Technology

ABSTRACT

When Australia was first colonised by immigrants from Britain in May 1829 they brought with them the social and cultural conditioning that was their heritage in the Northern Hemisphere. This included entrenched attitudes about what was deemed to be appropriate behaviour, which depended on age, class, wealth, marital status and gender.

In post Industrial Revolution England there was an inherent conflict between the capitalist industrialised world of manufacture, and the domestic realm, which was perceived to be a moral and spiritual refuge from work. A solution to this dichotomy was to separate the two, with the industrialised world seen as the male domain and the domestic sphere seen as the female realm. Within the walls of the home, though, spaces were also allocated a gender depending on their function, and this was reinforced through the use of applied colour to the domestic interior.

1. HISTORY AND CONTEXT

Arguably, formalised or permanent architecture in Australia did not exist until settlement by emigrants from Britain, although Aboriginal tribes had occupied the land for some 40,000 years. Nomadic by nature, their accommodation was transient, leaving little or no trace of its existence when its occupants moved on.

Australia was colonised by the British early in the 19th century when Captain Fremantle arrived in the *H.M.S Challenger* of the Indian Squadron and formally took possession of the whole of the west coast of New Holland. Four weeks later on the 2nd of June an official party, led by Lieutenant-Governor Captain James Stirling arrived on board *The Parmelia*. On June the 18th 1829 His Majesty's settlement in Western Australia was officially proclaimed.[1]

The early settlers of Perth were not well prepared for the rigours of a rural life in a climate significantly different from one they were used to – most were urban dwelling Britons with little or no farming expertise who believed that the key to independence and a comfortable lifestyle was the ownership of land.[2] Nathanial Ogle's *The Colony of Western Australia: A Manual for Emigrants* was pitched directly at people he described as '…the younger branches of the higher classes, and…the middle orders, who, under existing circumstances, are unable to find employment adequate to their numbers, education and habits.'[3] The prospect of ownership of freehold land was a persuasive incentive for many, and far outweighed any anticipated difficulties in establishing and maintaining a reasonable lifestyle – indeed, hard work and initiative were seen as tools for social mobility and self-improvement.[4]

Texts such as Ogle's painted a deceptively rosy picture of the Western Australian climate as 'equal, if not superior, to any on the habitable globe', responsible for the robust good health of the residents. 'Asthma, bronchial affections, tendency to consumption, and all the insidious pulmonary diseases, seem to vanish as by an enchanter's wand…'[5]

Early domestic housing replicated the British Georgian architecture, hastily modified with the addition of a verandah to stave off the summer heat and known as Georgian Survival style.

After initial use of timber, hessian and wattle and daub by settlers, building regulations proscribed the use of flammable materials and more permanent houses were generally constructed of limestone or brick with timber floors, doors, windows and panelling, and roofed with terracotta tiles or corrugated iron. Some workers' cottages were timber-framed with weatherboard walls.

Figure 1: 'Georgian Survival Style' from Apperley & Irving, *Identifying Australian Architecture*

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

After initial slow growth, there were two events that boosted Western Australia's population and economy. After initial resistance and vigorous debate, Western Australia joined the other states and allowed for the transportation of over 10,000 convicts to the State between 1850 and 1868, providing a source of labour for public works. In 1890, gold was discovered by prospectors in the mid-west and a mining boom followed that coincided with an economic downturn in the eastern states. As a result, there was a huge influx of people from other states, many of whom were not typical single male travelling prospectors, but were wage earners with families to support.[6]

2. THE FEDERATION HOME

The period this paper is focussed on falls between 1890 and 1914, the outbreak of the First World War. This timeframe and its buildings are frequently defined as the 'Federation Period' by architectural historians because of the federation of all Australian States in 1901, and stylistically it embraced Queen Anne Revival, Italianate and California bungalow, amid rigorous debate about the development of a truly Australian style.

For the most part though, houses were designed to demonstrate the occupants' adherence to the social mores of middle and upper class Britain and the post Industrial Revolution ideology of family and *home*, where family was the cornerstone of a secure and spiritual existence. There existed an inherent conflict between the industrialised world of manufacture, seen as harsh, competitive and driven by the desire for material gain, and the domestic realm, the refuge from this working life. The solution to the dichotomy was to separate the two: the capitalist world of industry was seen as male dominated territory and the home was the moral Christian haven to which he returned for respite in the embrace of his family.

Figure 2: 185 Stirling Street Perth c1895 from I. Kelly, *The Development of Housing in Perth*

Maintaining that haven and ensuring social, as opposed to material, gain was considered a female role, with women's natural desire to nest-build. Thus, it appears, each had their own sphere. The Ruskinian ideal suggested that men and women were inherently different, and suited to specific, but symbiotic roles:

> ...each completes the other, and is completed by the other: they are in nothing alike, and the happiness and perfection of both depends on each asking and receiving from the other what the other only can give...The man's power is active, progressive, defensive. He is eminently the doer, the creator, the discoverer, the defender. His intellect is for speculation and invention; his energy for adventure, for war and for conquest...but the woman's power is for rule, not for battle - and her intellect is not for invention or creation, but for sweet ordering, arrangement and decision...the man, in his rough work in open world, must encounter all peril and trial...the true nature of the home is [as] the place of Peace...and wherever a true wife comes, this home is always around her.[7]

3. ARCHITECTURE AND COLOUR

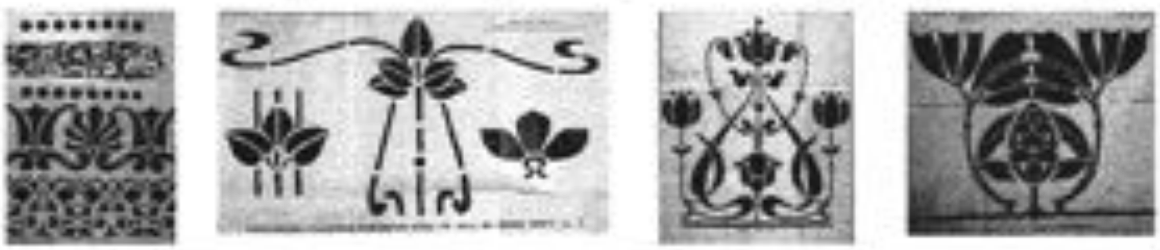
The design of middle and upper class houses reflected a British lifestyle, with a drawing room, a parlour and a formal dining room. There was an emphasis on maintaining proper standards of behaviour with the architecture, furniture and decoration - in the form of applied colour - used as tools to help perpetuate them.

As with the architecture, paint pigments were imported: colours were not the result of an evolutionary process of response to the local conditions, but were also a reflection of the ideologies of the immigrants who attempted to maintain links with the Mother Country. Evidence of the kinds of colours are found in paint charts with hand-painted samples and in requisition forms for government institutions such as the Fremantle Prison. However, the latter example is deceptive in that the British Standards 381 and 381C that controlled the naming of hues such as Brunswick Green and Venetian Red was not introduced until 1934, well after the orders were placed.

In domestic architecture, colour provided visual cues about structure and function. Applied externally to timber verandah posts, barges, balustrading and decoration the convention generally was to use two hues, one for structural elements and one for decorative ones. In some cases the hue used to identify structural elements was the darker one with a pale cream, for example, used to highlight decoration. Sometimes the convention was reversed. The pragmatics of pigments played a part in the selection of colours – the fierce Western Australian sun meant that pigments that broke down after prolonged exposure to UV, such as red and blue, were avoided. The verandah was a relatively recent phenomenon without the history of tradition attached to it that internal rooms such as a parlour or dining room had, but it was the source of some concern about slipping social standards because it 'induces the habit of sitting outside a great deal during the evenings…the dislike of being overlooked, which is so marked in England, is outweighed by the considerations of comfort and enjoyment.'[4]

For the decoration of the interior, journals such as the Australasian Decorator and Painter and The Colorist, produced by the Sherwin Williams Company and available in Australia provided colour plates illustrating suggested schemes appropriate to particular rooms, especially those visible to guests. These schemes promoted the use of finishes other than the simple broadwall application; most commonly they suggested the division of walls into three discrete sections: a dado from the skirting board to approximately a metre from the floor; a frieze of either 10 ½ or 21 inches (28 or 56 centimetres) and the body of the wall in between. A moulded plaster chair rail sometimes served to delineate between the dado and the main wall above; at other times a painted pin line, stencil or change of hue performed the same function. A picture rail sat at the junction of wall and frieze with a moulded cornice above. Along with suggested schemes the Australasian Decorator and Painter provided full-size stencil patterns that could be copied onto manila card ready for use.

With federation came a surge of nationalistic pride, and the appearance of stencil patterns that were derived from native flowers and animals; a move away from the traditional stencils that included Art Nouveau and Art Deco styles. As well as stencils, other application techniques were employed - marbling and graining of fireplace surrounds so that cheaper materials could emulate more expensive ones, the application of gold leaf, and hand-painted panels, for example.



Figures 3-6: Examples of stencil patterns from the *Australasian Decorator and Painter*, State Library of NSW.

Wallpaper does not appear to have been especially popular, partly because of the expense of importing bulky rolls of paper, and partly because of prevailing attitudes towards cleanliness and hygiene at a time when wallpapers could not be wiped because to do so would damage the pattern, until the later advent of so-called Sanitary wallpapers that had the pattern impregnated into the paper.

Books dispensing advice on appropriate colours and patterns depending on the function of a room abounded, Mrs Beeton being the most well-known example. The front – public – rooms had the most money and effort expended on them, with high skirting boards, deep cornices, ceiling roses and fireplace surrounds. In rooms beyond, the private realm of bedroom, bathroom and kitchen, even in large houses owned by wealthy families, simplicity prevailed, with simple, or no, cornices and skirtings. Bedrooms were effectively no more than dressing rooms, particularly in summer when children slept on verandahs to take advantage of the cooler night air, and in kitchens and bathrooms, issues of cleanliness, health and hygiene took priority over appearance.

4. GENDERED SPACE

Given a reasonably prescriptive set of parameters to work within, the rooms of a house could be furnished and decorated in such a way that a visitor could describe the function of a room within based on the visual cues of colour and decoration. They could also identify the gender of a space in terms of whether it was said to be the ladies' or the gentlemen's realm.

The concept of colour as a way of gendering space is linked to French philosopher Pierre Bourdieu's notion of the *habitus*: by determining the gender of a room, one implies a way of *being* in that room, unspoken but implicit. Occupants know the rules of the game and their place in it, depending on whether they are a resident or a guest, master or servant, adult or child and, of course, male or female. Applied colour in the form of interior decoration becomes a powerful tool in reinforcing expected behaviour in the home.

The concept of a 'masculine' or 'feminine' space was one of the driving forces in interior decoration:

> The character always to be aimed at in a Drawing Room is especial cheerfulness, refinement of elegance, and what is called lightness as opposed to massiveness. Decoration and furniture ought therefore to be comparatively delicate; in short, the rule in everything is…to be entirely *ladylike*.[9]

The drawing room is testament to the owner's good taste and given that it is the room that visitors see, it is the room by which the occupants are judged in terms of their social standing and aspirations. As its form represented the British ideals of gentility and domesticity, its decoration was derived from notions about the appropriateness of finishes and colours that were associated with the use of a space and its qualities and , of course, its gender. The drawing room is the female domain and the kinds of colours recommended are:

> …cream or soft duck-egg shell blue or French grey for ceilings, the walls fawn colour or a richer French grey or a deeper grey blue, approaching peacock shade…I think the judicious application of gilding in this room very advantageous.[10]

The dining room, by contrast, is the man's domain, decorated accordingly. He sits at the head of the table, symbolically and physically. The colours recommended for the dining room and the billiard room, if there is one, are those deemed to be masculine – deep reds, browns and greens.

By ascribing a gender to a space challenges the idea that there were two realms - the working world/male and the domestic world/female so that each has their own sphere. It suggests instead that the domestic interior is divided into masculine and feminine spaces in roughly equal shares: some spaces are his and some are hers.

However, the Ruskinian ideal of home is as:

> …the place of peace; the shelter, not only from all injury, but from all terror, doubt and division. In so far as it is not this, it is not home; so far as the anxieties of the outer life penetrate into it, and the…hostile society of the outer world is allowed…to cross the threshold, it ceases to be home…[11]

In other words, home was a retreat from the harshness of the post Industrial Revolution workplace, the competitive male-dominated realm. The man was returning from his sphere to a place of calm and moral virtue. For the woman, however, the home was not a place of respite from her duties, but the locus of it. The idealised image of a genteel life with servants overseen by the lady of the house was, to a large degree, a fallacy. Servants were difficult to secure and difficult to keep; domestic chores were hot, back-breaking, physical work.

Home was his haven, but home was her trap.[12]

REFERENCES

[1] R. & J. Oldham, *Western Heritage*, Lamb Publications, p2, 1961.
[2] I. Kelly, *The development of housing in Perth*, thesis (unpub) University of Western Australia, p13, 1992
[3] N. Ogle, *The Colony of Western Australia: A Manual for Emigrants*, John Ferguson, Sydney, b, facsim 1977
[4] W. Houghton, *The Victorian Frame of Mind*, Yale University Press, New Haven, pp4-8, 1974
[5] Ogle, *op cit*, pp26-27
[6] Kelly, op cit, p58
[7] J. Ruskin, *Sesame and Lilies: The Two Paths and the King of the Golden River*, The Home Library Book Co., London, p59, 1865
[8] R. Hamilton, "Domestic Architecture in Western Australia", *Journal of the Royal Institute of British Architects*, p21, 1906, facsim
[9] R. Kerr, *The Gentleman's House, or How to Plan English Residences* (1871) Johnson Reprint Company, New York, p107, facsim 1972
[10] A.Wells, 'Decorator' *Building Engineering and Mining Journal*, p186, 1892
[11] Ruskin, *op cit*, p59
[12] C.C. Marcus, *Home as Haven, Home as Trap: Explorations in the Experience of Dwelling* in P.Quinn & R. Baron (eds) *The Spirit of Home*, Washington DC 1986.

Color in present culture of European architecture

Verena M. Schindler*, Institute of Art History, University of Zurich, Switzerland

ABSTRACT

The influential architect Le Corbusier (1887-1965) was also involved in the adventure of contemporary painting, and color occupied half of his day, during twenty years, as he revealed in a study entitled „Architectural Polychromy"(1) written in the early thirties and recently published in 1997. In the present, contemporary architects in Central Europe are dealing with color in quite a different and exceptional way: most of them engage the artist to collaborate with them in their architectural projects. If painting is concerned with the interaction of color in the two-dimensional plane, architecture is deeply dependent on light and space, and deals entirely with the three-dimensional environment and its human perception. In the 1990s, the way architects and artists employed color in architecture was so striking that color offered a key to larger discussions and opened up an interesting aspect of architectural practice. It must be remembered that recent housing projects, such as the housing estate Pilotengasse in Vienna, Gigon & Guyer's Broelberg in Kilchberg (with Harald F. Müller), next to Zurich, and their Sport Center in Davos (with Adrian Schiess), Jean Nouvel's Cultural and Congress Center in Lucerne, or Sauerbruch & Hutton's Photonic Center and their GSW office building in Berlin have all been contributing to free color from its unconscious and dormant role. These works all impart qualities to color in architecture that were hitherto reserved to other materials and fields: they define the aspects of the interaction of visual and physical space, of materialization of volumes, and of the expression of wealth and luxury.

Keywords: color in architecture, collaboration of the architect with the artist, color theory, Central Europe, Le Corbusier, Jean Nouvel, Gigon & Guyer, Sauerbruch & Hutton

INTRODUCTION

The very method of Jean Nouvel's working philosophy is the conversation, which opens up onto often unpredictable things. The French architect has a specific term in order to determine someone who fulfil the very specific role of a dynamic conversationalist in his life: a „sparring partner". It is a person who has a different cultural point of view from his own. It is about talking and putting forward hypotheses, opinions, judgements. In a certain way, he argues, he is a vampire (2). He vampirises the theatrical, literary, critical, philosophic culture of the person he chooses upon these very particular criteria. Often, he says, the brainstorming sessions and meetings with his sparring partner take place around a table, with a good bottle of wine, in restaurants or late at night. A whole serie of actions, incidents, of reactions, confrontations impart complementary liveliness and creativeness to the architectural process.

In European culture, in the last decadesof the twentieth century, the architect has often chosen the artist to cultivate a dynamic dialogue and to collaborate with in architectural projects.

1. COLOR IN CONTEXT

In Jean Nouvel's Cultural and Congress Center in Lucerne, Switzerland, it is the artist Alain Bony who was in charge of the painting and the color concept of the building. The site, next to the railway station, at the border of the lake, offers a splendid panoramic scenery. The eye wanders over the old town of Lucerne with the world famous covered wooden bridge to the mountains of the Alps. In contrast, if we look at the center from across the lake, the building itself appears flat and dark. No modulation, no details seem to shape the surfaces of the facades. The contours of the huge cooper roof, which covers a whole range of different

---

* Correspondence: vmschindler@yahoo.com; phone 41 1 391 62 74; fax 41 1 391 62 74; Hochstrasse 13, CH-8702 Zollikon, Switzerland.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

concert and conference halls, restaurants and the art museum, can hardly be distinguished from the mountains in the background. Even the function of the building is difficult to identify due to the numerous ships anchored in the bay in front of it.

Standing closer to the building, however, we discover that the facades of the building are fragmented in various differently shaped volumes, and the windows cut up openings through the walls in different sizes. The diversity of form is here clearly unified by color. The southern and northern surfaces of the volume which contains the big concert hall, is structured by two different hues of color. A discreet dark red, which is dominantly shaping the front to the lake, is contrasting with a dark serene blue underlining the horizontally shaped cubes through which the corridors run in the interior. The blue is echoing the surroundings of the building at this corner of the site. It is the color of nature, of the lake, the sky and the mountains a short distance away. As with Le Corbusier, the senses are, at the same time, excited by the red plane background and calmed by the blue horizontal volumes. Depending on the light, the red facade appears in full light to be a vivid color and the blue acts as a contrast to it.

Approaching the building, we discover that the main facade to the West has a completely different character. The basement is a translucent glass front, which is completely determined by a sequence of entrance doors. The city skyline is mirrored in the glass surface. The coloration with a pale greenish turquoise of the upper part of the facade, which is structured irregularly by different openings, is but the opaque counterpart of the glass. It gives this side an unexpected lightness and ambiguity. Depending on the light, the greenish hue vanishes into a harmonious composition of light and shadow.

The colored surfaces and the materials, glass and metall, form a restricted color palette. However, it gives the building a distinctive character. The most important element of the building, the roof, which is immensely overlapping and smooth, is reflecting the colors of the water. The grey hue of the metallic surface changes with light into a blue sky. Water and sky becomes interchangeable. Standing on the open terrace, on the top of the building, the exceptional roof also reflects the city of Lucerne. And in autumn, the colorful trees change completely the character of the surface, by consequence, of the building. The reflections on the huge surface of the roof become a vibrating and changing spectacle, a sort of natural performance or scenery. The surface acts as a screen reflecting colored light and the movements of the world upside-down. We get into notions of depth, of reflection, of variations of architecture with light, with time, with seasons, with color.

Standing in the hall, the interior of the building is completely dominated by the panoramic view of the exterior. The blue light of the lake, of the sky and the distant mountains, penetrates the perforated interior spaces and highly contrasts with the exciting red and the reddish wood of the cherry tree which both dominate the interior spaces. We walk through intensely red colored corridors and enter a completely white concert hall. The contrast couldn't be bigger. The balconies and the walls of the concert hall are all white. It can be changed with lightening from a neutral white into warmer or cooler hues or colored light. The original color scheme, which was supposed to design the walls in dark blue and the balconies in red was forcefully rejected by the musicians. The blue color would have been too dark to be confronted with while playing in the music hall. However, red and blue are not completely banished from the concert hall. The ceiling is dark blue in reminiscence of the sky, and the resonance chambers, when open, spread a bright red color into the hall. As with Jean Nouvel, the white music hall symbolizes virginity, and the red chambers the hell.

The color experience of the exterior is discreet, related to the natural surroundings. The huge smooth roof is continuously performing the changes intrinsically related to weather, seasons and time conditions. The color experience of the interior is symbolic and intense, with strong contrasts. The concept of color was developed for a specific building and a specific place, multiple sensations within sensations. In Jean Nouvel's words: „The architect is an amplifier, he is someone who is going to capture emotions or sensations." If designing architecture is a conceptual act, it is the atmosphere of mystery and magic that gives the architecture its importance.

2. CAMOUFLAGE

Looking back at Le Corbusier's last building, located in Zurich, the attitude towards color in the early 1960s, is restricted to the basic colors. The Maison de l'homme is a private house and an exhibition hall at the same time. The colors are bright and vivid.

The panels are red, yellow and green, and black and white. There is no blue. Stepping on to the terrace, on the top of the building, we find the surface of the roof painted in a pale green color which melts with the greenery of the surrounding trees. Le Corbusier called this way of using color „camouflage". The contrasts are suspended, the building immerse in the color of the background.

3. COLORED PANELS

Experiments, which deal with the perception of colored panels in open and closed spaces, is the main subject of the Swiss artist Adrian Schiess. He is known by his „Flat Works". He is working with large, frequently monochrome panels, whose surfaces serve to manifest color in different ways. These panels are generally presented as floor installations. They are surfaces of pure painting that transcend the dimension of the picture. The limits explode by the means of reflection and color contamination. The exterior emerges in the interior, and the carefully located panels in the exterior are cast by the changing reflections of the surroundings.

The color concept of the Sports Center in Davos is a result of the collaboration of the artist with the architect. The Swiss architects Annette Gigon and Mike Guyer built a new Sport complex in concrete. The exterior of the building is covered twofold, by color panels and by an outer layer made of smooth pine lathing. It would be wrong to say, that Adrian Schiess did a three-dimensional painting set into the architectural frame. The color areas were pre-determined by function, although their distribution and disposition did not necessarily reflect the logic of the building structure. On the one hand the architects designed an architecture with structural clarity. On the other hand, the artist undermined the clarity of the structure by his use of color. Sometimes, for instance, the doors are enlarged with a color frame or a color panel. Sometimes the color of the window frames spread on the wall or even on the ceiling. Color expand differently than architectural space do. Colored surfaces reach limits other than architectural elements do.

The color palette is remarkably unconventional and refreshing. For the exterior, three colors were selected: a light orange, a complementary blue, and a luminous yellow. (3) Contrary to the first impression, color in the exterior and the interior is placed following quite a strict order. It means that the palette is restricted to nine different colors which are lemon yellow, light blue, orange, raspberry red, indigo, light green, white, turquoise and apricot. This choise is exceptional. We are now not dealing with the elementary combination of yellow, red and blue which was systematic in modern architecture of the 1930s. The color palette in itself is challenging the architecture. This color programme generates sensations. The free treatment of color is emotional, adding an irrational dimension to the architecture, in particular in the interior, where the ceilings are defined by geometric compositions in green and red, or, green and yellow. We encounter unexpected hues and unusual combinations of colors while walking through the building. This range of color is a specific one to a unique building and a single place.

European architecture, here and elsewhere, is very much concerned with flat surfaces, reflections and superimposed pictures.

4. TRANSFERS

A vivid and intense red in the interior space, sometimes we find in art museums, as it exists in an amazing exhibition room in the Dutch city of Groningen. Bright colors we find in private housing as well. The architects Louisa Hutton and Matthias Sauerbruch, Berlin, did a conversion of a building of the 1960s in London, completed in 1999. Each floor of the house was given its own distinctive atmosphere through color. On the ground floor an inside-door swimming-pool is separated only by a sliding glass wall, beyond which lies a garden. (5) Interior and exterior spaces mingle and unify. There is an ambiguity remaining between the physical reality of the built enclosure and the perception of its space. The dialogue between the intense color composition and the garden creates an experience of a dense combination of nature and architecture. We really don't expect this colored space to be in London, but somewhere in Mexico. The inside-door swimming pool in a colored space is indeed one of the main characteristics of the House Francisco Gilardi in Mexico-City, built in 1978 by Luis Barragán. The colorful minimalism of the Mexican architect had indeed an impact on young architects, in Europe and elsewhere. The interior of the house in London is defined by vivid colors. Most of the time, the use of bright colors is reserved to popular or indigenous cultures. A shift of paradigm, launched by postmodernism, freed bright colors in Europe of the 1990s from their restricted connotations and associations. The strongly-hued spaces in London offer a private, sensual and even luxurious world which strongly contrast to the European color culture.

5. ANIMATION

In Sauerbruch & Hutton's Berlin office tower, on the other hand, color is present and absent because of its interaction with the movement of the red shutters. Color relates therefore intrinsically to daylight, to natural conditions. If the sun is shining people will close the red shutters and the slightly curved building facade convert into an immense panel composed by a large amount of different hues of red. The facade appears to be a vibrating and animated surface. Not color contrast is the formula but familiarity. In the urban context, the building itself accomplishes a barometric spectacle - it is a graceful and courageous manifest of human activities by means of color.

CONCLUSION

In the late 1970s a new attitude towards color in architecture began to emerge. If in modern architecture of the early twentieth century, the new look was liberated from seduction, cleaned from historical styles, and liberated from past representational meaning, in the present day, architects, in collaboration with the artist, try to bring back all these qualities into architecture, with color. To summarize: In the 1990s, a shift of paradigm occurred. Bright, vivid colors began to occupy the surfaces of the buildings, in the exterior and the interior. Luminous colors, arranged with distinctive hues however, was not the expression of a primitive culture anymore, but the expression of the will to pleasure, freedom, wealth and luxury.

REFERENCES

1) Arthur Rüegg (Ed.), Le Corbusier - Polychromie architecturale, Birkhauser, Basel/Berlin/Boston, 1997.

2) Jean Nouvel Luzern. Concert Hall. Edition Architekturgalerie Luzern and Birkhauser, Basel/Berlin/Boston, 1998.

3) Annette Gigon, Mike Guyer 1989-2000. The Variegated Minimal. El Croquis 102, Madrid 2000.

4) Sauerbruch Hutton Architects, Brochure, Berlin 2001.

"Colour Words"
In Chromaticurbanscape

Michel Cler * Colour Consultant -Architect

ABSTRACT

In Urban Spaces and in Architectures information appear days and nights, using as medium the various colour appearances and texture aspects support. Meaning, identity, evocation, harmony... will depend from "colour words" organisation.

JUST FOR RECALLING

For a presentation on Chromatic approach, more in the specific field of Urban Planning and Architecture.
it is useful to remember that colour seems to be an illusion.

> Without light, no colour appearance..
> Without a glance on an enlightened support, this support has no colour appearance..
> More pragmatic, Colour appearances and Texture aspects of a support will look differently with light modifications during all day, or through seasons, and in accordance with geographical contexts or sites.
> Colour appearance by itself has no meaning , it may be hopeful or hopeless, it depends..

We are lucky to have the opportunity to be able to see, and then to look.
Together with touch, taste, audition, smell, vision gives us most of the information someone may need to survive in all sorts of "contexts". This information will help for "protection or (and) seduction".
On the other hand, if no message, no meaning, no evocation is involved in the colour aspect, we will not notice this "coloured appearance".
This colour message is not enough it has to be reinforced by other senses, for providing better information.
Individual or groups have to be trained to perceive, identify, and locate the message. Few individuals may be qualified to have a natural capacity for perceiving.
In fact more close to reality, what message?, who decides?, what target ?, when and where? What will be the colour words and their organisation?

Through this recall it is easy to understand why we should very prudent facing the overall technical aspect input in colour appearance production and use. For the reason, it does not provide more additional feeling and meaning aspects.
This presentation is based on our practice and sites studies: no final answer, no conclusion, it goes on.

URBAN SPACES

Frequently you may hear:

" ... just put some colour on the facades to make them look happy ..."
"... you are an artist so what is your idea to "coloriser" the town"...
"... For heritage reasons you have to use those 3 colours for frames and those 2 lime stones for walls, it is tradition...."
" ...we have tourists coming in, they want to see at traditional colours..." *
" ...from tastes & colours..."
" ... I do not know and understand colours, so I use greys (a well-known architect)

Or you may see some advertising as:

" think white..." a woman face in black and white print.
" life in grey is sad in front of life in colour go to supermarket A...

Or some symposium, or book:

"Colour in the city" - "Coloured city" - "The colours of A..." studied and presented as internal decoration theme

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

The word "Colour" is used as an "abstract" word with less and less "energy", meaning and sensual aspect.
Some one explains that Cézanne was painting apples, then he tried to introduce sphere, circles, squares, on the other side, and Cubists were using sphere, squares circles to design an apple...

All individuals perceive colour appearances much more easily than we read the graphic design used for words, (hieroglyph, cuneiform, Greek alphabet, Cyrillic, Asian ideogram...).
Some individuals or groups, for specific reasons, in some geographical areas, are trained by necessity to be more acute to some colour appearances family ranges.
For symbolic, cultural, social, religious aspects some colour appearance may have one meaning in a country and a different one in another.
Colour appearances associations are often different from one country to another e.g. traditional architecture colour chart, which is generally a clever mix of geographical, material, construction aspect mixed with economic, social and sometimes religious references

Our eyes and brains when we are just born are trained at the first beginning by the natural sunlight of the geographical area, then in school with pencil box which all have basic Red, Green, Blue, Yellow, White, Black, with slight variation and other colours which are different between major groups of countries.
(We may notice that computer basic colour range is a new systematic worldwide support with its own potentiality and limits to reveal colour appearances.)
Then with time being, individual knowledge in colour words, and how to use them, to translate messages will increase in relationship with the individual surroundings and the input of his other senses and general learning.
So quality, number, association of colour words will depend of each one.
To be an "artist" is important, however, this is not the complete translator of the colour words in Urban spaces
It is more useful for each individual to find way to feel in coherency and harmony with contexts and groups by using colour languages which may help him or the group to identify and to express them.
In fact, colour appearance is in relation-ship with one or two or more colour and texture aspects, it is the beginning of a colour sentence.

As for words, "colour words" belongs to various groups or systems
- Standard of colour for Chemical, Road, ... Security is "ruling" for protection, survival aspects.
- Tendency chart for Fashion, that is a rule for commercial purpose
- Computer colour range, that will be the new brained pencil or brush, abstract, efficient, easy to communicate promptly, perhaps a new prosthesis.
- "Good taste" or "bad taste" colour range refers simply to social impressions

---

How long does a colour word survive? Is it a perennial or a temporary aspect?

As words, "colour words" have a birthday, then their own life and rhythm, they disappear with their physical support or the lost of meaning or evocation.

Are colour word systems expounding? Very serious question out of the subject but included by default.

Even if some colour words or associations are moving in aspect, changing of location, they may have a certain variation of meaning.

"MATERIALS"OF URBAN SPACES

In fact to try to introduce some parts of answer and also to practise colour appearances, Urban spaces are the best living support.

The natural lights, the architecture, plants, water, landscapes in background, surroundings, will be basic supports for the moods, character, and identity of the town.
Other various rhythms have also to be included, and mixed in a global view.
Cars, trucks, buses, cycles short rhythm and various speed...
Building middle or long term renewal, (Heritage, rebuilding, new estate, "façadisme")

Pedestrian as inhabitants, workers, visitors, tourists
Fashion and clothes - Advertising - Street furniture- Lighting - Communication...

The quality, the energy, the diversity and contrast, the strength of colour words seems in Western culture to decrease toward a visual cultural consensus based on colour desaturation to white, transparency," limitude", abstraction, reification : no texture, no colour, no smell, virtual, clone.

In our practise we noticed that for "economical reasons", "efficiency", technical and industrial facts (20x80 rule), colour ranges from companies were moving under various rules which generally try to summarise or simplify the range and the colour associations.

This lost of complexity means less colour words certainly a reduced vocabulary, and simplified grammatical theme and other meaning, evocation.
Some other aspects have to be just recalled, it is another long subject which also help to reduce the necessary complexity of colour words and their meaning, including a strong modification or lost of identity: the building material market - the architectural input - the "exotic" and import aspects.

COLOUR APPEARANCES & TEXTURE WORDS:

Light is the most important material to reveal our environment.
Building Materials are basic supports for Colour Words: Plants, Water, Sky, Minerals & "Chemical".
Each of them provides texture (touch aspect), its own visual colour appearance, some of them suggests either a short term (temporary material) or long term (perennial) material.
Those materials may be opaque, transparent, translucide, rough-smooth, warm-cold, flexible-hard, hand made-industrialised... They appear differently under lights.
Paint appears as the basic non expensive colour word for messages to be used freely by everyone.
Paint includes expression, identification, temporary aspects, adaptation, and complexity.
For identification and communication on colour aspects, a visual vocabulary based on location in colour volume will be needed.
This neutral support will name colour being subject to controversy and difficult to understand for their references. That is just an internal code to each company. From some years, we are using the NCS system as an international tool for visual identification of colour appearances.

Slide Presentation of "Lights -Textures-Colour appearances & Meaning"

This short slides presentation of colour words materials in urban spaces and architecture is a point of view based on various studies.
How to provide those different approach of specific Colour culture (imbrication of various systems as memory, geography, social, material...) as a non closed subject, but a dynamic which need to be followed seriously by individuals and groups?
To whom? Decision-makers - Urban planners Architects - Inhabitants - Industrialised companies?
The answer needs to be adapted.

In fact more important are the inhabitants of the site, they need to have the largest range of appearances for their own information concerning the moods of their environment, its history, even it is a short one. When inhabitants recognise some colour aspects or their associations as part of the environment, this will involve in the process, as a complementary advice to decision-makers or even Urban planners and Architects...

CHROMATIC STUDIES

Identification and denomination of the various colour words and moods in various natural or urban surroundings, are based on Chromatic Studies "Lights - Textures - Colour appearances"
The Chromatic Study is based on:
1 Analysis/Diagnostic of the all components of the space to study-
2 Concept of the ranges which is a dynamic process -

3 Location on Urban maps -
4 Follow up on middle - long term.

The Chromatic Chart is a suggestion an open proposal support, not a rule.

The study area may be an addition of different geographical sites - a town - an architectural model built through various sites - some streets or plaza.... - Street furniture...

A Chromatic study needs to be taken into account at the first beginning of any decision on a site (from Impact study, till site works) with Landscapers, Architects, Inhabitants, Decision makers, Urban planners.

Slides Presentation of Chromatic Charts

Industrialised materials:

Perhaps after the sites chromatic moods studies, the most important target, building materials seems to be another tool to inform on textures and colours. That will be in the hands of the company and marketing group. Nevertheless one limit to modify or create a new complementary colour range is the economical 20x80, then all technical, security rules, production aspects...

Slides Presentation of Industrialised materials

Colour appearances moods are different in cities of the same "cultural" country, providing their own identities.

From a country to another mood variations may be consistent, but essential for the well being of inhabitants.

If some Industrialised colour ranges are imported in another country, would it not be interesting to suggest some adaptation, some new colour words being created in accordance with meaning, evocation of the country colour cultures.

Some "Tourist towns", e.g. translate their local Colour mood to be in accordance with what tourists have in mind concerning their city, that is one theme for the "facadism system".

In fact in our countries, we are all trained from birth, to perceive and view certain Colour appearances their associations, and have an impact on how we perceive, visually, the other groups.

Colour appearances meanings, always depends on who prepared and sent it. Is it a short, middle or long term message with a target, and on what basis?

In Urban spaces the diversity of networks providing day & night colour appearances information are mixed so it seems useful to keep this dynamic aspect. The link with memory, the "import" of other cultural aspects Colour words, the complexity, to avoid lost of meaning and poetical suggestion in certain areas (or perhaps the moving of meaning), needs to be reinforced.

TEMPORARY CONCLUSION

How to use Colour language not just as security function or artistic event? How to provide people some information on its meaning? How to have any discussion and work with council, planners, architects, landscapers, associations, contractors and introduce it in Urban maps and reports as Chromatictownscape study?

How to propose, to suggest to reveal complete the colour vocabulary for individual, or a group of inhabitants? How to suggest its further developments, (import, modified meanings...)?

Even if some try to create universal colour grids to put in order all those "colour words" and associations, for ambiguous reasons, those questions have no receipt,

Through a long-term practice in various situations and locations, some directions, some answers adapted to each project may only be suggested.

Colour words in the City means some various energies, with their rhythm, their diversity, that means to be open-minded for transmission and reception of messages.

To be followed...

REFERENCES

* amfcler@easynet.fr ; phone 33 1 45 80 91 15 ; facs 33 1 45 81 38 66; Atelier F& M. Cler, 64 Rue Vergniaud 75013 Paris FRANCE

Color Constellations in the Seattle Cityscape

Galen Minah*, College of Arch and Urban Planning, Univ. of Wa., Seattle, Wa.

ABSTRACT

Characteristics of color constellations observed in the Seattle cityscape were as follows: 1. The higher the chroma of hues within the color constellation the more distinct it became. These colors advanced and often appeared to float in a plane independent of the objects of which they were a part. Chroma was the most important characteristic in these constellations. 2. Hue variations within constellations were two steps on the NCS Index (i.e. Y70R to Y90R), and nuance variations were 10% or less (i.e.S1080 to S2070). 3. Color elements in a constellation were usually seen as fragments of buildings, structures, and objects in which their three-dimensional shapes were not as obvious. 4. Size and shape were similar in most color constellations observed. 5. Color constellations in chroma below c=50 were observed where distance, light, and/or atmospheric conditions obscured edges and the visual field appeared two-dimensional. This was consistent with Swirnoff's findings in model studies where color was the dominant factor in organization only to the monocular observer. 6. Color elements in a color constellation below c=50 occurred where background contrast was minimal. 7. Three or more color elements were necessary for the formation of a constellation.

Keywords: color constellation, selective emphasis, color organization, figural color.

1. INTRODUCTION

Lois Swirnoff, *Dimensional Color*, 1989, described experiments with colored cubes of different sizes positioned in an open-ended black box. When the cubes were positioned so all were equal in size as viewed from the open end of the box, with no spatial clues as to their position in the box, the most coherent grouping appeared to be by color. She referred to these as color constellations. When size, placement in space, and depth were made obvious, as in a three-dimensional field, color increased ambiguity in their grouping. Swirnoff concluded that color is a dominant factor of organization only to the monocular observer. The question of whether color constellations could be observed in an urban context where size, placement, and spatial position were fixed, and colors were real surfaces, was the point of departure for this study.

In June 2000, the Experience Music Project (EMP) by Frank Gehry was completed in Seattle. The EMP is an assemblage of six large organic shapes; each clad in a distinctive metal skin, and each having a dominant color and texture. The most striking skin is a glossy, high chroma red (S1085-Y90R) which can be seen from many viewpoints. The building has become a major figural object in the city. When observing the structure from a distance of 1000m, where a large portion of the city was part of the visual field, other reds of similar hue and chroma within this visual field formed a cluster of reds. These appeared to float in a single plane removed from their actual positions in space. This cluster consisted of red hues on parts of buildings, signs, flags, vehicles, and sometimes flowering trees. This phenomenon appeared to have characteristics of the constellations in Swirnoff's study (Figure 1).

From these observations three objectives were established for a study 1. To use the urban environment of Seattle as a reference frame and identify colors in this context which had a tendency to group and form clusters as a color constellation. 2. Measure the hue and nuance of colors in these constellations and record their variation. 3. Note the conditions and factors relevant to these observations, and record the characteristics of constellations observed.

2. RELATED RESEARCH

Much of the research related to color observation suggested that studies of this kind involve preconceptions and selectivity on the part of the observer. Floyd Allport, *Theories of Perception and the Concept of Structure*, 1955, discussed figural or configuration aspects of perception in which a part embedded in the context of a whole looked different from its appearance when it was experienced separately. In his fifth definition of six classes of perceptual phenomena, he described 'concrete object character" as a fundamental property of practically all our perceptions because it represented meaning. This meaning was not that of mere configuration or wholeness of the object, but the experience of what the object is. This implied that the

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

character of meaning of an object was related to the state of mind of the individual. In his sixth definition of the 'effect of prevailing set or state of mind' of the individual, he described the importance of selective emphasis. This effect determined what objects we are to perceive in our environment and which we are to ignore.

The importance of the prevailing set or state which accounts for individual differences, attention, motivation, and emotion is further supported by the work of Karin Anter, *What Colour is the Red House?*, 2000, who concluded that a reflective attitude was influenced by factors belonging to the field of cognition rather than perception. Studies relevant to her work apply to this study as well. Anders Hard stressed the importance of these factors in color observation and perception, and made no clear distinction between perception and cognition. Gunnar Tonnquist concluded that 'we see what we expect to see'. Mark Fairchild found in his color observations that he had seen exactly what his hypothesis made him expect. Maurice Merleau-Ponty distinguished between a reflective attitude and the unreflective 'living' perceptions. James Gibson discussed the obtruding of sensation on perception, which implied ambiguity in most situations where color was observed.

In the paintings of Abstract Expressionists, where color in dots, lines, and shapes are the primary expressive content, one can selectively identify the separate groupings and patterns of color elements. One can also assign relative spatial positions to these groupings. Some advance and are more figural, while others recede. In Jackson Pollock's, "Blue Poles: Number II", 1952, visual tension was created by numerous clusters of dots, lines and shapes, each in their own spatial layer, competing for figural status in the paintings. Urban colors often appear similarly as figural layers, although in two-dimensional fields, color can more readily be the organizing principle as Swirnoff has shown. Jasper Johns' experimented with color evocation by using stenciled color names in lithographs. In "Fragment According to What – Bent Blue", 1971, one sees yellow in the muted grays through word association with 'yellow' stenciled on the print (Figure 2).

Figure 1. Red hues in a color constellation in Seattle cityscape.

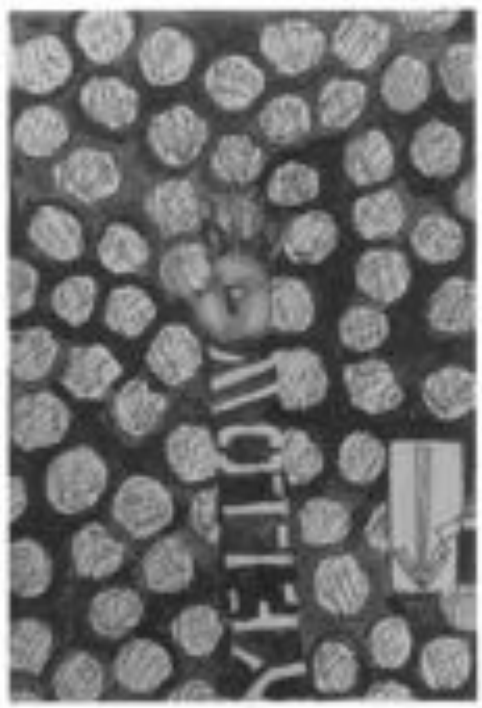


Figure 2. Author's sketch of Johns print evoking 'yellow'.

All of the illusory characteristics of color constellations could not be explained entirely by the viewer's state of mind. Simultaneous contrast did appear to play a role in these observations. In *Figural Color in the Seattle Cityscape*, Minah, 1997, it was observed that hues of high chroma relative to their background became figural in most light and atmospheric conditions. The figural status of buildings and object in an urban environment increase with and increase of (c) and by simultaneous contrast with their background appeared to advance spatially. In some abstract expressionist paintings certain combinations of color in high chroma could make the detection of color groups more difficult. Leon Polk Smith, "New

York City", 1945, used similar rectangles of high chroma red, yellow, and blue in repeating patterns over the canvas. It is difficult to see a color constellation in one hue because of interference from the other hues in the painting. This hue interference was observed in cities where high chroma is used in much of the architecture, as in Guanajuato and San Migel de Allende, Mexico.

3. METHODOLOGY

Seattle was observed from several viewpoints where large areas of the city could be seen up to a distance of 5 km. Seattle has several hills providing opportunities to view many parts of the city. Color constellations were photographed from these vantagepoints using 35-mm slide film (Kodak E100S) with a variety of lenses from 28mm to 300mm. Atmospheric and lighting conditions did affect the appearance of constellations, but were not the focus of this study. Some light conditions, however, affected how colors formed constellations. Shade, shadow, and the perception of high chroma were light factors that affected the identity of constellations. Most photography was done in clear, sunny conditions between 10am and 2pm. When constellations were identified, color elements were measured using the NCS Index. Background color was significant as contrast to the constellations, and noted as well.

5. CONCLUSIONS

From observations made in this study the following factors were characteristic of color constellations observed in the urban context of Seattle, where color elements could be seen as a grouping, sometimes independent of its three-dimensional context. These were as follows: 1. The higher the chroma of hues within the color constellation the more distinct it became. These colors advanced and often appeared to float in a plane independent of the objects of which they were a part. Chroma was the most important characteristic in these constellations. 2. Hue variations within constellations were two steps on the NCS Index (i.e. Y70R to Y90R), and nuance variations were 10% or less (i.e.S1080 to S2070). 3. Color elements in a constellation were seen as fragments of buildings, structures and objects in which its three-dimensional shape was not as obvious. 4. Size and shape were similar in most color constellations observed. 5. Color constellations in chroma below c=50 were observed where distance, light, and/or atmospheric conditions obscured edges, and the visual field appeared two-dimensional. This was consistent with Swirnoff's findings in model studies where color was the dominant factor in organization only to the monocular observer. 6. Color elements in a color constellation below c=50 occurred where background contrast was minimal. 7. Three or more color elements were necessary for the formation of a constellation.

Factors which tended to obscure the formation of color constellations within an urban context were those which accentuated the spatial characteristics of the visual field. These were: 1.Light conditions where edges became distinct and defined by shade and shadow. 2. Large variation of size and scale where a structure could dominate by its presence as a concrete three-dimensional object. 3. Hues of chroma below c=50 appeared prone to hue shifts by aerial perspectives as the distance between elements increased. 4. Infrastructure which informed spatial organization (i.e. city grid), would interfere with color groupings in a constellation. This followed Swirnoff's observation. 5. Color elements in a visual field of multiple hues in high chroma often competed with one another and obscured the identity of a color constellation in one hue. Here selective emphasis on the part of the observer was an obvious factor.

White or light-colored structures and objects, although numerous, did not appear to form constellations in the Seattle cityscape. These colors became associated with the background, and were not seen as figural. Structures in lighter hues would have distinct edges defined by shade and shadow, and were often seen clearly as three-dimensional objects. Distinct whites at a distance did become figural, but most structures were off-white and had a tendency to appear gray at a distance. Whites in the foreground were seen clearly as three-dimensional objects and did not form a constellation in these observations. Dark hues and blacks were not seen as color constellations in this study. Black figural colors are most easily seen in tall buildings against sky. When seen in the context of light backgrounds, dark objects were not numerous enough in these observations to form a constellation.

In a city, groups of buildings may be linked by color such as the predominant brick hues at the University of Washington, or the light pastel hues of San Francisco. This is color organization in an urban context, but are not constellations as defined in this study. Formal characteristics are the primary factors in their organization, not color.

The state of mind of the individual identifying color constellations in an urban context, selective emphasis, and preconceptions did influence what one saw, particularly in constellations of low chroma. However, when color elements in high chroma, (c=60, or above) were observed, simultaneous contrast did appear to be a factor in the tendency of colors to advance spatially. This phenomena did not appear entirely related to selective emphasis or preconceptions on the part of the observer, but more on the simultaneous contrast between color elements and their background. Color appearing to separate from its context in a three-dimensional field suggested a number of possibilities for future study.

6.APPLICATIONS AND FURTHER STUDY

It should be noted that aesthetics in architecture and urban design also involves preconception and selective emphasis. The rational use of color as both a conceptual and expressive tool in architectural and urban design is the prime application of these studies. Kevin Lynch, *Image of the City*, 1960, identified the elements of city image as paths, edges, districts, nodes, and landmarks. As a powerful tool in unit formation, organization and articulation we know that color can play a role in the definition of each of these elements. Color accidents in a city can provide ideas for the creative and rational use of color. While most high chroma colors are in signage, some are garishly part of architecture within the city. Finding other ways to use this color in architecture and urban design is a definite path for future study.

An architectural use of a color constellation is at Parc La Villette, on the outskirts of Paris. The architect, Bernard Tschumi, used large sculptural structures, intended to be functional objects, as points in space on a grid throughout the park. These 'follies' were each painted the same high chroma red. From an aerial viewpoint they formed a color constellation, but at eye-level the structures were too big to adequately provide the three-dimensional field intended. Smaller stuctures may have been more successful. Another example was from an University of Washington architectural thesis. Brad Kress, *T29N, R11E (a Survey)*, 2001, looked at how the U.S. Geological Survey grid of one mile squares intersected steep terrain in the Cascade Mountains. The grid is an arbitrary horizontal plane which intersects the topography at irregular elevations. At each point of intersection, Kress designed a structure which expressed the direction of the grid alignment and provided a shelter for hikers. These linear structures were painted a high chroma red and became figural against the green forest background. The result was a large 'room', defined by points of color, which gave scale and orientation to a very large natural visual field.

For further study in perception, the spatial illusion created by large areas of high chroma on buildings like the EMP, when seen from a distance, seem to contradict some of the principles of aerial perspective. The appearance of similar colors in a three-dimensional visual field which group under certain conditions and disconnect under others, suggests a closer look at color stereoscopy as well.

REFERENCES

1. F. Allport, *Theories of Perception and the Concept of Structure*, John Wily & Sons, Inc., New York, 1955.
2. K. Anter, *What Colour is the Red House?*, Royal Institute of Technology, Stockholm, 2000.
3. B. Kress, *T29N,R11E (a Survey)*, University of Washington, Seattle, 2001.
4. K. Lynch, *The Image of the City*, MIT Press, Cambridge, 1960.
5. G. Minah, "Figural Color in the Seattle Cityscape", AIC Color 97, Vol.II, pp. 883-886, 1997.
6. L. Swirnoff, *Dimensional Color*, Birkhouser, Boston, 1989.

*contact author: gminah@u.washington.edu, phone 1-206-543-4182; fax 1-206-616-4992; Department of Architecture, College of Architecture and Urban Planning, University of Washington, 208 Gould Box 355720, Seattle. Washington 98195-5720.

Increasing use of yellow colors in Kyoto

Munehira Akita * and Iwao Nara * *

ABSTRACT

Colors used for commercial signboards, displayed outdoors as well as indoors through windows, such as a store sign, an advertising sign, a sky sign, a poster, a placard, and a billboard were extensively surveyed in Kyoto City, Japan, in 1998. The survey showed that various kinds of yellow painted signs have increased rapidly and invaded a center area and suburbs of the city. Vivid yellow, what we called it the Y98 virus, is specially considered a color unpleasantly matched to the city image of Kyoto which was the capital of Japan for nearly 1000 years (794 to 1868) and is endowed with cultural and historic heritage. Discussions trying to find out what we could do to prevent the rapid spread of a big commercial display painted with vivid yellows what we called "the Y98 virus" over the city will be summarized in a main text.

Key words: Color usages in public, yellow colors, color harmony.

1. INTRODUCTION

At present Kyoto City hardly keeps a traditional artistic and cultural atomosphere with the strict enforcement of the city regulations for reserving historic sites and conserving the natural environment. The color usages harmonising with urban landscapes are requested strictly at the reserved historic areas: many regions around the foot of hills and mountains surrounding three sides of the city where many temples and shrines are located, and a few districts surviving within the city where traditional Japanese houses constitute beauty as a group.

The law enforcement works highly effective and contributes to keep many beautiful scenic landscapes in a city remaining. In addition, a lot of effort of residents play a vital role to create and build a pleasant living environment when they could have a chance to learn and understand about the importance of design and maintenance of a well−planned city. The purpose of this study is to show how a way of color usages in a city influences our impressions and images of the city, taking yellow colors in Kyoto as an example.

2. SURVEY METHOD

A color wachting survey about how much yellow colors can be seen outdoors and how many kinds of the yellow sign board along a town street was performed extensively from Spring to Summer in 1998 by a party of 10 color specialists who belonged to the Kyoto Study Group for Colors in Public Usage. Several areas were selected as being supposed to represent different features of Kyoto.

Evaluations of the yellow color displays in arterial roads were obtained on the basis of sensory impressions reported by each of the group members, and were supplemented with the colorimetric and/or visual color matching data when it was available. The outcome of the survey were collectively integrated through discussions exchanged among members of the party.

3. RESULTS

The results were reported qualitatively as an integrated summary of subjective impressions given by each member of the party, some with the supplement of quantitative measures.

9th Congress of the International Colour Association, Proceedings
of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

First of all, there were noticeably many yellow colors, almost every corner of the city, seeing at not only a sign board but also a poster, a banner, and even a building's huge wall.

Secondly, a large advertising sign with excessive use of a yellow color, e.g. 2.5Y 8/12, appeared once, then the same kind of a big yellow sign increased rapidly one after another, particularly along roads on the fringes of a newly developing city area. Soon after the yellow color what we called "the yellow virus 98" were found spreading into the central area of the city.

Thirdly, nearly all of people disliked those kinds of a vivid yellow as well as the other vivid colored commercial displays. They could easily anticipate these yellow colors caused serious damage to the harmony of landscape in Kyoto. On the other hand most people showed they liked a thing with moderate color, such as a Japanese sign−curtain (暖 簾) of moderate deep blue, one of traditional colors in Japan.

Fourth, a better design of a roadside external commercial display is another important factor to avoid or attenuate a hazard produced by the excessive use of vivid yellow. We could demonstrate with a technique of computer graphics that the reduction of total area and proportion of unpleasant yellowness as well as the change of letter size on a display is effective to make negative feeling less than before the modification.

Figure 1, positioned at the end of the manuscript, shows several photo pictures produced by a computer graphic simulation in order to demonstrate a power of design making a sign board more acceptable, and better in balance with an environment. The figure consisted of three groups of pictures: Group A, two pictures at the left upper corner, showing the effect of size changed from the original large display, violating the city rule, seen at the top to the smaller, but the legally maximum size, seen at the bottom; Group B, seven pictures arranged vertically at the right side, showing the effect of the value and the chroma changed from high (the original) to low (the revised) and Group C, three pictures at the left lower part, showing the three revised designs for a new disply proposed.

4. DISCUSSIONS

A phenomenon of prevailing yellow making the beauty of a town spoil was observed at the developing area where the city regulation was less reinforced, and new residents in the area not yet had a well organized way in order to convey their opinion to the city as a group.

Regulating outdoor advertisements, the Kyoto City Government issued a municipal code: City Ordinances Governing External Commercial Displays, which was excuted in 1956 and completely revised in 1997.
In 1994 17 temples, shrines and castles of Kyoto area cultural properties were listed in the World Heritage Site by the UNESCO World Heritage Committee. If the whole city area of Kyoto were designated as the site, it would be much better. Now it seems to be important for the city to change her principal policy to reserve the whole city area covered evenly beyond limiting to the special districts.

In addition, we need a more systematic and detailed guidelines controlling usages of outdoor colors in the city. The present city guidelines, regarding color usage, are only mention of avoiding the use of vivid colors and asking people simply not disturb the harmony with a neighbourhood, but with no further concrete statements and no obvious penalties for acts against the guidelines.

In our previous study given at the AIC 97 in Kyoto (Akita, 1997), we reported that the Japanese traditional colors such as the ju−raku(聚 楽), ben−gara(弁 柄), and shu−nuri(朱 塗 り) for a outside wall of a house were most appropriate colors matched well with the landscape of Kyoto. These three colors indicated with the Munsell notation are 1.7Y 5.3/2.9, 7.8R 4.6/8.6, and 8.0R 5.3/1.3, respectively. General speaking the Japanese traditional colors, as such shown above as an example, are essentially grayer or more saturated of character.

We understand easily how a big difference exists between a favour moderate yellow, the ju−raku, 1.7Y 5.3/2.9, of a house for living and an unfavourable vivid yellow, 2.5Y 8/12, of the big advertising sign for simply eye catching. The love of beauty "without being obvious" is very old with the Japan while advertisers are quite understandably interested in what they call "attention getting."

To the average observer it is reasonable to describe yellow, the color of sunlight, as a warm color. About color by itself, Eysench (1941) showed that the order of aesthetic preference for six common colors yielded the following: blue (the most), red, green, violet, orange, and yellow (the least). Ohmi et al.(1997) showed that vivid yellow strongly associated with emotions of joy and surprise for Japanese, Korean and American.

One important factor to be considered in connection with color impressions is the effect of a wide variety of backgrounds in ordinary daily circumstances against which colors are perceived. An unfavourable vivid yellow under one circumstance would turn to be a favoured color under other circumstances. We could say taht the same colored objects will have different emotional effects such as pleasant or unpleasant depending upon surrounding situations as backgrounds. The emotional effect of color is related to how big a gap is recognized between tha actual color perceived and the mental images to which it must confirm. The big gap will provoke the bad feeling.

While preserving our cultural heritage and trying to maintain harmony with the environments, there are also important issues for our concerns to create and develop the new modern society handling the rapid change of living ways very well.

5. CONCLUSIONS

Vivid, bright yellow color painted on an outdoor commercial display contaminates color harmony in Kyoto City which was established narrowly in balance between the old and new ways of colors usages. Both the value and the chroma controlled as low as less than 3 in the Munsell notation will be appropriate to make color hormony of a town better.

ACKNOWLEDGMENTS

We wish to express our sincere appreciation to the Kyoto Study Group for Colors in Public Usage for cooperating in the survey.

REFERENCES

1. M.Akita, "Colors in public usage: Priliminary studies in the historic city of Kyoto," Proceedings of the 8th Congress of the International Colour Association, 925−928, 1997.

2. H.J.Eysench, "A Critical and experimental study of colour preference," American Journal of Psychology, 54, 385−394, 1941.

3. G.Ohmi, S.Lee and S.Lee, "Cross cultural study of affective meanings of colors," Proceedings of the 8th Congress of the International Colour Association, 711−714, 1997.

* contact.m−akita@h8.dion.ne.jp; phone 81 75 381 7578; fax 81 75 394 5335; 26 Takazono−cho, Kawashima, Nishikyo−ku, Kyoto 615−8112, Japan; * * contact.nara@dd.iij4u.or.jp; phone 81 75 791 8578; fax 81 75 791 9127; Kyoto University of Art and Design, Uryuyama, Kitashirakawam Sakyoku, Kytoo 606−8271, Japan.

Figure 1. Original and the revised designs of a noodle restaurant sign board painted by yellow color: the Y98 virus. Group A: Two pictures at the left side, upper part; Group B: Seven pictures at the right side; and Group C: Three pictures at the left side, lower part. See the full details in the text.

Exterior colours of the traditional Northern Hungarian country houses

Karman Zs. Architect*

ABSTRACT

The main objective to be achieved in my research work is to preserve the traditional colouring of the country-houses in the Northern Hungary, at least defined - measured the colours - and in photos. The colouring traditions of the country-houses are more than hundred years old. These are based on people's impulzive colour choice.
The golden age of the vernacular ornamentation developed from the middle of the XIX.c. The places of the ornaments obviously first of all are on the streetfronts of the houses.
Whitewashing the walls developed in a lot of villages because some settlements ordained it. Some signs shows that blue painting of the walls - which was made first by blue mineral matters, later industrial paints- precaded or was in the same age as whitewashing.
Still, we can say, that the tricom harmony of red, yellow and blue colours and the complementer haqrmony of the yellow and blue colours are generally received on the original peasant-houses of the area. The lightness of these colours are average, but the saturation was intensive which was liked in the Middle Ages. You can find such houses nearly in every village. There are everywhere in the territory whitewashed houses with coloured pedestal,too.

Keywords: streetfronts , tricom harmony of red, yellow and blue colours , intensive saturation, whitewashing, blue painting

1. INTRODUCTION

The main objective to be achieved in my research work is to preserve the traditional colouring of the country-houses in the Northern Hungary, at least defined - measured the colours - and in photos. The colouring tradition of the country-houses are more than hundred years old. It is based on people's impulzive colour choice.
Traditional colouring is an elaborated art which created colour harmony.There are less and less original country-houses because of being pulled down or transformed. The colouring of the houses is simplified at renewal.The tradition of colouring is coming to an end. We have to save it because it is a part of Hungary' national values.
The most decorative part of the peasant-houses is generally the street facade .
The walls of the houses were made from mud, adobe or burned brick and these were painted after plaster-work. The houses were plastered over with mire earlier. The facades with plaster decorations from mortal have appeared in the 19th century, rarely in the 18th century.These facades[1] were made by skilled bricklayers. It's why the architectural details of the houses generally shows the result of the expert knowledge of the workmen and rarely imitation of the manor-house near. The roof of the houses was reed generally.

2. METHODS

I maked a stady on the colours of Hungarian country-houses. I looked in sources, asked people,who know this part of the country, if they remember where coloured country houses are.
I walked all around more than forty villages and towns in four countys: Pest, Nograd, Szabolcs-Szatmar, and Borsod-Abauj-Zemplen county. I took photos and sometimes slides of the outside look of the houses, which saved their old shapes and colours.
I measured the colours of the various parts of the buildings / pedestal, wall, ornament, door, window etc / , mainly with comparative method, using the Coloroid Colour Atlas from Nemcsics . I asked people, living inside and in neighbourhood if the house was the same colour in old times,what kind of colouring materials did they use, are there any natural coloured mineral surrounding.Sorry the owners coudn't answer generally.
Coloroid Colour System has been developed specifically for environment colour design - lead by Antal Nemcsics in Hungary at the Technical University Budapest. In this colour system[3] the colour space is continuous, the members of the colour space are aesthetically the same distance from each other.
Coloroid is in exact correlation with the CIE XYZ system. In Coloroid colours are treated as being mixed from tristimuli of boundary colour, black and white.

9th Congress of the International Colour Association, Proceedings
of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

The Coloroid Colour System[4] accomodates the colours inside an orthogonal circular cylinder so that hue varies /A/ along the cylinder shell, saturation /T/ along the radius and lightness /V/ along the axis. The spectrum colours and purples, which are the boundary colours of Coloroid accomodates along a line on the cylinder shell. Among boundary colours of the Coloroid System 48 approximately aesthetically equidistant colours with special codes have been adopted as Coloroid basic colours.Yellow colours are marked with the following"A" numbers - marking the hue varies - 10-16, oranges 20-26, reds 30-35, purple-violets 40-46, blues 50-56, coldgreens 60-66, warmgreens 70-76.

3. DECORATIONS

Possibilities to express relations to colours have always been delimited by known, available pigments, making them the decisive, objective conditions of colour preference. Originally, coloured minerals and plant juices have been used as pigments for decorating one's surroundings. Semantic messages have also been associated with colours. The longing for self-expression or to rejoice in colours urged man to extend his palette, and to add ever more colours and shades both to his environment and vocabulary.

It is typical of the whole folk[7] art , but mainly of the architecture that it has remaind only a few material and written relics from the time before the XVIII.c. We can't suppose for lack of material relics that there weren't carved, graved and painted decorations on the houses of lower nobles, the members of middle classes and the well-to-do peasants,since this kind of decorationn appeared on peasant-furnitures in the XVI.c. There was a more peaceful period and relative wealth in Hungary in the XVIII. c. which was necessary for the spread of decorations. At first only the privileged stratums and the free peasants of the privileged areas have built such houses where decorations were, these rated as luxury.

There are relics already from the first part of the XIX.c. :plank ridges, stone buildings. Until the middle of the XIX.c.when the emancipation of serfs in 1848 - we can hardly mention the decoration of the peasant-houses except the wood-carving.It had economical and mainly social causes. A well-to-do serf coudn't build an ornamental house because of the unwritten law.

The golden age of the vernacular ornamentation developed from the middle of the XIX.c. till 1900.This is that period in the Hungarian vernacular architecture when the most beautiful, - considered to be the traditional - houses have built.

The places of the ornaments obviously first of all are on the streetfronts of the houses,less the court-side where the most important decoration is the veranda what is general already at this time.It's prevailing structural forms supersede the applied ornaments.The veranda appeared on the streetfront of the houses on some territories.There isn't generally any ornament at the back side and at the side looking into the neighbouring tenement.

The colouring of the wooden constructions , doors , windows , coloums of the veranda, plank ridges were common, specially in the XIX.c. Red, blue and white colours dominated similarly to the works of the coloured folk art.

Plastering of the walls with clayey mud was used for to protect the houses, but at the same time it was an aesthetical claim,too. The plastered face was painted with clayey mud, which sometimes containd sand,too.People intended to use yellowish, bluish, whitish soil.Painting became rarer from about 1850, when the whitewashing spread widely painting was used only on the back side of the houses around 1900. The painted houses are very nice where the openings were stressed with frame whitewashing.

Whitewashing the walls isn't relatively an old custom. Some settlements ordained it.

Some signs shows that blue painting of the walls-which was made first by blue mineral matters, later industrial paints- precaded or was in the same age as the whitewashing.The blue walls were already rather rare in the XX. c. in Hungary, but there are yet in Hungary and we can find more blue houses in the neighbouring Slovakia and Romania at the present time.The whitewashed walls became generalin on some areas of Hungary in the XIX. c.

Painting the pedestal of the walls into darker colours became general for practical reasons.Darkbrown or grey earth to be found in the neighbourhood or soot was mixed and improvement of the delivery possibilities in consequence of the industrial often into the lime.

There are only a little datas about the ornamental paintings of the facades, as nobody has dealed with this topic.Such kind of findings came up accidentally .

The colouring of the peasant-houses haven't been constant.Long ago when there was only a choice of harmonizing earth pigments of a particular region the changing of the colours depended on the proportion of the components. In our days possibilities of coloration have become almost unlimited. The used colour still depends on the current pigment-choice and fashion.

4. COLOUR USING NOWADAYS

It's typical of North-Hungary that there aren't or if there are only very few peasant-houses which can be called original old ones.
I'm showing you the most characteristic types of the houses founded until this time during my search. These houses are about 100 years old. I'm defining the colours in Coloroid Colour System and looking for the connection between used colours.
We can say in general, that the tricom harmony of red, yellow and blue colours is generally received on the original peasant-houses of the area. According to the searches of colour preferences these are the most popular colours today. The lightness of these colours are average, but the saturation was intensive which was liked in the Middle Ages. You can find such houses nearly in every village. The complementer harmony of the yellow and blue colours is general, too. It is a matter of course - on the basis of the earlier-mentioned - that there are everywhere in the territory whitewashed houses with coloured pedestal. This convention has grown up -as I wrote - because some local order.

5. RESULT

5.1 Nograd county

In the North Mountain of medium height, near the Karancs hill, in Nograd county the most prefferred colours are the colours between yellow and orange (from A-12 to A-16). It is tipical, that there are several types of yellows on facades together. (A-12 staw yellow, A-13 light cadmium yellow, mimosa yellow etc, A-14 cement yellow,Chinese yellow, A-15 orange, Naples yellow, A-16 Indian yellow, oxide yellow) and it is complited with it's complementer colour the blue. (A-51 mauve blue, Babylonian blue, A-52 whitish cobalt blue, A-53 gentian, A-54 Medici blue) what is the pedestal or at least the fence.
In this territory you can see often the general trichrome harmony of yellow (A-12, A-13) the red (from A-25 to A-30) and the blue colours.

5.2 Pest county

In flat country in the lowland, in Pest county the most prefered collective colours are the harmony the blue (A-51 Babylonian blue, mauve blue) and its complementer colour the yellow (A-12 staw yellow, A-13 light cadmium yellow) , the other coommon harmony group is the yellow (A-14 orpiment, Chinese yellow) the red (A-26 rusty brown) and the blue (A-52 whitish cobalt blue) colours in trichrome harmony.

5.3 Szabolcs-Szatmar county

On the East edge of Hungary, near to the river Tisza, in regio Bereg , in Szabolcs-Szatmar county duality is typical . On one side the usage of the red, yellow and blue colours which are typical of the whole searched territory, appears here in such colours which saturation and lightness is less: rose-red colours, unsaturated yellow colours and light blue colours.Within this the most popular colours are the rose-red and the fallow orange colours. The dull shades were general in the Renaissance.You can find often more from these warm colours on the same facade. The white, shell-white (A 11) or yellow (A 12,13) ornament is common on the rose-red houses. On the other side we can see a forcefull lightness contrast on some houses.It was typical for the Middle age. There are darkblue, darkbrown nearly black ornament on the light walls (white, yellow)
The yellow walls are popular yet.Generally there is its complementer colour the blue: the window-freame , the ornament on the wall, the pedestal or the fence. There are saturated monochrome red (A 32 crimson) houses, too.

5.4 Borsod-Abauj-Zemplen county

In the northeast corner of Hungary, in the Hegyköz, in the Zemplen mountain, and in Hegyalja, in Borsod-Abaúj-Zemplén county the colours most of the remained houses are typical for the all territory. That is or the white or when the wall is red and yellow, the pedestal is blue. The difference from the territory's average is that

the yellow colours - used here - are lighter (A10 pale yellow, A11 pastel yellow etc.) and the red colours are more brown (A25 Memphis red, A33 copper brown etc.). The blue colours has generally little saturation and big lightness. It's common that the pedestal isn't blue but that red which is already on the facade. There are also monocrome red houses and with blue pedestal in this area.
There are nearly as many saturated, warm yellow coloured houses here (A13 Mimosa yellow, A14 cement yellow) as red. There are monochrome yellow houses, too, but rather with blue pedestal,sometimes with red pedestal, but there was black ,too. The yellow houses are often decorated with white or pastel yellow colours, there are red decorations in less number (e.g. A25 brick red).
We can find houses with big lightness contrast.Generally the colour of the wall is yellow (A13 chicken yellow, A10 yellowish white) and it is decorated with dark colours (darkbrowns, A43 aubergine) or black. This contrast can be find in opposite rate on a darkbrown house(A22 peanut) with warm broken white (A12) decoration. In this area are blue houses,too. It shows that the very old traditions remained yet.

6. FINAL WORDS

The characteristic[1] of the Hungarian popular monuments are the few and simple decoration. The decorations are markable and existant. The monumentarism is apsent from these houses. The space , the building materials, the constructs,the colours and the shape of each house are in a harmony and these form the tipical, independent style and character of the houses.These are the characters which give high art level.
The historical styles reach the vernacular architect always with lateness.The elements of the historical styles in the village-houses appear in unusual proportion, without logic.It can be because in the villages didn't work the best experts.They built irregular architectural elements.Later the home-made repairing, repeated paintings continued the changing of the elements.This was the way how the popular architecture, these special aesthetic value was born, with its origian shapes, relations and colours.
The number of the traditional coloured and designed country houses is growing less in Hungary. The painted plaster-works on the gable of the remained houses were changed into grey slate in many case. The facades of the houses had more colours formerly. Nowadays they are simplified at the renovation stage. The materials of the roofs are changed for burned tile mostly.There are a lot of cases when the original two little windows are exchanged for a bigger one.The colouring material of the houses is often sandstone powder .
The colours of the peasant-houses haven't been defined so far. This topic hasn't been investigated . I hope, my research work will be the beginning of these general work. Though , I could define only the colours which are on the houses now, these colours remained from old tradition and are worth to preserve them. The traditional colouring of the houses is a part of the national wealth.

ACKNOWLEDGEMENTS

This work was supported by the Research Support Scheme of the Open Society Support Foundation, grant No.: 331/1998.

REFERENCES

1. J.Barabás-N.Gilyén , *Vezérfonal népi építészetünk kutatásához/ A short handbook of Folk Architecture* , Müszaki , Budapest, 1979
2. J.Barabás-N.Gilyén , *A magyar népi építészet/ Rural Architecture in Hungary* , Müszaki , Budapest, 1987
3. A.Nemcsics, *Színdinamika - színes környezettervezés elmélete/ Colour-Dinamics - Environmental ColourDesign* , Akadémia, Budapest, 1990
4. A.Nemcsics, *Colour-Dinamics - Environmental ColourDesign* , Akadémia, Budapest, 1993

* Correspondence: Karman Zsuzsa, 1125 Budapest, Galgoczy út 50/b, karman5@freemail.hu, fax 00-36-1- 4830085

MEASUREMENT OF AREA EFFECT BY THE COLOR PANEL SIZE

JIN-SOOK LEE, CHANG-SOON KIM, OH-YON YIM, DEOK-HYUNG LEE

This study is aimed at making index with series of experiments in order to adjust the change occurring by an area effect in architectural color design. The basic experiment was performed to find the change of color regularly in the condition of fixing regular area and viewpoint.

1. Introduction

In planning colors of the interior and exterior materials of the architecture, it is common to select appropriate color suited for the image by the color samples and sample book. But we frequently see the finished color of the architecture is brighter and showier than the color presented in a small sample book. This kind of unexpected change of a color can often be occurred after completing the architecture. No matter how skillful the architect is, it is not possible to predict exactly the change of colors when the architecture is finished. By experience, color designers know that the area effect happens because of the color shift.

2. Outline of Experiment

Each quantity of color change according to the change of observing distance in the condition of fixing area(about 870mm × 580mm) and view point(width 10°) was measured in this study after previous study.[1]

2.1 Content of Experiment and Method

1) In case of same area

Observing window was adjusted that 10° from 3.3m observing distance and 3° high from 1m observing distance in order to suggest regular area(about 870 X 580mm) to the examine.

2) In case of same view point

The quantity of color change was measured with change 1m(area 264 X 176mm) and 3.3m(area 580 X 870mm) in the condition of fixing regular viewpoint (width10°)<Table. 1>

Table 1. Viewpoint and area by observing distance

Distance	Viewpoint(H)	Area (W X H)
1 m	10°	264 X 176 mm
	30°	870 X 580 mm
3.3 m	10°	870 X 580 mm

(light shading) : In case of same viewpoint

(dark shading) : In case of same area

We let subjects estimate the amount of color variation seeing the color panel equipped vertically through the observing window after 10 minute's adaptation to N5 under a xenon lamp in windowless space. Subjects recorded a color of the comparative color chart using N5 mask(1.8cm X1.2cm) which is the most similar to the color of the color panel seen through this observing window. If they couldn't find the exact color in the comparative color chart, they are allowed to respond interpolation. To prevent subjects' adaptation to the experiment, we observed time-limit less than 5 minutes. After finishing one experiment about the color panel, we made subjects adapted to N5, neutral color and performed an experiment about another color. We repeated the experiment three times each subject.

[1]. Jin-Sook Lee, A QUANTUTATUVE STUDY OF THE AREA EFFECT OF COLORS, AIC COLOR 2000, SEOUL, KOREA, pp. 236-238

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

2.2. Experiments

1) Variables and objects

The objects were the color panel. We chose the colors that included in the middle value and middle chroma of five basic colors- 5R, 5Y, 5G, 5B, and 5P on Munsell System. In the case of 5Y, we selected the color involved in a high value and middle chroma considering the value of primary color (5Y 8/12). We manufactured the color panel using the computer(MAC G3/400), printer(EPSON Stylus Photo EX) and color printing papers. The size of the color panel is 90cm X 60cm that can be seen from 1m's distance with 30˚ view.

2) Light sources

Two xenon lamps[2], which have the same daylight and spectral distribution, were employed as the light sources. We observed the color panel and comparative color chart in the 45˚ position from the central point. Illuminance in the experiment was 500lux.

3) Observing window

The researcher made three observing windows with an area of about 2˚ , 10˚ , and 30˚ view for the demonstration and one window for adaptation. And the observing windows can be made to change a size. For reduction of an exterior influence in estimating colors and color adaptation, we manufactured the observing windows using N5, neutral color<Fig. 1>.

4) The comparative color chart

The comparative color chart was produced with the same way as the color panel. We put the object colors in the central part of the comparative color chart and made colors changed. The comparative color chart that was 2.4cm X 1.8cm size was manufactured by connecting 64 pieces <Fig. 2>.

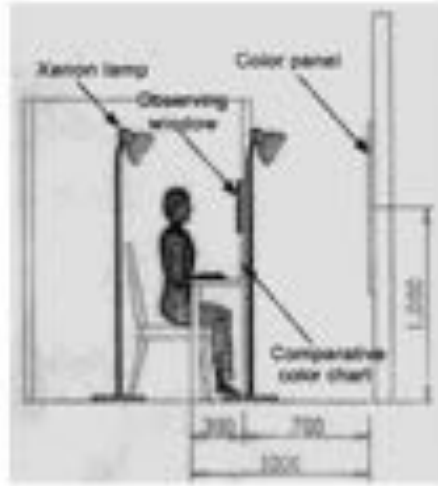


Fig. 1 The View of experiment

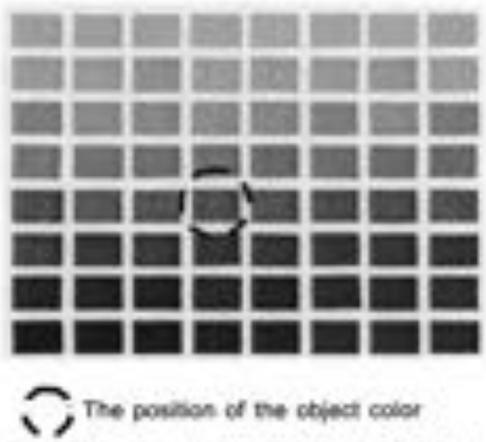


Fig. 2 The comparative color chart (5G 5/6)

2.3. Subjects

We selected nine subjects (4 males and 5 females) who have experienced the delicate experiment of a color variation after 100-Hue test[3] and color-blindness test to examine whether they are dyschromatopsia.

3. The results of experiment and analysis

Average value of data for each evaluating objective color was estimated and analyzed with statistic analysis program. But, in case of examinee respond interpolation middle value 0.25 was adopted because the comparative color chart was made as 0.5 brightness and 0.5 chroma level and reliability zone expressed 95% scope.

---

[2] Xenon lamps are very similar light to daylight in spectral distribution. (Color temperature: 5500K, color rendering index: 98 Ra)

[3] 100 Hue test was developed to grade and train people who examines a delicate color test. It selects 100 colors at the same interval in the color space of CIE 1964, value 6. And it can test an ability to identify colors as the unit of one level of CIE color difference

3.1 In case of same area

1) The change of value

In case of value, it expressed the tendency of raise with observing distance from 1m to 3.3m among all evaluating objective colors. Especially, the change of value of 5R 5/6, 5G 5/6, and 5P 5/6 were higher than others but 5Y 7/6, 5B 5/6 expressed small raising with law quantity of change<Fig. 3>

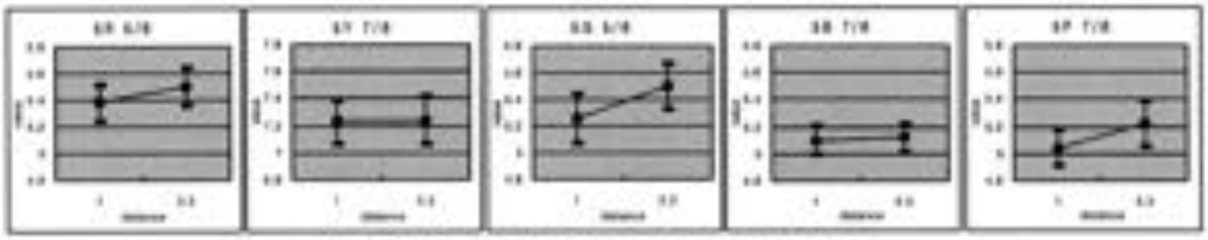


Fig. 3 The value variation in case of same area

2) The change of chroma

The change of chroma has difference for each color but has the tendency of raise of chroma as a whole. The quantity of change of chroma in 5R 5/6, 5B 5/6 was high but it was pretty law in 5G 5/6, 5P 5/6, 5Y 7/6<Fig. 4>

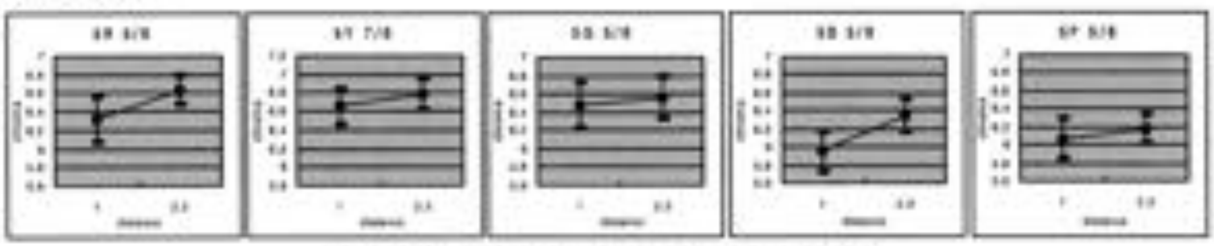


Fig. 4 The chroma change in case of same area

3.2 In case of same viewpoint

1) The change of value

The value expressed the tendency of raise with distance of observing distance from 1m to 3.3m in the condition of regular 10° viewpoint. Especially, the change of value was high in 5R 5/6, 5G 5/6, 5P 5/6 but in case of 5B 5/6, it the brightness was raised with small scale and the quantity of change was law<Fig. 5>.

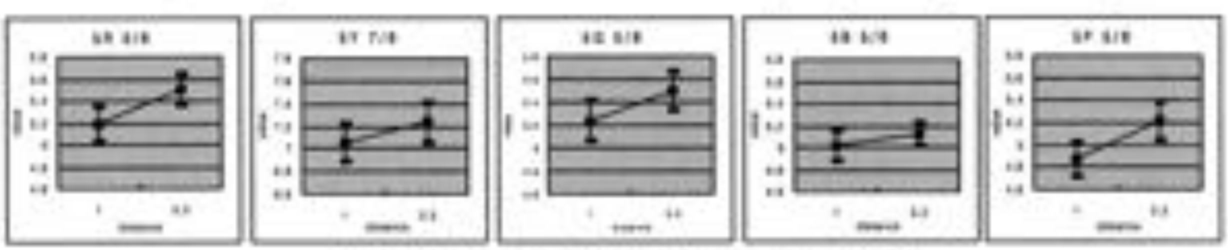


Fig. 5 The value variation in case of same viewpoint

2) The change of chroma

The change of chroma was different from color to color but expressed the tendency of raise as a whole. The quantity of chroma change was pretty high in 5R 5/6 and 5B 5/6 and it was law in 5G 5/6, 5P 5/6 and 5Y 7/6<Fig. 6>.

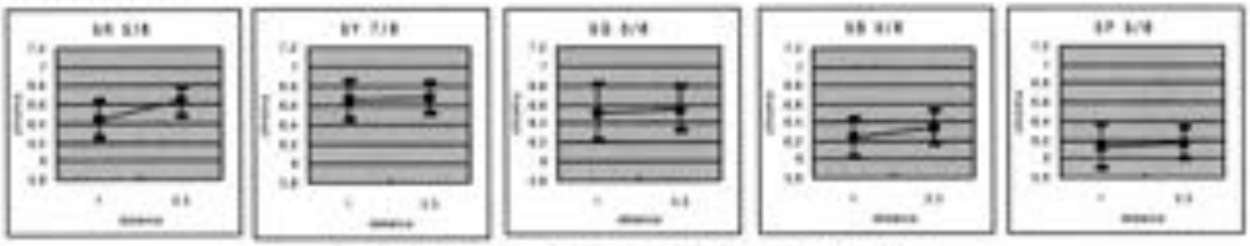


Fig. 6 The chroma change in case of same viewpoint

4. Conclusions

The results of the study is as follows;

1) The quantity of value change was getting high but it was changable according to the raising of observation distance from 1m to 3.3m in the condition that area and viewpoint are point.

2) The quantity of chroma expressed the tendency of raising chroma with distance in evaluating objective color because it expressed similar tendency in the case of same area and viewpoint.

3) The value and chroma were raised with the increase of observing distance in case of same area and viewpoint so it has the tendency of brightness and clearness.

The result will be used as a basic data of repeating experiment in order to make index to adjust the change might be occurred by area effect.

REFERENCES

1. Mark D. Fairchild, 「Color Appearance Models」, Addison-Wesley

2.Karen M. Braun, "Testing Five Color-Appearance Models for Changes in Viewing Conditions", Color Reach and Application, 1997

3. Natori Kazuyuki, " Study on the area effect for the wall colors", Summaries of Technical Papers of Annual Meeting Architectural Institute of JAPAN, 1999

4. Mitsuo Ikeda, "Formation of a Recognized Visual Space of Illumination with Increasing Initial Visual Information", Journal of the Illuminating Engineering Institute of JAPAN, 1996

AUTHOR'S ADDRESS

Lee Jin-Sook*, Kim Chang-Soon,** Yim Oh Yon***, Lee Deok-Hyung*

* Chungnam National University(CNU), Dept. of Architectural Engineering, College of Engineering

220 Kung Dong, Yousung-Ku, Daejeon, 305-764, Korea

Phone : +82-42-821-7733 Fax : +82-42-823-9467

E-mail: Js_lee@hanbat.chungnam.ac.kr

** Optics Group, Division of Auantm Metrolog, KRISS, Daejeon, Korea

***Dept. of Interior Engineering, Konyang University., Nonsan, Korea

Colour-Form Meanings:
Interconnections between perception, association and symbolism

Rachel Newton, Liverpool School of Art and Design, Liverpool John Moores University

ABSTRACT

Every form is as sensitive as a puff of smoke, the slightest breath will alter it completely.
Kandinsky[1]

The interaction between form and colour regarding this mutability of meaning is a subject that is ever elusive. At the same time, it remains a subject that merits objective and collective study, not so much to generate finite conclusions but to increase our visual awareness and sensitivity of the complex phenomena at work. Much has been accomplished but it still remains an all but unanswered question. Colour effects need to be seen to be believed and, as Albers stated in his *Interaction of Colour*, theory should follow practice. This paper presents recent developments in my painting practice by exploring the combined effects of colour phenomena through systematic practical experiment with changing colour forms. The work is systematic but embraces the intuitive, the sensual and the magical – closing the gap between intuition and formula. The wide range of meanings (associations, evocations, emotions) that Mark Rothko obtained from subtle changes of form and colour in the rectangles-within-rectangles format of his mature paintings, is evidence of the scope of this line of research.

Keywords: colour-forms, colour in architecture, perception, association, symbolism, synaesthesia

1. INTRODUCTION

The subject of this paper plays a central role in the work towards my doctorate. In the thesis title "Colour: An Architectural Alchemy", the word 'alchemy' is used primarily as a by-word for transformation - in this case transformation of architectural space through the use of colour. The research aims to examine this notion of transformation in its broadest sense, exploring the capacity of colour to generate change: perceptual, spatial, structural, psychological, physiological, social and cultural, by the way it is used within an individual building, a locale or a city. In addition, alchemy implies a development of spirit through rigorous study and experimentation with the physical world of matter – transforming the physical to develop the spiritual. This belief is of significance to the tenor of the research.
The research is rooted in my art practice. It extends my painting practice beyond the two-dimensional to conjoin with sculpture, architecture and urban planning. As well as expanding the territory and the dimension of "painting", the methods and media are to be considered in their broadest sense, so that the placing of materials in colour relationships (both perceptual and psychological) can equate to brush marks on a canvas, manipulating sensations of space and meaning.
The work presented for this paper are the preliminary outcomes of some smaller scale colour-form experiments used to develop ideas for full-scale architectural works.

2. RATIONALE

Windows of Appearances (appropriated from the Egyptian 'Window of Appearances' [2]):

Changes of colour change our perception of reality generating real experiences through so called illusion. In Swirnoff 1988[3] it is stated that "colour can be considered a dimension". My work explores this statement. Interactions of colours create perceptual deception, increasing or decreasing the sensation of volume, space, light, structure, form, shape, distance, and scale. Concavity can appear convexity; simple volumes appear complex and complex features can be simplified.
In Persian architecture this ambiguity and fluidity that colour can bring to form is used to create intrinsic relationships between surface and building mass.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

While colour appears to be on the surface, it is not superficial.
Swirnoff 1988[4]

James Turrell, using coloured light, reconfigures interior spaces. He creates fields of suspended colour that appear simultaneously to dissolve the architectural surface and project into the space.
Mark Rothko's colour field paintings similarly appear to dissolve the surface. The paintings are of a scale to envelop a viewer. Colour is suspended, hovers, shimmers within ambiguous depths.

The series of paintings I have been working on designed for the Gallery space at Liverpool School of Art and Design responding to the existing architecture of an interior colonnade (now blocked in) are intended likewise to bring into play spatial distortions, fantasy and illusion. Visual and theoretical referencing for these works have come from Islamic architectural theory and the supergraphics camouflaging World War II industrial buildings in the U.K.

Colour as Matter:

In the beginning a colour could not be designated by a concept of its own, it was like something: red as blood, white as snow, black as ebony.
Karl Gerstner[5]

As well as the visual phenomena that colour brings to our perception of space and form, it can also carry symbolism and associations of biological, environmental, cultural and purely personal natures.
In Mahnke (1996)[6], reference is made to comparative studies between colour symbolism of differing cultural origins. Evidence from these studies shows an evolution in all cultures from ritual symbolism based on colour experiences in Nature, leading into major emotional associations stimulated by particular colours and eventually shaping sociological, cultural and religious experience.
Goethe, in his colour theory, speaks of colour being inherent in bodies and being a manifestation of their inner nature. The philosophy is demonstrated in the work of Joseph Beuys, who sought the colour-matter appropriate to the image or object being created. His 'Beize', for example, reddish brown watery stain reminiscent of bodily fluids, provided a metaphor for vulnerability, fluidity and transformation. His 'Braun Krauz' was a denser, more stable substance, still earthy and bodily but having a quality of a protective covering or skin.[7] 'Braun Krauz' also has associative links to the 'Sick State' (in the image of the swastika) and the international 'healing' organisation of the Red Cross and hence was part of Beuys' philosophy of art as an agent for cultural healing and social change.

How relevant it is to consider such ideas in an architectural context.

How does the colour matter content of an environment affect our perception of that environment?

Colour Synaesthesias:

Appearances can effect our perception of size, weight, distance and temperature. Itten in his "Art of Colour"[8] identifies these "colour synaesthesias" as aspects of the cold-warm property of colour, giving an extended list of contradictory colour effects:

Cold	Warm
Shadow	Sun
Transparent	Opaque
Sedative	Stimulant
Rare	Dense
Airy	Earthy
Far	Near
Light	Heavy
Wet	Dry

These colour synaesthesias and associations can either work to reinforce or undermine the visual perception of a form. If colour can change our perception of form then it effects both the meanings that we attach to the form and our psychological and emotional responses to it. If this idea is extrapolated to the forms that we live in and that surround us, the same complex of phenomena are brought into play.

3. THE COLOUR-FORMS

Structure of Colour-form Experiments:

- One form in different colours
- One colour on different forms
- One form with different colour ways
- One colour way across different forms

Each of these categories can branch off into more detailed family trees of forms, sequences, scales and colours.

With respect to Josef Albers' "Interaction of Colour"[9] the following aspects have been considered in selecting shape, composition and colour:

- The interdependence of colour-meaning with placement;
- The interdependence of colour-meaning with quantity (amount, extension, recurrence);
- The interdependence of colour-meaning with quality (intensity of light and hue);
- The interdependence of colour-meaning with pronouncement (separate or connected boundaries).

Description of visual work presented:

The work presented for this paper are the preliminary outcomes of some smaller scale colour-form experiments used in the development of ideas for full-scale architectural works. It covers a small selection of colour-forms, derivatives from the 3 fundamental shapes – square, triangle and circle:

Shapes characterised by horizontals and verticals e.g. cross, rectangle and their derivatives.
Symbolising resting matter. (from Itten)[10]
Example chosen – Stripes

Shapes of diagonal character e.g. rhombus, trapezoid, zig-zag and their derivatives.
Symbolising radiant thought. (from Itten)
Example chosen – Islamic lattice built on framework of equilateral triangles.

Shapes of flexous, cyclic character e.g. ellipse, oval, wave, parabola and their derivatives.
Symbolising spirit in eternal motion. (from Itten)
Example chosen – Concentric Circles

Questions raised by the experiments:

- Responses to familiar objects changed from the colour norm.
- Implications for the built environment.
- Forms having associations and symbolism in their own right.
- How much are these associations altered by changes in their colour?
- Irregular forms used so as to be empty vessels to contain colour effects.

The complex issues surrounding symbol, sign and association require some reference to the primarily linguistic world of semiotics. Goethe, at the end of the didactic part of his Theory of Colour (1810)[11], made a distinction between symbol, which he defined as instinctive and universal, and allegory or culturally coded response. Kandinsky and Itten both explored the complex psychological interaction between colour, form and meaning, considering the instinctive associations rather than cultural colour meanings. My interest is also in the intuitive rather than the literary response but it is not always clear where one ends and another begins. To clarify my terms I use the division of "Sign" devised by Charles Sanders Peirce into Icon, Index and Symbol, where his Index can be "read" without any cultural knowledge (equivalent to Goethe's symbol), his Symbol has to be learned as meaning something within a particular culture and his Icon which reminds us of its object "by some complex kinds of resemblance"[12]

4. FURTHER STUDY

The research seeks to observe not only the physical, perceptual interaction of colour but also evidence of associative, symbolic and the psycho-physiological effects. It is anticipated that in the duration of the research, collective response will be sought through seminars and workshops, discussion, interview or through email. Those involved may be placed in specific groupings or pairings regarding e.g. age group, nationality, profession and gender.
I intend to present both closely related and widely divergent sequences of colour-forms in these sessions and to encourage stream-of-consciousness written response to the images.

---

1 Kandinsky, W. *Concerning the Spiritual in Art* pp.27-85, Dover Publications, 1977

2 Gottlieb, Carla *The Window in Art: From the window of God to the vanity of Man* Abaris Books, Inc. N.Y. 1981.

3 Swirnoff, L. *Dimensional Colour*, p.1, Birkhauser, Boston Inc., 1989.

4 Swirnoff, L. *Dimensional Colour*, p.5, Birkhauser Boston Inc. 1989.

5 Stierlin, Henri (ed.) *The Spirit of Colours: The art of Karl Gerstner*, p.53, Cambridge, Mass: M.I.T. Press, 1981.

6 Mahnke, Frank, H. *Colour, Environment and Human Response: An Interdisciplinary understanding of colour and its use as a beneficial element in the design of the Architectural Environment*, p.59, Van Nostrand Reinhold, U.S.A., 1996.

7 Temkin, A. and Rose, B.(eds.) *Thinking is Form – The drawings of Joseph Beuys*, MOMA N.Y. and Philadelphia Museum of Modern Art, 1993.

8 Itten, Johannes *The Art of Colour*, Van Nostrand Reinhold Company, N.Y. 1970.

9 Albers, Josef *Interaction of Colour*, Yale University Press, 1963.

10 Itten, Johannes *The Art of Colour*, p.120, Van Nostrand Reinhold Company, N.Y. 1970.

11 Matthaei, Rupprecht (ed.) *Goethe's Colour Theory*, Studio Vista Ltd. London, 1971.

12 Broadbent, G, Bunt, R. and Jencks, C. *Signs, Symbols and Architecture*, p.3, John Wiley and Sons Ltd. 1980.

Rachel Newton
Liverpool School of Art and Design
Liverpool John Moores University
68, Hope St.
Liverpool
U.K
Email: LASRNEWT@LIVJM.AC.UK

Rosario, a grey city

Adolfo del Rio, Carolina Rainero
Facultad de Arquitectura, Planeamiento y Diseño.
Universidad Nacional de Rosario
Argentina

ABSTRACT

Our work deals with the colour of the city. We propose the study of the urban built landscape crhomaticity, here in Rosario, Argentina. We're trying to find out the reasons that make our city looks in grey.
The project we're developing is based in the fact that urban environment has **a colour,** that is to say that, a dominant colour that makes the inhabitants feel the urban space that way.
We think that it may be introduced into the traditional tools used to study the urban development dimensions like colour at the time to interpret the urban environment.
The research and survey let us show the great importance that colour has as design instrument, even in the urban and the building scale.
It has been proposed a research model in order to consider the particularities of the city.
The model is apply to different paradigmatic fragments so as to know the real colour incidence in the perception of the city.
The work it's been developed through the following topics:

- Perceptive survey
- Downtown building survey
- Historic survey

Based in the interdiscipline work we try to contribute to the design and optimisation of the tools that let professionals and researchers understand the complex urban environment so as to make supporting cities.

Keywords: city colour, perceptive colour survey, urban environment, buildings colour.

1. INTRODUCTION

The project is part of a wide, large, research that aims digital models to study the changing urban environment. In this way different dimensions are researched and they allow the interpretation of the constructed environment.
If we recognise that the city architecture shows itself the historic urban process, this project, that propose the study of the city colour will show that the urban architecture appeared monochromatic and almost achromatic in a low saturation level.
When we say that the colour of the city is grey we are referring to the grey resulted image, that brings some homogeneous landscape atmosphere.
Is important to remark that the idea of a "city colour" is based in a perceptual urban space view.
Many cities have a long tradition in the use of painted polychrome colour, as in Salvador de Bahía, Brasil. We may also identify with a dominant colour cities like Siena , in ocre, or Amsterdan, in low saturation red, because of the nature of the facades material; the colour full the space dyeing it with a particular chrome.
Hence, Rosario is grey...and we believe that this colour is the result of different reasons that frame these work investigation lines.
Many researchers and professionals are dedicated to the study of the colour of the city but in a context like ours it is impossible to think about it. It is not even included in the architectural graduate degree.
In order to contribute to increase our urban environment we proposed an alternative colour recorders that allow us to prove the incidence of the colour in the urban image shape.

adelrio@sede.unr.edu.ar ; phone 54 341 447-0354; fax 54 341 440-4871; Facultad de Arquitectura, Planeamiento y Diseño; Riobamba 220 bis, Rosario CP 2000, Santa Fe, Argentina; crainero@sede.unr.edu.ar; phone 54 341 421-6911; fax 54 341 440-4871; Facultad de Arquitectura, Planeamiento y Diseño; Riobamba 220 bis, Rosario CP 2000, Santa Fe, Argentina.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

2. OBJETIVES

- To research on the incidence of colour in the urban space perception.
- To search the reasons why our city looks grey.
- To design a survey model that let us compile a colour date base.
- To study the use of colour in different buildings.
- To demonstrate that colour is a so important dimension in the urban environment that has to be included in the architectural graduate program .

3. METHODOLOGY

3.1 Concepts

1. ... the colour as an important dimension in the construction of the urban environment.

2. ... the colour as a urban design tool.

3.2 Development

We establish two researching lines to develop the precede concepts, a perceptive one and an objective one.
The perceptive line consider the colour urban environment as a social experience the other studies the real build space. Both lectures are presented in the research model.

3.2.1 Research model design

It has been proposed a research model in order to consider the peculiarities of the city.
The work has been developed through the following topics:

- **1. Perceptive colour survey.**
  Design a tool that let us evaluate the inhabitants city perception in terms of colours.
  We are, at the time, developing this step.
- **2. Building colour survey.**
  Design a building survey considering two approaching levels:
  a. Building's colour in the city.
  b. Building's colour itself.
- **3. Historic colour survey**
  We have to consider two different topics:
  a. historic documents.
  b. historic building survey.
- **4. Designers use of colour**
  Design a tool that let us evaluate how architects use colours in their designs.

3.2.2 Determination of the study area.

a. Rosario, provincia de Santa Fe, República Argentina.

Rosario city is placed in a particular good geographic situation. In a flat landscape by a great river, the Paraná. The architectural production is not base in environment condition but in historical, cultural and economics facts.

Historic city evolution

A city without foundation.
Urban consolidation.
Immigration impact.
Rosario in the XX century.

b. Central area.

To develop the first step of the survey we select the central area because it is the most consolidated and the oldest in the city and it has an important growing dynamic., including new architecture. It let's us compare a same site during the time.
Ancient works of the research team has been a great help at the time to begin the surveys and an elementary colour date base.
The model is applied to different paradigmatic fragments so as to know the real colour incidence in the perception of the city.

3.3.3 Testing the area with the research model.

To explain part of the survey method we present an example:

2. Building survey.

a. Building's colour in the city. (urban) Figure 1

b. Building's colour itself. (building) Figure 2

We selected, in a ALEATORIA way, blocks to make a date base

Block number	Number of buildings	Chromatic Building	Achromatic Building
B2 199	39	15	24

Figure 1

Place number		Building	Parts	Paint	Colour material
S1	Chromatic				
M261 / LOTE 20	Achromatic	•	•		•

Figure 2

3. Historic colour survey

a. Archive documents research.

We consult the municipal archives in order to get information about urban laws.

b. Historic building survey.

We made a survey and construct a date base about use colours in buildings.

We made several lectures in the urban buildings so as to know the use of colours through the time. Figure 3 and 4.

Note: **Data. Building selection.**

It was necessary to establish the guide lines that let us select them.

As we were interested in compiling a large survey, which includes not only the paradigmatic buildings or urban fragments but the industrial and the domestic architecture as well.

We began with the paradigmatic ones.

As an example of our urban architecture we include a few photographs ordered in two groups:

- 1890- 1925

1. **Tribunales Federales**. Oroño 940. Año: 1890.
2. **La Bola de Nieve.** Laprida y Córdoba. Arq. Le Monnier. Año: 1906.
3. **Palacio Recagno**. Oroño 1145/55. Arq. E. Sackmann. Año: 1915.
4. **Palacio Fuentes**. Santa Fe 1123. Arq. J. B. Durand. Año: 1924.

Figure 3

- 1930-1945

5. **Silos Davis**. Oroño y Av. de la Costa. Año:1935.
6. **La Comercial de Rosario**. Cia. de Seguros. Oroño y Córdoba. Arqs. De Lorenzi, Otaola y Roca. Año:1939.
7. **Edificio De Bernardis**. Oroño y Tucumán. Arqs. De Lorenzi, Otaola y Roca. Año:1940.

8. **Edificio Unione e Benevolenza**. Maipú y San Juan. Arqs. Fernandez Diaz y Funes. 1943.

Figure 4

3.3.5. Design of the digital support
We are preparing a digital date base to process the colour information obtained.

4. PARTIAL RESULTS

3. Historic colour survey
a. Archive documents research.
The Municipal laws restricted the use of colour by the end of the XIX century. (Digesto Municipal de 1889)..."only the public buildings are allowed to use different paints colours in facades...houses buildings have to appear in white"...Even though it was not proposed thinking in the construction of the urban space it was based in higienistic facts, it did it anyway.

b. Historic building survey.
We made several lectures in the urban buildings so as to know the use of colours through the time.
The different architectural languages go through the XX century did not consider the paint colours in the building facades.
The dominant material was, what we call, Paris stone, a front material.
There is a few paradigmatic buildings that considered the use of colour in a special way.

5. CONCLUSIONS

. . . in a way a conclusion
Nowadays, we are developing our project so we can not introduce final conclusions but we can make a few comments about our research:
There's no tradition in the use of paint colour in the Rosario's architecture.
Even though the urban landscape is bright coloured the constructive space is felt not coloured at all.
In a first approach the blocks in the central part of the city appeared less coloured than the surrounding.
Considering that colour is an important dimension in the urban space configuration it seems to be necessary to include the teach of colour in the architecture school.
The team was increased and the project is, by the time, developed through different areas at the Facultad de Arquitectura, Planeamiento y Diseño. Universidad Nacional de Rosario.

ACKNOWLEDGMENTS
We can not forget to mention that the photographs were taken by an architecture student, Miss Marcela Giacometti.

BIBLIOGRAPHY
Rogers, Richards, Ciudades para un pequeño planeta, Editorial G.Gili, Barcelona. Año 2000.
Wong, Wucius, Principios del diseño en color, Editorial G.Gili. Barcelona. Año 2001.

An Exterior Expression of Houses on the CG and a Color Assessment on the Method of Pair Comparison

SAKAHARA Koya
Department of Architecture, Hokkaido Institute of Technology

ABSTRACT

In this report, we produce the perspective views of 3 houses by using CG. These are 20 pictures making changes the color on a wall and roof. We assess these pictures to use the Method Paired Comparison. The colors on a wall and roof were decided to base on the research according to the color choice on a wall and roof in reference 1.

Keywords: The Method Paired Comparison, CG, a wall and roof

1. INTRODACTION

In this report, we show the basic index on a color planning in architect by the relation between the physical properties of color in each picture and the color assessment to use the Method Paired Comparison. In this time, on the index expressing physical properties of color, we show "the sum of scalar moment" that is "the color difference" times " area of color". We prepare 20 sheets of picture that are changed the color on a roof and wall.
We produce the CG pictures to use the 3Dstudio, measure the color with the MINOLTA CR200. The color system is CIEL*a*b*. The objects for the experiment on the Method of Paired Comparison are the 20 architecture students(Japanese, around 20 years old, male and female every 10).

Fig. 1 The perspective view
The number in this Figure is the section number in the Table 1.

Table 1 The major list on the values in the perspective view

Section Number	Name	Area (cm²)	The chromaticity		
			L*	a*	b*
1	The Sky 1	23.82	58.49	8.48	−35.99
3	The Sky 3	49.30	54.90	8.65	−38.99
5	The Sky 5	5.05	67.79	2.23	−29.91
10	The branch 1	2.33	88.98	2.13	−4.45
11	The leaf 1	14.17	55.81	−37.38	26.63
20	The fence 1	1.94	38.83	11.58	4.13
21	The fence 2	2.01	51.34	2.01	11.20
27	The sidewalk 2	5.77	48.44	27.07	20.38
31	The curbstone 1	3.04	79.16	2.75	−5.78
38	The roadway	21.94	38.43	0.43	−3.57
46	The flower bed 1	0.38	59.33	4.35	−7.35
47	The flower bed 2	1.97	73.26	2.78	−8.78
54	The flower 1	0.20	83.55	−8.09	82.40
57	The flower 2	0.27	42.01	38.60	14.62
80	The window flame	0.50	22.39	0.93	−2.01
85	The inside wall 1	0.48	64.56	5.03	−7.34
128	The door	1.60	60.83	3.86	−8.46
173	The car 1	0.54	90.47	2.56	−4.42
174	The car 2	0.29	67.26	3.69	−8.16

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

Table 2 A color Difference between a wall and roof on the Perspective Views

			Wall				
	Hue		Orange	Yellow Green	Blue Green	Purple	Achromatic color
		L*	81.24	80.73	80.46	80.64	80.94
		a*	5.27	−4.75	−5.32	5.44	1.59
		b*	5.75	4.54	−5.22	−4.94	0.85
Roof	Orange	50.01 8.57 8.82	31.55	33.76	36.29	34.59	32.89
	Yellow Green	50.33 −10.82 8.06	34.92	31.20	33.38	37.52	33.81
	Blue Green	50.61 10.62 −9.41	34.59	36.58	34.10	30.57	33.27
	Purple	49.80 9.33 −9.25	35.25	36.84	34.40	31.37	33.82

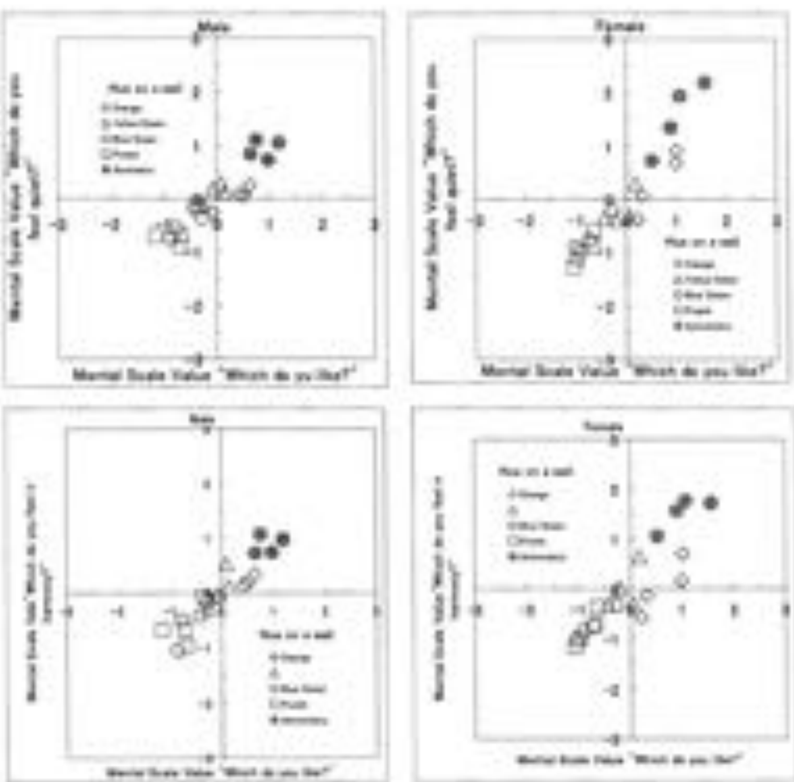


Fig. 2 A Relation between each the Mental Scale Value

The Fig.1 is a picture to use in this report. We measure the color and the area in the part of the Fig.1. In the Table 1,we show the major chromaticity on the picture. In the Table 2, we show the chromaticity on a roof and wall, the color difference between a roof and wall. On the research in the Reference 1, Japanese in Hokkaido select a high lightness and low chroma color on a wall and a middle lightness and chroma color on a roof. In deciding the housing color on a picture, we considered this point. We decide on a color difference between a wall and roof for 30-35.

2 The relation between each Mental Scale Value

The questions for the method of Paired Comparison are three. These are ①"Which do you like?", ②"Which do you feel quiet?" and ③"Which do you feel in harmony?". We calculate the Mental Scale Value in each male and female separately. The horizontal illuminance is about 500lx.

I n the Fig.2, we show the① as the transverse axis, ② and ③ as the vertical axis. We can see a little difference between a male and female. A female have a greater difference of a Mental Scale Value than a male. As the whole, we can't find out a large difference. We think that the both relation is a proportion. In seeing a hue on a wall, The Mental Scale Values are getting small for Achromatic color, Orange, Yellow Green, Blue Green and Purple orderly. In the case of the question ② on the female, the 4 colors in Orange have rather a different trend. The female have a greater Mental Scale Value than the male.

3 The sum of the scalar moment

On the index expressing the quantitative properties of color in each picture, we decide the sum of scalar moment The scalar moment is "the color difference from Medium Gray " times " area of color" And then, we calculate the sum of this values. We think that this index express color condition in each picture. We show the relation the relation between these values and the mental scale value by the Method of Paired Comparison. In the case that there are many colors, we hope these relations to be the basic data for "a comfortable balance".

The scalar moment is decided in the following. The basic point to calculate the color difference is [L*=60.0, a*=0.0, b*=0.0] on the chromaticity diagram.

The area of "i"(The"i" is the number in the Fig.1) Si

The chromaticity on the "i" Li*, ai*, bi*

The color difference between the basic point and the color "i"

$$⊿Ei = \sqrt{(L^*-Li^*)^2+(a^*-ai^*)^2+(b^*-bi^*)^2}$$

The scalar moment of "i" $⊿SEi = Si \times ⊿Ei$

The sum of the scalar moment in the picture $SE = \sum_{i}^{219}(⊿SEi)$

The Fig.1 is divided into 219.

In Fig.3, we show the relation between the Mental Scale Value and the sum of scalar moment. From upper part for an order, we show the Mental Scale Values of ①"Which do you like?", ②"Which do you feel quiet?" and ③"Which do you feel in harmony? ". The left side is a male. The right side is a female. We show hue in five groups, the regression linear and R squared

Through the whole, as the Mental Scale Value increases, the sun of scalar moment decreases. On the 6 cases, each intersection value of the regression linear and the y - axis is equal. In the case of male, the inclination is getting large for ②①③ orderly. In the case of female, the inclination is getting large for ①③② orderly. The inclination of ② and ③ in female are almost similar. The male have the larger inclination and the smaller R squared than the female

We can see a difference between male and female. But we cannot see a large difference between each question. In agreeable question, if we ask only question of "Which do you like?", we consider that we can get a satisfying result.

4 Conclusions

The followings are the conclusions in this report.

1. The picture that is a large sum of scalar moment has a small Mental Scale Value. The picture that is a small one has a large Mental Scale Value.
2. We can see a difference between a male and female.
3. The hue on a wall of house in the center of a picture gives an influence into a Mental Scale Value.

REFERENCE

1 SAKAHARE Koya, "A Color Choice for a Good Housing Environment; A Research on a repainting color over a Wall or Roof", Proceedings of 2000 AIC Meeting Seoul Color & Environment, AIC Color 2000, P7-P11 ,2000.11

2 Moon, P and Spencer, D.E, "Area in Color Harmony", J. Opt. Soc. Am., 34(2), 1944

3 The Color Science Association of Japan, "Handbook of Color Science [Second Edition], University Tokyo Press, 1988

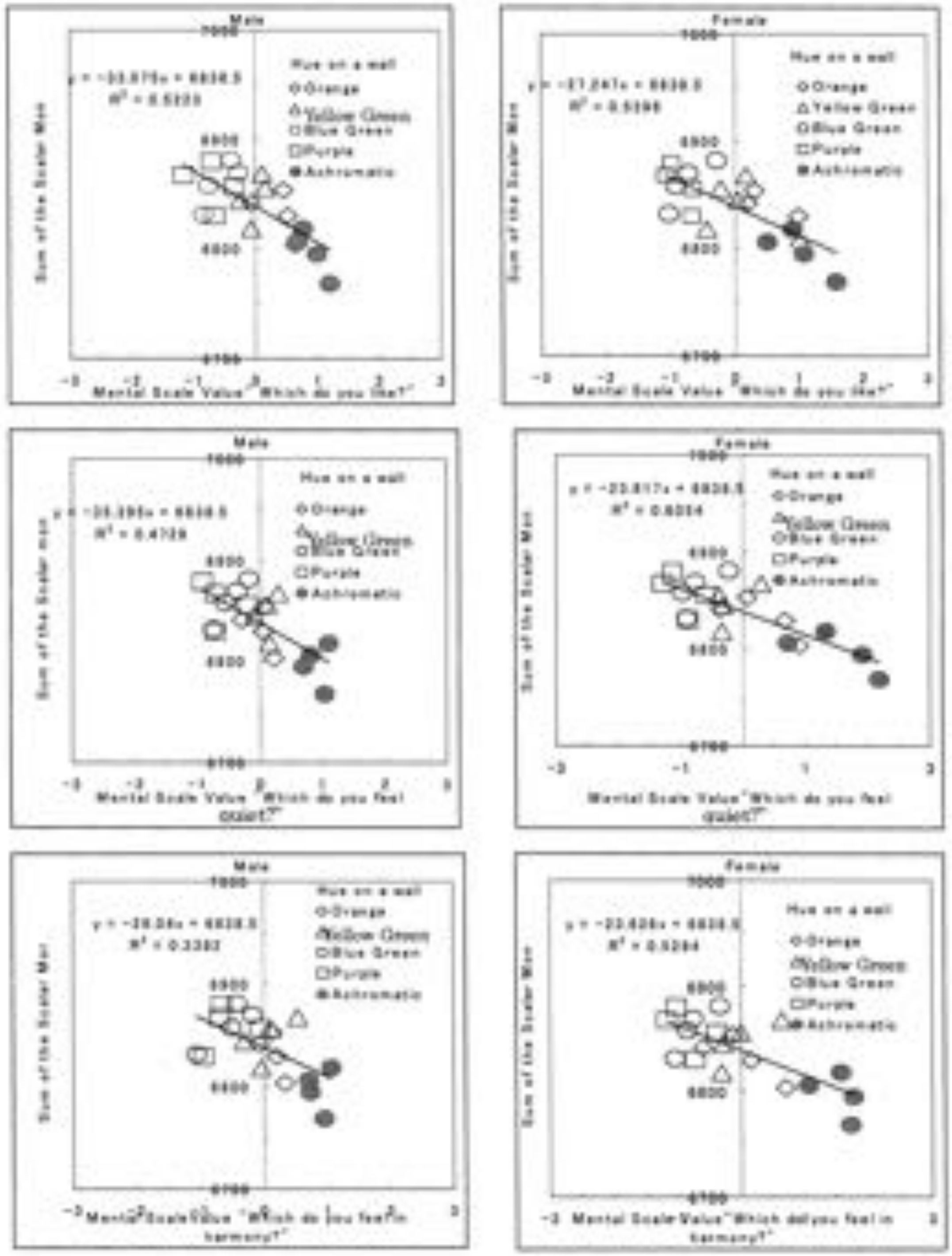


Fig.3 A relation between a mental scale value and a sum of the scalar moment

sakahara@hit.ac.jp; Phone +81-11-681-2161; fax +81-11-681-3622; Hokkaido Institute of Technology; 4-1,7-15, Maeda, Teine-Ku, Sapporo, Japan

Renaissance:

The color between the ideals of Beauty and reasons of Freedom

Angel Tomás Lázaro Puebla, prof. JCCM

1. INTRODUCTION: DREAMS FOR A NEW WORLD

Throughout the Renaissance period, some of the most important and more influential bases in the expressive means of the painting are going to be created. The memes units of information with which the culture is made up and, at that period, were creating in the paint world were crucial during several centuries, and in this way, it appeared what we can call the real genetics of the occidental painting. But art does not exist without intention, in every painting there must be a mixture of essential factors which module the shaper and settle the colors. We wonder how artists in the 15 th and 16 th centuries faced up to their task of thrilling and moving and what role the color played in all that mess. Vasari, for instance, reminds us the work must represent with one blow the author's purpose and not something without meditating. Color and intention are joining together in artists's hands.

A new kind of individual, the universal man appears. The artist's figure waved on the wind practically assuming the demiurgic characteristics of the divinity. In Marsilio Ficino's words skys could be built if the materials were found.

Maybe the first thing needed in order to build a New World are dreams. God's dream had been Man and Man's dream was God. A God that in the Renaissance period took the shape of Utopia, Infinity and Freedom. Utopias of ideal states and cities, an infinity full of countless stars that destroyed the barriers of a Cosmos wrapped up in a fixed number of spheres and a freedom governed by the free will, able of granting the man an active role on his own destiny. Painting played a crucial role in this adventure of freeing the creator genius and dreamt of thinking up a harmonic visual world capable of setting up the high ideals of humanism in the spectator captivated by the beauty. Together with the dreams of painting, also the color dreamt a new order.

2. THE COLOR'S ROLE IN THE ARTIST'S DREAM

The painter's glance has being situated where he considers it is transcendent, where he considers freedom that a mysterious fate promises the man. Freedom lets the man lives his own greatness –if the man raises himself up to the highest grade, he takes the world itself to fullness- thinks Baoulle. In this sense, artists turned the ideal of beauty into the key to their liberation, something they could reach the elevation with. Beauty, which should seduce awakening the love in the spectator, fascinates in order to provide knowledge to him. Beardsley considers that the platonic religion of art, a form of artistic religiousness, is created then, and appoints Marsilio Ficino as the author.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

When the artist in the Renaissance appeals to the sense to build his piece of work two things happen: firstly, he must discover how the laws of sight work; secondly, when he uses these laws to build his piece of work he assumes that he is opening " windows " in the world whose reality is filled at least with artistic intentions.

De Pictura written by Alberti was the first great treatise on painting and it answers to a need for founded the sources with which the pictures and their themes are built. Ciceron, example for the humanist, thought that the public can become inflamed with speeches. In his speeches he took into account an *ethos*, who defends what is right and a vigorous *pathos* capable of shaking the spectator's spirit. In a similar way the figure of the artist has a value like a visual speaker and he appeals to the same principle. The spasm of the tragic sight and the astonishment at the heavenly sight has the charm of making us move around away from everyday life.

Generally, painting in this time is linked to a story. Color and drawing are joined in this intellectual ability of moving the visual thought. Color is arranged to face the challenge of fitting together with a visual argument able of captivating and shaking. Color is related to Beauty and beauty is related to truth and to the world of ideas. So, color can also express itself by means of its own worth, by means of an almost dialectic system of opposites: light-dark according to brightness, bright-dull as far as the saturation is concerned, harmonized-contrasted according to nuances. Ficino understands that color is the same as numbers and shapes, a kind of light that is in itself effect and image of the intellect.

In order to reach the whole eloquence of color, some new ways of combining are needed. We are going from a certain predominance of unit of saturation and a unit of brightness in the previous period to a collection of more complicated chromatic relationships. To the medium tones some lighter and darker ones will be added making it richer with gradations of brightness and saturation, making the chromatic balance that should be harmonized in the conquest of beauty, freedom and infinite more complicated.

3. COLOR AND THE DREAM OF BEAUTY

How is this harmony of color made up of ideal and nature achieved? The idea that order the nuances consist of that painter should choose the best tone possible of an range starting from the tone by the model offering; taking this into account, the leaves in a tree should be painted in green, but the most harmonious with the rest of the piece of work among all the green tones would be chosen. The picture had to reflect the majesty and the beauty of balance. In each painting the transmutation of turning each color into its best possibility was practiced.

As far as the saturation is concerned, color should be placed in a balanced position. This search for harmony is made out in the valuations that Vasari makes not only against too dark color but also against too dull colors and also in the observation that colors must be used in harmony like lights and shadows:

" The color too vivid offends the drawing and the color too dull and pale looks like something dead, old and burnt. However, the color in a mixture between bright and dull is perfect and the eye loves it the same as the hearing loves a piece of music united and harmony. "

Cutting down brilliant contrast seems to be other principle. Alberti recommend that if the painter wanted to rebuild the visible world he should search for, with screwing up eyes, the different chromatic nuances, so that the light can be seen softened as if they were seen through a veil. The chromatic tensions are cut down with this veil and harmony is given to the piece of work. This veil will be used by painters such as Fra Angelico.

4. COLOR AND THE DREAM OF FREEDOM

For the first time Leonardo carries out an extensive study on the shadow and defines it as a lack of light and pure obstruction of luminous rays through the dense bodies. Shadow comes from the world o darkness, light from the world of lightness. The first hides, the second reveals. They are always linked to the bodies in mutual company.

The dark-light helps to make things with volume and relief, which makes them look earthlier an corporeal if we take into account what the senses offer to us, but it also gives color a reason of freedom. The possibility of choosing between good and bad becomes the man a free being, in the same way the possibility of choosing between light and dark gives mobility to color and consequently freedom In our opinion colors are going to share the characteristics of the conception of man by Pico de la Mirandola. A free human being and sovereign author with the ability of shaping himself, who can degrade himself in the lower things on according to his wishes he can regenerate in the upper things.

The problems closely tied to the concept of man such as free wild and destiny, good and bad, life and death find a parallel in the illumination, in the polarization between light and darkness. As a philosopher the painter shapes his essays whit color and the shadow is going to mark the rhythm. The life of color, its birth and death, its regeneration or degradation is comprised between white and black.

5. COLOR AND THE DREAM OF INFINITE

Very often the world that is originated in the inner of man when it overturns over the outside dresses of a visual formula that allows to show it as if we see throw windows of surrounded environment but in fact they are opened with a lot interest to the complexity of the human universe. The concept and application of the flight point are going to be the key of such visions. This element will affect at the same time to the relation of universal macrocosm and of human microcosm, the flight point will be their connection point. We can make a philosophic reference and quote Nicolas of Cusa who says that in each point can be the center of the universe. The flight point depends on the observer situation. According to Panofsky the discovery of the flight point is at the same time the concrete symbol of the discovery of the infinite itself.

The lineal perspective has its just complement in the chromatic perspective, Leonardo is who deepened in his study in the Paint Treaty. He manifests clearly this connection between the chromatic perspective and the formal perspective when he says that the first colors must be simple, and its degradation must suit with its gradual distance in the space. When the objects are nearer flight point they will have a smaller dimension, this is more punctual; in the same way color will participate more of the color of its horizon, when the colors are nearer to it. The background tone will go impregnating the other colors. In this way the color will manifest with more liveliness and proportion, with a bigger saturation, when the observator is nearer. But this perspective doesn't affect only to tone but also to the luminosity. This kind of perspective justifies the diffuse images, few concrete, like insinuated chromatic stains, the stain of the fume or of the air gives to the color a mysterious quality about the concrete drawing.

6. SUMMARY: COLOR AND DREAMS OF THE RENAISSANCE

With the dream of the utopia, an ideal beauty full of order and proportion was taking forms, capable of attracting the human hearts and in which color should take part by establishing harmonic relationships and showing its kinder side. With the dream of freedom, light could move around between the good an the evil and the colors were organized in a magnificent gradation between light and dark. With the dream of the Magic, every element of the sensitive world included the colors joined together with the world of the ideas allowing, according to what was though, the strange abduction to the divine contemplation. With the dream of infinity the perspective broadened the flat surface in painting; as a result of this, colors could go beyond the limits of drawing and create distances. Although at first view the color of renaissantist painting seem some simple the truth is that is hides a great richness of human inquietudes. The Italian Renaissance painters created, in their application of color, a complex chromatic formula that combined simultaneously some principles of elevated nature. They wanted to get the center itself of human spirit and this wonderful formula was their chromatic weapon to get it. Color should answer then the law of harmony us well as the law of beauty in order to attract and reveal the sacred order, the law of distances to locate the objets in the space and shows the infinite, the law of relief in order to create volume, the law of expresive eloquence in order to draw attention and teach, the law of the magic in order to unite the microcosm with the macrocosm the law of freedom in order to conquer self-conaciousness face up to destiny. This endows to the world of the color, in the painting, of some unique characteristics which differentiated it mainly of the before time, Middle Age and it allows a development to the expectancies of Mannerism and Baroque. Man though he was touching the infinite and created for him self with shapes and colors the dreams of his highest dignity.

7. ACKNOWLEDGMENTS

I wish to express my sincere appreciation to Esther Lillo Bravo and Nuria de los Reyes for their to translation of this text

A method for simulating paint mixing on computer monitors

Ferdinand Carabott*, Garth Lewis** & Simon Piehl***

School of Fashion & Textiles, Central St Martins, The London Institute

ABSTRACT

Computer programs like Adobe Photoshop can generate a mixture of two 'computer' colours by using the Gradient control. However, the resulting colours diverge from the equivalent paint mixtures in both hue and value. This study examines why programs like Photoshop are unable to simulate paint or pigment mixtures, and offers a solution using Photoshops existing tools. The article discusses how a library of colours, simulating paint mixtures, is created from 13 artists' colours. The mixtures can be imported into Photoshop as a colour swatch palette of 1248 colours and as 78 continuous or stepped gradient files, all accessed in a new software package, Chromafile.

Keywords: paint colour, pigments, colour mixing simulation, gradient, paint swatches, parent colour, colour palette, Photoshop, Chromafile

1. INTRODUCTION

Mixing coloured pigments is fundamental to an artist's practice. New colours are obtained from combinations of two or more colours, e.g. mixing yellow and blue produces a green as the mid-colour in a progressive mix. Computer programs like Adobe Photoshop can generate a mixture of two 'computer' colours by using the Gradient control on the tool bar. This blends one colour progressively to another. However, the mid-colour produced by the Photoshop gradient control is different to the mid-colour mixed with paints, e.g. with warm yellow and cobalt blue as parent colours, the gradient control produces neutral grey, not the green we expect with paints. Moreover, the Photoshop gradient produces a middle colour significantly lighter than that mixed with paints. This study examines why programs like Photoshop are unable to simulate paint mixtures and offers a solution by using Photoshop's existing tools. Also described is the Chromafile software that developed from the research.

2. WHY PAINT PROGRAMS CANNOT SIMULATE PAINT MIXTURES

Colour for computer programs is organised around a conventional colour space. Adobe Photoshop utilises the **Lab** colour space whereby any colour can be located by reference to three co-ordinates: **L**, **a** and **b**. Figure 1 shows a schematic arrangement of **Lab** colours on three axes, in three spatial dimensions: on one plane are two axes: for yellow to blue (+**b** to -**b**) and the other magenta to green (+**a** to -**a**). The third perpendicular axis (**L**) represents the value range from 0 (black) to 100 (white). As colours approach white or black, the area of possible colours is ever diminishing.

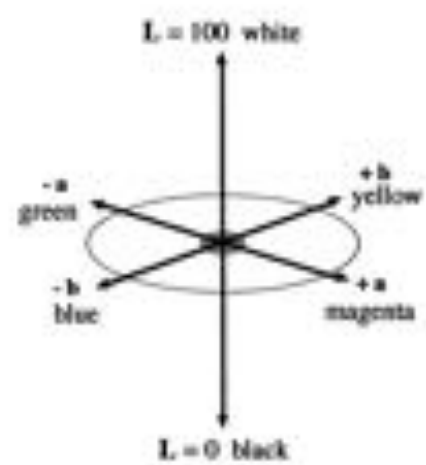


Figure 1: Schematic diagram of **Lab** space

If we generate a gradient from warm yellow to cobalt blue with the gradient tool, Photoshop will create a straight line path within the **Lab** colour space. Figure 2, shows that this path passes through grey territory, with no identifiable green. Therefore we cannot generate a green from these parent yellow and blue on computer using the Gradient control. There are other program tools in the 'Layers' window that 'mix' colours by overlaying transparent colour layers. 'Multiply' and 'Darken' are the most relevant, but even these produce variable results with several major unexpected hue changes as well as value inconsistencies that make them ineffective for purposes of simulating paint mixtures. To achieve the mixture that extends into green, the Photoshop gradient needs to be 'bowed'. There are no direct or specific tools in Photoshop to perform this transformation.

3. EXPERIMENTAL

When the paint swatches in a progressive mix from warm yellow to cobalt blue are measured with a spectrophotometer and mapped in **Lab** space, the path of the paint mixture follows a curve bending into green territory, as shown in Figure 3. If we compare this with the Photoshop gradient path we can see that the shift at the midpoint is in the direction of green. If we add a layer of green to the Photoshop gradient, increasing the strength at the mid-point, we can shift its colour towards the paint colour gradient. In **Lab** terms, this means a significant shift towards a negative value **a**.

To do this, a new Photoshop layer is created to go on top of the original Photoshop (yellow to blue) gradient. This green *correction gradient* is made and is faded towards colourless transparency as it moves from the mid-point towards the parent colours.

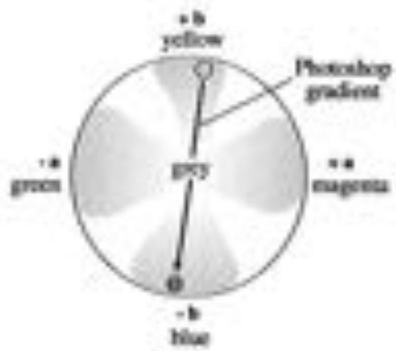


Figure 2: Path of gradient between yellow and blue with Photoshop.

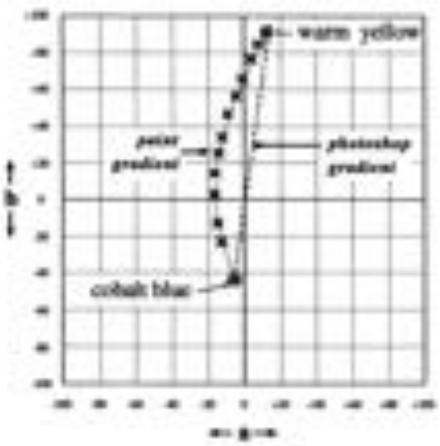


Figure 3: Path of paint gradient between warm yellow and cobalt blue.

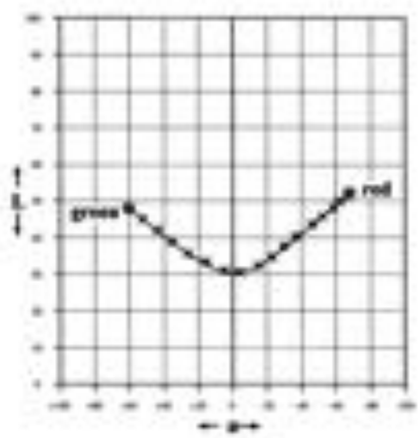


Figure 4: Curve of red-green paint mixture on the **L-a** axes of **Lab** space

This layer is then switched to the 'Multiply' option for the layer. The resulting gradient follows the green path in terms of hue, but does not fulfil the value condition of the paint colour (Figure 5a and 5b). The darkening was simulated by decreasing the brightness (**L**) value of the green correction layer. Some paint mixtures (e.g. red to green) produce mid-colours markedly darker than both their parent colours (Figure 4).

The **Lab** space was devised to show visually regular steps of hue and value. The mid-point of two parent colours can then be located on a graph of the **a** and **b** axes. The deviation between the straight Photoshop gradient and the curved paint colour path can be measured directly. Figure 3 shows the deviation from the straight line gradient to be -27 **a** units. This is added to the Photoshop gradient with the 'Multiply' tool producing the hue shift. The mid-point paint value is lower, so the adjustment to the **L** value is also made.

Figure 5a: Paint swatch of yellow to blue

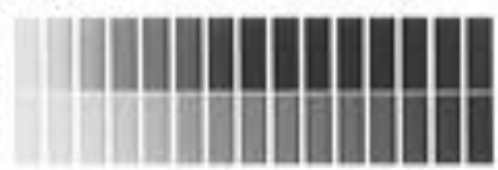


Figure 5b: Middle values darker with paint mixture (top) than with Photoshop gradient (bottom)

This method was applied to the intermixtures of eleven paint colours, representing primary, secondary and tertiary colours, and to black and white. Gouache was used for its consistency, opacity and fast drying. All the pairs were mixed to produce visually (roughly) regular stepped colour scales. These steps were measured with a spectrophotometer (X-Rite Colortron II) and its software (Colorshop 2.5). Measurement was standardised using D50 lighting conditions (simulated daylight) and the results were saved in **Lab** colour space values. Colorshop allows information to be exported either as tabulated data (for spreadsheet or graphing programs) or as colour swatches for imaging software (such as Photoshop). The resulting colour mixing steps were saved as swatch files in Colorshop allowing them to be imported directly into Photoshop. Tabulated data were imported into a graphing program (Deltagraph v.4.5) where paint mixing curves could then be displayed in **Lab** space in two and three dimensions. This provided familiarisation of paint mixture behaviour and allowed graph printouts of both the hue and value planes. Figure 6 shows the location of the parent colours on the **a** and **b** axes and Figure 7 shows the same colours on the **L** and **b** axes, together with black and white.

Other colour combinations produced **Lab** curves which differed from the yellow to cobalt blue but in general most colour mixtures followed some form of curve. Only a few followed straight lines where paint and computer colours were a close match. Although straight line mixtures needed little or no hue correction, the majority of colours, straight or curved, required value adjustments. When no hue change occurred, a neutral grey correction gradient was created to correct the value mix in the same way as for hue correction.

Mixing black and white with paint colours causes a change of hue as well as the intended value change, e.g. the mixture of white paint with magenta produces a violet shift in the mid-colours. When yellow is mixed with black, the mid-colour is greenish, demonstrating a blue influence in black pigment. When these mixtures are compared to the Photoshop gradients there is a discernable colour difference. Therefore mixtures between white, black and the eleven hues needed to be measured and plotted in the same way as the other colours. Figure 8 shows a selection of curves created by colour mixtures with black. White mixtures show similar hue changes.

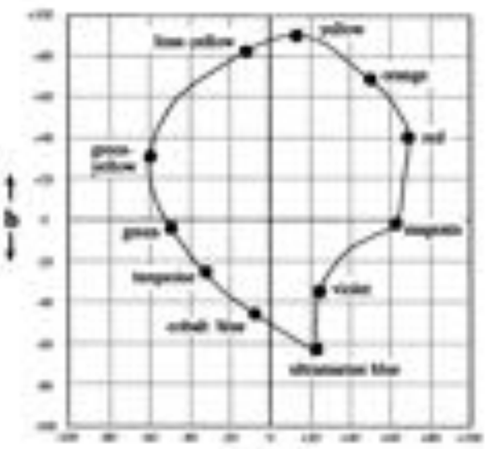


Figure 6: Location of the 11 paint colours on the **a-b** axes of **Lab** space

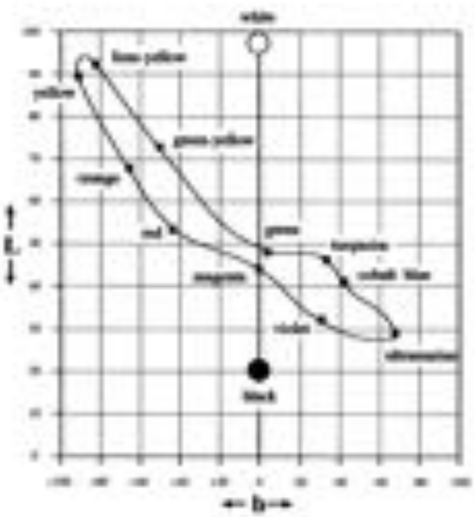


Figure 7: Location of the 11 paint colours on the **L-b** axes of **Lab** space

4. CREATION OF CHROMAFILE

All the corrected gradients were saved in Layers as Photoshop format files allowing fine tuning as required. Copies of these files were 'flattened' to one layer, enabling saving in TIFF format to be imported into other painting and drawing programs such as Freehand, Adobe Illustrator and Painter. The eleven hues plus black and white produce 78 colour gradients; each can be viewed as continuous tones or a mask can be switched on to view the gradient as stepped swatches. Any colour on the gradient can be spot sampled.

A swatch palette of 1248 colours has been created and is organised in a systemic colour order; the default number of steps for each set of parent colours is 16. The colours are grouped in rows of six and follow on from each other in the order of the colour circle. A particular colour can be found by identifying either of the two parent colours - if one is looking for a mixture, for example, between yellow and cobalt blue, this can be found in either the yellow or cobalt blue section. The Swatch palette can be placed permanently in the Photoshop Swatch folder and loaded from the Swatches Dialog Box.

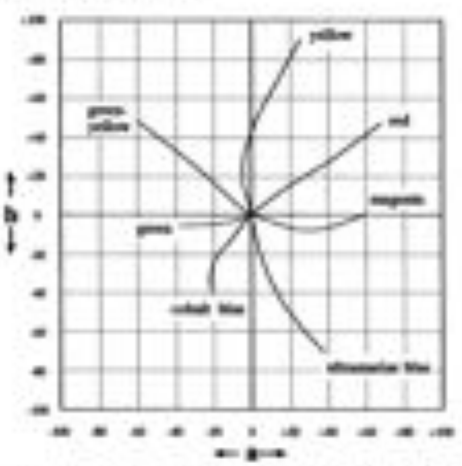


Figure 8: Selection of curves of paint colours mixed with black on the **a-b** axes of **Lab** space

In addition, Chromafile paint colours can be used in the Photoshop gradient control to make new gradient mixtures. For example: to mix a low chroma lemon yellow of normal value, a middle neutral colour is selected from the violet to lemon yellow gradient. This is mixed as a gradient with white to the value of lemon yellow. A final gradient is then created from the light neutral to lemon yellow, to produce a series of low chroma yellows. The same procedure can be applied to other colours, and if the colours are chosen strategically, by applying paint mixing principles, new colour mixtures can follow the paint colour model, thus not reverting to the RGB model.
Finally a stand alone Interface was designed with Macromedia's Director to allow automatic colour recall. Eleven colours plus black and white are shown at either end of the interface, clicking on any two colours generates a fifteen step gradient (Figure 9). The background to the colours can be changed from white to black or grey, and the steps can be viewed in steps or butted together.

Figure 9: The Chromafile Interface

The interface, swatch palette, gradient files, plus PDF files describing the paint mixing simulation and an illustrated guide to colour, are brought together in the Chromafile software package.

Any colour can be sampled from either the gradient files and the swatch palette and be opened and viewed alongside created art work (Figure 10).

There is scope to redesign the interface to incorporate the function of the separate gradient files, possibly as a Photoshop Plug-in.

The educational applications of this work range from the simple interface to a sophisticated colour course. Graphic designers, illustrators, animators; textile, fashion and interior designers, architects, painters and computer artists will find Chromafile a useful tool, bridging the disparate disciplines of analogue and digital colour.

Figure 10: Artwork together with Chromafile Swatch and a selection of gradient files

Correspondence: * ferdinand.carabott@virgin.net ** g.d.lewis@csm.linst.ac.uk ***sp@alldesign.demon.co.uk

Optical fusions and proportional syntheses

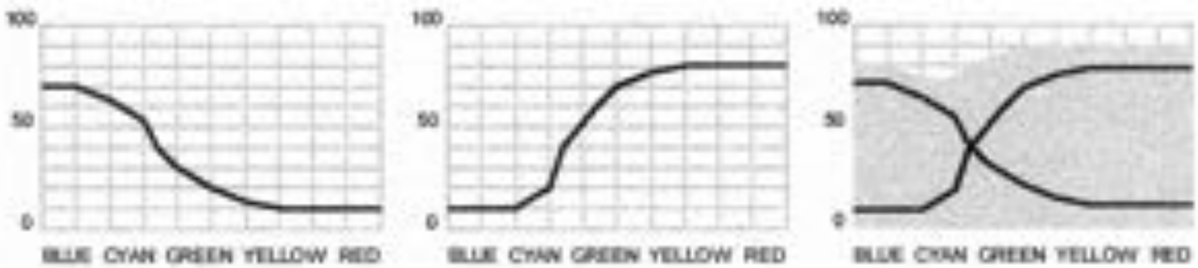
Michel Albert -Vanel
ENSAD - PARIS / Fédération Française de la Couleur

ABSTRACT

A tragic error is being made in the literature concerning matters of color when dealing with optical fusions. They are still considered to be of additive nature, whereas experience shows us somewhat different results.
The goal of this presentation is to show that fusions are, in fact, of "proportional" nature, tending to be additive or subtractive, depending on each individual case. Using the pointillist paintings done in the manner of Seurat, or the spinning discs experiment could highlight this intermediate sector of the proportional.
So, let us try to examine more closely what occurs in fact, by reviewing additive, subtractive and proportional syntheses.

THE ADDITIVE

When we examine two colored complementary ***lights***, such as a yellow and a blue, superposed onto a white screen, we see that both radiations add their respective energy spectra. In this way, the impression of white light is effectively recreated.



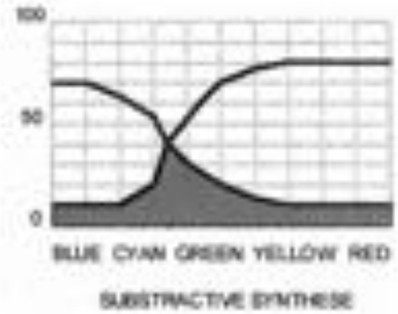
Complementary couples : green and purple, or also turquoise and orange will equally produce white in synthesis.
Trichromy, because of its constituents blue, green and red, reconstitutes equally, beyond a given distance, the impression of white. This occurs on the TV screen, with the fusion of luminous triplets constituting the pixels.
This occurs actually in conformity with the theory. However, we should underline here that this occurs in the case of luminous radiations, when their energy flows are effectively added. That is exactly where the term "additive syntheses" comes from.

THE SUBTRACTIVE

When dealing with ***materials***, such as pigments, colored inks or superposed color filters, everything occurs in a slightly different way. Moreover, there, luminous energies, instead of being added, are more or less absorbed during their passage through matter. One can say, from an energy point of view, that an actual "subtraction" occurs there.
In addition, one can go further than this simple observation, because the primaries change. So, from : blue - green - red, they become : yellow - magenta - cyan. And the same occurs in each color reproduction by printing.
This fact explains, partially, the incomprehension between painters and physicists, since the former proceed with matter and the latter with light.
So, the painter knows well that when mixing onto his palette yellow with blue, he will not obtain a white, but a green ! He knows, also, that mixing green with red will not give him a yellow, but a dirty brown !
The filters, conforming to their nature, will absorb one part of the light, and the resulting color will be composed only by the colors that can pass through both filters. That is why blue and yellow may produce green.
However, we shall observe, equally, that if the filters are selective enough, nothing passes through, and we shall deal there with black, in spite of the colors used !

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

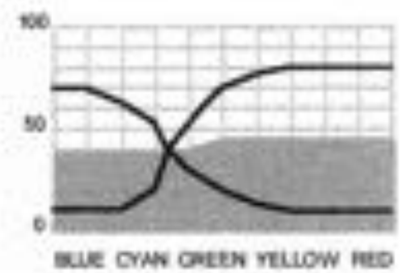
The experiment using the superposition of colored filters gives us a better understanding of the occurrence :



Therefore, when superposing red and green filters we shall obtain a dark brown, or even a black, according to their selectivity. The results will be more or less subtractive, depending on the case.

OPTICAL AND PROPORTIONAL FUSIONS

Therefore, what distinguishes optical fusions additive, subtractive, and proportional, from one another ?
In order to understand this, let us turn back to the experiment of the rotating discs. When the velocity of rotation is superior to 2,000 turns per minute, the eye no longer distinguishes between the different colors put in juxtaposition onto the disc. Above this threshold, a fusion into a uniform tint occurs, and even if one increases the speed, nothing will change. So, given that the colors on its surface were equilibrated, a disc painted in yellow and blue will give, at fusion, a grey.
A measuring instrument, placed in front of the rotating disc will « see », like the human eye, a uniform color.



Let us analyze, first, the spectral reflection curves of this blue and this yellow, before rotation, and during their synthesis on rotation. And, what a surprise ! **The resulting curve of the fusion passes exactly through the cross-section point of both curves and remains equidistant to their minima and maxima.**
This means that we are no longer in the additive, nor in the subtractive, but in the intermediate case !
Now we can understand why we obtain, by rotation, a grey, and no longer a white nor a green !

ROTATING DISCS

In order to simplify, let us undertake the same experiment, using a white and a black.
The measurements tell us that the black we are using is reflecting 4 % of the incident light and the white 80 %.
Given in each case that one is dealing with only one half of the disc, it is convenient to divide every measure by two.
The synthesis gives us : 4 % / 2 + 80 % / 2 = 42 %. The resulting grey is a 42 % grey, which gives us a very light grey.

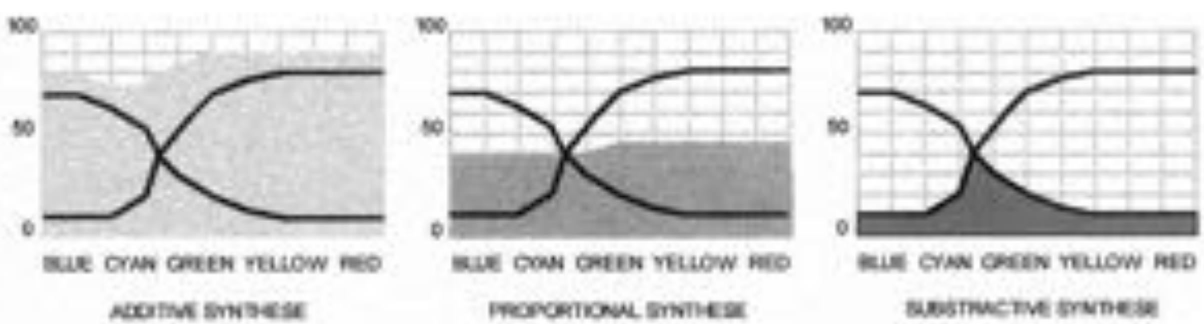
One may be surprised by this result, but it arises from the fact that white is much more energetic than black.
And one knows, since Fechner, that the progression is logarithmic.

In order to obtain a grey, which is close to the medium grey, one will have to reduce the part of the white to approximately ¼ of the circle.
One will have, in this way : (4 % x 3/4 = 3 %) + (80 % x 1/4 = 20 %) = 23 %.
Or, effectively, a grey close to medium grey.
Therefore, it is sufficient to apply the rule of three, by rationing the spectral reflections for each one of the colors, conforming to their respective area onto the circle.

One can understand, from now on, why this type of fusion is called **"proportional"**.
The same will be valid for the various colors. However, when dealing with white, one will have to reduce the parts of yellow and red, with respect to the blue and the green, in order to obtain an entirely neutral color of fusion.
So, one will have, in this way, for example :
(Yellow (48 % x 1/8 = 6 %) + (Red 24 % x 2/8 = 6 %) + (Green 16 % x 3/8 = 6 %) + (Blue 12 % x 4/8 = 6 %) = Grey 24 %. (These figures are given here as an example, of course...)

CONCLUSION ON THE IMPORTANCE OF PROPORTIONAL SYNTHESES

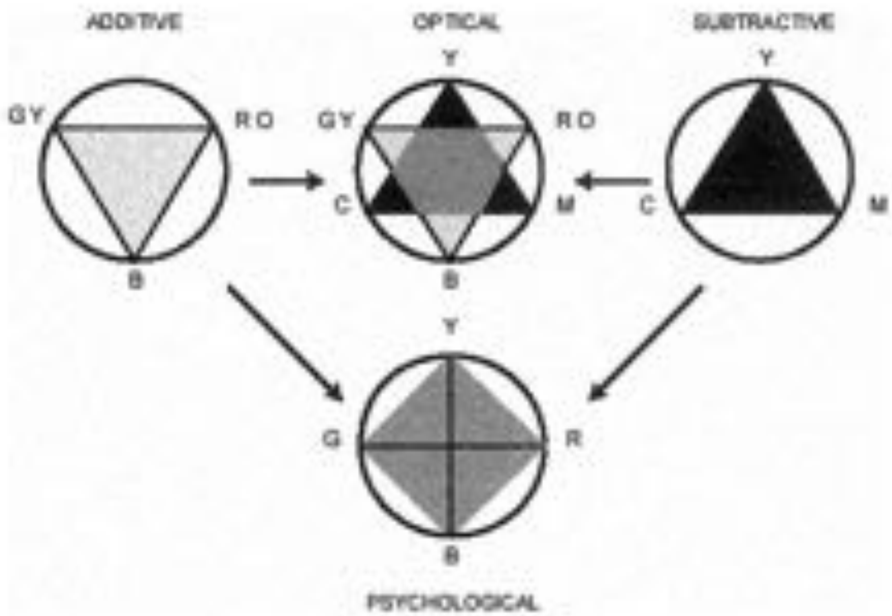
It is no matter if one is dealing with ***rotating discs*** or with painting conforming to the ***pointillist technique***. The result is the same, and in both cases, one obtains syntheses. The difference arises simply from the fact that in pointillism, distance replaces the speed of rotation. In other words, space is substituted for time...



As a result of the theories of chromatics, which were much in vogue at the end of the 19th century, and in particular, those of Charles Henry, Charles Blanc, Ogden Rood and **Eugène Chevreul**, the painters **Georges Seurat**, later Paul Signac, and others, believed that it was possible to reconstitute the light of landscapes into their paintings, thanks to optical fusions.
According to the theory, when juxtaposing minuscule points of pure colors, the fusion should occur at a distance and reconstitute the color white, as it was supposed to occur on rotating discs... Nevertheless, we have seen that this was not true !
This experience brought nothing but disappointment to the painter, despite the enormous labor it occasioned him !
And this denounces the danger of blindly following a theory !
In fact, when the human eye sees a painting, a landscape or an object, it operates with nothing but optical fusions, according to the distance, and therefore, with proportional syntheses.
In a landscape, the leaves, the flowers or any other element will be more or less dissolved into the context and their details will gradually disappear, gradually, into a general dominant.
This proportional synthesis, quite often forgotten in the literature, is nevertheless the most important one, because it is the synthesis of our everyday color vision.

PROPORTIONAL PRIMARIES

Since, when dealing with the proportional, one is in an intermediate position between the additive and the subtractive, one has to resort, at the same time, to the additive primaries : blue - green - red, and to the subtractive ones : yellow - magenta - cyan, which gives us six primaries.
Experience shows, indeed, that in the case of rotating discs, one could not be satisfied with the use of three primaries only, regardless of their specific nature, when reconstituting, by fusion, the ensemble of nuances of the chromatic circle.
However, do we need all six tonal primaries ?
As a matter of fact, no, since the blue of the additive and the cyan of the subtractive are very close to each other, and the same is valid for the red of the additive and the magenta of the subtractive.
Four tonal primaries therefore remain indispensable : yellow - red - blue - and green.
And, along with white and black, these are exactly the **« psychological » primaries of Hering**, which justify their experimental importance.
The various cases are never clear-cut or absolute !
So, in offset printing, by example, we are dealing with the juxtaposition of color points, which are partially superposed. Therefore, there is a fusion with a tendency to the subtractive. Nevertheless, there is not pure subtraction, so we have to add black.
The same is observed in television, where luminous points will fusion at a distance, and we know that yellow, for example, will be not be of excellent quality here. Here again, fusion is just tending to additivity, without total domination.
In the case of a tendency to additivity, the importance of yellow will be attenuated.
In the case of a tendency to subtractivity, it is the importance of green, which will be attenuated.



That is why we choose these primaries, called **"psychological" primaries by Hering**, as the basic constituents of the **"Planetary System of Colors"**. Because, for most cases of our everyday life, we do nothing but experience, proportional optical syntheses even without realizing it.

One may even risk generalizing the principle and say that, finally, color vision occurs essentially on the basis of optical and proportional syntheses.

Simply, according to each case, the synthesis will show a tendency to additivity, or to subtractivity.
Therefore one may conclude that these proportional syntheses were somewhat ignored by science whereas they are the most important ones !

Applications of the three color zone system: A cinematographers tool to understand color

Salvador Melita
Department of Audiovisual Communication. School of Fine Arts.
La Plata National University, Argentina

ABSTRACT

The Three Color Zone notation system is originated in the need that the directors of photography have of working with color together with the illumination. The system offers a tool that uses well known units, such as stops, exposure values (EV), or zones [1], classifying colors (surfaces or filters) according to the zone in which every layer of the photographic emulsion is exposed.

The main idea of the system is to integrate all the aspects that the directors of photography work with. We can also extend the system to color temperature and the color rendering of light sources.

The aim of the paper is to show, by means of images, how the system works.

Keywords: color zone system, notation, cinematography

1. DESCRIPTION OF THE SYSTEM

The Three Color Zone System is originated in the need that the directors of photography have of working with color together with the illumination. The system offers a tool that uses well known units, such as stops, exposure values (EV), or zones [1], classifying colors according to the zone in which every layer of the photographic emulsion is exposed. In this way, the white color of a sheet of paper would be 7.3/ 7.3/ 7.3 (meaning that white is exposed in the zone 7.3 of the red sensitive layer, 7.3 of the green one, and 7.3 of the blue one), a saturated red would be 7/ 4/ 4, a light red 7/6/6, a printed black 2.5/ 2.5/ 2.5, and so on. As a result, we were able in this way to classify every sample of the Natural Color System atlas.

On the other hand, also starting from densitometric measurements, the usual gelatin filters are classified also into zones according to their degree of absorption for every primary color: Red (R), Green (G), and Blue (B). Thus, a red filter would be 0/-2/-2, which means that it transmits all the red while making the transmission in the green and blue zones to decrease (1/4 for each one, two zones). We have also classified a Lee set of about 200 filters. If we classify a series of gelatin filters Yellow, Magenta, and Cyan as Y =-B, M = -G, C = -R, we can reproduce any color of the gelatins by only superimposing them in the adequate proportions. In example Rosco Calcolor.

The main idea of the system is to integrate all the aspects that the directors of photography work with. We can also extend the system to color temperature and the color rendering of light sources:

source + filter + surface color = resulting color +/- zone difference

For instance, let us suppose that we have two colors, cyan and magenta. The notation for cyan is 3.5/ 5.5/ 5.5, that is, red is exposed in 3.5, green in 5.5, and blue in 5.5; thus, it is a medium dark cyan. For the magenta, red is exposed in 6.5, green in 3, and blue in 5. Now, I am going to add a 0/0/-2 gelatin (yellow) to these two colors. It does not alter red, nor green, but makes blue to decrease in two points. What happens? With this gelatin applied to cyan, red and blue are decreased to the same level, then, the result is a somehow desaturated green color (3.5/5.5/3.5). In the case of magenta, the yellow gelatin transforms it into red (6.5/ 3/ 3).

Finally, in order to unify criteria, all samples (from the atlas and from the gelatin collection) were photographed and measured with a densitometer.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

Table 1. CZS notation for different gelatin filters

	Lee filters	- R	- G	- B	Rosco	Calcolor filters	
7	PALE YELLOW	- 0.1	- 0.1	- 0.8			15y
36	MEDIUM PINK	- 0.1	- 1.7	- 0.8		30+15m	15y
61	MIST BLUE	- 1.1	- 0.5	- 0.1	30c	15m	
88	LIME GREEN	- 1.0	- 0.2	- 2.5	30c		60y
109	LIGHT SALMON	- 0.1	- 1.3	- 0.9		30+15m	30y
117	STEEL BLUE	- 1.6	- 0.5	- 0.1	30+15c	15m	
121	LEE GREEN	- 2.0	- 0.3	- 2.3	60c	15m	60y
131	MARINE BLUE	- 3.0	- 0.7	- 0.7	90c	15m	15y
138	PALE GREEN	- 0.8	- 0.1	- 1.8	15c		30y
144	NO COLOUR BLUE	- 3.5	- 1.1	- 0.3	90c	15m	
156	CHOCOLATE	- 1.2	- 2.1	- 2.9	30c	60m	45y
201	CTB FULL	- 1.9	- 1.3	- 0.3	60c	30m	
170	DEEP LAVENDER	- 0.7	- 2.0	- 0.8	15c	60m	15y
298	0.15 ND	- 0.4	- 0.4	- 0.4	15c	15m	15y
209	0.3 ND	- 1.0	- 1.0	- 1.0	30c	30m	30y
210	0.6 ND	- 1.9	- 1.9	- 2.0	60c	60m	60y
211	0.9 ND	2.9	2.9	2.9	90c	90m	90y
	Rosco filters	**- R**	**- G**	**- B**	**Rosco**	**Calcolor filters**	
#44	Midle rose	0	- 3	- 0.4		90m	15y
#59	Indigo	- 6.3	- 6.1	- 1.8	90c+45c	90m+30m	
3220	Double blue	- 4.8	- 3.3	- 0.8	90c+30c	60m+15m	
Rosco	**Calcolor filters**	**- R**	**- G**	**- B**	**Rosco**	**Calcolor filters**	
	cyan	- 0.8	- 0.4	- 0.4	15c		
	cyan	- 1.4	- 0.4	- 0.4	30c		
	cyan	- 2.6	- 0.7	- 0.6	60c		
	cyan	- 3.9	- 0.9	- 0.8	90c		
	magenta	- 0.4	- 0.9	- 0.5		15m	
	magenta	- 0.5	- 1.6	- 0.6		30m	
	magenta	- 0.8	- 2.9	- 0.9		60m	
	magenta	- 1.0	- 4.1	- 1.1		90m	
	yellow	- 0.2	- 0.2	- 0.7			15y
	yellow	- 0.2	- 0.3	- 1.2			30y
	yellow	- 0.2	- 0.3	- 2.3			60y
	yellow	- 0.2	- 0.3	- 3.3			90y

2. PAINTING WITH LIGHT

Suppose that we have a white wall in the background of the scene. We can paint it putting a filter in the light source, for instance -0.1/ -0.8/ -5.4. Subtracting from the white (7.3 / 7.3 / 7.3), we obtain 7.2 / 6.5 / 1.9: yellow (S-0570-Y). If we are underexposing 1.5 stops, it results in a darker yellow 5.7 / 5.0 / 0.4 (the nearest NCS sample is S-2070Y). Note that the limits are linked with the film latitude. In the opposite way, if we are overexposing, we obtain a lighter color.

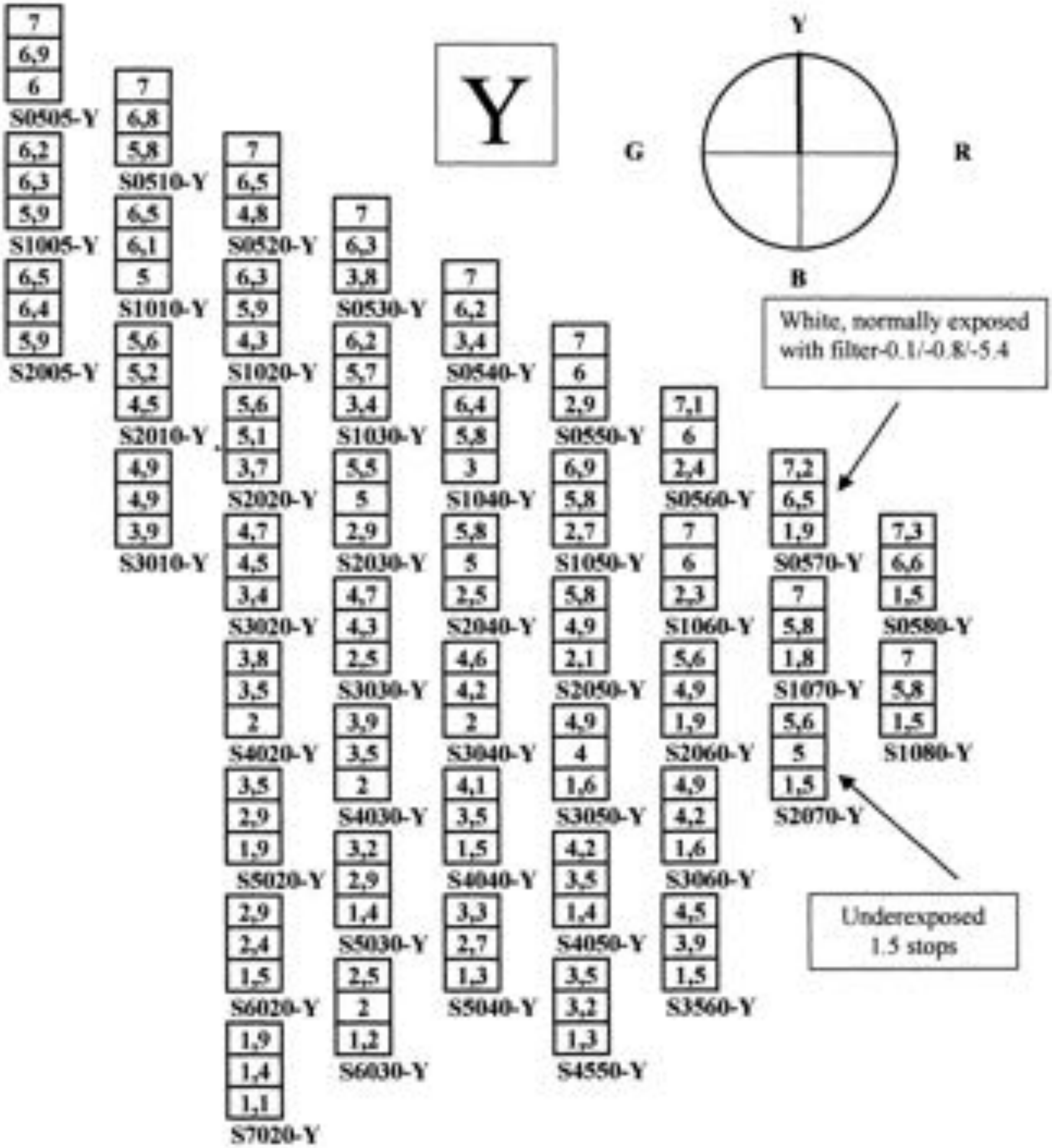


Figure 1. Page from the NCS, renotated according to the CZS.

3. PUSHING

With this system, we will analyze now a photographic process like pushing (underexposing and overdeveloping). When some film is pushed, it is underexposed, first, and then overdeveloped. For example, if we take a red 7/ 4/ 4, and we underexpose one stop, i.e. we expose it as 6/ 3/ 3. Then, when overdeveloping, the main differences will appear in the high lights; and finally, the resulting red color will be 7/ 3/ 3, having reduced the gray content with respect to the original one, becoming more saturated.

As a conclusion, we can point out that this system may also be useful as a tool for the analysis of the different processes.

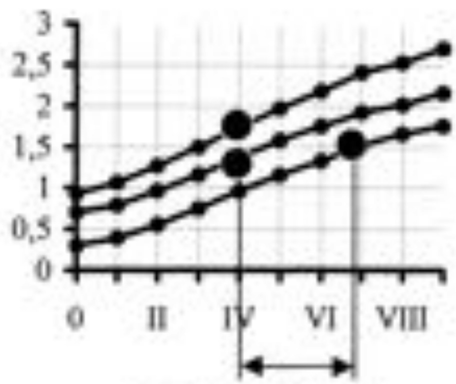


Figure 2a. 7, 4, 4: Normal.

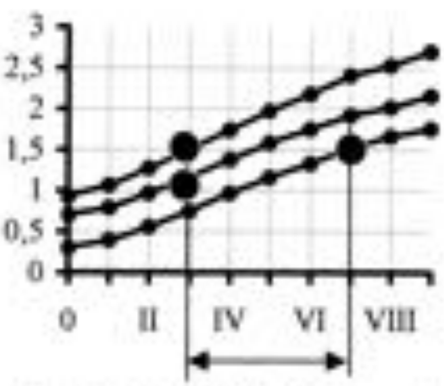
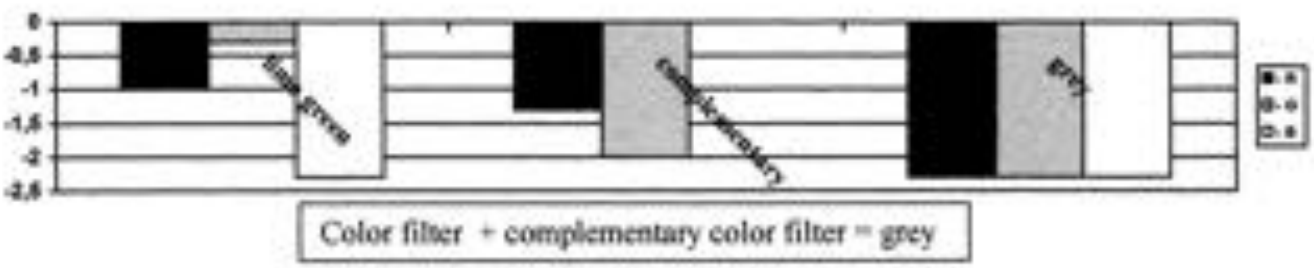


Figure 2b. 7, 3, 3: Pushed, higher saturation.

4. COMPLEMENTARY COLOR

If we see the spectrum of white light, and then we apply a filter, we will see that some color disappears, it is the complementary of the filter. Hence, we can refer to the complement as the lacking component to make the nearest gray mixture. Take, for instance, the lime green filter from LEE, whose CZS values are –2/ –0.3/ –2.3, the nearest gray is –2.3/ –2.3/ –2.3, and the difference is –0.3/ –2/ 0, this being the notation for the complementary filter.



(-1/-0.3/-2.3) + (-1.3/-2/0) = (-2.3/-2.3/-2.3)

ACKNOWLEDGMENTS

We are indebted to Industrias Audiovisuales Argentinas (Videocolor and Cinecolor Laboratories) for facilitating the film and the measurement devices.

REFERENCES

1. Adams, Ansel, *The negative*, 12th ed., Little Brown & Company, Boston, 1992.

smelita@iam.com.ar; phone 54 11 4956 0206; fax 54 11 4956 0206; Mexico 2766 (C1223ABF) Buenos Aires, Argentina.

Colour, light and altruistic creation

Yves Charnay*

ABSTRACT

It seems necessary to me to combine a certain technical inventivity with plastic creation, a particular poetry arises from this relation. The sources of inspiration for works, especially works in which colour plays a pre-eminent role, do not only come from nature. The fantasy of the creators evolves and changes thanks to discoveries and technological inventions .
My work as a painter has made me particularly sensitive to the diversity of the plastic writings in general and to the chromatic writings in particular. (1). Environmental creation imposes a renewal of the means of creation. Conducting experimental works, I study the particularities of light, mainly its incidence on materials (transmission, reflection, colours, textures, etc) and its mobility. These works are a source of inspiration for my architectural works and nurture my lectures at the Ecole Nationale Supérieure des Arts Décoratifs (National College of Decorative Arts).
Environmental creation also imposes some qualities on the artist since he, whether he serves a social entity or a person, serves the whole collectivity. Environnemental creation has to be envisaged as an altruistic approach.

Keywords : colour design, altruism, theatricality, chromatic writings, poetic " bricolage ", contemporary art.

1. INTRODUCTION

Colour is not a wave, a pigment or a colouring : it is neither liquid, nor solid ; neither opaque nor transparent or reflective. It is a feeling that our brain creates and that our mind transforms into art. (2)

Light and colour give works their singular dimension. Colour plays an important role, plastically, conceptually and symbolically. Chromatic choices give meaning, as Jacques Fillacier explains very clearly in his book « Pratique de la couleur », since they classify, structure, associate or distinguish. ... (3) Light and colour, while transforming space, "build meaning". Light and colour greatly contribute to the expression of an environment (4). Environmental creation has to be considered as a whole, as a work in itself since the fragmentation of the interventions hardly makes it possible for a synthetic expression.
Nowadays plastic works naturally include space, temporality and dynamics in their fields of expression. On this adventurous ground, new forms are invented and new creation processes which cross areas such as visual communication, design or scenography are set up. Contemporary art, in some of its orientations, attempts to integrate- whether conceptually or plastically- all the modes of expression in a global expression. Nowadays, the fusion of the new forms of creation revolves around "*poetic gestures*".

2. SOURCES

2.1 Evolution

The evolution of technical practices opens up new ways for creation. Since the twenties especially, some artists such as Duchamp for instance, have not hesitated to use the new technical resources offered by science : fluorescent lamps, polarized glasses, cathodic tubes, ultraviolet light, coloured shadows or even, later, lasers to accomplish their works. In France, these experiments were reconducted notably in the sixties by the artists from the « Groupe de Recherche d'Art Visuel ». (Resarch Group on Visual Art). As shown by the digital « revolution », technological innovations constantly renew our modes of expression.

2.2 Nature

Willow leaves rustling in the wind, the irradiant red of a field of poppies, incandescent curls coming out of a volcano, the golden brightness of the sand against the blue ocean or a tiny rainbow appearing in the iridescent cloud of a waterfall : the variety and proliferation of forms in nature is a never-ending source of inspiration.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

Natural materials and their rich textures, leaves, trees and minerals constitute complex constructions of colours and the reflection-quality of their surfaces, the particularities of their transparency offer an infinite number of paths to light. Our very daily environment is full of « natural plastic events » to which we do not pay much attention.

2.3 Architecture

The way people have built their towns, houses, castles, churches or temples proves the ressources of invention they have resorted to in order to make the materials « live » through their colours, their textures and the rich forms on which light plays. The sunlight on the bluish walls in the town of Gardahia, in the South of Algeria, gives the limpid and fresh shade of lagoon water to this harsh city of the desert.

The troglodytic architecture in Cappadoce, (Turkey) has brilliantly used the geological particularities of the region to fit in the landscape, creating a camouflage protecting the populations. The gopuram of Tiruchirapali, in India, bright with colour, expresses the intensity of the inhabitants'faith (5). In China, in the traditional gardens of Suzhou, a clever interweaving « nature and architecture » in which vegetals and minerals form a whole, expresses a trend of the Chinese thought (6). When the dazzling sunlight appears between clouds and invades the chapel of the Cistercian Abbey of Noirlac, it transmutes the grey and bare walls into gold (7).

Ceaseless hubbub seems to rise from the millions of lights that pierce through the walls of the skyscrapers in New York. In Seoul, in front of a temple and away from the bustle, fragments of paper hanging from thousands of Chinese lanterns, creating a sort of multicoloured roof, discreetly sway prayers in the night.

2.4 Materials

The world of science and technics invents amazing materials and new products with outstanding visual properties. Although they offer new resources to plastic creation, they are often not so well plastically mastered as the traditional materials and products. Generally offering a wide range of colours, they also enrich the palette of textures.Their properties of reflection, diffusion and transmission of light give the creators new resources of expression (8).

2.5 Light

It has been observed that natural light is not enough taken into consideration in environmental creation. The daily and seasonal changes of sunlight which are also induced by the climatological variations moderately influence the expression of an internationalized architecture. We rather observe a restriction of the diversity of expression. Artificial lights too are often neglected as a means of creation. Yet, since the sixties new sources of light have appeared. They have grown different in size, shape, power and quality. New enslavement devices increase their manageability.

2.6 Appearence

The visual appearance of things cannot be properly understood, thus well apprehended, if we set aside the fact that our brain interprets the information – and this sometimes with difficulty. The well known phenomenon of contrast modifies colours under certain circumstances. In fact, any « object » present in our field of vision is interpreted. More or less consciously we estimate distances, differentiate colour shades, associate or distinguish surfaces, identify lines, recognize shapes, etc in a complex relation of interacting phenomena. Some of these phenomena are explained in a recent article by Françoise Viénot (9)]. It is useless to point out here all the points evoked in the article, it is better to refer to it. I only wanted to underline here that we can count on our mind to continually interpret reality. It is a kind of intellectual exercise of which the artist sometimes takes advantage.

2 . POETIC « BRICOLAGE »

The universe of colour is huge, indeed whether natural or created by man it integrates "lightings" as well as materials in the immense variety of their appearances.

Colour cannot exist without light and light does not only mean lighting whether artificial or natural. Light takes part in the expression through its plays on the appearance of the materials, the textures, the transparencies and reflexions of the surfaces.

I have created devices which capture light, classify colours or master substances. Some of these devices have been patented. My aim is to create works which bring into play the fluidity of light, the movement of shadows, the

metamorphosis of colours, the singularity of textures or the mobility of reflections. Somehow a sort of « bricolage » has to be done, not only a technical, but a « poetic bricolage ». (10)
The poetry of the plastic events that we create for our environment has to help us to find harmony with the world.

3. CREATIONS

Without excluding traditional techniques, I often favour light for its features of fluidity, immateriality, lightness or mobility to render the emotions inspired by a site. I also use from time to time more or less complex techniques, some of them have given birth to patented devices.

My first work for an architectural environment was carried out in 1968. This work was commissionned by a supermarket belonging to a chainstore that was opening its first shop near Paris. Because of its great dimensions, the work was an event itself in the area. As the inhabitants could do their shopping at night, I used a discreet analogy with fun fairs. The variations of colour due to the change of the lighting metamorphosed the coloured graphism and induced a feeling of movement. An electronic programm had been especially conceived to manage the variations of frequency of the lighting sequences.
I have worked several times in collaboration with Jacques Fillacier, notably to colour a motorway tunnel : the tunnel of Saint Cloud, which was inaugurated in July 1974 in Paris. The project was incredibly original since its conception took into account the dynamics of the traffic flow. The colours of the shapes painted on the walls of the tunnel had been chosen so that they would change according to the predominant colour of the lighting. The transformation of the shapes on the walls had been imagined in agreement with the officials in charge of the safety to incite the drivers to slow down.
The colourization of the Research Centre of the firm Rhône Poulenc, carried out with Jacques Fillacier, was the occasion to create a specific plastic work. To achieve this work, I set up an original inclusion technique for liquid crystals : cholesterols. The appearance of this 3 square metre work changed according to the variations in temperature and the angle of incidence of light. The surprising appearance of this work located in a strategic zone of the site and the innovative feature of the process which had been used have played an important role in the expression of modernity and inventiveness claimed by the firm.
In 1985 I was commissioned by the Ministry for the Arts to carry out some works. One of them was part of an event called « La rage de lire » *(the will to read.)*. The aim was to incite people, youngsters especially, to read. I chose to use the image of germination to express the pleasure of reading. The lighting was ultraviolet light.
In March 2000 I created in a chapel in the South of France an environment which exploits the properties of sunlight. The chapel has now become the Music School of Apt, a town in Provence. The title of the installation is « *Des couleurs tombées du ciel* » (11) *(Colours fallen from heaven)*. Set in openings between the inside and the outside, a device made of wooden slats catches the sunlight like stained-glass windows. The diffuse reflection of light lights the inner space of the chapel. When the sky is cloudy, the intensity of the colours changes. The atmosphere changes between morning and evening. Artificial lighting replaces natural light.

4. CONSTANTLY EVOLVING DISCIPLINES

Today' s modern society sets a rythms, work methods, and an economy which is suited for new media such as visual communication, design or scenography.
Design and scenography precisely renew practices which are naturally included in the field of decorative art. Decorators are particularly reproached for working more on signs which show the hierarchic distinction of a social representation instead of authentically creating new expressions. Do design (12)| and scenography really offer new approaches to contemporary creation or do they only cover an obsolete discipline with a veneer of modernity ?

As the opposite effect of the progress in the knowledge and practice of colour, an "aesthetic of the efficency" has established itself and perpetuated aesthetic choices which were sometimes questionable. The industry makes products which are « formated » according to the demands - real or supposed - of the « average consumer ». In a globalized economy, industrial production enhances this trend. In order to turn colour into a « product » similar to the others, it had to be stripped off its ephemeral, fleeting, unstable, transient properties. Its fundamental qualities had become "defects". The possibilities of creation are being shrunk.

In the environmental area, maybe none of these disciplines is able to synthesize the new artistic practices. The digital techniques aimed at helping creation have attracted brilliant operators yet deprived of artistic experience. Prompted by the development of new technologies, this highly advertised field hides the fact that machines do not create. Yet, the recent evolution requires skills which, transgressing the traditional boundaries between arts, draw a bridge between architecture and plastic arts. Some experiences in contemporary art can maybe pave the way.

5. THEATRICALITY

Planning a public or private space consists in representing a person or a community and expressing his/her or its values (13) plastically. The expression of a site synthetizes the relations which unite a population with a space in its physical and historical dimensions. An environmental realization is subject to the site's " theatricality ", the dramaturgy of which has its source in social life. The natural tendency consists in intensifying a fixed social hierarchy with plastic signs. This negative side of the staging of everyday life has to be offset. The concept of theatricality broadens the notion of environment beyond the user, up to the inhabitant, the citizen. Taking into account the scenographic dimension of the space opens up a large variety of modes of intervention for artistic creation.

The renewal of environmental creation has to be also performed through the exploration of the territories opened by the new artistic methods.

6 . CONCLUSION

I may seem to wander from the main subject but I believe that, on the contrary, I bring the question of creation back at the centre of the debate. Whatever the discipline is or whatever the used techniques are, creative invention remains the key element for the renewal of the expression of our environment while respecting the others. Art links people together so it is important that she we should now move away from the too technocratical notions of planning. In our democratic societies the expression of a person or a collectivity has to be performed while respecting the identities of the others. It is not a limitation but, on the contrary, one should make clear that conceiving a human environment requires an altruistic approach from the creator.

In fact, wouldn't it be more appropriate to consider that artistic creation as a whole is altruistic ?

ACKNOWLEDGEMENTS

I am particularly grateful to Jacques Roire for his advice and documentation which he generously passed on to me. Jacques Fillacier's book « Pratiques de la couleur » gave me precious food for thought.

REFERENCES

[1] YC. « *Des couleurs en un certain ordre assemblées* ». Edition EREC, in : *actes du colloque sur la couleur au Musée de La Villette*. 1996. Paris.

[2] YC. « *Le revêtement inexistant des choses* », in Journal des Arts Décos. Juin 2001. Paris.

[3] Jacques FILLACIER, « *Les fondements de la psychométrie* ». édition ENSAD, Paris 1974.
« *Les cahiers de couleur* », collectif, édition ENSAD et Ministère de la Culture, 1987, 1988, 1991, Paris

[4] Jacques Fillacier, « *Pratique de la couleur* ». Edition Dunod, 1987, Paris
Bernard Lassus, « *Ville paysages, couleurs en Lorraine* ». Edition Batigère, 19, Paris
Bernard Lassus, « *Une poétique du paysage. Le démesurable* », C C I, Centre Pompidou. 1975, Paris

(5) YC. « *La couleur des dieux* ». Documentary film 52'. 1990. La Sept-FR3 Production

(6) SONG Jian Ming, « *Les couleurs en Chine* ». Doctoral thesis. Ecole Nationale Supérieure des Arts Décoratifs. 1993, Paris.

(7) YC. « *Une forteresse de prière, Noirlac abbaye cistercienne* ». Documentary film. 26'. 1997. FR3 Production.

(8) George A. AGOSTON, « *Color theory and its application in art and design* ». Springle Verlag, Berlin 1987

(9) Françoise Viénot, « *Couleur et perception* ». Article published in « Techne » n°9 – 10. Published by the Centre de Recherche et de Restauration des Musées de France. CNRS – UMR. Paris. Décembre 1999

(10) Here the word « bricolage » does not designate only technical operations but a set of intellectual operations which aim at efficency but without following a scientific approach.
I have borrowed this concept from Claude Levy Strauss and hope I have not betrayed his thought too much ! « *Tristes tropiques* ».

(11) « *Des couleurs tombées du ciel* », juin 1999. Edition EREC, in : *actes du colloque sur la couleur au* Muséum d'Histoire Naturelle, Paris.

(12) « *Le design* », in « Architecture d'aujourd'hui ». N°155, April, May 1971. Paris.

(13) YC, « *La fin de l'art décoratif* », in ETUDES, Assas édition, April 1998, Paris.

*** Contact auteur** : ycharnay@club-internet.fr. ; **téléphone** : 33 – 1 – 42 33 94 45 ; **fax** : 33 – 1 – 42 60 14 63 ; http://yvescharnay.free.fr ; **Ecole Nationale Supérieure des Arts Décoratifs, 31 rue d'Ulm, 75005, Paris, France.**

Effective Colour Design for Displays

Lindsay W. MacDonald*
Colour & Imaging Institute, University of Derby, UK

ABSTRACT

Visual communication is a key aspect of human-computer interaction, which contributes to the satisfaction of user and application needs. For effective design of presentations on computer displays, colour should be used in conjunction with the other visual variables. The general needs of graphic user interfaces are discussed, followed by five specific tasks with differing criteria for display colour specification – advertising, text, information, visualisation and imaging.

Keywords: Colour selection, design, graphic user interfaces, information display, visual variables.

1. INTRODUCTION

Colour in a display cannot be specified in isolation but must be considered as one aspect of a user-centred design process. Analysis and design choices must take place at several levels:

- Application – organisational context, business needs, transactions, database structures, compatibility, conventions.
- User needs – task requirements, physical and visual ergonomics, viewing environment, motivation, experience.
- Interaction – dialogue design, controls, response indicators, menu selection, information structures, links, navigation.
- Presentation – layers, composition, regions of interest, form, tone, typography, colour.

Colour is one of the principal presentation-level visual variables[1]. For effective design of presentations on computer displays, colour should be used in conjunction with the other visual variables of position (x,y co-ordinates), value (lightness), size, shape, orientation, and texture. This will help a colour-deficient person to interpret the display, even when he (fewer than one percent of women are colour deficient) cannot distinguish the colour codes. A good principle is first to ensure that the layout works in monochrome, then add colour sparingly to reinforce the message. Graphic designers, caricaturists, engravers and photographers all achieve very effective results using only black-and-white or greyscale. In fact, the absence of colour may enhance human perception in the other visual dimensions — nuances of tone, sharpness, texture and so on. Much can be discovered about a design's effectiveness by examining how its visual elements are grouped and perceived as a whole. The Gestalt laws of proximity, similarity, continuity, closure and figure-ground provide powerful organising principles that apply to all aspects of design, including colour. Colour may be used for both association, indicating that certain elements in a design have common properties, and differentiation, indicating that certain elements differ in their properties from the others.

In general, for a set of colours to work well in a design, some unifying attribute should tie them together, following the Gestalt law of closure (completeness). This could be a particular hue or range of saturation or lightness that appears throughout the composition, relieved by small areas of a contrasting accent colour. Artists have often employed this technique to create a chromatic unity in their paintings, most notably Titian, Caravaggio, and Velázquez. In Monet's paintings of his Japanese garden, the colour palette serves not only to depict the scene but also to establish for the whole picture a coherence, or "perceptual envelope" as Monet himself called it.

In the design of graphic displays, the intents of decorative colour may be distinguished from those of functional colour. Decorative colour enhances a display by making it more aesthetically appealing, creating a mood, or establishing a characteristic style. Functional colour conveys information explicitly or provides the user with some other operational benefit. Independently, the colour relationships within the display may be classified as either absolute, where each colour stimulus is precisely specified, or relative, where the meaning arises from the interplay between colours, e.g. foreground/background, centre/surround, or juxtaposition. These two dimensions produce a matrix of colour usage:

Colour Intent	Absolute	Relative
Decorative	Textiles, fashion palettes	Art paintings, image rendering
Functional	Corporate logos, warning signs	Text, icons, maps, charts

* L.W.MacDonald@colour.derby.ac.uk; phone +44-1332-622217; fax +44-1332-622218; http://colour.derby.ac.uk; Colour & Imaging Institute, Kingsway House East, Kingsway, Derby, DE22 3HL, United Kingdom.

2. GRAPHIC USER INTERFACES

A graphic user interface (GUI) assists the user in viewing and interacting with an application. It must therefore provide all necessary functionality, yet remain unobtrusive, helping the user to perform appropriate tasks without distracting attention from the content. The general rule is to make form indicative of function. The designer should create all the components of a GUI, such as window frames, sliders, buttons, icons, and dialogue boxes, in monochrome and then add colour with discretion to enhance usability. Understatement of the design is preferable, with unnecessary embellishment kept to a minimum. Strong colour may be effective in small regions (up to 2 mm in diameter), but should be avoided in large regions.

Take icons as an example. An icon is a symbol that looks like what it represents. Icons are widely used because users can immediately recognise them, provided that: (a) they're well designed; (b) not too many of them appear on the same screen; (c) they are consistent throughout an application; and (d) their functional behaviour is congruent with that of the metaphorical object. Design of an effective icon within the confines of a small grid of pixels requires clarity, simplicity, and careful consideration of what the user will see at the normal viewing distance. Line and form are more important than tone and colour. Indeed, colour should be the last component added, and then used only minimally to reinforce the symbolism. The choice of colours for a GUI is less important than their consistent use throughout all screens. Every effort should be made to achieve both consistency within the application and externally with other applications, systems, and real-world conventions.[3]

The 'principle of least astonishment' that guides dialogue design applies equally to colour. The user should quickly recognise each functional element and not get confused by unexpected changes in the assignment of different colours to similar functions. Details such as this contribute significantly to a GUI's overall stylistic integrity – its 'look and feel'. A limited palette of distinctive colours (no more than about 10) suffices to provide the in-fills for all icons and graphical symbols. When chosen consistently, these colours also help to establish a harmonious visual style. If the application lets the user choose colours through control panel settings, e.g. for title bars, menus and backgrounds, ready-made schemes of harmonious colours should be provided wherever possible. Some rule-based systems generate such schemes automatically.

Colour selection guidelines

- Use colour consistently throughout all screens in an application.
- Use strong colour in small details only, such as icons and graphical indicators.
- Use a limited palette of colours and offer predefined harmonious combinations.

3. ADVERTISING

An advertising display first attracts attention and then persuades the viewer to buy, do, or believe something. Colour can be very effective for both these phases, and the rules that govern its use differ substantially from those of information display or prolonged interaction. Visual engagement with an advertisement must be very rapid, within the fraction of a second that the observer is receptive. Examples occur in computer graphics displays in multimedia kiosks, broadcast television and video, animations, and Web site banner pages, where browsing users flick from one page to another. Bright colours clamour for attention, and, if sustained against a dark background, they can excite or arouse the observer like neon signs or discotheque lighting. Designers achieve this 'Las Vegas effect' by using pure primary and secondary colours on a black background.

Bright colour should not be sustained for long, because it loses its effect as the eye rapidly becomes fatigued. It should give way to a more balanced colour scheme, within which the advertiser conveys the qualities of the product by informing or entertaining the viewer. Colours themselves can help to persuade, through their associated qualities and the emotions they elicit (both positive and negative). These qualities derive from natural occurrence, cultural norms, and conventional usage. At the end of the period of engagement (usually less than one minute) the viewer should retain something memorable.

The Web is an important new medium for computer graphics, in which colours on the screen depend on the originator (author) of the pages, the person viewing the pages via a browser, and the software tools and graphics hardware used for encoding and display. The Web is a tabloid medium in terms of its vastness of extent, millions of users, low information content per page, and "in-your-face" presentation style. Like other tabloid media such as newspapers and television, it has a variety of purposes, including entertainment, advertising, and the conveyance of graphical information and text passages. A subset of 216 colours, known as the browser-safe palette, has become the *de facto* standard for encoding colour graphics and images for Web display. Careful use of this palette can substantially improve the colour quality of both graphics and images.

Colour selection guidelines

- Use bright, highly saturated colours to grab attention, but not for prolonged viewing.
- Take advantage of the psychological associations of colours.
- For Web graphics, use colours from the browser-safe palette.

4. TEXT

In all systems in which the user's principal task is reading or processing text, the most important criterion is legibility, the ease with which the user can read text or other symbolic information on the display. Most human-computer interfaces employ text in various ways, so legibility always poses an important design issue.[3] The principal determinant of legibility is the luminance contrast ratio between foreground and background, which should be a minimum of 3:1 and preferably at least 10:1. Generally, the best text displays for sustained viewing, e.g. in a word processing application, should use black text on a light grey background. Large areas of white on the screen should be avoided because the glare may lead to visual fatigue, increase the chances of the viewer's seeing flicker in the periphery, and also reduce the life of the display. For coloured text on a coloured background, relative luminance of the different hues must be considered. The most legible combinations have the highest contrast, such as black or blue on white or yellow, and vice versa. Certain combinations, particularly those involving red, green, and magenta, may produce unpleasant visual 'vibrations', and so make reading more difficult. In general, a good rule is never to use coloured text on a coloured background where legibility is important – colour either the text or the background, but not both. Legibility also depends on text size. The optimum size depends on the foreground-background colour contrast. For achromatic text (black on white) the peak visual sensitivity occurs at about 5 cycles per degree subtended at the eye, equivalent to a line width of 0.1 mm at a viewing distance of 60 cm from the screen. The optimum character height recommended at this viewing distance is 3.5 mm, equivalent to a 14-point font size.

Attention to presentation and font design will help to achieve satisfactory legibility. Colour may be used to good effect for differentiation – for example, highlighting in yellow the results of a word-search. In such applications, the colour should appear to be a light transparent dye, like a highlighter pen on a paper document. The exact colour is relatively unimportant, provided that it doesn't detract from the legibility of the text, yet is conspicuous enough to be seen easily.

Colour selection guidelines

- Ensure good legibility by providing adequate contrast between text and background.
- Avoid coloured text on a coloured background.
- Use the metaphor of a highlighter pen to draw attention to areas of text.

5. INFORMATION

Colour can provide a very effective means of increasing the information content of a display or making it easier to interpret. The principles of good graphic design apply just as much to computer information displays as they do to more traditional media. Key issues to consider are clarity, comprehensibility, and how well the user will be able to pick out the desired information and understand its significance. Contributory factors include:

- Discernibility – how easy it is to distinguish an item from its background;
- Conspicuity – how obvious the item is relative to its neighbours; and
- Salience – how well the item "pops out" from the display as a whole.

Tufte advises using strong colours sparingly on or between dull background tones: "Colour spots against a light grey or muted field highlight and italicise data, and also help to weave an overall harmony."[4] With nominal colour coding, we assign a set of unique colour codes to the different parts or states of a system. Such a code is nominal in the sense that it neither indicates differences in value nor implies an order of priority. Two human factors constrain the maximum number of colours for unambiguous colour codes: first, the observer's ability to discriminate visually between the different colours; second, the observer's ability to remember the meanings of the colours and to associate those meanings correctly with the visual stimuli. Both factors lead to the same conclusion, that the number of colours should be limited to the range five to seven.

Ordinal colour coding uses a graded sequence of colours to represent the value of one or more variables. The perceptual ordering of colours for the variable(s) should be unambiguous. Colour can be very effective when it draws on natural or application-related associations, such as the ordering of colours in natural phenomena. The hues of the rainbow, for example, form the familiar spectral sequence from red to violet. The colour of a radiating body changes from black through red to yellow, white, and blue as the temperature increases. The key should always be included alongside the colour-coded display to aid interpretation. Two separate ordinal colour scales may be combined to produce a bivariate display.[5]

Colour selection guidelines

- Use colour in conjunction with other visual variables for effective presentation.
- Use strong colours sparingly on or between muted background tones.
- Limit the number of colours in nominal coding to seven or fewer.
- Use natural or application-related associations for ordinal coding.

6. VISUALISATION

Visualisation means the bringing out of meaning in data by providing graphic representations that facilitate the visual communication of knowledge. Colour should not be introduced if it does not support or add to meaning, because unrelated colour can cause confusion.[5] Visualisation goes beyond information display to provide simulations of real-world objects, structures, or systems, allowing the user both to see and to interact. Colour can therefore be used in two ways – first to emphasise the desired information and second to render the environment presented to the user. Monitoring applications present the user with a graphical representation of the state of a real-time system, such as the parameters of an industrial plant or the physiology of a medical patient. It is important both to conform to the cultural or technical norms of the application and to choose colours that enable the user to interpret correctly the meaning of the information displayed. Under normal operating conditions, colours should be low in saturation, with the main emphasis on the legibility of essential data. Only in exceptional conditions, such as when an alarm threshold has been exceeded, should strong colour come into use.

In modelling applications, the display represents the appearance of an object or scene, with the purpose of predicting how it will look when constructed. For best rendition, a large number of colours should be used to provide continua of tone, hue, and saturation, taking care not to use an excess of colour. Subtle coloration can enhance a scene without distracting attention from the essential line, form and proportion. Such considerations become more important still in virtual-reality displays, where colour cues must remain consistent with the structure and depth of the virtual world in which the user is immersed.

Colour selection guidelines

- Don't use colour that doesn't support or add to the meaning of the information displayed.
- Use colour in monitoring applications to indicate changes of state.
- In modelling applications, use only enough colour to create a realistic effect.

7. IMAGING

Imaging displays include one or more photorealistic images as the primary elements. Examples of applications include desktop publishing, product catalogues, photo libraries, and virtual galleries. The purpose of an imaging display must be clearly understood. Is it to portray a real-world scene, object, or product as realistically as possible, or is it to influence the observer into believing something about the product represented by the image? The most important criterion is to preserve the intended appearance of the image, which requires a quiet background and absence of any bright graphics that would disturb the visual perception of, or distract attention from, the image itself. The background should always be a neutral grey to prevent unwanted simultaneous colour contrast effects. Photographic viewing standards recommend a background luminance of 20 percent of the white level, corresponding to a perceived lightness of approximately 50 percent. Light backgrounds make images look darker and lower in contrast. Dark back-grounds make images look lighter and higher in contrast. Text captions should be black or white, to optimise legibility depending on the lightness of the background. A narrow (3-mm to 6-mm) white border around an image has the effect of isolating it from the background and providing a white reference for more accurate visual judgement.

Accurate colour reproduction of an image requires knowledge of its origin (the medium, how it was digitised, encoded, etc.), the characteristics of the display, and the reproduction objectives. Frequently, the reference colour primaries and encoding method are not known, so images processed for one workspace gamma may be displayed with a quite different gamma, causing significant changes in the tonal rendering. This problem will be resolved only when all computer operating systems provide reliable colour management facilities, able to calibrate displays and compensate for image characteristics.

Colour selection guidelines

- Always use a neutral grey background when displaying colour images.
- Put a narrow white border around an image to stabilise its colour appearance.
- Use colour management software when accurate colour reproduction is required.

REFERENCES

1. J. Bertin, *Semiology of Graphics*, trans. W.J. Berg, Univ. of Wisconsin Press, Madison, Wis., 1983, pp.60-97.
2. L.W. MacDonald, "Using Color Effectively in Computer Graphics", *IEEE Computer Graphics & Applications*, 19(4), 1999, pp.20-35.
3. R.N. Jackson, L.W. MacDonald and K. Freeman, *Computer Generated Color*, John Wiley & Sons, Chichester, UK, 1994, pp.145-163.
4. E.R. Tufte, "Color and Information", *Envisioning Information*, Graphics Press, Cheshire, Conn., 1990, pp.81-95.
5. R. Spence, *Information Visualization*, ACM Press / Addison Wesley / Pearson Education, Harlow, UK, 2001, pp.66-69.
6. P.R. Keller and M.M. Keller, *Visual Cues: Practical Data Visualization*, IEEE Computer Soc. Press, Los Alamitos, Calif., 1993, p.20.

A Study of Color Harmony Relating with Area Ratio

Shing-Sheng Guan, Dep. of Visual Communication Design, NYUST, Taiwan, R.O.C.

ABSTRACT

Among thousands of color combination, how to arrange and create color harmony? What is the best ratio in arranging color area? This study is based on "Tone" concept to arrange the experiments whereas it was developed and issued by Nippon Color Design Research Institute. This study aims to explore how area ratio relate to color harmony. As well the experimental results were used to verify Munsell's Law ($A_1(V_1C_1)=A_2(V_2C_2)$) and Moon & Spencer' Model ($A_1[C_1^2+64(V_1-V_N)^2]^{1/2}=A_2[C_2^2+64(V_2-V_N)^2]^{1/2}$) .

Key words: color harmony, tone, Munsell's Law, Moon & Spencer' Model

1. INTRODUCTION

Colors play important roles in daily life. Yet what order does color arrangement follow to exist? Munsell and Moon & Spencer had derived the color harmony formulas based on the area ratio of color combinations. Their color harmony formulas separate value from chroma. The formulae may be understandable to designers to use, but not applicable to the public who even not know the definition of value and chroma. Besides, people view color as a whole. They cannot separate value from chroma to tell color features, calculate required area ratio. Hence, this study used the systematic color notation that people commonly familiar with in Taiwan. By means of planning and executing the experiment, this study adopted Shigenobu Kobayashi's NCD130 color chart to carry on this study concerning color combination and area ratio relating with color harmony. The contents of this study include 1. Investigating color combinations composed of different hue with same tone and find out their area ratios relates with color harmony, 2. Applying color combinations composed of two different tones to analyze their area ratios relates with color harmony and conveying data to verify the Munsell and Moon & Spencer's law.

With respect to color area influence on color harmony, Field [1] was the pioneer researcher. His study noted that any color combination in spinning wheel would be medium gray after mixture and resulted into color harmony. Munsell carried out a few experiments following such concept in 1905. His study showed color area with product by value multiplying chroma became inverse ratio leading to color harmony. Thus he invented Munsell's Law, i.e. $A_1(V_1C_1)=A2\ (V2C2)$ · Moon & Spencer [2] considered that scalar moment in color space influenced color area. Scalar moment in color space among each composing color should be equal or simple integer ratio in order to achieve color harmony. As a result, they invented Moon [3,4] investigated spatial balance for hue, value and chroma respectively. They tried to verify the Munsell and Moon & Spencer's color harmony theories by arranging color areas with different value and chroma. They found the adjacent color and complementary color combinations with same chroma and different value failed to support such theories; but it could be right if same value and different chroma colors used and the observers' response tended to be consistent.

2. Experiment design

PCCS (Practical Color Co-ordinate System) Harmonic Color Charts 201-L, revised in 1991 and added colors to 201 colors, were used in this study. Its color combinations approach color harmony accompanied by various harmony rules and features. Koujimachi Chiyoda-ku [5] mentioned that color combinations of contrast hue or contrast tone would produce larger proportion of color area. Twelve observers had normal color vision and good distinguish ability according to Ishihara test and Farnsworth-Musell 100 hue test respectively. The experiments were carried out under a D65 simulator in a viewing cabinet The experimental results were analyzed with ANOVA provided by SPSS statistics software to verify the Munsell's Law and Moon & Spencer's Model.

This study used "tone" concept to test color harmony by color difference in same tone (first phase) and two tones (second phase) to achieve our purpose. First phase was to study vivid tone. Finding out the color area ratios associated with color harmony between different hues. Munsell and Moon & Spencer thought the attribute of hue had nothing to do with color harmony and color area ratio. In this phase, the experiments were carried out to test if hue affected relationship between area ratio and color harmony. In consideration of color samples integrity, the author selected 10 hues of vivid tone from NCD130 color charts to arrange color combinations. According to the type of color combination by Lin [6] (refer to Table 1), we selected color samples subject to interval of angle in color circle. The forty-five sample pairs were used at this phase.

Second phase was to study color combination by different tone resulting in color area ratio and its relationship with color harmony. According to the PCCS Harmonic Color Charts 201-L mentioned, contrast hue combinations or contrast tone combinations were influential to color area ratio. Therefore, contrast tone was selected in this study. The author referred to the type of tone rule by Lin [6] (see Table 2) to pick out the pairs of bright tone and dark tone. To make contrast study, we also picked out the pairs of light tone and bright tone, similar tones based on Table 2. As for hue, the distribution of color samples were considered so that the author picked out same hue, similar hue and contrast hue (Tone on Tone combination rule) to study. As a result, 15 pairs of each tone combinations (bright tone and dark tone; light tone and bright tone) were tested. The sample pairs were presented to observers by random.

Table 1: The type of color combination

Hue combination	Interval of angle
Same	1~36 degree
Adjacent	36~72 degree
Ambiguous	72~108 degree
Contrast	108~144 degree
Complement	144~180 degree

Table 2: The type of tone rule

Hue type	Dif. Value	Dif. Chroma
Same	Below 0.5	Below 1
Adjacent	0.5~2	1~2
Ambiguous	2~3	2~4
Contrast	3~5	4~8
Complement	Over 5	Over 8

This study adopts Hue and Tone System derived by Shigenobu Kobayashi in Nippon Color Design Research Institute (NCDRI) to select samples based on 130 color charts issued in 1991. The author put two color charts in sliding board of 36cm*18cm test equipment (self-made) as the board was moveable. On top of the test equipment set a test board with a 15cm*10cm window at the center. The frame of test board was colored with medium-gray (N5), a common color used in color experiment. Observers would view color through window and move either the right or left sliding board. Observers could stop moving when they perceived balance. And then recorded the area ratio for this color combinations.

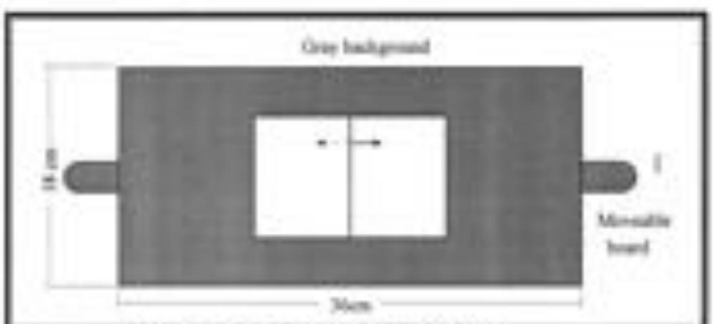


Figure 1 : Self-made equipment device

3. ANALYSIS OF EXPERIMENTAL RESULTS

Firstly, we got data resulting from large area divided by small area. When left area was larger than right one, we marked positive value, but right area was larger than left one, we marked negative value. For example, 5R of vivid tone was on left and 5Y was right, when 100cm^2 of color area for 5R associated with 50 cm^2 for 5Y, we marked+2 , but when 50cm^2 for 5R with 100 cm^2 for 5Y, we marked -2. Finally, the author used those data to make various analysis.

3.1 Analysis on 45 pairs of color samples of vivid tone

After transferring the experimental data, One-way ANOVA was used to analyze if 45 pairs of color combinations had any difference. The results showed that 45 pairs of color combinations had not significant difference ($F=1.34$, $Sig<0.078$). In other words, the 45 pairs of color combinations had the similar color area ratio. According to the color differences and color area ratio in Figure 2, most of color area ratios exist around 0. It means that observers felt visual balance of area ratio was 1 : 1.

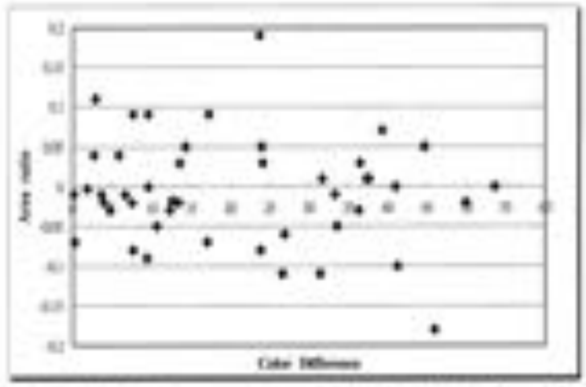


Figure 2 : color difference and area ratio of vivid tone(45 sample pairs)

3.2 Analysis on color combination of contrast tones and adjacent tones

One-way ANOVA was also used to analyze the 15 pairs of contrast tones and adjacent tones respectively. The author tried to find out if the area ratio of their combination had significant difference. The experimental results showed that 15 pairs of contrast tones had not significant difference ($F=0.56$ · $Sig<0.89$), so did 15 pairs of adjacent tones ($F=1.125$ · $Sig<0.34$). However, the T test was used for contrast tones and adjacent tones, they had significant difference ($T=-14.57$ · $Sig<0.00$). Therefore, contrast tone and adjacent tone have different color area ratio. Area ratio for contrast tone is 0.19 (It nearly equals to 0). We could arrive at a conclusion the area ratio of color combination for contrast tone is 1:1. The area ratio of adjacent tone is -2.7. It means that adjacent tone is around 2.7 times. The area ratio for light tone is 2.7 times than that of bright tone. (As bright tone is at left side of light tone in the experiments, negative value means right color sample area is larger). As Figure 3 shows, the relationship between each color combination color difference and area ratio in first and second phase. Moreover, the color area ratios of contrast tone and adjacent tone are different in second phase.

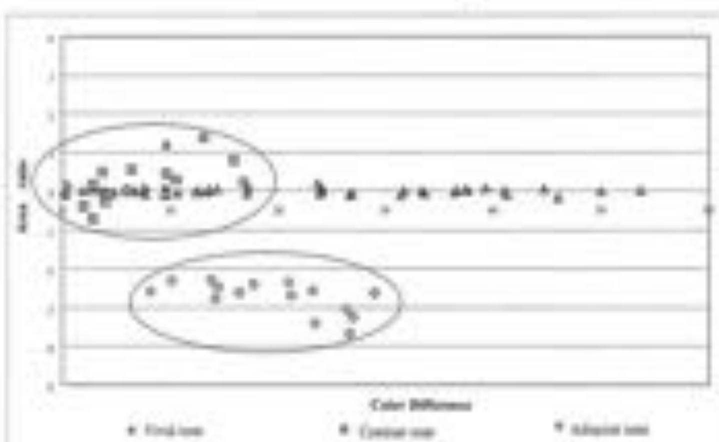


Figure 3 Color difference and area ratio of vivid tone, contrast tone and adjacent tone

3.3 Verification for Munsell's Law and Moon & Spencer's Model

The color samples of contrast tones and adjacent tones were measured by spectrophotometer. The tristimulus resulted in Munsell's value and chroma was collected. These data were used to verify Munsell's Law and Moon & Spencer's Model. Based on Figure 4 & 5, the results from observers tend to stable, not like said formula result leading to obvious change for color area ratio. Munsell and Moon & Spencer's curve shows turn and twist when yellow color combined the others. Therefore, the influence of yellow value on color area as the said formula predicted is less than expected.

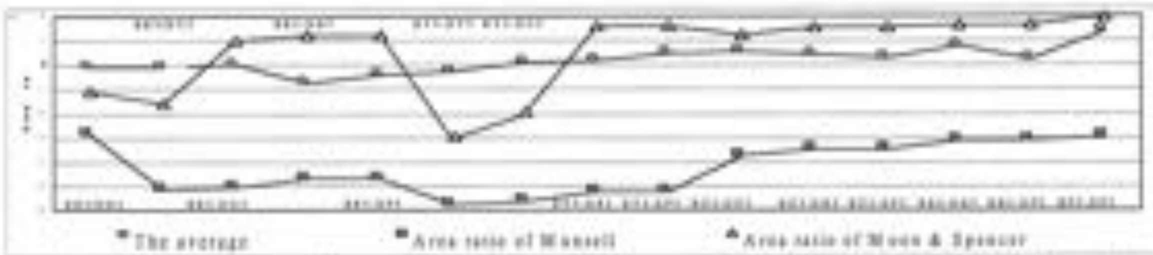


Figure 4 : verification for contrast color combination (cross axis B5R means Bright red , D5Y means Dark yellow , etc., left marker is at left side)

Except four groups of color samples in A & B area, area ratio curve falls around Munsell and Moon & Spencer's curve and near Moon & Spencer curve (See Figure 4). The author further study carefully four groups of color samples in A & B area. They are combination of red and yellow. Again, it proves that value has little influence for whole color judgment.

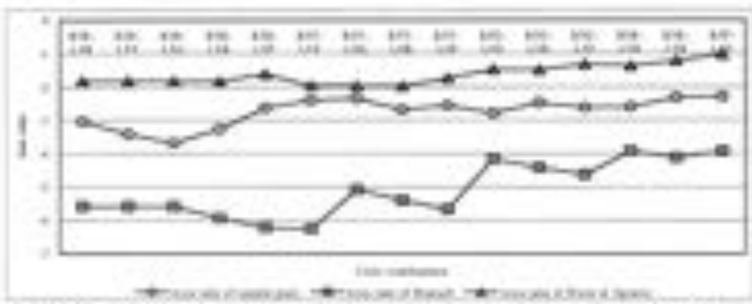


Figure 5 Adjacent color combination (cross axis B5R means Bright red , L5YmeansLightyellow,etc, left marker is at left side)

4. CONCLUSIONS

The public lacks enough color knowledge to use color area and color harmony formula. They usually distinguish color by integrity instead of value or chroma. In consideration of the fact, this study thus cuts in "tone" concept to arrange experiment and verify Munsell's Law and Moon & Spencer's Model. Our study results are as follows : (1) Color area ratio is 1 : 1 in the same tone (at case of vivid tone) which also proves Munsell and Moon & Spencer's theory that hue may be neglected. (2) But for contrast tone, color area ratio is still 1 : 1 which differs that of theory. We further made analysis on difference of observers. They could be divided into two groups (Sig<0.00). That is, some deemed high value and high chroma color with larger area while others allowed low value and low chroma color with larger area and area ratio was 1 : 1.5 。(3) Adjacent tones we selected in this study are light and bright tone. Observers' perception is very consistent, light tone is 2.7 times as large as bright tone.

ACKNOWLEDGEMENT

This project has been finished on time favorably with Nation Science Council's support (project number: NSC 892411H006006).

REFERENCES

1. G. Field, *Chromatics*, London, 1845.
2. P. Moon & D. E. Spencer, *Area in color harmony*, J. of OSA 34, p.93–p.103, 1944.
3. R. H. Morriss, & W. P. Dunlap, *Influence of Value on Spatial Balance of Color Pairs*, J of General Psychology, 114 (4), p.353–p.361, 1987.C.
4. R. H. Morriss, & W. P. Dunlap, *Influence of Chroma and Hue on Spatial Balance of Color Pairs*, Color Research and Application 13(6) p.385–p.388, 1988.
5. K. Koujimachi, *PCCS Harmonic Color Charts 201-L*, Japan Color Enterprise Co. Ltd. Tokyo, 1991.
6. S. Y. Lin, *Chromatics*, San Ming Publishing Co. Ltd. Taipei, p285, 1990.

The development of a large colour range for a paint company

Peter L. McGinley*, Dulux Australia

ABSTRACT

Experience with the Master Palette system of 6000 colours lead to a specification for a new colour range where the primary design feature is the control of the paint tint formula. This design approach met a market-derived requirement for sample pots and fractional-strength colours. The layout process employed was able to display the colour capability of the paint system and generate an array of colours with controlled spacing similar to Master Palette. Updated pigment selections and the introduction of additional coloured bases completed the system specification of improved opacity and every colour being exterior durable.

Keywords: Colour atlas, Paint colour systems, colour gamut, exterior durability, opacity

1. BACKGROUND

Paint companies commonly have colour ranges displaying 1500 to 2000 colours. These are usually presented in fan deck format, which is compact and convenient to use, but inappropriate for the display of the 3-dimensional structure of colour space. A colour range that has an underlying colour space structure is better shown in an atlas format with pages of constant hue. The production cost of the atlas is significantly greater than that of the fan deck for the same number of colours so the fan deck is usually favoured. The maximum number of colours that can be presented in a fan deck is about 2000 before the deck becomes too bulky to manipulate. Large colour systems of significantly greater than 2000 colours are best displayed in atlas format with pages of constant hue.

The well-known colour order systems are often unsuitable for paint companies, as the colour range may not match the colour capability of the paint system. The high-chroma samples displayed in colour order systems can present particular problems with reproduction in fully opaque paint systems. The commercial requirements of market exclusivity can also be difficult to satisfy. Often the well-controlled distribution of colours in colour order systems is of secondary importance to colour specifiers who simply want a colour selection that is deliverable in the products they want to use with acceptable application, opacity and durability performance.

Large colour ranges for paint companies may then have structural similarities to, but objectives different from, colour order systems. The requirement of a colour system for a paint company is that it demonstrates the colour capability of the paint colour system in which the colour is delivered. It should also supply sufficient number of colours to meet the needs of established colours and future colour trends. The purpose of this paper is to outline the development of the Dulux Colour Specifier system from its predecessor, the Master Palette.

2. THE MASTER PALETTE SYSTEM

The Master Palette colour atlas was designed by Glidden Paints[1] and it demonstrates the colour gamut of their system of tinters and bases used at the time of its development. It has 6134 colours arranged into 47 hue pages and additional pages of greys and brights. Each page (Fig 1) contains 118 colours that plot within a trapezoidal shape on a Lightness-Chroma plot (Fig 2). The most chromatic corner of the trapezoid is defined by the most chromatic paint shade that can be delivered for that hue. The other corners define the darkest and lightest shades displayed. A grid drawn within the trapezoid reflects the number of columns and rows per page. The points of intersection of the grid lines define the Lightness and Chroma values of the colours. This design method delivers a smoothly varying colour set with a population density that increases into the pastel colour area which is ideal for a paint colour range. Since 1992, Dulux Australia has, with great success, used the Master Palette colour system as the colour offer for the professional colour specifier.

1 Developed at Glidden Paints, Cleveland, by John Runcis and Jim Grabowski.

The strengths of the Master Palette system include the wide colour gamut, smoothly varying colour flow on each page and the high presentation standard. The problems experienced in our market related more to the way the colour was delivered than the colour system itself. So the initial approach was to improve the performance of the paint system.

3. NEED FOR IMPROVEMENT IN PERFORMANCE

3.1 Some performance below expectations

The implementation of the Master Palette colour range into the Australian market required several new tinters and bases to provide a colour capability similar to the Glidden system, which would enable the matching of the colours. The colour range and system presentation was very well received by the market. However, for some colours made from the new tinters and bases, the opacity and durability performance was below expectations.

3.2 Opacity

The poor opacity issue was centred on the red, orange and yellow colour areas and particularly in the highly chromatic range. These colours were delivered from a clear base so the cause was the low pigment concentrations that were present in the tinted colour. The specification of grey undercoats eased the problem when they were used, but the better solution was the introduction of three new coloured bases – red, orange and yellow – with the necessary pigment concentrations to achieve good opacity.

3.3 Exterior exposure

Of the 6134 colours, 32% were rated as not suitable for exterior use. This arose through the use of economical but non-durable pigments or insufficient opacity to protect a timber substrate from UV exposure. The coloured bases to be introduced used durable pigments so as well as improving the opacity, they also met the demand for increased exterior colour stability. The system revision had the objective of every colour being available in exterior durable quality.

4. ADDITIONAL REQUIREMENTS FROM THE MARKET

4.1 Loss of access to Master Palette

The separation of Dulux Australia from the ICI Paints group in 1997 brought a 3-year limitation on the right to distribute the Master Palette system. This meant that the new base and tinter system being developed would not be applied to the existing Master Palette colour range, but to a new colour range to be developed. The opportunity was then presented to address not only the product opacity and durability performance, but also refine the colour selection to include the additional requirements of fractional strength variants and sample pot capability. The challenge was whether it was possible to meet the additional requirements whilst retaining the strengths of the Master Palette system.

4.2 Half-strength colours

A frequent service request was for examples of Master Palette colours at "half-strength", "quarter-strength" or even "eighth-strength". The variant is produced by tinting with only the fractional amount of tinter or using the same tint formula in a higher base strength. This process of selection of a colour on a small colour chip and then specifying another at a lower strength recognises the apparent development of colour strength when viewed in larger areas. If these variants could be readily selected from the colour system then the requests for low-strength variants could be eliminated.

4.3 Sample Pots

Sample pots have become an established requirement in the Australian market, so all colours had to be deliverable in 250mL quantities. This requires that the tint formula for the sample pot have no dispense amount that is not an integral multiple of the smallest dispense amount which is 0.25shots (0.11mL). This places significant restrictions on the structure of the tint formula and hence the colour intervals. For the Master Palette system, where the sole determinant for the tint formula was that it should match the target colour, only 400 of the 6134 formulae were able to tinted into sample pots. The new system was to have every colour sample pot capable.

5. THE COLOUR SPECIFIER DESIGN

5.1 Atlas Design – Hue Circle

The atlas was built by first defining the hue circle of 48 high chroma colours made from maximum tinter additions into the weakest white base. The hue spacing was visually graded with a consumer colour preference biasing the selection to a slightly stronger representation of reds, oranges, yellows and greens compared with turquoise, blues and violets when compared against CIE Hue scaling.

5.2 Atlas Design - Hue Page

Each hue page was constructed using the paint system (tinters and bases) for which it was designed. This ensured that the maximum chroma range of the paint system was displayed and only colours that could be delivered were displayed. The two bottom rows on each page were reserved for colours from special bases such as coloured bases (four used – red, orange, yellow, and blue) and a clear base (TiO2-free). All the rows three and above, were produced from white bases at three levels of TiO2 concentration. The page layout is shown in Figure 3.

The most chromatic colour, located on the right hand end of Row 3, was defined first with the chromatic tinters at maximum concentration. This colour was then reduced in chroma by replacement of the chromatic tinters by black and white to produce the other seven colours in the row.

Each colour in the row above (Row 4) was required to be the half-strength variant of the Row 3 colour, and was produced from the same formula in the next higher strength base. Row 5 colours used half the tint of Row 4. Row 6 changed base again and Rows 7, 8 and 9 are each half-tints of the row below.

This process greatly accelerated the colour layout, as only Row 3 required careful development and the rows above followed a roll-out process. It was not possible to extend the process beyond Row 9 as many formulae then had tinters at their minimum level and hue control would be lost if one chromatic tinter was eliminated before another.

The half-strength relationship between adjacent rows, was one of the two design determinants. The second was the sample pot requirement. This requirement for all colours was met by carefully selecting tinter amounts at the Row 3 levels which will always lead to sample pot capable amounts after the roll-out in Row 9.

An unintended outcome of this process is that all colours in a column have the same pigmentation. The benefit there is that colour combinations based on strength differences, commonly used in trim and broadwall schemes, will not display unexpected colour shifts with changes in lighting.

The two rows (1 and 2) at the bottom of the page were produced using either one of the four coloured bases or a clear base. The lower concentration of white pigment in these bases allowed access to a range of chromatic but low-Lightness colours. These rows matched the hue of the white-base colours but the fractional strength relationships were not always possible. Some pages to show a discontinuity of colour flow between Rows 2 and 3 as can be seen in Fig 4. This is not expected to be a problem to the users and reflects the range of colours that can be produced by the paint system.

Throughout the process the selection of colours was monitored visually and on Lightness-Chroma plots to ensure acceptable spacing between the colours and constant hue on each page. Figure 4 shows the Lightness-Chroma plot of a typical page that shows great similarity to the Master Palette plot of Fig 2 despite the very different design approach.

5.3 Additional Whites, Greys

In common with the experience with all of the colour order systems when applied to architectural paint colour selection applications, the hue page layout does not provide enough colours in the very pale pastel and neutral grey areas. This problem was addressed by adding supplementary double page arrays of 144 colours for the whites and for the greys.

6. SUMMARY

The unusual feature of the Colour Specifier design approach is that the colours generated were the result of a process designed to meet a market requirement for sample pot capability and fractional strength colours. Normally the colour is defined first and the paint tint formula is developed to deliver the colour. The Colour Specifier method of construction produces a colour atlas that is uniquely tied to the characteristics of the paint system for which it was developed. The colour gamut of the atlas is an exact match to that of the paint system. The objectives of sample pot capability and exterior durability were achieved for every colour. In addition to the Atlas, the Colour Specifier system has fan deck of 1800 colours, a colour register of A4 colour samples and a retail selection. Only the atlas displays all 3744 colours and is similar in presentation to the Master Palette system that it replaces.

ACKNOWLEDGMENTS

This success of this project would not have been possible without the project and data management skills of Stuart McEwan and the colour matching ability of Pamela Ogilvy. Their contribution is sincerely acknowledged.

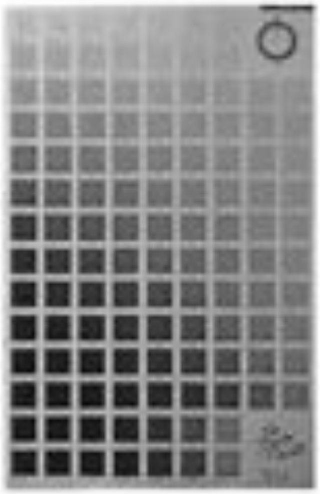


Figure 1: Typical Master Palette hue page (in greyscale). The most chromatic colours are on the lower right corner and the lightest at the top. There are 118 colour per hue page and 47 hue pages.

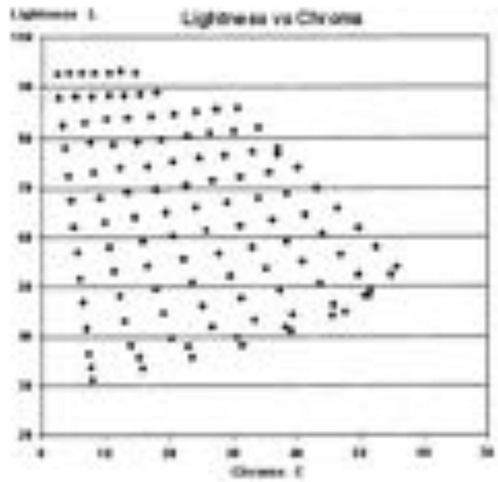


Figure 2: Colours from one Master Palette hue page in the green sector plotted as CIE Lightness against Chroma. The regularity of the spacing results from the layout process of drawing gridlines to define the page rows and columns and the grid intersections defining the colours.

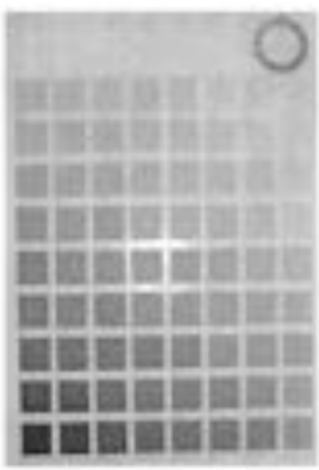


Figure 3: Typical Colour Specifier hue page (in greyscale). The most chromatic colours are on the lower right corner and the lightest at the top. There are 72 colours per hue page and 48 hue pages.

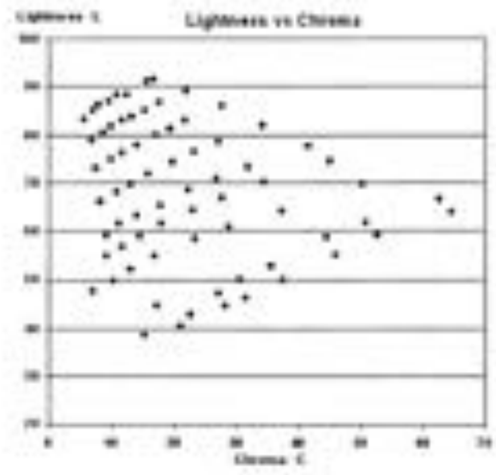


Figure 4: Colours from one Colour Specifier hue page in the green sector plotted as CIE Lightness against Chroma. Despite the layout process being focussed on the tint formula, the colour spacing is acceptably uniform for a colour selection system.

* contact author at Dulux Australia, P.O. Box 60, Clayton South, Victoria, 3168, Australia; phone +61 3 9263 5733, fax +61 3 9263 5730; e-mail peter.mcginley@orica.com

How can we find and handle colors with the same undertone? A proposal of method to specify and quantify undertone

Takashi Sakamoto*, National Institute of Advanced Industrial Science and Technology (AIST)

ABSTRACT

A method to specify and quantify undertone is proposed based on CIELAB color space. This method enables us to deal with colors according to their undertones (their ratio and Lab coordinates). The method also enables us to discuss undertone from the viewpoint of color appearance, being isolated from personal color analysis.

Keywords: Undertone, visual perception, color appearance, quantitative method, personal color analysis

1. INTRODUCTION

This paper proposes a method to specify and quantify undertone. This method enables us to deal with colors according to their undertones (their rates and color coordinates). The method also enables us to generate, handle and display colors with same undertones on the computer.

The expression "undertone" is a kind of technical term especially used for personal color analysis and consultation. Undertone is used for the judgment of color harmony and personal colors. It seems one of aspects on color appearance and visual phenomenon, but there are few research reports on undertone from the scientific viewpoints. Indeed the present situations as follows are not so good for doing research about it:

1. The term "undertone" does not have a regular definition as a terminology of color science, vision, optics and so on.
2. There are a large number of how-to guides on personal color analysis, but they do not write about undertone with psychological reason and scientific ground.
3. What conception undertone is, what attributes undertone has, and what color system can be used for are unknown.

The author thinks that undertone can be discussed more as one of research themes, because it has been substantiated through longtime and wide practical usage in personal color analysis and related areas. It is just a frontier theme of research and may be a key to make the distance closer between scientific research and practical usage of color.

This paper finds the research theme "undertone" from the field of personal color analysis and consultation, but aims to discuss undertone objectively, being isolated from personal color analysis. Therefore this paper does not deal with personal color analysis itself (its methods, its usage, its categories, its validity, and so on). Also this paper does not deal with practical usage of undertones, subjective impressions of colors, and color harmony.

2. PROBLEMS FOR SOLUTION

2.1 Motivation

This paper aims to solve three problems (see subsection-2.2) about undertone specification and handling, without using personal color theories. The reason why the author raises these problems is motivated by a personal experience as follows. The author had a chance to develop designing support systems few years ago, collaborating with the teaching staff working at the institute of art and design in the university. While doing this system development, the author experienced that the color designing was affected by the visual effects of colors (e.g. contrast, balance, motif and accent). Then the author also tried to examine the effects of undertones on the computer, according to some personal color theories, but the result was unsuccessful in specifying and handling undertones.

2.2 Three Problems

The first problem is that the conception of undertone is quite ambiguous in the personal color theories. Undertone seems to explain from the viewpoint of color appearance, but the distinction between the effects of color appearance and the other aspects of undertone is blurry in their usage. Indeed the ordinary term "undertone" used for personal color analysis seems to express the effects of color appearance (e.g. yellowish, bluish), the effects of color impression (e.g. warm, cool) and the effects of color association (e.g. spring, summer, autumn, winter). Their theories seem to be based on many case studies, without psychological reason and scientific ground. Many guides about personal color analysis mention the conception of undertone, but they were too simple and intuitive to understand and agree their bases.

The second problem is that the personal color theories can not quantify undertone content of a target color (or an undertone-containing color). For example, they can not explain how much yellowish undertone a target color has. This fact also means that a target color can not be divided into undertone color and another component color. We can not know the relation between undertone quantity and its visual effects, unless we can divide a target color into undertone and the other component colors.

The third problem is that no color system (or color space) can deal with undertone numerically on color coordinates. The personal color theories have their own color system, but they only divide colors into 4 categories or less. If we want to generate, handle and display colors with same undertones on the computer, we can do nothing but taking colorimetric values from color drape (or color samples) used for personal color analysis. The number of colors used for color drape is no more than 100, so that the number of colors we can use is also limited no more than 100. This situation will cause severe inconvenience to many users such as graphic artists and product designers.

2.3 Other reports

There are few research papers about undertone from the viewpoint of color perception, but advanced research reports can be found: Report [1] analyzes color drape using Natural Color System (NCS). The authors of this report take colorimetric values from color drape and map them onto NCS coordinates. Then the relation between personal color categories and NCS notations has been disclosed. Report [2] is written on skin color appearances. The authors of this report find that skin color makes "reddish" or "yellowish" perception and these modifiers are not consistent with the three attributes of target skin colors. These reports deal with only color drape or skin colors; therefore, they have less generality as undertone analyses.

3. DEFINITION AND METHOD

This section properly defines the conception of undertone and the condition to perceive it, after that a method to specify and quantify undertones is proposed on the basis of these definitions.

3.1 What is undertone?

To solve the first problem, this paper uses its own definitions of undertone which has no relation to the personal color analysis, subjective impressions of colors and color harmony, so that we may not confuse some aspects of undertone. The following definitions consist of only the visual aspects of undertone, without psychological and the other aspects. These definitions are suitable to discuss undertone from the viewpoint of color appearance:

1. An undertone can not be perceived from a target color when a target stands alone.
2. An undertone can be perceived from a target color when a target appears with the other colors together.
3. An undertone is perceived as a tinge (or an included color, an underlying color) in a target and the other colors.
4. A property of undertone can be expressed by modifier(s) related to color appearance, such as "reddish", "yellowish" and "bluish".

Additionally there must be a supplementary explanation about the differences between undertone and other similar conceptions. Undertone perception is one of visual phenomena, but it is different from known visual effects, such as color contrast and color assimilation. It is also different from the conception of tone (e.g. vivid, deep, light grayish) used for color scheme. The modifier used for color naming and the "resemblance" used for Natural Color System (NCS) have the similar expression to the undertone modifier, but the former two concepts are quite different. The color-naming modifier and the resemblance are only used for color identification, and they fix a color uniquely on a color system, so it can not be used for such as "bluish yellow" and "yellowish blue". On the other hand, the undertone modifier can be used for them.

3.2 When does undertone appear?

This subsection specifies the condition that undertone can be perceived as mentioned in definition-2. This specification does not mention undertone modifiers in definition-4, because this paper aims to specify undertones numerically, instead of color name such as "blue" and "yellow". This paper develop the discussion about the numerical method to deal with undertones on the basis of following two conditions:

Condition-1: An undertone can be perceived from a color generated by mean value color mixing between two different original colors, when these three colors appear together. These three colors can be named undertone color, another original color and undertone-containing color (generated by mean value color mixing) each.

Condition-2: An undertone can be perceived from undertone-containing colors generated by mean value color mixing between an undertone color and each original color, when all undertone-containing colors appear together.

The term "mean value color mixing" applies the uniform color space such as CIELAB and CIELUV. Of course, meaning of undertone is based on the definitions in subsection-3.1

3.3 Proposed method

A method to specify and handle undertones quantitatively and systematically is proposed by the formulation of Condition-1 and Condition-2. This method can indicate undertone-containing colors by internal ratio or external ratio between an undertone color and another original color.

Let U and A be any two colors. The color difference between U and A, and its scale can be considered, if U and A have appropriate color notations to describe color difference, such as CIELAB or CIELUV. Color U and A are represented by the two ends of the scale, as shown in Figure 1. Let L be a color difference between U and A. If there is a color B and color differences from U to B and from A to B are equal to 0.7L and 0.3L respectively. Then B can be placed on the scale line as seen in Figure 1. Any colors placed on this scale line can be expressed by the internal ratio between U and A, without consideration of distance L. For example, internal ratio of UB to AB is 0.7 to 0.3. Then this numerical relation can be written as follows:

$$[B] = 0.3\,[U] + 0.7\,[A], \qquad (1)$$

where [B], [U] and [A] mean color notations of (or vectors in) CIELAB or CIELUV, such as $[A] = (L_A, a_A, b_A)$. When color B can be written in the form of equation (1), let us regard color U as an undertone color of color B. In other words, it is defined that color B contains 30% of color U as undertone, in the sense of equation (1). (Color A also can be another undertone of color B, but this case is without consideration for simplicity.)

If color A is replaced with any other color A', as seen in Figure 1, and new color B' is placed on the scale line between U and A' according to the internal ratio of 0.7 to 0.3, then color B' also contains 30% of color U as color undertone. According to the Condition-2, we can perceive the same undertone from every color that has a fixed undertone and a fixed internal ratio, in the sense of equation (1).

A color space to define color A, B and U must specify colors uniquely and define color differences (or distance between colors). CIELAB or CIELUV seems appropriate to this use, but the other color spaces may be used practically. In this paper, CIELAB is used for this purpose. Equation (1) can be generalized as

$$[B] = \alpha\,[U] + (1-\alpha)\,[A], \qquad (2)$$

where α means an undertone content (or undertone-containing rate) by an internal ratio or an external ratio. Color U and A are the components of color B, in the sense of the composition of two vectors. In the case of external division, color B doesn't really contain undertone color U, however we treat it ideally and regard B as undertone-containing color. If α may take on any numerical values, and U and A may be any two colors, equation (2) can work with all colors.

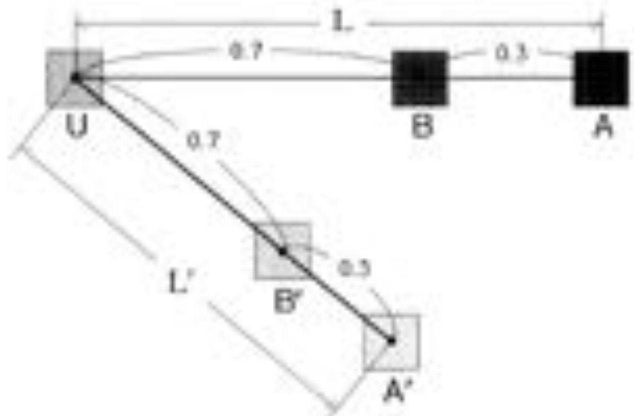


Figure 1. Both color B and B' contain the same undertone color U at the same rate 0.3.

If undertone color U and its rate α are fixed, then equation (2) defines a set of color Bs (referred to as {B}). The color set {B} is uniquely defined by undertone color U and its content rate α (without the case of α =1). Every color in the set {B} contains the same undertone at the same rate. This means that the color set {B} makes us perceive undertone (color U at the rate α).

4. TECHNICAL MERITS

The method proposed in subsection-3.3 can be regarded as a color system, which does not mean color order system or color specification system, but means that it can handle colors numerically on the uniform color space such as CIELAB. This method has the remarkable merits that the other existing color systems do not have:

Firstly, it can work well effectively in the following purposes:

1. To understand a conception of undertone from the viewpoint of color appearance
2. To express undertone colors, undertone-containing colors and their component colors, quantitatively and systematically
3. To compose a set of colors composed of the same undertone at the same rate
4. To compose a set of colors according to the variations of undertone content rate
5. To transpose a set of colors uniformly from one of condition of U and α into another

Secondly, this method is constructed on an existing color system (or a color space expressed by three attributes), such as CIELAB or CIELUV. Therefore color notations, color coordinates axes of color space and the other several definitions (e.g. color difference) can be used to specify undertone colors and so on. And more, a basic principle of proposed method can be applied to more than two color spaces equally, then these results can be compared with each other.

Thirdly, it can be calculated on computer easily. This method may be used for a computer display, when RGB colors on the computer display are well related to CIELAB or CIELUV. In this case, the proposed method realizes computer-based color system that can generate, handle and display colors with same undertones on the computer.

This method is not related to personal color analysis, but it can be used to examine the color appearance and the other effects of undertone psychologically. It is expected that this method can be used for the purpose of color research, color education, art and design, color planing, color consultation and so on, making the most of above-mentioned advantages in these works.

5. CONCLUDING REMARKS

The author aims to elucidate visual effects of undertone from the viewpoint of color appearance. In order to achieve this aim, the following two research tasks must be done:

1. Theoretical estimation of the color appearance of undertone
2. Psychological experiment on the color appearance of undertone

These two themes are mutually complementary, so the research will be incomplete without either of them. This paper stands on the former side, and makes the discussion about the method to specify and quantify undertones, but without experimental results. Therefore, the method in this paper has to be examined by psychological experiments. The reason why the author proposes this method in this paper before psychological experiments is as follow:

1. It has technical merits that enable to handle undertone on the computer.
2. It can be examine through practical use in the field of art and design, color consultation and so on.

These psychological experiments and practical usage will be reflected in this method finally.

REFERENCES

[1] M. Kobayashi, et. al.: "Characteristics of color-drapes used in personal color analysis", Color Forum Japan 2000 Proceedings, pp.137-140 (2000)

[2] T. Suzuki, A. Munakata: "The analysis of the psychological criterion for the perceptual classification of the skin colors", Journal of the Color Science Association of Japan, Vol.25, 1, pp.2-11 (2001)

* Correspondence: Takashi.Sakamoto@aist.go.jp, phone & fax +81-298-58-0277; Human Perception and Cognition Group, Neuroscience Research Institute, AIST Tsukuba Central 6, National Institute of Advanced Industrial Science and Technology, Higashi 1-1-1, Tsukuba 305-8566, JAPAN

Color in graphic design: An analysis of meaning and trends

Barbara E. Martinson and Carol Clare Waldron, University of Minnesota

ABSTRACT

Graphic design is visual communication through the selection, arrangement, and presentation of words and images, most often for the printed page which offer the designer almost limitless options for color use. The objective of this project is to identify patterns of color use. Ethnographic content analysis was used to document color use in annual reports represented in two publications, Print and Communication Arts, 1993–2000. The analysis focuses on the selection, combination, and contrast of hues; and their use with achromatic values. An analysis of the entire sample indicates that one-third of the annual reports used a palette that include black, white, and a hue from quadrant one (red to yellow). Nearly one-fifth of the designs used black, white, and colors from quadrants one and three (cyan to blue). The large samples for Technology, Health Sciences, Financial, and Civic organizations follow the first pattern. Food Service, Business products and services, and Transportation industries favor the second pattern.

Keywords: graphic design, color palette, annual reports

1. INTRODUCTION

Graphic design is visual communication through the selection, arrangement, and presentation of words and images, most often for the printed page. Printing processes offer the designer almost limitless options for color use. Color choice is therefore conscious and purposeful, playing a prominent role in meeting the communication objectives of the client. Color selection and treatment in the non-verbal elements help to create an image, and then through color that image is linked to the verbal content. While legibility demands certain levels of value contrast between text and ground and moderate chroma levels in one or the other; hue selection for text, ground, and all color choices for illustrations and supporting elements are open to the designer. What, then, informs the designer's color choice? This study seeks to identify patterns of color use to determine influences on color selection. Color use was evaluated in annual reports, which represent important communication between organizations and their shareholders. Annual reports are less likely to be subject to color limitations imposed by budget constraints or specific content representation of other print genres.

2. COLOR IN GRAPHIC DESIGN

Color composition in graphic design may be influenced by a number of factors. Traditional concepts of color harmony or balance based on hue relationships mapped across a color wheel might be selected to convey a sense of unity and stability. Most graphic designers have been exposed to color theory including Munsell, Itten, and Albers. Munsell advocated balancing opposite qualities of his three dimensions: light/dark (value), warm/cool (hue), and bright/dull (chroma). Itten teaches contrast of extension relative to balanced proportions of complements which he attributes to Goethe. Albers advocates a perceptual definition of complementarism, balancing hues with their afterimages. Graphic designers use media that employ CMY and RGB primary systems, which adds a variation on traditional complementary, split complementary, and triad color plans.

Color trend forecasts by CAUS (Color Association of the United States) and CMG (Color Marketing Group) are published annually in Communication Arts, a widely read graphic design publication, and one of the journals used as a source for our study. Both the influence of such trends on designers' color selection and the conscious implication of embracing or eschewing such trends have the potential to communicate something about the client company. Does the company represent itself as with or above the trend? Graphic designers might employ color based on modern or popularly held symbolic color associations, such as green for growth or fertility, red for dynamism. Such color associations may already be established within the organization's identity system, providing a potential starting point for an annual report color scheme. Graphic designers develop a concept that guides the visual portrayal of their client: if this concept involves specific representational images, these might be the basis for the developed color palettes applied to non-representational images as well.

3. MEASURING COLOR FREQUENCY

The objective of this project is to identify patterns of color use and to develop hypotheses about the reasons for such use. Are certain colors associated with particular types of business or organization? Do the colors used in annual reports relate to modern or popular color symbolism? Are there color trends in relation to time?

Ethnographic content analysis was used to document color use in annual reports represented in graphic design annual competitions in two publications, Print and Communication Arts, over the eight year period between 1993 and 2000. Annual reports were chosen as representative of an organization and its operations. The annual report is an opportunity for an organization to define itself for existing and potential stakeholders. Unlike other marketing or 'branding' products, an annual report is not required to have instantaneous impact: rather it is intended to be studied and referred to at length. The effect of the annual report can have significant impact on the organization's future. This import is reflected in the investment of time and money in annual reports. At the same time, annual reports offer a degree of freedom to use less literal representation of a client and its products or services. This may allow a designer more latitude to select color as a mode of symbolic or expressive representation.

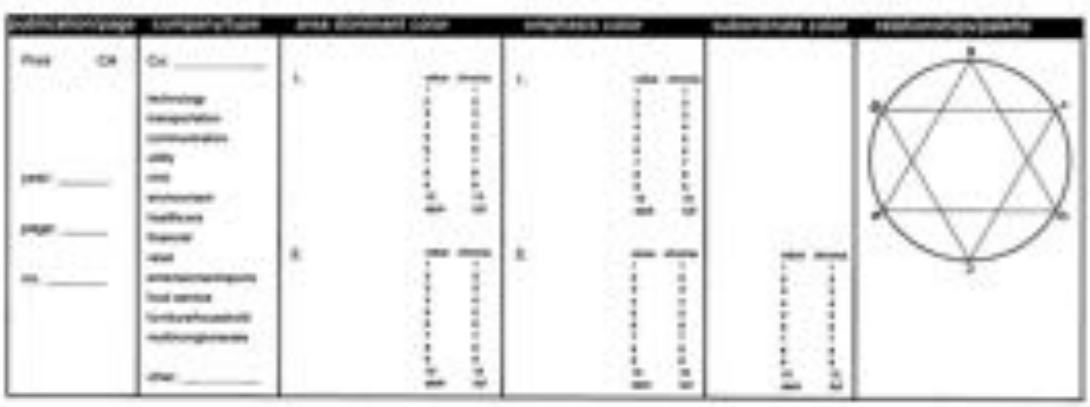
The use of the sample of convenience, graphic design annuals as a source of annual reports, presents certain limitations: although design publications have high print quality, the color representation is a generation removed and significantly smaller than the original. Design competitions are open to all designers, though the same agencies and clients tend to be represented. The advantage of this sample selection is that the reports theoretically represent the best graphic design in the genre for a given time period. The analysis focuses on the selection, combination, and contrast of hues; and their use with achromatic values; though broad ranges of expression are achieved with variation of value and chroma relationships. Assessments of value and chroma were documented, but have not been included in the analysis for this report.

Each annual report represented was coded for area dominant color, emphasis color, and subordinate colors. The authors/coders are both visual designers, and found that palettes could best be represented by plotting colors within a color model with equidistant CMY and RGB hue primaries and secondaries.

To answer the central question: "how is color used to communicate in graphic design?" the results were sorted by type of corporation or organization. Of the sample size of 518 reports the greatest number represented technology businesses (108, 21%). Health sciences (76), financial (68), and civic organizations (62) were next greatest representations. Within types of organization, results were sorted by time periods, 1993/1994 and 1999/2000, to determine if variations in results could be attributed to stylistic trends.

The results were tallied by a numerical rating based on the quadrants of the color wheel represented in each report. Quadrants were defined in such a way to ensure that commonly used primaries did not fall directly on a border. The role of black, white, and achromatic gradation palettes alone or in conjunction with hue palettes was noted. (Black ink on white paper being the most basic, and prevalent mode of graphic communication.) In addition to the numerical rating of the quadrant(s) represented, types of specific hue relationships such as complementary pairs, split complements, and primary (triadic) palettes were noted.

Figure 1.
color coding sheet



4. RESULTS

The data was analyzed in four ways: an overall analysis, followed by grouping the data into types of corporations, an examination of apparent trends, and the use of complementary colors.

Figure 2. Color wheel with quadrants

Overall analysis

An analysis of the entire sample indicated that one-third of the annual reports used a palette that included black, white, and a hue from quadrant one (red to yellow). Nearly one-fifth of the designs used a color scheme that included black, white, and colors from quadrants one and three. Many of these schemes contained complementary colors providing both contrast and color balance. Colors in quadrant four (blue-violet to magenta) occurred infrequently.

Table 1. Overall frequencies per color quadrants, including black and white N=518

quadrant	N	percentage
1	170	33
1,3	99	19
1,2,3	87	17
1,2	59	12

The most frequently occurring color combination was black, white and 1 or more colors from quadrant one. This combination was most typically black, white, and red. There were also many reports that used variations of brown as the color of the background or support—similar to cardboard intending a natural look.

Color use within business categories

The frequency of quadrant one is consistent across most of the individual business categories (see Table 2). Frequencies of less than 10% are not included.

Table 2. Highest frequencies for color quadrants (q) per type of corporation

corporation type	N	q	%	q	%	q	%	
Technology	108	1	27	1,3	20	1,2,3	25	
Health Sciences	76	1	33	1,3	17	1,2,3	13	
Financial	68	1	34	1,2	18	1,2,3	19	
Civic	62	1	37	1,2	11	1,2,3	16	
Retail	41	1	32	1,3	29	1,2,3	10	
Food Service	28	1	18	1,3	32	1,2,3	14	
Natural Resources	25	1	40	1,3	31	1,2,3	18	
Business Products	22	1	23	1,3	27	1,2,3	18	
Transportation	20	1	35	1,3	40	1,2,3	10	
Communication	19	1	32	1,2/1,3/1,4	11	Achro	16	
Utility	14	1	36	1,2	21	1,2,3	14	Achro 14
Entertainment/Sports	13	1	31	1,3	23	less than 10		
Furniture/Household	14	1	16	1,3	16	1,2,3	33	
Industry/Mfg	8	1	37	1,3	25	Achro 25		

Changes in color use

In addition to measuring color frequency, we also measured frequencies between two time categories, 1993-1994 and 1999-2000. There were two cases of substantial increase, however, due to the use of a convenience sample, these trends would need to verified with future research. There were no meaningful changes within each business category.

Table 3. Change in color use within quadrant categories across all business types.

quadrants	level of change
quadrant 1 with black/white	48% increase from 93/94 to 99/00
quadrants 1,2 with black/white	129% increase from 93/94 to 99/00

Use of complementary color schemes

Cases that emphasize the use of opposing colors were noted on the rating forms. Overall, 34% of the color palettes used complementary colors. This percentage in reflected in the data for each type of business in Table 4. The highest number of complementary palettes occurred in Business Products and Services and in Furniture and Household. Complementary contrast occurred in only 12% of the Financial annual reports. There were no cases in the Utility sector.

Table 4. Use of color opposites/ complements for balance or contrast

type of corporation	%	type of corporation	%
Business Products and Services	46	Food Service	32
Furniture and Household	41	Communication	31
Entertainment/Sports	38	Transportation	30
Industrial/Manufacturing	37	Civic	29
Natural Resources	36	Retail	29
Health Sciences	35	Financial	12
Technology	32	Utility	0

5. SUMMARY

The large sample sizes for Technology, Health Sciences, Financial, and Civic corporations may yield the most reliable results. In each of these groups the color plan including black, white, and one or more hues from quadrant one are most prevalent. In the Natural Resources category, 40% of the designs used this color plan. The need to communicate business information may influence the selection of this palette. It is historically significant—the first books were printed on a white ground using black ink with the color red used for emphasis. This classic look is appropriate to the function of the annual report. The designs reviewed ranged in style from traditional to very innovative. Designers are using this color plan in dynamic and dramatic layouts. The second most frequently occurring palette is black, white, and hues in quadrants one and three. Frequently these palettes used complementary colors providing either contrast or color balance to the composition.

6. FURTHER STUDY

During the data collection stage, more information was collected than was possible to analyze for this paper. We intend to return to the data to investigate other color relationships, specifically those of value and chroma. Future studies could expand the time period covered, view actual reports rather than reproductions, and examine color palettes in more depth.

REFERENCES

A. H. Munsell, *A Color Notation*, Munsell Color Company, Baltimore, 1946.

J. Itten (tr. E. Van Hagen), *The Elements of Color*, Van Nostrand Reinhold, New York, 1970.

J. Albers, *Interaction of Color*, Yale, New Haven, 1963.

A. Hope and M. Walch, *The Color Compendium*, Van Nostrand Reinhold, New York, 1990.

Colour planner for designers based on colour emotions

Ka-Man Cheng*, John H. Xin* and Gail Taylor*
Institute of Textiles and Clothing, The Hong Kong Polytechnic University

ABSTRACT

During the colour perception process, an associated feeling or emotion is induced in our brains, and this kind of emotion is termed as 'colour emotion'. The researchers in the field of colour emotions have put many efforts in quantifying colour emotions with the standard colour specifications and evaluating the influence of hue, lightness and chroma to the colour emotions of human beings. In this study, a colour planner was derived according to these findings so that the correlation of colour emotions and standard colour specifications was clearly indicated. Since people of different nationalities usually have different colour emotions as different cultural and traditional backgrounds, the subjects in this study were all native Hong Kong Chinese and the colour emotion words were all written in Chinese language in the visual assessments. Through the colour planner, the designers from different areas, no matter fashion, graphic, interior or web site etc., can select suitable colours for inducing target colour emotions to the customers or product-users since different colours convey different meanings to them. In addition, the designers can enhance the functionality and increase the attractiveness of their designed products by selecting suitable colours.

Keywords: colour emotions, colour planner, product design and designers

1. INTRODUCTION

Conventionally, the designers select colour(s) for their products according to their judgment and preference. Many researchers have pointed out that different colours usually have different meanings to people[1], and during the colour perception process an associated feeling or emotion is induced in our brain. This kind of emotion is termed as 'colour emotion'. The researchers in the field of colour emotions have put many efforts in quantifying colour emotions with the standard colour specifications and evaluating the influence of hue, lightness and chroma to the colour emotions of human beings[2-7]. In this study, a colour planner was derived according to these findings so that the correlation of colour emotions and standard colour specifications was clearly indicated. Since people of different nationalities usually have different colour emotions as different cultural and traditional backgrounds, the subjects in this study were all native Hong Kong Chinese and the colour emotion words were all written in Chinese language in the visual assessments.

2. METHODOLODY

2.1 Visual assessment

Seventy subjects in the visual assessments were native Hong Kong Chinese aged around twenty, with half of whom were male and half female. Each subject was asked to take the Isihara Colour Blindness Test before doing the visual assessment in order to ensure their normality in colour vision. Two hundred and eighteen colour samples with a size of 1.0 cm x 1.5 cm were used. They were selected from the SCOTDIC PLUS 2000 system which is a textile version of the Munsell colour order system. The visual assessment was conducted under a Verivide artificial daylight D_{65} with colour temperature 6500K and the colour of background was neutral gray. When viewing the colours, a neutral grey mask was used to cover the surround of each colour sample in order to ensure that the assessment was not influenced by the colour of surround. The colour samples were illuminated along their normal, i.e. directly facing the light, and viewed at approximately 45° to the normal. Each subject was asked to fill in the questionnaire during the visual assessment. In the questionnaire, there were two pairs of words for describing the human emotions. They were warm-cool and striking-subdued. These word pairs were written in Chinese language since all subjects were native Hong Kong Chinese using Chinese as the mother-tongue language.

2.2 Method for quantifying colour emotions

After viewing a colour sample, each subject was requested to select a more appropriate word to describe the colour from each word pair. In assessing a colour by each word pair, +1 point was given to the selection of 'warm' and 'striking'; while –1 point was given to the selection of 'cool' and 'subdued'. For example, when the 'warm-cool' colour emotion of colour sample 5R1 was assessed by the subjects, the calculation of the 'warm-cool' percentage (WC%) of 5R1 became:

$$WC\% = \frac{x \times (+1) + y \times (-1)}{x + y} \times 100\% \tag{1}$$

where x and y are the number of subjects selecting warm and cool colour emotions for colour sample 5R1 respectively; and $x+y$ is the total number of subjects, i.e. 70 for subjects representing general customers and 5 for designers.

If all subjects selected 'warm' to describe the colour, $WC\%$ is equal to 100%. If all subjects selected 'cool' to describe the colour, $WC\%$ is equal to −100%. The 'striking-subdued' colour emotion percentage was also calculated by this method.

2.3 Creation of colour planners

The calculated colour emotion percentage were used to find out the quantitative relationships between colour emotions and the CIE colorimetric attributes, L^*, C^* and h. Mathematical multiple regression by optimization using C++ programming was used as a tool to derive models for representing the relationships. Since h ranges from 0^0 to 360^0 and the hue at 0^0 is equivalent to that at 360^0, indicating similarity by perception but with a very large difference in magnitude, two models were derived for each colour emotion pair. One model is for $0^0 \le h < 180^0$ and the other is for $180^0 \le h < 360^0$, so that the contribution of hue to those colour emotion pairs could be better represented. The colour planners showing the relationship of colour emotions and colour specifications were then created according to the derived mathematical models. There were four planners for each colour emotion pair and each planner was used for representing one hue, i.e. red (hue angle=0^0), yellow (hue angle=90^0), green (hue angle=180^0) and blue (hue angle=270^0).

3. RESULTS AND DISCUSSION

3.1 'Warm-cool' colour emotion

Among the three colour specifications, chroma of colour was found to be the dominant parameter in 'warm-cool' colour emotion and hue was also observed to have influence on it whereas no significant correlation was found between lightness of colour and 'warm-cool' colour emotion. As the chroma of colour increased, approaching 'warm' colour emotion was induced to the subjects' mind. According to the findings, 'warmer' colour emotions were given to the subjects when perceiving red and yellow colours while 'cooler' emotions were given when perceiving green and blue colour. The colour planners showing the 'warm-cool' colour emotions for red, yellow, green and blue colours are illustrated in Figure 1 to 4 respectively.

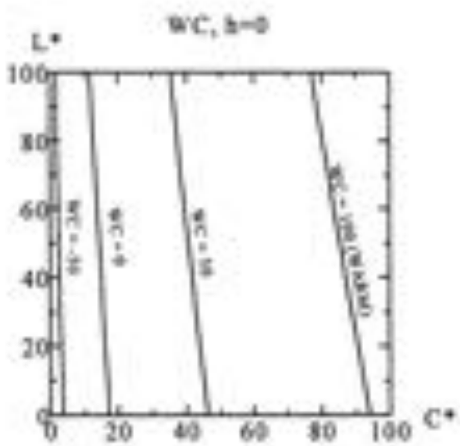


Figure 1 Colour planner for 'warm-cool' colour emotion at h=0^0

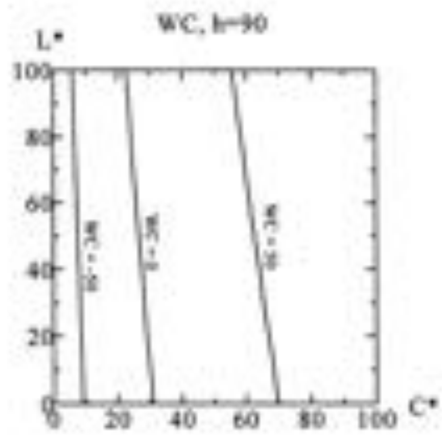


Figure 2 Colour planner for 'warm-cool' colour emotion at h=90^0

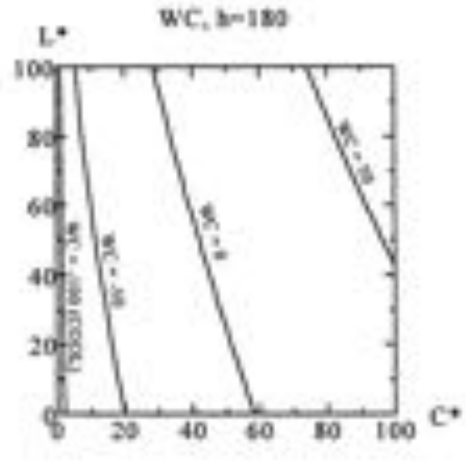


Figure 3 Colour planner for 'warm-cool' colour emotion at h=180°

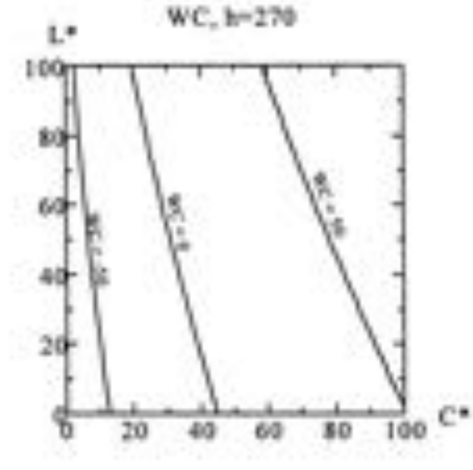


Figure 4 Colour planner for 'warm-cool' colour emotion at h=270°

Figure 1 illustrates that a 'warm' colour emotion, WC=100, is given to the subjects when C^* is between 80 and 95 and hue angle=0°, i.e. red colours, no matter what the lightness of the colour is. However, at the same range of chroma for yellow colours, hue angle=90° (Figure 2), the 'warm-cool' colour emotion tends to be less 'warmer' with WC smaller than 100 but larger than 50; while for green colours, hue angle=180° (Figure 3), the colour emotion tends to be much less 'warmer' with WC equals to around 50. In Figure 3, a 'cool' colour emotion, WC=-100, is obtained at C^* around 2 and this represents for those green colours with low chroma, they will induce 'cool' impression to the subjects during perception. For those yellow and blue colours at the same chroma, C^*=2, the induced emotion is not as 'cool' as green colours, and their WC values are smaller than -50, which are shown in Figure 2 and 4 respectively; whereas for the red colours at C^*=2, the induced emotion is much less 'cooler' that WC is around -50. Apart from these, the influence of lightness in green and blue colours is observed to be larger than that in red and yellow colours (Figure 1-4). For example, Figure 4 shows that a rather 'warm' impression, WC=50, will be induced during the perception of blue colours at L^*=70 and C^*=70 or L^*=20 and C^*=90, so that either changing the lightness or chroma of colour will induce similar 'warm-cool' emotion to the subjects. From the colour planners of the 'warm-cool' colour emotion, it can be concluded that colours of higher chroma tend to induce 'warmer' emotion to the subjects, and red colours will induce 'warmer' emotion than green colours even they are of the same chroma.

3.2 'Striking-subdued' colour emotion

Chroma of colour was also found to be the dominant parameter influencing the selection of 'striking-subdued' colour emotion as 'warm-cool' colour emotion. However, the influence of lightness in 'striking-subdued' colour emotion was observed to be more obvious whereas the effect of hue was found to be less significant as those in 'warm-cool' colour emotion. As the chroma of colour increased, a more 'striking' colour emotion was induced to the subjects' mind; while increasing the lightness of colour would give a more 'subdued' emotion to the subjects, no matter what the hue of colour was.

Figures 5-8 illustrate the 'striking-subdued' colour emotion for red, yellow, green and blue colours respectively. The main difference of 'striking-subdued' colour emotion among these hue is that 'subdued' emotion, SS=-100, is induced at high lightness and low chroma of red and yellow colours as shown in Figure 5 and 6, while no such 'subdued' emotion is found in the green and blue colours as shown in Figure 7 and 8. Although chroma of colour has the largest impact on the selection of 'striking-subdued' colour emotion, lightness of colour also shows its influence on it. For example, for the red colour, i.e. hue angle at 0°, of L^*=50 and C^*=70, a 'striking' impression, SS=100, will be given to the subjects; if a designer desires to convey the same 'striking' emotion to the customers but using a lower chromatic colour, he can reduce the lightness at the same time in order to maintain the 'striking-subdued' colour emotion to be at the same level.

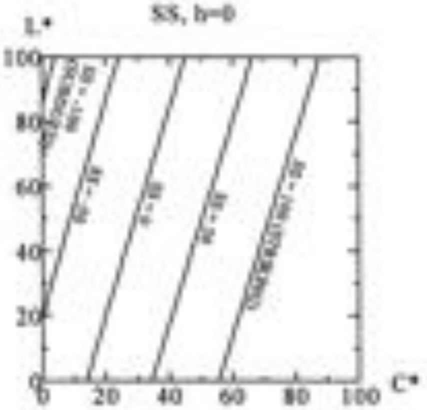


Figure 5 Colour planner for 'striking-subdued' colour emotion at h=0°

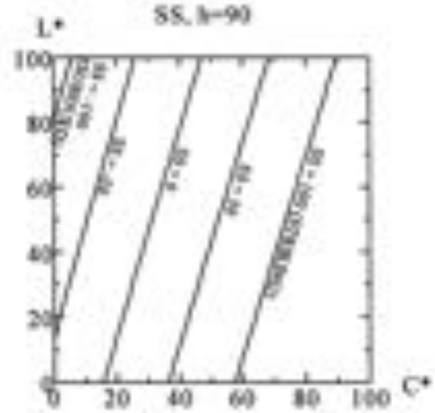


Figure 6 Colour planner for 'striking-subdued' colour emotion at h=90°

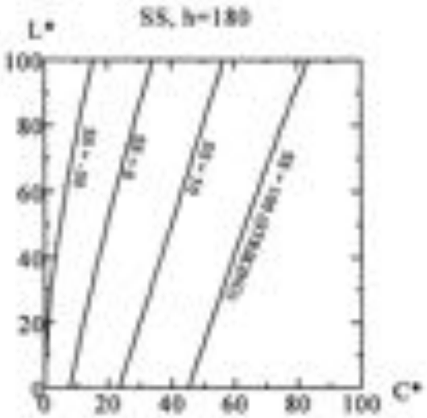


Figure 7 Colour planner for 'striking-subdued' colour emotion at h=180°

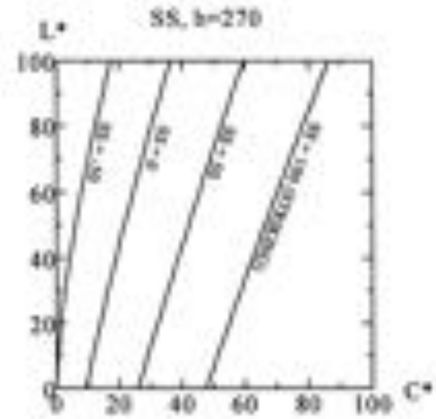


Figure 8 Colour planner for 'striking-subdued' colour emotion at h=270°

4. CONCLUSIONS

In this study, the colour planners for 'warm-cool' and 'striking-subdued' colour emotions were developed. Through the colour planner, the designers from different areas, no matter fashion, graphic, interior or web site etc., can select suitable colours for inducing target colour emotions to the customers or product-users. In addition, the designers can enhance the functionality and increase the attractiveness of their designed products by selecting suitable colours. As colour emotions are directly correlated to standard colour specifications in the colour planner, this can avoid the misunderstanding between the designers or colour users and the colourists during their communication by using the numerical terms.

ACKNOWLEDGEMENT

We wish to thank the Hong Kong Polytechnic University for supporting the funding of this research project. We would also like to thank Dr. T. Sato in Kyoto Institute of Technology for the advice and the colour samples used in this study.

REFERENCES

1. Kobayashi, S., The Aim and Method of the Colour Image Scale, Colour Research Application, **6**, 93-107, 1981.
2. Nakamura, T., Sasaki, Y., Sato, T. & Teraji, K., An Attempt for Instrumental Expression of the Colour Image Scale, Sen-I Gakkaishi, **48**, 96-101, 1992.
3. Xin, J. H., Cheng, K. M., Chong, T. F., Sato, T., Nakamura, T., Kagiwara, K., and Hoshino, H., Quantifying Colour Emotional Scale-What Has Been Achieved, The Research Journal of Textiles and Apparel, **2**, 46-54, 1998

* Correspondence: [illegible]; phone 852-2766-6520; Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hong Kong

Colours fallen from heaven

Yves Charnay*

SUMMARY

« *Colours fallen from heaven* » is the title of an environmental creation which uses a particular lighting device. The site is a baroque chapel which has now become the concert hall of the Music School of Apt, a town in France.
One of the properties of the works realized with this device is to be set in front of openings such as stained-glass windows. They take part in the expression of an architecture. In some versions, the lighting is composed of one or several sources of artificial light.

A SITE

Formerly set in the Hôtel Dieu, the chapel appeared as a peaceful island in an ocean of pain.
The pain rattle and the cries of despair that carried away the sick to their tragic ends have fallen silent.
The complaints and moanings have been replaced by trills of new voices with incertain tones. The nuns and doctors have let their places to teachers and conductors. The prayers have made way for music. Hesitant at first, music now, asserts itself, carried by the splendour of trumpets, the warm sound of clarinets or the murmurs of cellos.
Highest reward given to those who have come to an agreement : express together, in a concert, a found harmony.

AESTHETIC

Baroque light is multiform : radiating or diffuse, soft or insistent, warm or cold. Sometimes bright and direct as beams of theatre spotlights, the rays of sunlight, in which golden dusts sparkle, pierce through the openings of a dome. Or as if diffracted by the bumps in the architecture, the light bounces in cascades on the walls splashing them with colurs.
On the ceilings and walls God, the saints, men and angels often hail each other amidst a proliferating mineral vegetation. The memory of these vanished figures still watches over the glorious universe of their origins. Colours send us back the echo of disappeared chorus, ultimate harmonies as well as the memory of all the voices of the music instruments which have formed our taste since centuries.

AN EXPRESSION

Colours fallen from heaven plays with the empty space of the chapel to shape the light which floods it into coloured reflections. Whether discreet or intense, the light reflects on the ceiling and the walls a multitude of enveloping and diffuse nuances which clothes the edifice in velvet shades.
In the light specific to each season, the scenographist-sun dramatizes space. The cycle of the daily variations of the sun sets the quality of light. The intensity of the lighting is modulated by the flows of the clouds. The baroque edifice, a medium between men and cosmos, plays whimsical meteorological scores in which the moods of our star are transcribed.
Then the vault of the edifice, echoing the vault of heaven, matches its tones with those of heaven.

REFLEXIONS

The lighting device metamorphoses the aspect of heavy and opaque materials such as stone, wood or iron. It endows the architecture with a sense of lightness and immateriality.
The transmission of colour through the reflection of light presents a high plastic interest. My studies on the properties of diffuse reflection gave birth to works called «*Solar Sculptures*». The materials used for these works are quite varied, wood, plaster, metal or concrete. The choice of the materials depends on the site whether it is an open site or not, whether it is protected from bad weather or not. The shapes are linked to the quantity of sunshine and to the axis of vision.
The shapes and the ways of assembling are determined by the management of the axes of reflection.
The mixtures of colours change according to the angle of incidence of light. The tone and the brightness of the colours evolve during the day.

* Auteur ycharnay@club-internet.fr , http://yvescharnay.free.fr, Ecole Nationale Supérieure des Arts Décoratifs, 31 rue d'Ulm, 75002, Paris, France.

Color management in creating of fabric season collection

Darko Golob*, Mojca Strafela**, Vera Golob*
*University of Maribor, Faculty of Mechanical Engineering, Textile Department, Slovenia
**Textile Factory SVILA Maribor

ABSTRACT

A novel approach to color design for a fashionable collection of dyed and printed fabric is the incorporating of color management and colorimetry into production process. Color design for the collection is performed on advanced computer-aided color management equipment. This process includes pattern design and scanning, the preparation of color combinations on monitors and their printing out. Individual patterns are prepared in different color combinations. Colorimetry and computer match prediction is used to evaluate the color combinations of fabric collections and to produce recipes for the dyeing and printing processes.

Key words: design of fabric collection, color management, colorimetry, dyed fabric, printed fabric.

1. INTRODUCTION

The producers of fabrics usually design two main collections yearly: spring/summer and autumn/winter. The planning of collection always begins by selecting the newest trends and ideas at fairs (Paris, Florence, Milan,…),from the literature (Peclers, View, Textilwirtschaft,…), from renowned customers, from acknowledged dye producers, auxiliaries, raw materials, etc. This first step is a very important work phase, because the success or failure of any collection depends on these decisions. New fancy pattern card should be completed using some classical color shades. This pPattern card is often divided into different sections e.g. ethno style, yesterday, today and tomorrow, the city by night, gipsy etc., and includes both dyed and printed fabrics.

The designing of the pattern is an innovative art based on the designer's subjective understanding of fashion, whilst the inclusion of computer-aided color management into color design enables the designer to create a large number of color drafts and color combinations. In this way the creative arts of design and advanced computer technology are combined in creating a seasonal fabric collection.

In this paper a modern approach is presented for the creating and production of a fabric collection, which introduces color management into the whole production process from the initial idea to the quality control of dyed and printed fabric. The color design of the collection was created by employing advanced computer technology. This procedure consists of pattern scanning, color selection and preparation of color combinations on the monitor, and the printing out of the collection on a color printer. Devices should be calibrated to produce the same color on different media. All colors were measured and expressed by Lab values, which are device independent. When an exact color was impossible to reproduce, the nearest color was shown together with remarks about the difference and exact color values.

The designers and technologists collaborated as a working team to select substrates, which contemporarily determine the choice of dyes and dyeing and printing technologies. The collection was prepared for two different viscose fabrics using reactive dyes. The colorimetry and computer match predictions used in producing of fabric collection were implemented, which mainly facilitated working accurately when producing recipes for dyeing, and transferring dyeing recipes in the production using various machines.

2. COLOR MANAGEMENT – MODERN CONCEPT OF CREATING A FABRIC COLLECTION

This modern method of designing a collection aided by computers differs greatly from the classical approach. The creator uses a computer system that includes:

- A color calibrated computer monitor for design and color presentation
- A viewing cabinet for color samples and monitor color comparison
- A spectrophotometer for exact measurement of colors
- Color calibrated printer for printing of color samples on the paper
- A system for computer match prediction

For color choice different color notation systems (Munsell, RAL, NSC, ...) are integrated in to the computer which can be cross-linked. Color date input can be obtained by measurement (spectrophotometer, scanner, camera) or directly as an electronic art.

The fashion designer chooses the appropriate colors on the monitor and compares them against existing collections and fashion trends. He (she) also checks the harmony of the color combinations. The colors are picked up from different color notation systems and appropriately modified or created from scratch. The designed collection is printed on a color printer and checked in the color viewing cabinet against the color on the monitor. Designed samples can be electronically sent to customers, clients and technologists who must have the same color calibrated systems. When the collection is approved, the computer recipe for dyeing is calculated based on the dye database and the technology of dyeing considered.
All colors are converted in the reference color space (CIEXYZ, CIELAB) and presented on each device in its own color system.

Each device for acquisition, processing or reproduction of color is based on its own color space depending on the technology used:

- Scanners, digital cameras and monitors use RGB color space with additive mixing of red, green and blue color.
- Printers use CMYK color space with subtractive mixing of cyan, magenta, yellow and black on paper of different whiteness.

Beside color space a color gamut is also very important. It embraces all colors that can be acquired or presented on particular device and depends on technology and characteristics:

- Scanners define their color gamut with precision and sensitivity of each color sensor,
- Monitors' gamut is limited with the position of red, green and blue phosphor on the color diagram
- Printers create gamut by selection of CMYK ink or toner considering the whiteness of paper.
- At textile dyeing the color gamut depends of dyestuff appropriate for that kind of material and differs for particular groups of dyestuff.

For correct color presentation the color must be converted from the color space of input device to the color space of output device. There are two possibilities:

1. Conversion from each input device dependent color space to each output device dependent color space. We need a conversion algorithm for each pair of devices.
2. Conversion from devices to reference color space (XYZ) and vice versa. We only need one conversion algorithm for each device.

3. EXPERIMENTAL

Experimental work on the production of fabric from the initial idea to the end product ran as follows:

- Drawing of pattern design sketches for the printed fabric collection
- Scanning of pattern
- Selection of colors for the collection and creation of color combinations on the monitor
- Printout of the selected colors on a color printer
- Selection of the substrate, dyes and dyeing and printing technologies
- Colorimetric evaluation of collection

Drawing of pattern sketches for the printing fabric collection
The collection consists of several patterns, some of them are shown in Figure 1.

Scanning of pattern
The drawing pattern sketches were scanned on the HP ScanJet 5P scanner and prepared for computer-supported colouring. The contrast and brightness were adjusted to eliminate the spots caused by paper surface; the shading made by pencil was left. Then the discontinued lines were repaired in order to enable easier painting.

Selection of colors for the collection and creation of color combinations on the monitor
The patterns of the collection were designed in various color combinations. Colors were selected by the designer on the basis of fashion trends and ideas from fairs.

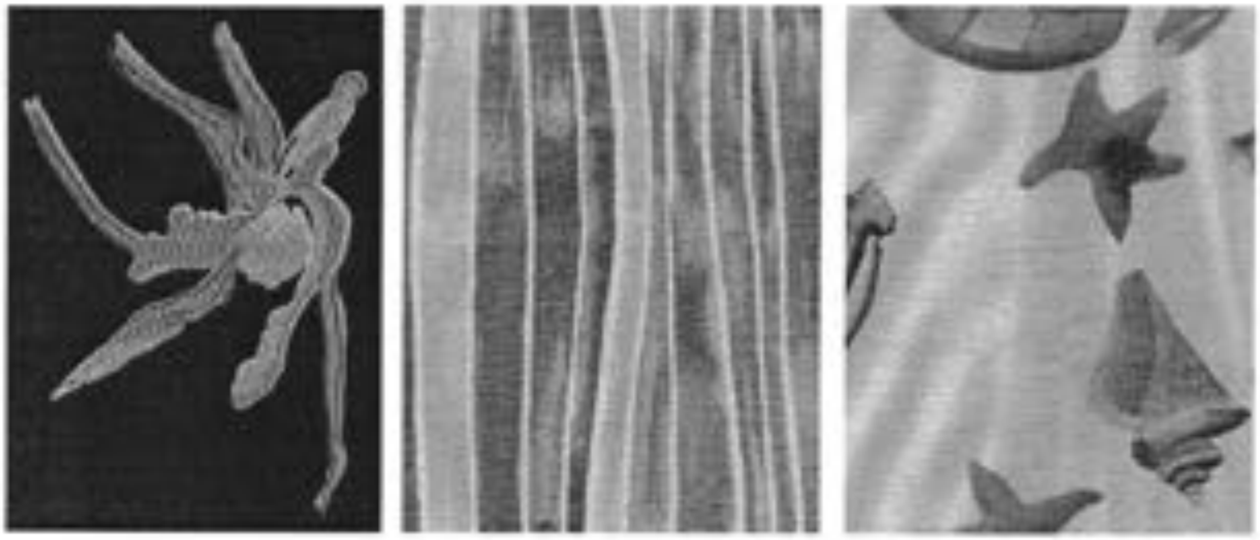


Figure 1: Pattern sketches for printing fabric

Print out of the selected colors on a color printer
Color preparation on a monitor differs from the output on the printer. While printers use a subtractive mixture with CMYK inks, monitors use additive mixing with RGB phosphors. Printed colors also depend on printing art (inkjet, laser, wax) so it is very hard to predict the output color on the basis of monitor color. The selected colors were adjusted to achieve the same shade on the printer using the CMY based color palette.

Selection of the substrate, dyes and dyeing and printing technologies
Two substrates were selected for the seasonal collection, which contemporarily determined the choice of dyes and technologies.

- ***Fabric 1:*** Warp: 110/40 dtex 1300 CVF ; S+Z;
  Weft: 60/1 Nm 1700 CVY; S+Z;
  Fabric weight: 123,9 g/m^2 ;
  Dyeing technology: exhaust dying in rope (jet dying machine).
  Printing technology: **discharge** printing
- ***Fabric 2:*** Warp: 20/0/0 dtex PES;
  Weft: 60/1 Nm 1700 CVY; crepe;
  Fabric weight: 71,8 g/m^2;
  Printing technology: **direct** printing

In the case of Fabric 1 reactive vinylsulphone reactive dyes were applied for dyeing of fabric:

- C.I. Reactive yellow 17
- C.I. Reactive red 22
- C.I. Reactive black 5

Discharge printing was performed with vat and reactive dyes:

- C.I. Vat Orange 1
- C.I. Vat Blue 5
- C.I. Vat Black 30
- C.I. Vat Violet 3
- C.I. Vat Red 2

Colorimetric evaluation of collection
Paper patterns were measured using a spectrophotometer and recipes were prepared by computer match prediction for both dyeing technologies. As an example color differences between the paper pattern and each fabric, are presented in Tables 1 and 2 respectively.

Table 1: CIELAB differences of fabric 1 (standard: paper pattern)

Color pattern	ΔE^*	ΔL^*	Δa^*	Δb^*	ΔC^*	ΔH^*
1	3.606	-1.309	-1.789	-2.844	-3.324	-0.490
2	2.260	-1.288	-1.757	-0.601	-1.663	0.825
3	5.501	-5.431	-0.303	0.822	0.203	0.852
4	4.321	-1.937	-1.688	3.474	-2.806	2.654
5	6.828	-2.255	-2.966	5.722	-6.012	-2.322
6	3.538	-0.914	-1.266	3.174	-1.715	-2.956
7	3.115	-2.266	-1.177	1.783	2.071	-0.525

Table 2: CIELAB differences of fabric 2 (standard: paper pattern)

Color pattern	ΔE^*	ΔL^*	Δa^*	Δb^*	ΔC^*	ΔH^*
1	6.314	-4.955	2.259	-3.195	-0.828	-3.825
2	5.463	-4.066	1.194	-3.448	-1.398	-3.370
3	10.079	-9.563	2.796	1.523	3.176	-0.230
4	7.561	-7.281	2.021	0.266	1.748	1.049
5	6.251	-5.652	-0.779	2.551	-2.638	-0.399
6	4.512	-4.389	0.148	-1.035	0.865	0.588
7	4.897	-4.785	-0.982	0.344	0.972	0.372

Colour differences are significant but still acceptable in regard to the fact, that it is the company's own collection, where those colour trends are only the orientation for designing and not as an obligatory rule.

Fabric 1, dyed by exhaust process:

- All samples, dyed according to computer recipes have negative Δa^* and are darker as standard (ΔL^* is negative)
- By increasing of concentration of yellow dyestuff the depth of colour is also increased, which leads to conclusion that the degree of exhaustion and fixation of yellow dyestuff is probably higher than the degrees of exhaustion and fixation of red and blue dyestuffs.

Fabric 2, dyed by the Pad – batch technology:

- All the samples are to dark (ΔL^* is negative), which means that the degree of fixation of yellow dyestuff is higher in comparison to the red and blue dyestuff and the differences in lightness (ΔL^*) have a major influence on the colour difference (ΔE^*).
- In contrast to the first fabric there is no rule about the relationship between Δa^* and Δb^* as with the exhaust dyeing.

Color differences for printed fabrics are similar.

4. CONCLUSION

Color management can be used for the preparation and production of dyed and printed fabrics and represents a great assistance for production preparation from the initial idea to the final product. Results of colorimetric checking show that recipes made on the basis of the paper standards are substantially different, especially in lightness but for your own collection it is tolerable and enables a greater scope for choice.

ACKNOWLEDGMENT

We wish to express our sincere appreciation to the Karl Miescher Foundation for their financial support for color management equipment purchase.

REFERENCES

R. E. Burger: Color-management, Springer Verlag, Berlin 1993

L. W. MacDonald: Developments in colour managements systems, Display 16 (1996) 4. pages 203-211.

P. A. Rhodes, M. R. Luo: A system for WYSIWYG colour communication, Displays 16 (1996) 4. pages 213-221.

* Correspondence: darko.golob@uni-mb.si; phone +386 2 2207895; fax +386 2 2207990; University of Maribor, Faculty of Mechanical Engineering, Smetanova 17, SI-2000 Maribor, Slovenia.

Chromatic harmonization concepts applied to indoor environments using computer simulation

Berenice Gonçalves *; Alice T. Cybis Pereira ** and Patricia Silveira Neves
Dept. de Expressão Gráfica. UFSC/ SC. Brazil

ABSTRACT

This work analyses the use of color in indoor environments, as well as the importance of computer simulation aimed at the study of chromatic harmonization principles. For this purpose, light and tone composition qualities and the characteristics that allow chromatic "space" construction and perception are explored. This work highlights the very important simulation tool that Computer graphics has became when applied to indoor environment simulation, since the color relations can be better evaluated through the use of virtual manipulation of environmental characteristics and design aims. Finally, some examples are presented which originated from indoor chromatic harmonization-based computer simulation.

keywords: Indoor environment, color, harmonization

1. INTRODUCTION

Presence or absence of light is responsible for the sensation of colors. Light is a physical phenomenon, but the perception of colors rely on the interaction between light, visual system and brain, therefore being considered a psychophysical phenomenon. Man reacts to the chromatic language according to its physical conditions and cultural influences[1]. Because of its expressive appeal, color is an important tool to manifest ideas.
Recently, color has been rehabilitated to be used in indoor environments, as well as in outdoor environments. When used in indoor environments, colors enable a space to be seen and perceived in a different way. When used in environments intended for work or leisure, as well as for domestic or public use, colors can provide visual comfort and more satisfaction while people carries out different kinds of activities. However, reactions caused by the same color can include different space perceptions and psychic sensations, according to its use. Therefore, the proces of chromatic planning should be improved and the study of colors supported by computer simulation becomes an ever important designing tool.

2. COLOR AND SPACIOUSNESS

Different chromatic interrelations generate spatial mobility. Visual distances can become relative and flexible[2]. Even the volume of an object can be altered by the use of colors. A white surface always seems larger because the light that is reflected creates an appearance of amplitude. Dark colors, however, decrease the space. A dark wall always seems to be closer. Colors can also be considered a weight element. The composition can be balanced or not, within a bidimensional or tridimensional space, by the different colors that are applied in the context. This balance can be provided by the sensations stimulated by colors when each one is applied to its right spot.

Hot colors can be applied to small parts of the space because they increase the space sensation, while cold colors decrease the space sensation when applied to small areas. Red, for instance, has a static representation, while the yellow expresses enlargement, and blue represents emptiness. Color in dark tonalities seem to be heavier than the ones in light tonalities. They represent spatial deepness, sensuality and dynamics.

The use of sequential tonalities generates a linear movement that characterises shape and space. The interrelation between primary and secondary colors originates a flat appearance of the space. The numerous tonalities of the same color work together in group. Hot colors seem to jump out of the surface. They are salient, aggressive. On the other hand, cold tonalities (blue, green and violet) create an illusion of deepness and backward movement. We have an impression that the objects are located behind the plane that actually contains them[1].

In indoor environments, the light colors increase the volumes and the dark ones approximate the surfaces. In order to lower the ceiling of a room, for example, we can paint it in a dark color. It will seem lower and the room will seem more welcoming in addition, if we paint the walls in light colors, they will "move back" and the environment will become larger. Light colors should be applied to ceilings even in indoor environments and show windows, in order to provide a good reflection of light. Saturated colors seem to decrease the space, reason why they are not recommended for small spaces [3]. However, they can be largely used on small surfaces to emphasise an object within a neutral environment. Shinning colors reflect light, making the environment lighter, while the opaque ones absorb light, making the environment darker. Thus, color is also dimensioning because it apparently increases or decreases the space perception within an environment. Therefore, the objects seem to be closer or farther, as well as the distances seem to be longer or shorter.

3. COMPUTER SIMULATION OF THE HARMONIZATION PRINCIPLES WITHIN A SAME ENVIRONMENT

Computer Graphics involve all the methods and techniques concerning the conversion of data to graphical representation devices through a computer. Therefore, it represents any task within the computer field that involves the use o images.
Computer graphics was used in this work to simulate different chromatic propositions for the same environment. The meaning of simulation was limited to testing and visualising the perceptive and spatial characteristics provided by the use of different color combinations within the same indoor environment. To Levy, virtual simulation can be used to test the phenomena or situations within all the imaginable variations, so that it is possible to think about the consequences and implications of a hypothesis, get to know objects or complex systems better, or even to explore imaginary universes in a playful way. When the simulated phenomenon is visualised, we can manage the variables of the model in real time and observe the resulting changes on the computer screen at the same time. The examples presented in this study do not concern interactive simulations [4].

3.1 Examples: bedroom and living room

Different harmonization studies were applied to the following examples by the authors of this project. The original design was provided by the architect Ana Teixeira. After developing the project by using a vectorial software, the phase of rendering and correction with an image treatment software (raster) takes place.
Figure 1 represents the bedroom to which was applied a desaturated green tone. The whole composition gives an impression of spatial integration and amplification due to the use of the monochromatic principle. In figure 2, we can notice that to the same environment was applied an opposition of temperature: hot/cold (yellow/blue), from what we can observe a different result regarding space: the elongation of the room.

To figures 3 and 4 (living room) were also applied different colors. Figure three represents an attempt to achieve spatial unity using the analogy principle between desatured tones of green and blue. This alternative generated the sensation of amplification. However, in figure 4, with the use of complementary contrast, we have as a result an image with higher visual density and weight. The dark red tonality applied to the back and the living room as a whole are in contrast, what creates an area of spatial interest and dynamics. However, this red spot seems to get closer to the observer and, therefore, decreases the space sensation of the environment.

Figure 1. Bedroom: monochromatic principle with green tone.

Figure 2: Bedroom: use of contrast of temperature.

Figure 3. Living room: analogy principle between tones of green and blue

Figure 4. Living room: use of complementary contrast dark red and green.

4. RESULTS

Chromatic planning of an environment, using the concepts of chromatic harmonization, demands a designer to master the psychophysical and functional principles of colors. In any indoor environment, the choice for one of the harmonic compositions or colors dispositions should be made concerning the size of the project (dimension), the objective (kind of work, activity or task that is going to be carried out in the environment in matter), the user profile and the kind of lighting intended for the place.

A successful computer simulation demands the mastering of a software able to provide a broad range of colors and different resources, besides the knowledge of the content and details of the project. Thus, it is possible to simulate the different lighting possibilities and the physical characteristics of the space, besides the chromatic elements. Therefore, the same environment can be seen and perceived in different and pre-determined ways. We also point out to the importance of lighting, that affects space perception as it stands as na articulation element of shadows, colors, shape, rhythm and texture. Light can elicit shapes, flat walls, tridimensional spaces, architectural details, sculptures and furniture. As well as color, light can increase or decrease the size of the elements in the environment.

We point out to the fact that the best way to evaluate color before using it in an indoor environment or even in an urban environment is the simulation, whether it is virtual or done by a scale model. Computer simulation provides diversity, quickness and a final touch. With the study of different chromatic interrelations for the same environment, the professional broadens the range of choices regarding the visual elements. The decision making process becomes easier when there is the possibility to simulate the different ideas concerning chromatic harmonization. Therefore, simulation is the best way to evaluate the use of colors in each context, within indoor environments or even urban environments.

ACKNOLEDGEMENTS

This study is a part of a larger project that is being carried out by the Program of Post-Graduation in Production Engineering with collaboration of the Graphical Expression Department from Universidade Federal de Santa Catarina.

REFERENCES

1. PEDROSA, I. *Da cor à cor inexistente*. Rio de Janeiro, Léo Christiano editorial. 1980.
2. ALBERS, Josef. *La intracion del color*. Madrid: Alianza, 1996
3. HIASCHMAN, Jessica, Paint & Color – Little, Brown and Company, Boston
4. LÉVY, Pierre. *As tecnologias da Inteligência*. São Paulo: 1999.
5. GOLDING, Mordy. *Guia de cores para web designers* - Pantone Web Color. São Paulo: Ed. Quark, 1999.
6. KUPPERS, Harald. *Color*. Origem, metodologia, sistematização e aplicação. Barcelona: Lectura, 1973.
7. THE COLOR, Reed International Books Limited - San Francisco in 1997.
8. LEVINE, Melinda. *Living rooms*, Colors for Living, 1997.

* beronice@cce.ufsc.br. Departamento de Expressão Gráfica. Universidade Federal de Santa Catarina. Campus Trindade, s/nº. Florianópolis- SC. Fone: 55 48 3319892. Brazil ** pereira@cce.ufsc.br. UFSC-EGR Universidade Federal de Santa Catarina.

Line, space and color

María Elena Ligory S
Faculty of Architecture, Universidad del Zulia, Venezuela

Abstract

Blends and combinations that occur in the world of color are of a great variety. The combinations vary from barely perceptible changes to the most intense contrasts.
The vast world of color is explored in search of criteria for its organization, its diversity and complexity being evidenced, identifying three strategic fields for performing work: the surroundings, the object and the perceiver. These fields are recognizable rather than separable as the integration is confirmed in this study.
Before this complexity, we decided to begin in a way that contrasts with the nearly most elemental criterion for organizing colors, the criterion of gradation, from complex to simple.
The gradual order is a sequential order and of transition between two given color values. In principle, it is an order of linear conceptualization.
Let us broaden the approach and consider the line, firstly its single-direction aspect and then in space which is also chromatic, and apply the same criterion of gradation between the structural elements, line and space. We can perceive that the line tends to abandon its limitations, to combine and interact with the surrounding space and shows us with this its freedom, from the simple to the complex.

Gradation Complexity Surrounding Criterion Perception

1. Introduction

Color. Expansive and unlimited space of tones, shades, intensities, materials, brightness, reflections, opacities, is shown from its most intensive contrasts to the hardly perceivable variations.
These two extremes in the world of color, intensive contrast and the tendency to soft uniformity of a gradation, structure this paper. The elements from other fields that were selected, line and space, from the field of the figure, from form itself, are analyzed under circumstances and with a similar approach, from contrast to gradation. Approaching the subject in this way with the intention of experiencing the subject of color, from the concepts and ideas, adapting it to the possibilities of a manuscript.

2. General description of the set to be explored

The blends and combinations that occur in the world of color are of a great diversity; the combinations go from imperceptible changes to intense contrasts.
This refers to wholeness.
The aspect and the quality of color depends on numerous variables that are part of the great set which we have decided to divide into three large fields:

1. The variables belonging to the object itself, such as the material, the consistency, dimensions, shape, brightness and opaqueness and others.
2. The variables that derive from the environment of the object, surroundings, brightness, immediate, neighboring, contracting sets, and
3. The variables we have characterized as internal perceptions of each human being, psychological structure, interests, tastes, inclinations, level of sensibility.

The three fields affect one another, producing overall a dynamic phenomenon.
In principle, the three fields sufficiently well-defined:

1. object, reference element, color, on which this study is based
2. extreme environment that surrounds the object, quality of the surroundings, and
3. subject or perceiver, who finding him/herself, action and effect in this phenomenon express the permeability of its limits.

The dynamics of the development of the techniques of color and color materials, lighting, transparent and reflective materials have recreated the very world of color and its essence tends to spread in an atmosphere of reflections, radiating its effect and participating in the creation of its own surroundings.
The surroundings, in their role as a container, represent the greatest dimension and therefore a great variety, as the effect of many changes.
The perceiver becomes present in this situation between object and surroundings, discovers and rediscovers it and at the same time the surroundings displays in changes in the object, reappraises or fuses it, producing a situation which we qualify as **highly complex**.
This complexity is broad and diligent, and it is also intricate and often unpredictable, if we compare it with the limited form we have for giving it a rational, methodical and organized explanation of the phenomenological dynamic processes that affect the perception of color.
This complexity which is given to the development and evolution of the phenomenon leads us to take decisions regarding knowing and handling criteria which lead us to a more grasping intervention within this situation which we understand to be integrated, and as integrity is one of its essential characteristics, we reaffirm it and establish it as a condition for approaching this study.
We explore this vast world of color, full of variety, diversity and complexity in search of criteria for its organization and decide to begin, in contrast to the complexity, with nearly the most essential elemental criterion for organization applied to the field of color, the criterion of gradation, and we select also natural conditions that existed before this study, that are expressed in the environment, up to a certain point simple, that consist in the natural presentation of the phenomenon of color, when light affects surfaces in a determined position and results in a luminous gradation that affects the perception of color, guiding us generally with regard to the position of the light and of the objects in space.
The perception of this effect allows us to orient ourselves with regard to the various elements in the environment. One of these: where is the light source? Behind, in front, above, below, exposing in this gradual evolution of this process of orientation, a sequence of complexity.

3. Formal Line-Space Structure

Observe a line that extends in the distance. It seems to have a single direction, the distance. In the remoteness of the line, where the intensity of the sensorial stimulus is absent, gradually disappears into endless space.
In this process of absence which generally begins with the precise and limited capture of the line, a gradual process occurs, in which the line as it runs into the distance looses sharpness and disappears, vanishes into the space which it penetrates, into the space which surrounds it, into a space which we commonly describe as empty or free.
If we perform the study partially, first we have a precise perception, with a predominating direction. **The Line** contrasted with a second imprecise perception, mutidirectional, more overall, the more enveloping **space**.
A phenomenon of perception of dimensions, first the perception of the single predominating dimension of the line, due to the effects, among others, of the precise and concentrated attention we pay to it.
If we prolong our attention, broadening our approach, we observe that it with its direction there is a transformation of dimensions, it takes with it movement, an almost static movement.

The back, front, past, future, present, and so forth is identified, and we are almost there. We change position or change the position of the line and put it horizontally in front of us and thus loose its predominating direction into the depth in front to softly show the depth of the sides, around it, and as if it could spread in multiple directions in space.
We can also observe the space expressing itself on the line.
Line and space seen integrally, reconciling one another, they enter into their own process of gradation, of transition.
This in regard to the formal structure, Line-Space.

The materials that constitute both elements are an important part in complementing the above described situation. Space has its material well defined, it is ethereal. The line may or may not be from ethereal to some other solid material. Line and space may both be of ethereal, intangible materials. The line of light and the line of shadow that form part of space and float in it and are drawn, hidden, and appear on the objects that intercept it. This is not the most frequent case with regard to the line, but it is with regard to space. The essential characteristic of space is its multidirectional capacity, reaffirmed by the fluid qualities that typically constitute it, qualities that induce us to give space qualities of freedom, with regard to the object, and to understand it in its ability to give it movement. Having stated this situation in this way that opens the way for us to the criterion of gradation with which it has been decided to develop this idea, and this criterion. It is the ethereal environment that continues the process of mediation. It leads us to explore the internal nature of the criterion of gradation itself.

3. Gradation

The criterion of gradation is given by the change between two different values, and is therefore structured internally by similarity and difference, in an organized sequence in a continual way.
Similar and different are terms that imply qualities of the interior world of things, as well as of their exterior worlds.
From the interior world it is established that the things have different as well as similar components.
The same occurs in the exterior world; we discover similarities, analogies and resemblances among them, as well as distinctions, differences, diversities and inequalities.
Therefore, these two criteria that structure the principle of gradation:

1. Affinity groups together similar components.
2. Differentiation, distinction, inequality, variety group together different components.

From this point of view and up to now, these two criteria seem to act in opposite ways and the constitution of our interior and exterior world seems to be like this.
Let us return to the idea that we have been developing regarding the line, considered in its single direction in constrast to the space with its multidirectional aspect, and we see that it deals with opposite values, in the same way as the initial structuralization of the process of gradation.
Let us continue broadening the approach and include the spatial surroundings, ethereal, fluid, permeable, penetrable, crystal clear, free and habitable. The environment in which the blends manage to dissolve, dilute and even become confused. Where the light in lines, in planes, shapes and volumes occupy it silently, then we can understand the most appropriate means for realizing the criterion of gradation.
The environment, then, enters through the concrete criterion of gradation to soften and dispel the differences one by one, the differences, the similarities, do it so silently that the change between that value that seeks to transform itself into another different value is unnoticed, highlighting the values of the other or also hinding its differences.
Atmosphere, ethereal matter where the opposition enters in harmony, becoming solid at dawn!
Atmósfera, medio etéreo donde la oposición entra en armonía, concretándose al amanecer.!

4. Reflexes and reflections

The criterion based on sensory perception which we give to the line in space, gives an order of knowledge regarding the line and its space, that leads us to understand as the interaction and effect of the nature of the space that surrounds it.
The limitation of the line is to follow its single direction, while the unlimited multiple directions of the space are displayed. As the line runs through space, space absorbs it, it transforms it in tenuous points until a point where the other successive points are scattered into the space that dilutes it and returns as space, as enveloping.
The case of color in gradation and that of the line that dissolves into space, are cases of transition, of mediation, in which a minimum of two values intervene. One of the given values gradually cedes in space its components to the presence of the components of the other.
This criterion based on sensory perception, which we give to the line in space, give us an order of knowledge regarding the line and its space which leads us to understand it as the action and effect of the nature of the space that surrounds it.
From this approach of integral characteristics, in which our perceptive conditions must be considered, the following questions and reflections arise:
Up to which point is the object affected by its surroundings and up to which point are the surroundings influenced by the object in their center?
In order to state this phenomenology in a graphical way, a work is prepared with a constant base, that is, with a minimum of formal variety of linear characteristics, and the gradation is worked on.
And in this order of ideas, the line makes space and the color in gradation, in linear order, it inhabits it, evoking the same phenomenon that is present in the nature and in some other fields of knowledge.
Arithmetic order: 3,4,5,,...6,7,8,...
Natural gradation: .....flight of pigeons, seagulls, herons,.....swans.
Musical order,.........me, fah sol.____re, doh,....
From the simple to the complex, located in the field of design, where are the frontiers between reality, virtuality and illusion?
Are the frontiers really in the surrounding or in use, the perceivers?
frontiers between linearity and nature?
between color, linearity, space and emotion?

Integrated in this way, colored and painted the concept of linearity in space, inhabit my interior space and… is it capable of making me long for freedom?
In a similar way to how the line is affected by space?
These questions and their possible answers are stated in design. It is left to the judgment of the perceiver, who is considered as our truest and final measuring instrument.
It has to do with a minimum number of formal variables and with almost the same criteria of order, the potential of color.
In a gesture of freedom!

The Multi-Dimensional Effects of Color on the World Wide Web

Jill Morton

ABSTRACT

Color is the most powerful building material of visual imagery on the World Wide Web. It must function successfully as it has done historically in traditional two-dimensional media, as well as address new challenges presented by this electronic medium. The psychological, physiological, technical and aesthetic effects of color have been redefined by the unique requirements of the electronic transmission of text and images on the Web. Color simultaneously addresses each of these dimensions in this electronic medium.

Keywords: color, world wide web, design, psychology, optics, technology, aesthetics, computers

1. INTRODUCTION

This paper examines how four primary disciplines affect how color functions on the web. While not all visual effects can be scientifically qualified, our eyes, minds and emotions react to the colors transmitted by the computer-generated RGB color space of the World Wide Web.

2. PSYCHOLOGY

Color delivers powerful associations that either enhance the underlying theme of a web site or work against it. Unfortunately, color symbolism is extremely complex. The associations of any color or color combination are affected by age, sex, nationality, geographic locale, race, religion, socio-economic status, exposure to other visual media, current events, fads, as well as other subjective factors.

Age alone plays a significant role in reactions to color and specifically to color fads. For example, young people are more susceptible to the latest color trends; mature people are less susceptible. This is clearly demonstrated by the current "popularity" of yellow-green. Shades of this color have not been well received by those who remember the avocado refrigerator days of the 70's in the U.S and elsewhere. Consequently, a web site that employs neon-lime as a symbol of cutting edge products or services may not be interpreted as such by all site visitors.

Gender also plays a primary role in psychological reactions to color. Women show a preference for red over blue and yellow over orange. Men prefer blue over red and orange over yellow[1]. Furthermore, women are more sensitive to variations in hue than men[2].

Cultural associations are extremely influential and differ from culture to culture. An example of the diverse symbolism of any given color is green. In the United States, it is the color of currency and is commonly associated with monetary affairs. Such is not the case in other countries whose currency differs in hue. Furthermore, green has unique associations in other cultures. For example, it signifies adherence to the faith in Islam. All of this is amplified by the geographic fact that Islam began and flourished in parched parts of the world where any green meant the presence of life-saving water.

Cultural associations are also influenced by other factors. For example, white is predominantly associated with weddings in Western cultures. In direct contrast, it is associated with death in China and is not accepted as a color for a wedding gown. Nevertheless, many young Chinese brides are breaking with tradition and choosing this color. Consequently, cultural associations must also be cross-referenced with age, gender, and other relevant factors.

Finally, each individual's personal preferences come into play. Many people have very strong feelings about color, especially those they dislike. These vary from individual to individual and are impossible to predict.

Given the diversity of the global audience on the World Wide Web, natural associations with timeless symbolism, such as blue/sky, red/fire and green/vegetation provide a departure point for further analysis of the specific hues.

3. PHYSIOLOGY

Color must address the mechanics of the human eye to ensure visual efficiency. Sustained viewing of images and text on a monitor is not as comfortable as hard copy for many people. Color plays a significant role in delivering visual comfort or generating visual fatigue.

First and foremost, the readability of text is the basic requirement of all web sites. The right color combinations create strong contrasts between text and background for maximum legibility and visual comfort. Black characters on a white background elicit faster reading performance than white characters on a black background[3]. Most very dark colors on a very light background also suffice.

Gamma's effects on color readings play a role in determining sufficient visual contrast. Contrast may appear to be sufficient on a computer system with fully corrected gamma of 2.2 but insufficient on other systems with uncorrected gamma and/or gamma of different values. Previewing designs on other computer systems is a means by which ideal contrast may be determined.

Although high contrast is essential for readability, low contrast in the colors used on the page's design components creates visual comfort. This contrast can be applied to the values (lightness and darkness) of the colors or to the actual colors.

In addition to contrast issues, the human eye requires a high degree of comfort for sustained viewing of a web page. Large areas of highly saturated colors are irritating and distracting. In fact, any strong color demands voluntary and involuntary attention. The more muted the color, the more comfort is felt when viewing an image. How much saturated color is relatively contained in the image has also been shown to be a critical factor affecting visual comfort[4].

Furthermore, the mechanics of the human eye determine which colors are perceived as advancing and larger, and which colors are perceived as receding and smaller. The visual effects of color movement can be used to draw attention to critical tasks, such as a "Help" or "Order" button and to minimize secondary functions or areas.

In some situations, visual effects, such as the advancing character of pure red, may conflict with psychological meanings, such as red's associations with stop signs. There are those who argue that real world associations are equally meaningful in a computer-generated environment. On the other hand, the high visibility of a red hypertext link in the midst of black text on a white background actively attracts attention and generates a response from the viewer, thereby losing its associations with stopping.

Color also influences the accessibility of a web site for the visually disabled. The colorblind and aging population constitute a significant percentage of the web population. Combinations of red and green and/or gray are not visible in the most common form of color blindness. Mature audiences have different needs. The aging eye is characterized by a steady decline in color discrimination between all colors and especially blues and greens[5]. Strong color and value contrasts are essential for this audience.

4. TECHNOLOGY

Although the human eye can see approximately 10 million colors, not all computers have a wide range of color vision. Approximately 15% of all computers are limited to 256 colors (8-bit). Newer computers are equipped with 64 thousand colors (16-bit) and the highest quality systems deliver 16.7 million colors (24-bit).

Color on the web exists within the RGB color space of each user's computer and is subject to variables unlike any previous medium for widespread information delivery. The ability to deliver color accuracy on the web is extremely complex due the differences in the components of each user's computer system and how these components work together. Although color profiles can easily be included in today's web graphic file formats, web browsers are not able to deliver this data and not all operating systems can be profiled. Consequently, profile embedding and adjusting the colors of web images to match the profile of each user's operating systems remain a hope for the future.

Server-based technologies deliver the highest color accuracy but only for individual sites. Unfortunately, these require time-consuming steps, such as requiring the web site visitor to download specialized plug-ins or to participate in a calibration process. Devoted customers of a site may be willing to sacrifice time for color accuracy but most people won't.

Given the existing computer and web technology, the highest degree of color accuracy for a web site begins on the designer's computer system. This system must consist of the highest quality components that work in perfect unison. It requires fully corrected gamma and a high quality monitor.

Furthermore, the web-safe or browser-safe palette is a means by which web sites can employ colors that are common to all computers and browsers. They are a common set of 216 colors — defined by RGB (red, green, blue) and HEX (hexadecimal) formulas — that display, without dithering, on all computers. Web-safe colors don't guarantee the same colors on all machines but they do ensure that the "palette" matches the basic colors built into all Windows and Macintosh computers. This palette also delivers non-dithering colors for the minority of 8-bit systems that can only display 256 colors on the screen at any one time.

Color accuracy also exists within the technology of graphic file formats. The two most commonly used formats are GIF (Graphic Interchange Format) and JPEG (Joint Photographic Expert Group). Each one deals with color in a different way. GIF is best suited for line art and solid colors; JPEG for photographic and other continuous tone images. Converting images to the correct file format not only delivers the best colors and the best images possible but it also lowers file sizes and shortens the download time.

4. AESTHETICS

Color on the World Wide Web exists with the context of formal principles of design. In the western world, these concepts are the result of 30,000 years of a linear evolution of visual forms. In the eastern world, the evolution is non-linear and dates back even further. In all cultures, the aesthetic ideal is a harmonious visual image.

Color plays the primary role in the creation of a visual harmony and even more so within a medium whose physical and technical characteristics vary. The colors used in the components on any web page — the navigation system, banners, buttons, text and photographic or line art images — must create a balanced composition and they must do so on monitors ranging in size from 1280 x 1040 to 640 x 480 pixels. Furthermore, these visual images exist within the varied color capabilities generated each viewer's computer system.

Although color harmony is not an absolute science, traditional color harmonies, such as those developed by Johannes Itten, are quite adaptable to web design. Simple harmonics consisting of a minimum number of colors are most successful. Too many colors make it impossible to focus. The brain is more capable of understanding and organizing information when a minimum of colors and shapes are visible.

Color, although two-dimensional in character, moves in space as if it were a three-dimensional form. The advancing and receding characteristics of warm and cool, light and dark, highly saturated and less saturated establish a hierarchy of dominant against less dominant visual features. In formal art theory "emphasis and subordination" is a critical component of visual harmony.

Unlike previous media, a web page is not a fixed visual entity. A web page (and the entire site) is a flexible space through which the viewer navigates. Consequently, color's capabilities to structure space are ever present. Spacious layouts are a difficult task given the flexible dimensions a web page may occupy. In spite of these constraints, color capably organizes space. First, color functions by grouping similar items together. Second, organizational graphics, such as colored horizontal and vertical bars, serve as structural elements. They define where a space ends and where the next space begins, thereby establishing clear areas for the eye to travel. Third, color (or the absence of colored forms) creates negative space — those areas where the eye can rest.

As is the case with other visual forms, color's behavioral characteristics relate to the size of the area it occupies, the shape of the area it occupies, its placement and surrounding colors.

Proficient color design produces an attractive web site, one that makes the viewer feel welcome and comfortable. On the other hand, a chaotic, unsightly web page jolts the eye and makes the viewer feel uncomfortable.

5. SUMMARY

Color is the most relative of all media. As a primary component of the visual language of the World Wide Web, it can not be isolated within any one discipline — be it art or science. Consequently, it is essential that web site designers be well informed about the multi-dimensional effects of color. Successful web sites result when appropriate symbolic colors, professional artistic color design, suitable user-interface, and content adhere to the highest standards for computer and human vision.

REFERENCES

1. Deborah T. Sharpe, *The Psychology of Color and Design*, p.54, Nelson Hall, 1982.

2. Deborah T. Sharpe, *The Psychology of Color and Design*, p.126, Nelson Hall, 1982.

3. H.L. Snyder, J.J. Decker, C.J.C. Lloyd and C. Dye, *Effects of image polarity on VDT task performance*, Proceedings of the Human Factors Society 34th Annual Meeting, 1447-1451, 1990.

4. Ken Sagawa, *Visual comfort to colored images evaluated by saturation distribution*, COLOR RESEARCH AND APPLICATION, vol. 24 N 5, John Wiley & Sons, October 1999.

5. Deborah T. Sharpe, *The Psychology of Color and Design*, p.90, Nelson Hall, 1982.

* Correspondence: jmorton@colorcom.com; phone 808-738-1118; http://www.colorcom.com/, http://www.colormatters.com/, http://www.colorvoodoo.com/; Colorcom, 3905 Maunalilu Place Suite C, Honolulu, HI, USA, 96816

The Treatment of Light With Matter

Research Group *Constitution and Interpretation of the Artistic Image*. HUM 480 of the Autonomous Regional Government of Andalusia, Spain

Abstract
The experimental workshop that is presented combines 3 fields. 1) Visual artists (Maribel Doménech and Margo Sawyer) 2) Students, mostly postgraduate level 3) Teachers/Researchers from the Research Group. It is carried out in the School of Fine Arts, University of Granada, Spain, in May of 2000.

1/Guest visual artist.
Maribel Domenech is researcher at the Laboratorio de Luz of Facultad de Bellas Artes, Valencia (Spain) and teacher at the Universidad Politecnica in the same city. As a plastic artist she works on the metaphor of inhabiting, to knit and to recover especially on subject of dress, using x-ray, light (blue and black) that assembles private and public, interior and external. Their works are materialised in and from architecture, private spaces, heading objects to evidence the presence of the absent body, their space, and their zeal to be meant.

Margo Sawyer work settles in a territory shared by the current interest toward the installations and a return to the primitive roots of the art like expression of the sacred. Both territories to understand art beyond the object and giving to spaces symbolic resonances. She creates spaces restricted in the way of megalithic cameras or Budhist temples, impassable and even untouchable, the vision can only travel its surfaces. Their sequential view demands the spectator's displacement around the installation.

Margo Sawyer and Maribel Domenech made us discover along their abundant and enriching interventions in the workshop their search of the light in the materials -industrial materials as the electric threat, diverse fabrics, bread of gold and silver in the different ways of use, glass badges, glass and metal balls, roasted or coloured of opaque or iridescent colour wood- materials that cause shines, reflections, games with the light, qualities that are near attributes to the sacred in many cultures.

2/ Students, mostly postgraduated level.
Team 1: Manuel Espejo, Gema Garrido, Amaya Martinez, Noelia Márquez, Ana Mañas.
Materials: Wood wall pieces, fluorescent blue light.
Team 2: Jesus Pedraza, Teresa Saracho, Diego Fajardo, Antonio Collado, Agueda Fernández.
Materials: glass, light.
Team 3: Antonio Carrillo, Raquel Ramos, Antonia Reyes, Nicolás Rodriguez, Nicolás Rodriguez, Susana Román, Elena Vicente, Mika Murakami.
Materials: Box, Light/ fish bowls, spotlight.
Team 4: Natalia Díaz-Mella, Mónica Espinoza, Alvaro Gálvez, David López, Rosana Martinez, Angeles Rivas, Carmen Sosa, Joaquin Peña-Toro.
Materials: Fabric, net, curve wall, white and elastic threat.
Team 5: Aurora Alcaide, Susana Encinas, Alicia Jiménez, Juan Saldaña, Helena Úbeda, Maria Angeles Garrido.
Materials: Black Light, differents kinds of white.
Team 6: Juan Francisco Casa, Eugenio Montoro, Daniel Santo, Silvia Valverde.
Materials: Glass elements reticulated, black light.

3/ Teacher/Researchers from the Reseach Group:
Miguel Peña, Jesus Díaz, Fernanda Garcia (Professors at the Faculty of Fine Arts, Granada University), Joaquin Casado de Amezua (Professor at the Architecture School , Granada University), Justo Romero, Juan G. Lerma, Santiago Cano, Rosa Cubillo.

Key Words:
Art, education, light, material, appearance, image, language.

Contents

-The group provides the theoretical structure for the issue of treating light with material. This particular project is part of one of its areas of investigation: appearance as a physical and allegorical phenomenon. Appearance acts as a macrosystem capable of bringing together the interraction of the elements and the constitutive phenomena of images in general, and of artistic images in particular. Appearance as spatial distribution of light becomes the descriptive nexus of the creation of the image. In this activity it is possible to experiment with open methodologies and interdisciplinary contents that are difficult to blend in the teaching of plastic and visual arts.

Our work are orientated to the constitution and interpretation of the artistic image. This last is understood as a construction of the mind from the external referents. Our study of the artistic language are in direct relationship with the genetic elements that it made possible: Light on the matter and, in front, an ineludible viewer (spectator) and therefore to the space too. In this relationship all the constitutives elements are articulated of each one of the images by the way we known our environment.

The sensation produced by the standart of colour and the sensation produced by the colour outline, the sensations of the contrast, spaciality, pocaity, reflection, translucency, transparency, ... involve all the constitutives elements of the vision field that constitutes the images of the world.

We understand like genetic elements: light, space and matter. From its relationship we get different kinds of incidence:

1/Light-matter incidence. Colour surface, spectral radiation. The variations of the structure of the surfaces and the light incidency of light: texture.

2/ Space-matter incidence. Delimitation of matter: shapes; thing system and object system.

3/ Light-space incidence. Environment colour, spatial distribution of light that are attached in turn with the incidence 1(light-matter: light is not visible if not come into collision with matter. Our atmospheric space is gaseous matter).

This circuit is closed in a circular manner, that is to say, by its own nature its can't produce separately in the image. This is a studio strategy that brings resources to understand the construction of the visual and plastic languages.

This cosmogony of the creation of images we takes like referent of the artistic creation that allow us a revision of the languages coincident with the strategies of the works of art in the 20th century and today.

-Technical knowledge of luminous media that can be used as constitutive elements of the work: the delimination of the same.

-Artists invited to contribute to the research bring their own ways of working, which in themselves make up a methodology, revisiting the creation process of their works, in which special attention is given to light as a search for these new nodels of expression.

Introduction to the Workshop's Development

Lectures by the Artists on their plastic research.

After the lectures, working groups are formed.

Projects are generated by the students.

Discussion of the problematics of carrying out the projects.

The viable projects are carried out.

IMAGE ROOM. The nerve center containing projectors and light sources, as well as a variety of other materials. From the center, the faculty enclosure as a whole is involved in the work, including the gardens.

Information card used in the research:

Physical description of the piece.

Incidents during its creation.

Interpretation of what has been done.

Comparison of the technological aspects of light with purely linguistic points in the incorporation of light in art.

Purpose of the Research: to search for the linguistic field, for expression and meaning, which accompanies the specific use of light technology and its relationship with matter and the rest of generic elements. The use of this natural substrat have an complex lately development at the fields of aesthetics, psychology, philosophy, ethics, ... in relation with the image interpretation in general and arts in particular.

In Arts this knowledge of the elements and its infinite relationships, become in gramatical and syntactic knowledges and, at last it give the developments of the language games that made possible determined typologies of images. Then, light and matter are studied like structural compositive elements or constitutives of the images.

Conclusions:

The study of light and matter become part directly of all the strategies that made possible the constitutive processes of each one of the images in order to be created or to be interpretated.
As a novel element, it would be the incorporation of the phenomenon of appearance in art, and the fact that appearance can be combined with other typologies of creation and analytic processes and of plastic and visual works. The first effect caused in the students by this confrontation of their artistic objectives, the new materials and different types of light sources is a large degree of chaos. The surprise came when the students began to deal with them, to handle them and, when they tried to understand them within the macrosystem of spatial distribution, the students began to have good ideas, and the successful results were obtained.
In short, the conclusions are:
-Art-Science links: Metaphors of the physical aspects of light and materials. The physical appearance system articulated as an allegorical appearance system, and the latter as the most open and, in our opinion, the most correct, way to approach knowledge regarding the constitution of the plastic image.
-Phenomonology and the creation process.
-Hermeneutics to give meaning and the means for reflection as regards interpretation.

References :

AA.VV., *Arte, Proyectos e Ideas*, nº 0,1,2,3,4. LUZ, Laboratorio de Luz. Facultad de Bellas Artes. Universidad Politécnica. Valencia, 1992-96.
AA.VV. *Search Light. Consciousness at the Millenium.* Thames and Hudson . London, 1999.
BACHELARD, G. *La tierra y los ensueños de la voluntad.* F.C.E. , Mexico, 1994.
BUTTERFIELD, J. *The Art of Light+space.*, Nancy Grubb., 1993.
CAIVANO, J.L., *Apariencia (Cesia) : construcción de escalas por medio de discos giratorios.* Universidad de Arquitectura. Buenos Aires. 1996.
- *Cesia : su relación con el color a partir de la teoria tricromática.* Argencolor, GAC. 1996.
DEBRAY, R. , *Vida y muerte de la imagen.* Paidos. Barcelona, 1994.

Authors :

Grupo de investigación "Constitución e Interpretación de la imagen artística" (HUM 480 de la Junta de Andalucía)
-M. Peña Méndez, J. Diaz Bucero, F. Garcia Gil. Professors at the Faculty of Fine Arts. University of Granada.
-J. Casado de Amezúa, Professor at ETS of Architecture. University of Granada.
-J. Lerma Pelaez, J. Romero Torres, S. Cano Turrión, R. Cubillo Robles. Researchers.
Post Adress : Universidad de Granada. Facultad de Bellas Artes. Avenida de Andalucia, s/n. Edif. Aynadamar. Granada 19071. Spain.

" The Contribution of the Contemporary Use of Colour and Light to the Evolution of Mankind: a Designer's Viewpoint"

Th. F. Tosca, Department of Architectural Design and Visual Arts, School of Technology, Aristotle University of Thessaloniki

ABSTRACT

In the recent years there has been an enormous transformation of the western man-made environment in favour of bigger complexity of form, colour and mobility. The reasons for this are both sociofinancial (increase of cluster and diversity of population) and cultural (universality, new scientific achievements). It is argued in this paper that colour can play a major role in the maintenance of a degree of environmental stimulation favouring cognitive function, well-being and aesthetic reward. This is possible through the replacement of the "natural selector"-based evolutionary processes by design-based ones, natural selection being impaired by the impossibility of isolation.

Keywords: evolution, emergence, organism, consciousness, continuity, system, design

1. INTRODUCTION

May it have all started with the primitive man's rituals, the Minoan bullfights, the ancient greek theatre, the roman gladiator shows, the Apostle's Colourful Jerusalem, the medieval public executions, our children's games, our phantasies, our fights, war itself? It is not quite clear. The fact is that we, technological era humans, enjoy, to the limits of our sensory-representational capacities, the unprecedented experience of multiple flights into "reality", virtuality, imagination, memory, anticipation, reverie. The media and marketing try to offer us endless opportunities to realize these trips, not to mention the pathological escape of drugs. Diversion to the point of distraction, sensuality to the point of wantonness, instability, irresponsibility, apathy or the very opposite hypersensitivity, lurk at the corner of the unparalleled life-path of the contemporary city dweller.

This emerging life experience cannot be described by any known rules, for it would not have been novel. How may we, 3d millennium people, cope with it, indulge in it or be protected from it? Sure enough, as emergence, it triggers evolution [1]. For R. A. Fisher, the British geneticist, all evolution is deterioration because every increase of the fitness for survival of certain organisms is accompanied by a corresponding in antagonising ones. The whole system comes to nothing but a higher degree of complexity. Given, though, man's restricted perceptual capacities (our brains are still simple compared to the universe), we must represent a vast multitude of possible states using a relatively small vocabulary of mental categories, therefore understand very little. Unless we "design" our own evolution towards the increase of our intelligence [1]. Hence, the legitimacy of designing our evolution by designing environmental colour, as envisioned by the AUTH Colour and Lighting Design Workgroup under the author's direction.

2. DESIGNING FOR COMPLEXITY

The twentieth century expansion of population has caused urban accomodation to become vertical cheap, repetitive and colourless. Layout, planned or random, is also uninteresting. Decorativeness gave place to the oversimplification of industrialized standardization. Traditional textures and colours were gradually replaced by artificial materials poorly matching those of adjacent older buildings and aging badly. Finally, there is a big variety of scale and form due to new construction techniques.

Sociofinancial reasons dictated new land uses resulting in ghettoing and urban fragmentariness. Worse still, for questionable city prestige, isolated public or business buildings sprang up here and there which often further violate the cohesion and identity of the environment with their irrelevant morphology and showing-off. Advertisement posters and signboards, often of colossal dimensions, ruin all sense of intimacy day and night, along with the unceasing traffic noise and pollution. Finally, striving for self-expression individuals, trapped in cell-like apartments, attack privacy daylong with their tuned-up electronic sets.

Information in the environment challenges living things. The environments of humans should provide sufficient complexity of stimuli and information to challenge and thus exercise neurons in the brain as well as other tissues and organs. Complex, changing and inviting environments stimulate the brain and body [2]. Overstimulation, though, can lead to indifference [3]. On the other hand, increase of complexity in sound or visual frequencies causes harmony to decrease [4]. Yet, man is made to inhabit the earth as a poet [5].

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

So, to address the need of contemporary urban dwellers for complexity, but aesthetic quality, too, our Workgroup has carried out over the last 15 years several research-based projects for the city of Thessaloniki, focusing on rehabilitation of the existing urbanscape through colour alone, as the cheapest and most radical means of intervention. Our objective was the creation of a new man-environment system in which every collective environmental change, however confusing or "ugly", is acceptable for the sake of continuity and has to be counted with in future interventions, as long as it represents urban events (planned or spontaneous). These events, themselves liable to perpetual change, become the recyclable values of the new man-made environment best fit to realize by constantly shifting colour or/and light on top of the material structure.

Aiming at continuity and identity we focused our approach on the establishment of an overall Colour Scheme (Colour Palette + Colour Pattern)[6] which varied locally in conformity with the palette of the reference landmark of each area (most often a roman or byzantine monument) (fig. 1).

Fig. 1 Colour Scheme for the Centre of Thessaloniki

The Colour Palette was represented by regions of the Natural Colour System (NCS) colour solid of 7-step appropriateness defined by preference-based inquiries with dwellers. It does not consist in a finite number of colours but in finite regions of infinite colours - much in tune with nature's way. Also, the regions thus specified were defined by the collective consciousness of the examined population. Especially, since there was on no occasion judgement of one single colour but of colour combinations semiotically correlated along semantic codes for representative facade cells[7] (fig. 2).

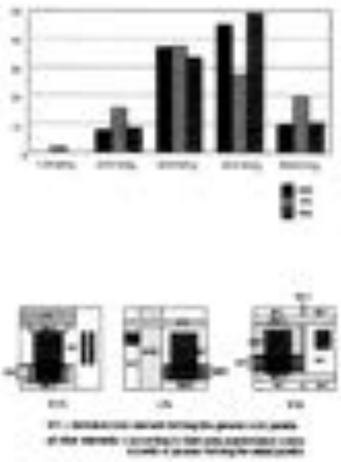


Fig. 2 Polychromy preferences for the three building types (above). Representative façade cells (below)

As for the Colour Pattern, the research results suggested that for the contemporary greeks:

- façade details or foreground colours must be distinctly colourful against a colourless background
- hue combinations are preferred to blackness or chromaticity combinations
- the visual information must be analysed into many forms
- generally preferred high degree of polychromy must vary inversely to the standard of the building (apartment house, public apartment house, individual house) (fig. 2)
- earth colours are preferred to "fancy" (pertaining to the R<B and B<G regions of the colour solid) colours
- the colour elements must coincide with the structural elements of the facades

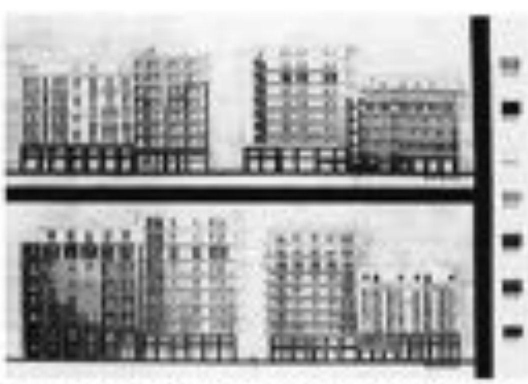


Fig. 3 Recoloration project for Karolou Diehl street

Our recoloration projects (fig. 3) were never realized for lack of funds, horizontal ownership issues, the instability of pigments, excessive pollution, and the unsuppressable ubiquity of advertisement posters and sign boards.

3. MAKING STILL FORMS INTO TURNING WORLDS

Designing environments that are sufficiently complex to maintain or even restore (as in the elderly)[3] a high level of mental and physical functioning should become a primary future concern. However, according to the information theory, when a recipient of a message has already received the message and knows it is being repeated, no new information is being transmitted. When the system is at equilibrium, complexity disappears. Therefore, continuous, intelligible change is an additional issue to be addressed.

In his Six Memos for the Next Millennium Italo Calvino[8] specifies the 6 major properties of a work of literature for the new millennium as: a) lightness, b) quickness, c) exactitude, d) visibility, e) multiplicity, f) consistency. By extrapolation into environmental design the replacement of solid colour by light, as a major space shaper and an expressive tool, seems a plausible idea. Light-associated colours are cheaper, capable of reacting to every change of situation, to transform one space into another in an instant and to create an entirely different atmosphere.

In the second half of the 20th century there was a worldwide explosion of dazzling lighting design productions which constantly gain ground. Initiated by Abe Feder in 1932, the science and art of lighting design has found many fields of application, starting with the stage, through architecture, landscape design, shows, exhibitions, conferences, to open spaces, etc. The progress of illuminating technology has greatly contributed to this.

Believing that art is independent of scale and richness of means and that it may have other objectives additionally to the exhilaration of an intellectual elite or the stupefaction of big crowds, our Workgroup undertook a small-scale research on the restructuring of space by colour and light. This time we focused on the individual residence which has taken worldwide - especially thanks to the online communication - multiple usages associated with various everyday activities. People live, work, entertain, even participate in group activities without moving from home. This, however convenient it may seem, implies often loneliness and cutting off from public life. Public life is not merely an attraction, it is primarily a reassertion of the self (by being physically acknowledged and by acknowledging others), an exercise (walking, running, dancing in group) and a multi-level sensory- motor experience.

The outdoor space having evolved largely mobile and ever-changing through dense traffic, 24hour electronic advertising and the recent light animation of buildings and of other open space elements is highly stimulating in comparison with the indoor space. In order to reestablish continuity between indoor and outdoor space, as much as possible, we planned a study of home reaccomodation by light and colour. So, in a given single-room residence we were to represent its various functions during the 24hour day merely by lighting, the furniture being folding and storable inside a closet in a wall recess for reasons of simplification of the design. The project should give solutions for 9 time-schemes: 08.00, 10.00, 12.00, 14.00, 18.00, 20.00, 22.00, 24.00, 02.00.

The working schedule considered free, the tasks carried out by the occupant of the space at the above times were specified along with his/her character (particular activities, habbits, sense of comfort, likes and dislikes as to space use, decoration, atmosphere, etc.). The lighting design would rely on known and/or projected technologies (i.e. polarizeable glazing, reflective coatings and/or finishes, slide and video projections, etc.). For the daylight design a latitude, azimuth, orientation and sky condition were specified. The intensity and colour of daylight from dawn to dusk should also be counted with. The factors of brightness, scale and texture were carefully balanced with illuminance levels, especially in combination with colour. The psychological effects of colour in association with the various tasks carried out in the room in each of the above schemes were critical. Space-related issues (spaciousness, division of space, etc.), cultural issues (local palette for interior design) and the personal likes and dislikes first of the occupant and second of the designer were, also, taken into account.

Fig. 4 8.00 time-scheme (left), 24.00 time-scheme (right)

We came up with a set of solutions, examples of which are here given (fig. 4). Our objective was the establishment of continuity and of a semiotic correspondence between interior and exterior space by a man-environment interrelation based on the chaos of images in the user's mind and not on prior systems of experience or culture. Through specifically provided electronic controls the user should next be able to switch from one time-scheme to another or improvise at will.

4. VISION-RELATED EMERGENT EVOLUTION

The space-images in the user's mind were of four categories: a) real and/or reflected, b) imagined or represented, c) remembered and d) visualized. Wanting to study the possible structure (= terms of interrelatedness and relations of these terms) of the user's consciousness within the above spaces we undertook to illustrate, in still or/and sequential compositions, examples of it. In them we tried to represent our individual concepts of, say, our personal spaces, mainly in terms of colour and light. We optionally interlaced images of broader contexts (of the outdoor space and/or of affectively, culturally, semiotically or symbolically related spaces), of eventual objects in them and of the self. Finally, we also considered fluidity of events.

The images we came up with are not just abstract compositions: they represent the structure of the emergent vision-related system on the level of the human consciousness. They are coloured things in extrinsic relation to compresent person with quality of aesthetic consciousness. The objects in them have a character which they would not have had except for this relation (fig. 5).

Figure 5 My room 1 (left), My room 2 (right)

5. DISCUSSION

Colour or/and lighting design may, as suggested here, smooth out environmental complexity (City Colour Scheme) by tuning down discord or produce very complex and subtle frequency ratios (animated lighting design). Complex harmonic relationships, though, are interesting only to those with the visual sensitivity to perceive them. By the rest of the receptors they are often perceived as disorderly, chaotic. Chaos appears with non-linearity and is associated with novelty. Chaotic phenomena are highly unstable but describe, according to modern mathematics, the new reality of "real" life [9].

Consequently, modern environmental design should be oriented to primarily high complexity and secondarily discontinuity and instability in order to produce the emergent environment of the 3d millennium. Deconstruction architecture has already gone far in this direction not with indisputable results. Lighting design seems more suitable to this end because it can offer (through technical control) an endless variety of effects for the parallel planning of the evolutionary process of man himself. The emerging "man-machine" entity, in replacement of the old "man" entity, will be able to perceive, enjoy and produce multi-layered structures in most fields of activity (art, science, communication, finances, etc.) [10]. In the meantime, though, this evolution is not taking place without side-effects (abolishment of popular culture, bland tolerance, challenging of all values, emotional death, pessimism, environmental vandalization, etc).

Machine-dependent or not, we are physical entities that can appreciate and create placeness through sensory awareness with input from memory, intuition and from our collective unconscious containing generic spatial configurations and cosmological images encoded in our genes. Our machine-related abstract conceptual skills and the ability to compute and reason are good but still better is our love for what we experience. With this love we can create liveable environments far from being synthetic, consisting of pastiches of other times and places (real or fictitious). To this end colour and light seem to be the best means of reinstating identity and poeticness where constant changeability leaves its traces. Our new understanding of the cosmological law is constant regeneration, not finality and we may continue to be human with this in mind.

REFERENCES

1. D. J. Chalmers, *Thoughts on Emergence, 1990.* http://www.u.arizona.edu/~chalmers/notes/emergence.html
2. A. W. Davidson, *Environmental Complexity: Information for Human-Environment Well-Being.* http://www.antiques-southwest.com/aliceny/irlces2000.htm
3. D.E. Berlyne, *Pleasure, Reward, Hedonic Value*, Chapter 8 in *Aesthetics and Psychobiology*, Appleton-Century-crofts, New York, 1971
4. M. Pivato, *Example: Aesthetics and Harmony*, 1999, http://www.math.toronto.edu/~pivato/latex/div/node11.html
5. P. Sansot, *Poétique de la Ville*, Klincksieck, Paris, 1984
6. Th. F. Tosca, *Dreams of Light for the City*, COLOR: Research and Application, John Wiley & Sons, Vol. 19, No 3, 1994, p.p. 155-170
7. J. Ph. Lenclos, D. Lenclos, *Les Couleurs de la France: maisons et paysages*, 'Éditions Du Moniteur, Paris, 1982
8. Italo Calvino, *Six Memos for the Next Millennium*, greek translation, Alexandria Editions, Athens, 1995
9. F. Chaitin-Chatelin, *Mathematics of Life for the Third Millennium: A Mathematical Tale. 1997* http://www.mindship.org/present.htm
10. M. Minsky, *The Society of Mind*, greek translation, Katoptro Editions, Athens, 1995

The Future Role of Color in the Three Dimensional World

Shashi Caan, Skidmore Owings & Merrill Architects

An end is a beginning. Times are changing. Here today and gone tomorrow. These are some of the expressions that we all use that seem today more applicable than ever. We are living in exciting times. We are subjected to many conflicting influences. Fashions and trends seem to change faster than ever and what is new today is old tomorrow. Our times are truly exciting because with change also comes opportunity.

Several major forces are at work today. The world in which we live has gotten bigger and smaller at the same time. Globalization has broken down many of the regional and local barriers forcing an uniformity that sometimes seems synonymous with anonymity. The technology that makes all of this possible continues to become smaller, from hand to palm to fingertip, while at the same time becoming intuitive and responding directly to us through face and voice recognition. On the biomedical and genetic engineering side, the growing abilities to replace parts of us with mechanical devices or to control or predict the outcome of biological processes creates the chimera of mankind slowing morphing into a clone of itself.

Our world may look familiar but it has become alien at same time. We feel no longer secure and safe. In our direct home and work environments, our senses are equally dulled. The sensory stimulation that is so much of the experience of our existence is being eliminated in the name of uniformity, flexibility and change. To create one fits all, that what makes something unique has to be removed and repressed. Work environments, for example, have become anonymous.

Within the context of these enormous changes, the role of the senses has become ever more important to fight the growing feeling of disorientation. While other designers and professionals are addressing this issue in various forms, for me the importance sits with color. Unique opportunities exist of color creating that sensory stimulation and sense of comfort and belonging that is so quintessential to our happiness. It is time to look at the past and design for the future.

In the last two centuries considerable explorations have been conducted with regard to color. At the one hand we see the empirical of scientists, on the other we see the work of different artists working with color and its phenomena. We have begun to understand the phenomenal interaction of color in the two dimensional plane. Goethe and Albers, for instance, have demonstrated some of the rudimentary principles and profound interactions of color, which affect our world and us constantly. We, however, still have little knowledge and perception of the interaction of color in the three dimensional world. Getting a better understanding of that interaction is quintessential to the creation of supportive environments.

With the growing complexity of our world, with economies changing from local to global, with technologies requiring the development of new languages to al low us to communicate, new demands are placed on art, architecture and design to help make new meaning. Our visual language needs to be much more concertedly integrated within our teaching and professional practice today. The globalization of communications, the use of the same words and concepts worldwide described with the same terms, the proliferation of entertainment, games, movies and music has led to general uniformity. On a linguistic level some cultures worry about losing their distinction or the distinctiveness of their language. For example, jokingly reference is sometimes made to "Denglish" , the use of so many English words (media or internet based) used in the German language, which has led to completely new hybrids. Similarly the issue of regional color can be raised. For many centuries distinctive colors and color schemes were found in different parts of the world. Often originating in the availability of local dyes or natural materials these schemes have evolved into a feature of the region. The shared culture is slowly being replaced by the global culture that is the same from New York to Mumbai, from Beijing to Madagascar. While a certain uniformity of color and use may develop, the regional light still remains and influences the perception of color. However, today the question of a more predictable global color is very omnipresent.

The growing uniformity may lead to a loss of a sense place and in many ways is indicative to what is happening in each of our worlds. Although changes may not be stopped, it is important that designers begin

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

to preserve and capture "the spirit of place". This need can be extended without question from regions to cities to our personal environments. These environments have to give greater sensory support but also provide that sense of place that is quintessential to a sense and perception of safety and security. This duality of the need to balance the individual with the world at large, to provide safety and uniqueness and flexibility at the same time is the challenge for the designer in the next decades and may be called 'the new humanism'.

Within the context of this new humanism the role of color is ever more important. For the designer to effectively manipulate the three dimensional world with color, we have to:
- Have an understanding of our senses to nurture a deeper knowledge and integration of color theory, science and visual perception
- Learn and develop the visual literacy to understand and manipulate color
- Understand and practice the art of color in order to create the spatial poetics that enhance our lives and uplifts our spirit.

After all the one thing that still binds us together is our humanness, our need to touch, taste, smell, see and hear to make "sense" of this globe. This surely is the most predictable aspect we have today.

Painting with Light: Enlightening Your Architecture with Color

Paul Gregory, Focus Lighting Inc*

ABSTRACT

The objective of this presentation is to emphasize the importance of lighting in architectural design, and how it can be increased with the use of color. It can be shown, through examples that innovative and creative lighting with color can manipulate one's perceptions and experience of the spaces around them.

Keywords: Architecture, lighting design, interior design, color

1. INTRODUCTION

With light having become a medium for art as experienced in the work of Dan Flavin, James Turrell, and others, the realization has grown that light is one of the most important elements in our three dimensional perception. Without light we would not be able to define the forms and spaces around us. This presentation is explanatory of how the use of colored light can enhance and excite our architectural surroundings and create an emotionally captivating environment. Although, there are many methods to lighting design, this presentation will discuss one such method that has been successful over the years to principal designer and President of Focus Lighting, Paul Gregory.

2. PAINTING A PICTURE

As each architectural structure is considered for lighting, it is viewed as an entire picture that has a focus, a foreground, a background, and is contained within a frame. Certain questions must be asked before one begins to artistically paint with light. What is the focus? What is everyone's attention drawn to? How can that focal point be enhanced with light? Taking also in to consideration, what lies in the background of this soon to be masterpiece, is another step in the process. How will this foreground and background interact? If your background were lit with a rich blue light and your foreground a bright yellow, this would offer a favorable contrast. If the foreground were to be changed to a deep violet, there would be very little contrast, and would easily go unnoticed. Creating contrast between shadow and light, and using appropriate colors together is essential to drawing the viewer into the experience. Using specific color combinations, a designer can achieve different emotional reactions. As a general statement, warmer colors such as red, yellow and orange may incite vital, energetic and even intense emotions. Cooler blues, greens, and violets can be calming, and intellectual. When combining these elements together, it should create a complete and awe inspiring portrait of light and architecture. Using this perception of "painting a picture" will assist in following the lighting design method used by Paul Gregory, which will be explained in further detail. Another concern may be that you are not the only person involved in a particular lighting design project. In that case, there is a challenge to ensure that all those participating are trying to create the same picture, and the same look.

3. THE FIRST LOOK, THE TRANSITION, AND THE TASK

The "first look" is the first impression of the viewer. You only have one chance at making a first impression, and therefor, it should be poignant. Creating a first look can either be dramatic or subtle, depending on the look one is trying to design. If the look is to be dramatic… bright, bold, and contrasting colors are effective. The Empire State building in New York, and the Entel Tower in Santiago, Chile are

* 255 West 101st Street, New York, NY 10025; phone: 212-865-1565; fax: 212-865-4217; http://www.focuslighting.com

just a couple examples of this exciting style. Both use exhilarating, bold blasts of color upon their exterior surfaces, making them stand out against an already impressive skyline. Yet, when the design is meant to be subtle and clean, white light and simple colors that coordinate to the environment are highly effective. Whatever the "first look" is, it should grab the attention of those viewing it. There should be an image or focus that draws them into the picture. Perhaps it is a wall that is lit with color, and the viewer must step into the room to get a better look. When this happens, they are drawn into the picture, and now have become apart of the experience.

The "transition" is the view on the way to the "task". If you are in a restaurant the transition might be the view on your way to the table. What is interesting about the view? Could it be small red flames projected above the fireplace at the Tribeca Grand Hotel, or perhaps it is the golden sparkling bar in the restaurant, Le Cirque 2000? Perhaps the look you desire is subtle, such as small white lamps streaking the walls, highlighting their texture, while illuminating your way to the table. The transition can be a grandiose or continual view on the way to the task. It can also consist of many smaller and interesting images. When in a restaurant these transitional views can also be the images that the patrons will casually look at during their meal. In a store, the transitional view can be what guides the customer's attention to the different areas of merchandise. Again, color plays an important role in how it can effect the consumers, patrons, and passers-by. The chosen colors must satisfy the end result of what you would like the lighting to achieve. In retail, colors may be bright and bold in order to grab the attention of the shopper. In restaurants, the choice of colors usually depends on the type of dinning environment one is lighting. Generally however, the colors are not usually harsh, or bright. They are dim and/or soothing to view so that the dinning experience is relaxing and pleasurable.

The "task" is the lighting that is available for the functionality of the space. You want to be able to see the person that sits across from you, the menu, the table surface or place settings, and the area around the table. At the same time, you want to create an atmosphere with the lighting that is pleasurable and does not take away from the dinning experience. If the lighting is too dim, you won't be able to read the menu, or see the face of the person sitting across from you, or see the beautiful details of the place settings before you. If the light is too harsh, it can be disruptive and intrusive to those dinning. The duality of practical usage and aesthetically pleasing imagery is not always an easy one for the designer to accomplish. Knowing and understanding the technical aspects of lighting is important for this phase of the design method. Knowing which lamps and fixtures to use in a particular area or space can save time, energy, money and work. Knowing how to adjust them so that they are not shinning in the patron's eyes, or taking away from the integrity of the architecture is essential to maintaining a beautifully lit space.

4. A COLOR THEORY AND THE USES OF COLORED LIGHT IN ARCHITECTURE

Paul Gregory maintains a theory of color that he has used in his many years as a lighting designer. Colors that are used in a design should mirror those colors that occur inherently within nature. Colors such as the deep reds, oranges, yellows, blues, violets, and pinks that transpire during the process of a sunset. The rich turquoise, blues and greens that can be found in tropical seas is another example of a source of inspiration for color. If a group of colors can be found in a natural environment, they will be highly effective choices when displayed within an architectural design. They will be able to induce similar emotional reactions as a sunset or a clear blue ocean might have on an individual.

The Entel Tower in Santiago, Chile is the tallest building in their country. The tower is bathed in a continual nighttime feast of colors. Its dramatically colorful exterior lighting has transformed this structure into one of the most prestigious and well-known buildings gracing the Santiago skyline. The dynamic lighting scheme utilizes technology that works well with bold and pastel hues. Lighting effects range from dramatic high-speed color shifts to subtle cross-fades, making it possible to achieve any lighting mood to suit particular seasons or celebratory events. The colors that bathe the building in light range from solid washes to gradations of up to five colors, automatically changing every half-hour. Searchlights were added to the top of the building to emphasize the unique height and profile of the tower.

The "Burj Al Arab" in Dubai, UAE is the tallest hotel in the world at 1,053 feet to the top of its spire. The hotel is illuminated by 148 Irideon AR500 computerized color-changing fixtures. The tower's impressive fabric "sail" façade provides a prominent surface to be lit and viewed from great distances. Large (400'x130') colored images are also projected onto the "sail" by four 7KW PIGI large format scrolling projectors (located 985 feet away). One projector is used solely for projecting faces of Arab dignitaries onto the tower. This in combination with the bold colors splashed upon the "sail" creates quite an exciting view from the exterior.

The Tribeca Grand Hotel maintained a lighting design that worked to emphasize richness and luxury while paying close attention to detail. The hotel's dominating feature is an 8-story open atrium capped with a 50' skylight. Steel columns at its perimeter are streaked with light by metal mesh sconces. Ceiling coffers in guest floor hallways, open to the atrium, are up-lit in amber. Each floor becomes progressively deeper color, creating even more depth. At the top, the skylight is lit from above in deep blue for striking contrast and effect. Theatrical fixtures provide down-lights into the atrium and allow for infinite control between areas. Many smaller looks contribute to the grand effect. At the entry, a curved scrim wall is back-lit in a water effect created by custom wave projectors and a blue MR16 color wash. In glass elevators, a ceiling of inverted glass prisms sparkle when lit from above. In the Private Dining Room, a chandelier and sconces are fitted with individually controlled lamps on a flicker generator, custom-built to ensure a believable flame effect. The final lighting effect is successful without overwhelming of dominating the architecture, and is beautiful and memorable.

Loews Cineplex Entertainment wanted it's newest high profile, 13-screen multiplex in Times Square, New York to stand out from the ordinary. In the midst of the billboards and flashing lights of 42nd Street, the subtlety and elegance of Loews E-Walk's columns and old Broadway theatre house marquee stand out from the crowd. Focus created a colored star display of moving lights to pan across the façade and also on the sidewalk below. More impressive than the moving lights and projections, the chasing lights, the neon signage, and the other fixtures, is the E-Walk's Blade Sign. The blade sign was a massive project in itself, incorporating a quarter of a million pixels and 2,700 control channels. Focus Lighting worked with Color Kinetics to develop their standard DMX controlled color-changing LED fixture into a "pixel" format designed specifically for this sign. A simple touch screen control makes accessing the system's many capabilities simple, so new programs and shows can be easily added to the sign's rotating "repertoire". The blade sign produces brilliant blasts of prismatic colors, which can be seen as far away as Park Avenue and the Hudson River.

Other projects that use color to accent architecture that may be discussed are: the restaurant Le Cirque 2000 in New York City, Pennsylvania Plaza located in New York City, Lidia's restaurant in Kansas City, the restaurant Rosa Mexicana near Lincoln Center in New York City, and San Francisco's Ultimo showroom.

How Does Color Work?

Modes of appearance and the physical circumstances which contribute to the perception of surface, volume, film, illumination and illuminant colour ...how the eye/brain converts physical stimuli into experiences of colour

Paul Green-Armytage

Vision

Oral Sessions

Aguilar, Urtubia, Direct and inverse contrast interaction in a periodic test viewing
Ishida, Assessment of color search performance in photopic and mesopic illuminances based on color identification data
Okajima , Tsuchiya, Yamashita, Age-related changes in color appearance depend on unique-hue components
Shaw, Fairchild, Evaluating the 1931 CIE color matching functions
Shinoda, Ikeda, Transition between color contrast and assimilation by perceived size manipulation
Viénot, Benhalima, Brettel, Bourdoncle, Colonna de Lega, Rating of tinted ophthalmic lenses
Yamauchi, Williams, Brainard, Roorda, Carroll, Neitz, Neitz, Calderone, Jacobs, What determines the unique yellow,L/M cone ratio or visual experience?
Ayama, Eloholma, Hyvärinen, Eda, Kon, Mukai, Kanaya, Halonen , Whiteness perception in Japanese and Finnish under cool and warm fluorescent lamps
daPos, Sponga, Fluorescence thresholds for some reddish colours
Funt, Ciurea, Control parameters for retinex
Nakano, Yamashita, Fukuda, Suehara, Yano, A uniform color space based on color vision mechanisms
Ripamonti, Westland, Perceptual transparency
Sagawa, Visual comfort evaluated by opponent colors
Guth, ATD01 model for color appearances and differences
Aoki, Shinoda, Ikeda, Floating phenomenon and mode of color appearance

Poster Papers:

Awano, The effect of the luminous of the peripheral visual field on the binocular vision: aspects of three-dimensional seeing on the different color stimulus observation with stereoscope on CRT display
Gavrik, Tetrachromacy of human vision: spectral channels and primary colors
Graham, Thiem, HVC color vision skill test: technical update
Hirschler, Gay, Ferreira, Field trials of three tests for colour vision and colour aptitude
Ichihara, Nakadomari, Takeuchi, Miyauchi, Kitahara, The difference between seeing a random colour dot picture and reading shapes from the same colour dot picture in the Ishihara pseudoisochromatic plates
Kawai, A phenomenal observation on transparency and layer of depth
Mattiello, Chague, Buglione, Movement and colour: independent or complementary channels?
Ronchi, On the transfer of visual data from the laboratory to the real world
Sakata, Colour also decides motion direction
Yamaguchi, Shinoda, Ikeda, Size recognized visual space of illumination influenced by color scheme of interior
Samu, Wenzel, Ladunga, Colour and luminance contrast sensitivity function of people with anomalous colour vision

Mochizuki, Yoshioka, Suzuki, Ichihara, A study on color conspicuity at the Purkinje shift

Color Physics

Oral Sessions:

Hernández-Andrés, Romero, Nieves, Daylight spectral power distribution recovery through a linear model and few filters

Callet, Sève, From mean diffuse external reflectance to color and visual appearance representation

Liu, The iridescence color of shells

Poster:

Yourukova, Kolentsov, Kehlibarov, New advances in brightness and color characteristics of hybrid electroluminescent display structures

McCann, Image processing analysis of traditional Gestalt experiments

Vozchikov, To question about chromatic theory light mixing

Zoch, Even color triangle

Color Preference

Oral Session:

Saito, Matsumoto, Date, Li, Comparative study in Japan and China concerning aspiration of Asian women towards quality of skin fairness

Camgoz, Yenner, Effects of hue, saturation, and brightness on preference: a study on Goethe's color circle with RGB color space

Lee, Cross-cultural differences in color preferences: implications for international film distribution

Lee, How life is associated with colors in Chinese culture: utilizing colors based on Chinese five-essence theory

Ohno, Koizumi, Mood perception of interior colors in a gym

Sato, Kajiwar, Xin, Hansuebsai, Nobbs, Numerical expression of colour emotion and its application

Poster Papers:

Iwase, Study on sports and colors: the color effect of team shirts on basketball games

Lee, A new comparison of psychological meaning of colors on samples and objects with semantic ratings

Other Poster Papers on "How does Color Work?":

Matsushiro, Ohta, Orthogonal spectral reflectance model

Kurioka, Ohnishi, Iwata, Tanaka, Influence of light source and illuminance on Benham type subjective colors

Serov, Semantics of color and determination of information

*** denotes invited papers**

Direct and inverse contrast interaction in a periodic test viewing

M. Aguilar*, C. Urtubia **

ABSTRACT

A concrete case of the effects of the use as adaptation field of a white-black Ronchi's grating (square grating) on the view of a chromatic periodic test (red or green) is studied here. The influence of the grating orientation on the value of this effect and the minimum frequency under which this effect disappears are determined.

Keywords: Bezold effect, periodic test, colour vision, contrasts.

1. INTRODUCTION

It is well known that with the physic magnitudes of a test colour (dominant wave length, purity and luminance factor) remaining fixed, its psychophysic magnitudes (hue, saturation and lightness) can vary in terms of its neighbourhood colours; these variations are mainly due to the simultaneous contrast (direct contrast) and the Bezold effect (inverse contrast) (1)

The behaviour of simultaneous contrast (direct) is opposite to that of the assimilation effect (inverse contrast) that emerges when two colours alternate in the visual setting with a high frequency, in which case, each one of them invades (perceptually speaking) the other's space.

As we have mentioned, high frequency is a "sine qua non" condition, although the interval among colours must be enough for them to be differentiated and not observed as chromatic mixture (pointillist painting). Fig.1

Figure. 1. Bezold effect

2. DISCUSSION

We believe this effect can be psychologically explained through Gestalt theory and without undermining the possibility of the inverse effect being susceptible to be physiologically explained by the existence of receptive units of various sizes in the area in which the retinian image is formed (Hurvich -2).

The alternation of black and red or green squares, not only produces the perception of a line (continuity principle) but also generates the perception of a darker colour than that present in the colour squares, expanding black all throughout the line.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

This explanation is suitable for the view of the sequence of white squares intercalated in red or green squares (lighter vision sequence)

Using a grating as adaptation field and three lineal successions of small different-colour stimuli placed alternately to the back grating (fig. 2) as test, the direct contrast (effect parallel to the grating) and the inverse contrast (effect perpendicular to the grating) are added. This way we obtain a much larger perceptual change than that obtained with uniform adaptation fields, in which, depending on the test, only the change produced by one contrast or the other will be perceived.

The deterioration of visual acuity (worse visibility) favours inverse effect, since inverse effect is a consequence of an *invasion*; on the other hand, direct contrast (parallel to the grating) improves as visual acuity does (better contour definition), since punctual details acquire strength and individuality inside their series.

This total variation (direct contrast plus inverse contrast) decreases as the frequency of the grating forming the adaptation field does, until it reaches a limit frequency in which it is annulled.

The critical size of the squares in the chromatic series (size given by the width of the stripes of the limit frequency) depends on the test variables (geometric and chromatic), the adaptation field variables and (as the rest of the perceptual behaviour) on the training of the observers.

Figure 2. Ronchi's grating as adaptation field

3. EXPERIMENTAL

We have experimentally analysed the view of three vertical series of small red or green squares placed on the white or black stripes of a horizontal Ronchi's grating with stripes of width equal to that of the squares (6 cm) (Fig. 2). We have proven that the lateral series with squares overlapped on the white stripes, experiment a colour variation (darkening plus saturation) due to the expansion effect (darkening) and the direct contrast (darkening and increased saturation); and that the central one with the squares overlapped on the black stripes experiments an inverse variation (decreased saturation and increased lightness).

The observer, placed at a distance of 5 metres, gradually approaches until no difference can be appreciated between the central and lateral series. Two sessions were performed with the screen illuminated by 300 luxes, and another two were performed with an illumination of 2000 luxes; the observation was repeated three times in each test (two red ones and two green ones).

The time spent on each test was 1 minute, so each observer spends 3x4 (red plus green)= 12 minutes, alternating with 12 minutes of another observer. This time added to the 10 minutes needed for pre-adaptation grant a total of 34 minutes.

Each final sum is the mean of 6 observations, 3 with each luminance. The observers are university students 20-25 years of age, suffering from emetropia or with corrected ametropia.

The trials in the orientation study have been performed with the tests represented in figure 3.

The grating period is 2 cm. The observer is placed (for every measurement) 4.5 metres away (grating angular frequency υ=4 cycles/degree).

The protocol for the experimental sessions and the characteristics of the observers are analogue to those in the former study (this time the observer remains set).

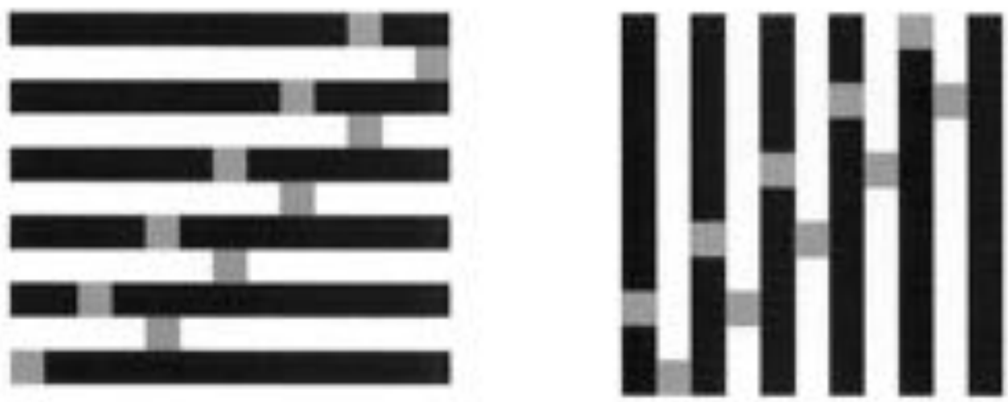


Figure 3. Orientation and visual perception

The quantification of the chromatic difference perceived is determined starting from a scale 0 (white colour) and up to a scale 10 (the value of colour in the dark series). The observer indicates the value that, on his opinion, the light series must have; if it were 8, the contrast perceived would be (10-8)/10=0.2, and this sum would quantify the effect of contrasts (direct plus inverse).
As in the former case, no significant differences have been found depending on colour and illuminance.

4. RESULTS

4.1 Limit frequency of the grating

We have worked with two illuminances (300 and 2000 luxes) and four periodic tests, two red ones λd=615 nm (red 1; P=0.5 β=0.26, red 2; P=0.7 β=0.18) and two green ones λd= 556 nm (green 1; P= 0.6 β=0.26, green 2; P=0.8 β=0.21), and no significant differences have been found with respect to these variables.

The limit frequency of the grating with 5 untrained observers ranges from 0,68 to 0,70 cycles/grade. With this frequency, the critical size of the squares viewed from a 2 m distance ranges from 2,5 to 2,7 cm.

The limit frequency of the grating with 10 trained observers ranges from 0.17 to 0.20 cycles/grade. With this frequency, the critical size of the squares (red or green) viewed from a 2 m distance ranges from 8,5 to 10 cm.
This means that a lower limit frequency would result in a stronger effect of contrasts (direct plus inverse) on the chromatic vision.

The wide difference existing among trained and untrained observers indicates the importance of training in precision visual tasks.

4.2 Grating orientation
From a group of 15 observers, 3 have found no difference; the remaining 12 have answered as follows:
With vertical grating: Dark sequence 10, light sequence 8.89 ± 0.2 Chromatic contrast (10-8.89)/10=0.11
With horizontal grating: Dark sequence 10, light sequence 7.65 ± 0.2 Chromatic contrast (10-7.65)/10=0.24

The perception of chromatic contrast with these 12 observers has improved with the horizontality of the grating, until practically doubling the contrast 0.24/0.11= 2.

The improvement in the perception of the chromatic contrast when substituting the vertical orientation for the horizontal orientation can be explained, on our opinion, by accepting that with colours, the deterioration of visual acuity in horizontal gratings subsist with respect to that of the vertical ones (3). This deterioration justifies the improvement on the assimilation effect (Bezold effect) that increases (as mentioned on the discussion) as the difficulty in distinguishing the parts that form a set (a punctual sequence forming a line, in our case) does.

REFERENCES

1. Bezold von, W., *The theory of color* (United States edition). Prang and Company (1876)

2. Hurvich, L., *Color vision*. Sinauer Associates inc. Massachussets. 1981

3. Aguilar, M., Soriano, J.C., "Efecto horizontal en los umbrales de la visión". *Atti Foundation G. Ronchi*. 1989

---

* Laboratory of colour. Department of restoration and conservation of cultural heritage. Polytechnic University of Valencia (UPV) Spain.
**Department of optics and optometry. Polytechnic University of Catalonia (UPC) Spain.

Assessment of color search performance in photopic and mesopic illuminances based on color identification data

Taiichiro Ishida
Department of Architecture and Environmental Design, Graduate School of Engineering
Kyoto University

ABSTRACT

Color is an effective attribute as an aid to a visual task. Appearance of colors, however, remarkably changes with viewing conditions. In particular, lighting environment has strong effects on the appearance of surface colors. To use colors effectively, we must know how colors are identified under various lighting conditions. In our previous studies[1,2], we obtained the data on identification of colors under illuminances from photopic to mesopic levels. In this study we examined performance of a color related searching task under photopic and mesopic illuminance levels, and evaluated it based on the color identification data. Subjects searched the target three-digits printed on a card from among 45 cards. At the same time, a color chip was pasted on each plate as a clue. Before each trial the subjects were informed of the number and color name for the target on that trial. If the subjects could identify colors properly, the searching performance must be improved. As might be expected, the performance of the task declined with decreasing illuminances and size of the color chip. It was found that the searching performance correlated with probability of being identified as the target color.

Keywords: color search, color identification, illuminance, stimulus size

1. INTRODUCTION

Colors are widely used as aids to our visual tasks in various ways such as signs, classification, labeling. Appropriate use of color information makes our living environment safe and comfortable. The effectiveness of the color information, however, largely depends on their appearances that may change with various factors such as lighting, viewing size. To make proper human-environment interface with colors, we must consider the characteristics of color appearances. We have accumulated the data on color identification at illuminances from photopic to mesopic levels[1] and for various stimulus sizes[2]. The aim of this research was to examine the efficiency of color search task at photopic and mesopic illuminances, and to evaluate it based on the color identification data.

2. COLOR IDENTIFICATION DATA

I summarize the color identification data[2] at first. We examined identification of surface colors at illuminances 1000, 10, 1, and 0.1 lx for stimulus sizes 4, 2, 1, and 0.5 deg of visual angle. Subjects gave one of the 13 pre-selected color names to a color chip presented on a gray (N5) background. The pre-selected color names are as follows: red, orange, yellow, yellow-green, green, blue-green, blue, purple, pink, brown, white, gray, and black. The number of color chips to be tested was 76, which were selected from Munsell Value 4, 6 and 8 planes. The results of the color identification for 5 subjects are presented in Figure 1 for two illuminance conditions 1000, 1 lx and two stimulus sizes 2, 0.5 deg. The abbreviation of a color term is given to each color chip if more than 3 subjects gave the same color term to that color. Also a plot symbol with a thick circle indicates that the color was given the same color term by more than 4 subjects. As we can see from Figure 1, the color chips

9th Congress of the International Colour Association, Proceedings
of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

were identified consistently in 1000 lx, however they were identified in considerably different way in 1 lx; typical color confusions occurred between green and blue, pink and orange. It was also found that the stimulus size had little effect in 1000 lx, but considerable effects in 1 lx. The main interest in this study is whether performance of a visual task with color clues is explained by the color identification data as shown here.

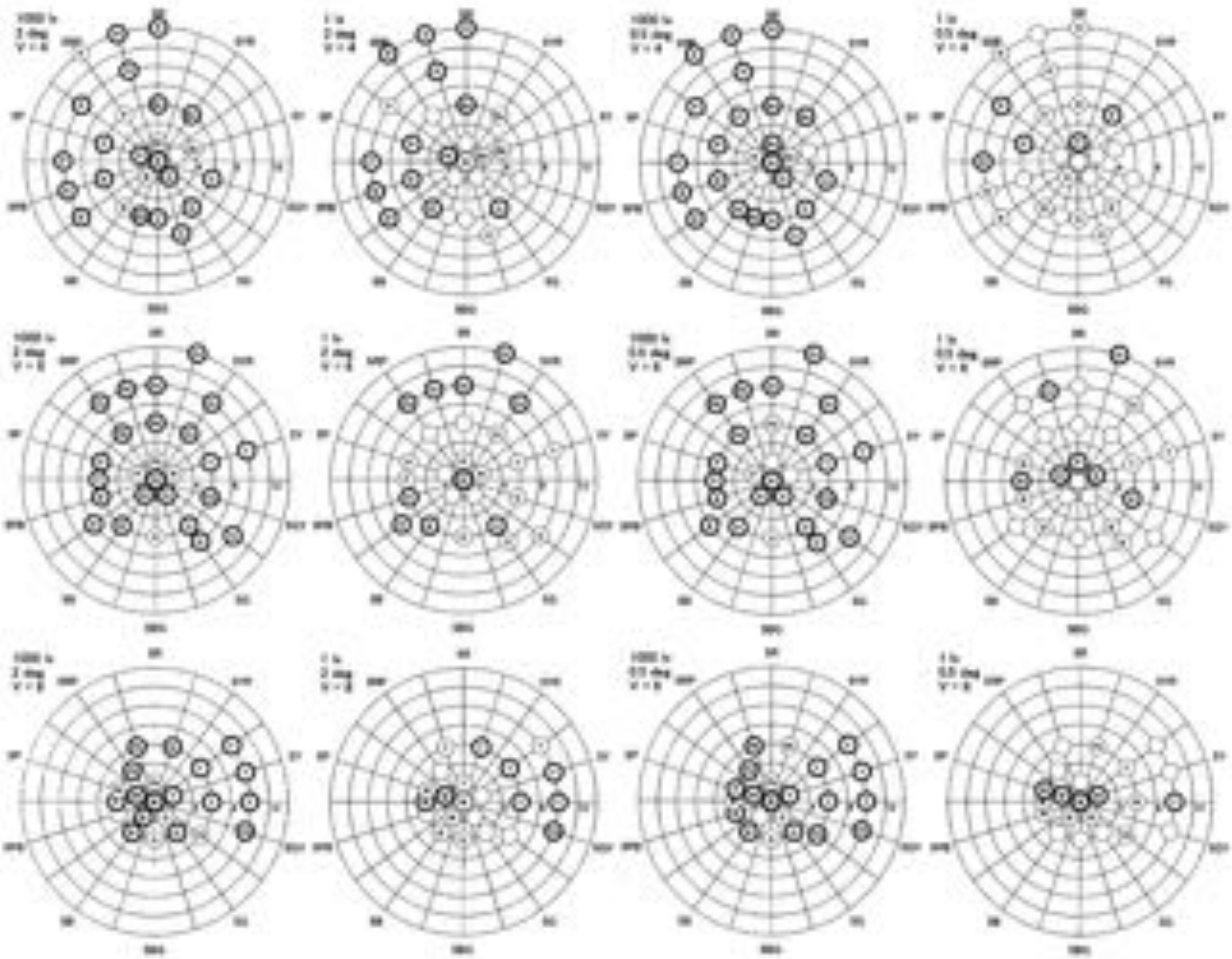


Figure 1. The results of color identification (1000, 1 lx; 2, 0.5 deg)

3. EXPERIMENT: VISUAL SEARCH WITH COLOR CLUES

3.1 Methods

We prepared 90 paper cards (searching card) on which a color chip and 4-digits number were pasted as shown in Figure 2. The task of the subjects was to search the first 3-digits of the 4-digits from 45 searching cards placed on a table[3]. Before starting a trial, the subjects were informed of the target 3-digits and the color name of the color chip pasted on the target card on that trial. The 90 color chips were selected in the range of V=4–0.5, 6–0.5, and 8–0.5 from a set of Munsell color chips. The color name allocated to each of the color chips was determined by referring the identification data shown in Fig.1.

If a target color is identified categorically, the searching for that target will be facilitated. Because subjects may pay attention to only the cards that appear as that color category.

The experiment was conducted under two illuminance conditions (1000, 1 lx) for two sizes of color chips (2, 0.5 deg). The 90 searching cards were prepared for each of the two color sizes and each of the 90 cards was divided into two sets of cards, making four sets in total. A set of the searching cards consists of 45 cards that included the 16 target cards. A set of cards was placed on the experiment table. The subjects searched the card that had the target first 3-digits as soon as possible, and answered the last digit to confirm if they searched the target correctly. On one experimental session, searching times for the half of the targets in each of the four sets were measured at one of the two illuminances. Four sessions were conducted per subject to complete all conditions.

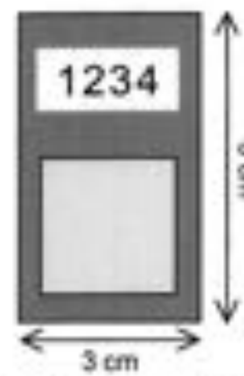


Figure 2: The configuration of the searching card

3.2 Results

Figure 3 presents the results of the searching time averaged over the 6 subjects for each of four conditions. As we can expect, the searching time was strongly influenced by the target colors. Also the searching performance was decreased in 1 lx condition. The color chip size had little effect on the searching performance in the photopic illuminance, however, it was significant in the mesopic illuminance. Table 1 summarizes the searching time averaged over the target cards and the standard deviation for 4 conditions.

Table 1: The average search time

Illum.	Size	Mean	SD (s)
1000 lx	2 deg	5.5 s	3.7 s
1000 lx	0.5 deg	5.2 s	2.2 s
1 lx	2 deg	9.0 s	4.9 s
1 lx	0.5 deg	11.2 s	5.5 s

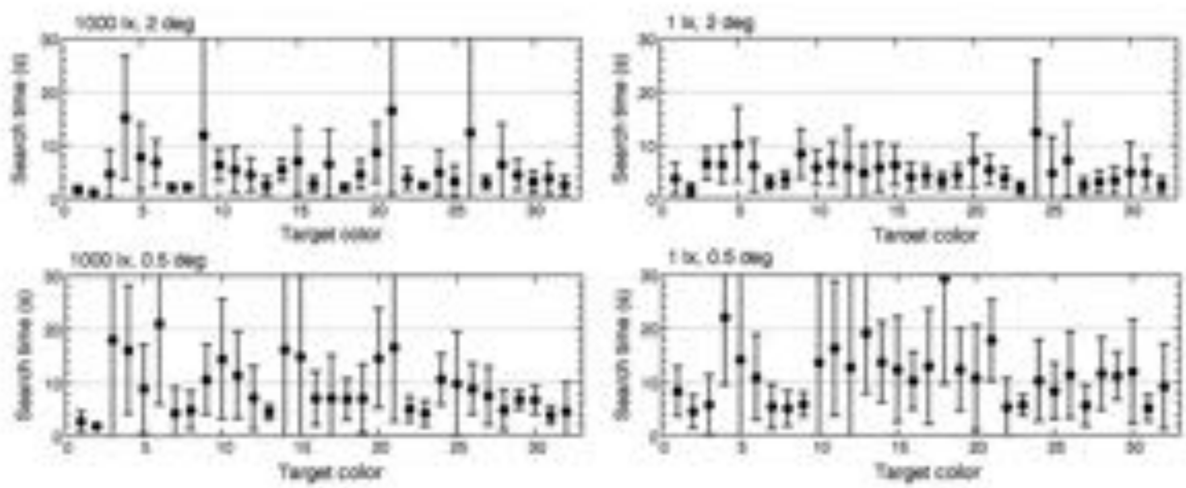


Figure 3. The results of the searching experiment

3.3 Analysis based on the color identification data

To evaluate the color searching task based on the color identification data, we estimated the probabilities with which the colors used in the experiment would be identified as each of categorical colors First, we applied interpolation operations to the color identification data measured in the previous study[2]. Then we obtained color identification maps that gave estimated probabilities of being identified as each of the 13 color categories to every color on the Munsell plane. As an instance, the color identification maps for two color categories (Yellow, Blue) in two conditions (1000 lx-2 deg, 1 lx-0.5deg) are given in figure 4. It is shown that the identification probability distributes in some definite area in the photopic and larger size condition, however, it spreads widely and overlaps with other categories in the mesopic and small size condition.

We calculated some variables using the color identification maps as possible factors that affected the searching performances. The variables we extracted were as follows: probability of the target color being identified as the allocated category: *Pr*, the number of the searching cards that identified as the allocated target color with more than 80% and 20% probabilities: N_{80}, N_{20}. Also we employed Chroma of the target color *C* as an independent variable. Finally, we did a multiple regression analysis to the mean searching time using the four independent variables. Figure 5 presents the correlation between the predicted search time and the measured search time. It is shown that the searching performance positively correlates with the prediction based on the color identification data. We must obtained more statistically reliable searching times by many subjects and consider their strategy for the task to predict the relations more accurately. The present study provide a method of using the color identification data to evaluate the performance of color related visual tasks, and indicate its usefulness to design appropriate color information.

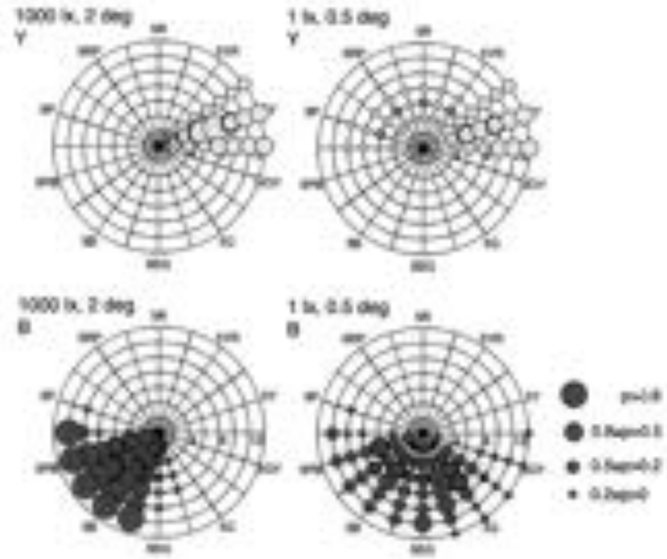


Figure 4. Probability distribution of color identification (Color identification map)

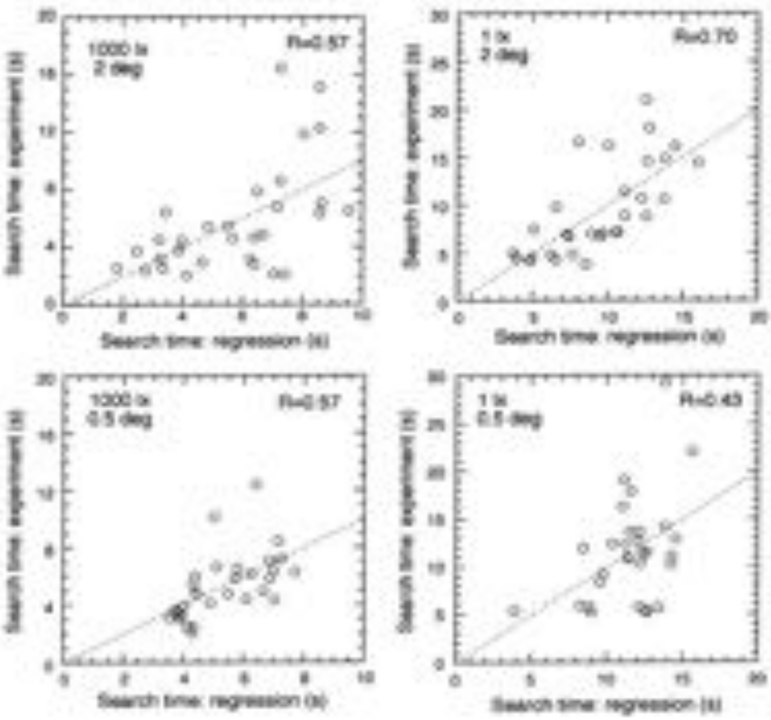


Figure 5. Correlation between the predicted and measured searching time

ACKNOWLEDGEMENTS

I would like to thank Mr. Masaru Ryuchi for his contribution to the experiment. This research was partially supported by Japan Society for the Promotion of Science, Grant-in-Aid for Scientific Research(C) 11832014 to TI.

REFERENCES

1) T. Ishida: "Systematic measurement of color identification under wide range of illuminance levels", Proceedings of 24th Session of the CIE, **1**, 57-61 (1999)

2) M. Ryuchi and T. Ishida: "Color identification under mesopic lighting environment: effect of stimulus size", Proceedings of AIC Interim Meeting, 39-42, (2000)

3) M. Cahill and A. Carter, Jr.: "Color code size for searching displays of different density", Human Factors, **18**, 273-280 (1976)

* Correspondence: ishida@archi.kyoto-u.ac.jp; Fax +81 75 753 7466; Dept. of Architecture and Environmental Design, Kyoto University; Yoshida-Honmachi, Sakyo-ku, Kyoto, 606-8501, JAPAN

Age-related changes in color appearance depend on unique-hue components

Katsunori Okajima[*a], Nao Tsuchiya[b], Kazuyuki Yamashita[c]
[a]National Defense Academy; [b]Toyo Ink MFG. Co.,Ltd.; [c]Toppan Printing Co.,Ltd.

ABSTRACT

In order to compare color appearance as seen by elderly and young people, we conducted an experiment where the subjects responded to the color appearance of 75 color chips using a categorical color naming method and an elemental color scaling method. The results show that categorical color naming between elderly and young subjects is almost identical for most color chips, but there were significant differences in the elemental color scaling between the two age groups depending on unique-hue components. The differences in yellow and blue components between elderly and young subjects suggest that the neural mechanism of color vision in elderly people may over perform on constancy of color appearance so as to compensate for the age-related change of the human crystalline lens. In addition, the chromatic components in elderly subjects indicate higher values than those in young subjects for low saturation color chips, whereas the chromatic components in elderly subjects indicate lower values than those in young subjects when viewing high saturation color chips. These results show that the age-related changes of unique hue components strongly depend on saturation of colors, and suggest that the practical range of color appearance in elderly people is small in comparison with young people.

Keywords: categorical color naming, elemental color scaling, opponent color mechanism, aging vision

1. INTRODUCTION

In most countries, the population ratio of the elderly to young is increasing quite rapidly[1]. For such societies, technical establishment of color design so that the elderly can live a safe and a comfortable life is an important subject. Visual characteristics of older people can be classified in terms of the aging effects on the ocular system, retina, optic nerve and brain stages[2)3]. In particular the age-related change of the crystalline lens in the human ocular system produces a modification of the spectral characteristic of the light arriving at the retina of older people[4]. Therefore, it would be expected that color appearance seen by older people is different from that seen by young people[5]. According to previous studies[6)7], however, there is no significant difference between young and old subjects in their color appearances, even though the color discrimination ability of older subjects obviously decreases in comparison with young subjects[8]. This fact suggests that a compensation mechanism of color vision to keep the same color appearance throughout our lives should exist during visual aging[10].

In the present study, we qualitatively examined the performance of this "color appearance compensation" in the elderly at two illumination levels (50lx and 500lx). To compare color appearance as seen by older and young people, we conducted an experiment where the subjects responded to the color appearance of 75 color chips using a categorical color naming method and an elemental color scaling method. We found that the age-related changes in color appearance depend on the unique-hue components, and that the characteristics depend on saturation of colors. Our results will be useful in considering color designs for the elderly people as well as universal designs for all ages.

2. METHODS

2.1 Subjects

Six elderly subjects (average age = 69.5) and six young subjects (average age = 20.7) participated as volunteers, all the subjects having normal color vision and no eye defects. Both age groups included three men and three females. All subjects were naïve; none of them having previously been in any psychophysical experiment like the present one, and were not familiar with color or color vision in general.

2.2 Stimuli

We used 75 color chips selected from Toyo-Color-Finder-1050 (Toyo Ink MFG. Co.,Ltd.) which distributed widely and uniformly in the a^*b^* chromaticity diagram (Fig.1). Lightness values (L^*) of 32 chips (filled lozenge symbols) out of 75 were around 30, and those of other 31 chips (open square symbols) were around 60. The remaining 12 chips (gray triangle symbols) were selected as high saturation and/or typical hue colors with L^* values of between 23 and 87.

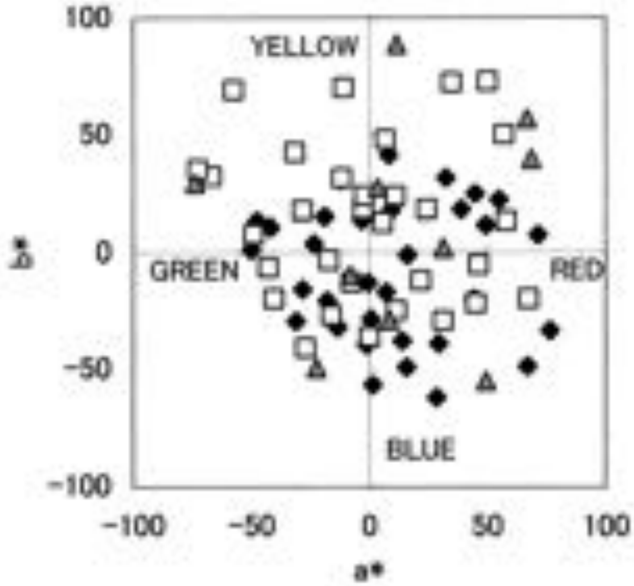


Figure 1. The stimuli plotted on the a*b*-chromaticity diagram.

2.3 Experimental Conditions

Twenty-four fluorescent lights whose color temperature was D65 white were set in the roof of a booth. The illumination level was set at 500 lx or 50 lx during one session by controlling brightness of the lights. One session consisted of 75 trials for all the color ships. Three sessions were repeated at each illumination level for another three days. Subjects observed the test color chip on an N5 gray background with binocular natural viewing. The distance between the eye and the chip was around 45cm, and the visual size of test chips was approximately 2.1 degrees (H) and 6.4 degrees (V).

2.4 Procedure

The subjects first adapted to the illumination level for 10 minutes. The test color chips were presented in random order and the subjects were initially asked to give (i) the ratio of the achromatic and chromatic components in the test color chip, (ii) the ratio of whiteness and blackness in the achromatic components and (iii) the ratio of the four unique-hue components (redness, greenness, yellowness and blueness) in the chromatic components (Fig.2). The subjects were then asked to choose one color name out of 11 basic color terms (RED, GREEN, YELLOW, BLUE, ORANGE, PURPLE, PINK, BROWN, WHITE, BLACK and GRAY) to describe the chip's color. One session took between 1 and 2 hours depending on subject and day.

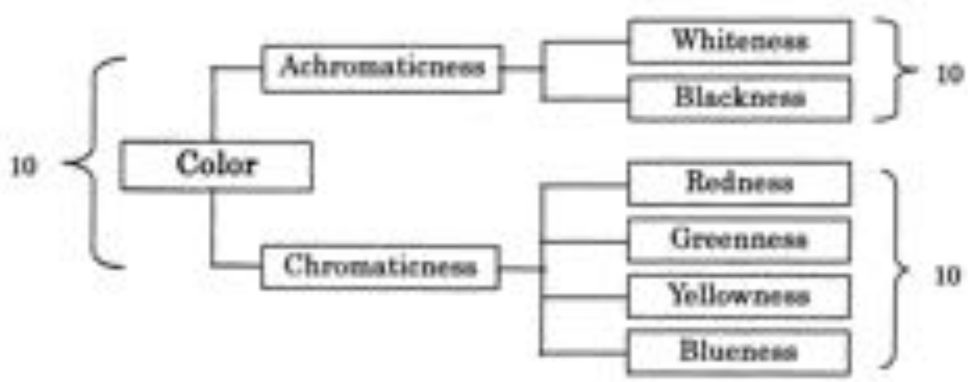


Figure 2. Schematic diagram of elemental color scaling method.

3. RESULTS AND DISCUSSION

The results show that categorical color naming between elderly and young subjects is almost the same for most color chips, but there were systematic differences in the elemental color scaling between the two age groups. To clarify these general differences quantitatively, we analyzed the ratios of unique-hue components (redness, greenness, yellowness and blueness) separately and compared the results of two age groups directly. Figure 3 is the correlation plots of the results (open lozenge symbols) between two age groups. All data at 50 lx and 500 lx were plotted together because there was no significant difference between the data at two illumination levels. We found that the response values of redness and greenness components in elderly subjects are slightly lower than those in young subjects (Fig.3 **a** and **b**) and that the response values of yellow component in elderly subjects are lower than those in young subjects (Fig.3 **c**). In contrast the response values of the blue component in elderly subjects are slightly higher than those in young subjects when the blue component value is low (Fig.3 **d**). These differences in yellow and blue components between elderly and young subjects suggest that the neural mechanism of color vision in elderly people may over perform on constancy of color appearance so as to compensate for the age-related change of the human crystalline lens.

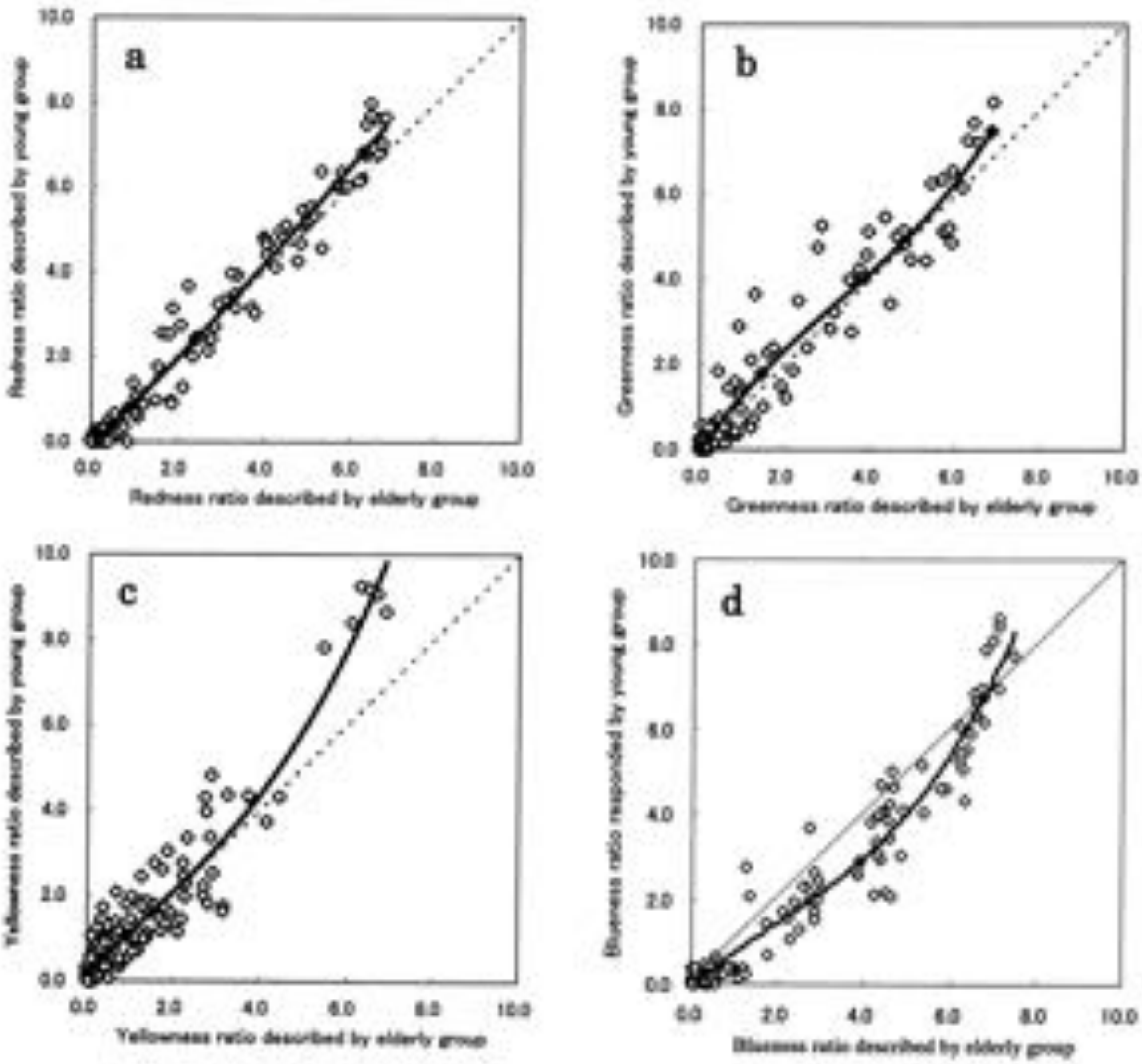


Figure 3. Correlation plots of each unique-hue component (**a** Redness, **b** Greenness, **c** Yellowness and **d** Blueness) between two age groups. Open lozenge symbols are the data, and solid bold lines are regression curves. The horizontal axis indicates mean responses of elderly subjects and vertical axis indicates those of young subjects.

Figure 4 shows the age-related change of chromatic components (open lozenge symbols) for 32 chips whose lightness (L^*) were around 30 at 500 lx. The chromatic components in elderly subjects indicate higher values than those in young subjects for low saturation color chips, whereas the chromatic components in elderly subjects indicate lower values than those in young subjects in high saturation color chips. These results indicate that the age-related changes of unique hue components strongly depend on saturation of colors, and suggest that the practical range of color appearance in elderly people is small in comparison with young people. It may be a cause of why color discrimination declines as one ages.

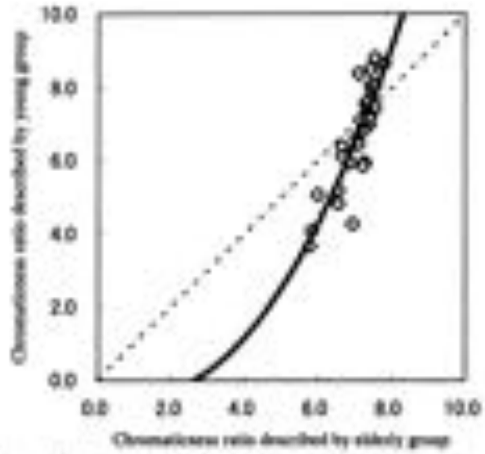


Figure 4. Correlation plot of chromatic components between two age groups. (L^*=30, 500 lx)

4. SUMMARY

Categorical color perception appears to be independent of aging but saturation and hue perception change with age. The age-related changes of elemental color scaling depend on unique-hue components. The results show the characteristics of a color constancy mechanism in human color vision so as to compensate for the age-related change of the crystalline lens. In addition, we showed that the age-related changes of unique-hue components depend on saturation of colors and that the practical range of color appearance in the elderly is small in comparison with young people. Our results will be useful in considering color designs for the elderly as well as universal designs for all ages.

ACKNOWLEDGMENTS

We wish to express our appreciation to K. Watanabe, Y. Takamura and M. Mizutani for their generous support.

REFERENCES

(1) S.Tuljapurkar et al., "A universal pattern of mortality decline in the G7 countries," Nature, **405**, pp.789-792, 2000.

(2) J.S.Werner et al., "Light, vision and aging," Optometry and Visual Science, **67**, pp.214-229, 1990.

(3) J.S.Werner, "Visual problems of the retina during ageing: compensation mechanisms and colour constancy across the life span," Progress in Retinal and Eye Research, **15**, pp.621-645, 1996.

(4) J.Xu, J.Pokorny and V.C.Smith, "Optical density of the human lens," J.Opt.Soc.Am., **A14**, pp.953-960, 1997.

(5) K.Okajima and M.Takase, "Computerized simulation and chromatic adaptation experiments based on a model of aged human lens," Optical Review, **8**, pp.64-70, 2001.

(6) B.E.Schefrin and J.S.Werner, "Age-related changes in the color appearance of broadband surfaces," Color Res. Appl., **18**, pp.380-389, 1993.

(7) J.S.Werner and B.E.Schefrin, "Loci of achromatic points throughout the life span," J.Opt.Soc.Am., **A10**, pp.1509-1516, 1993.

(8) K.Knoblauch et al., "Age and illuminance effects in the Farnsworth-Munsell 100-hue test," Appl. Opt. **26**, pp.1441-1448, 1987.

* Correspondence: okajima@cc.nda.ac.jp; phone +81-468-41-3810; fax +81-468-44-5912; http://www.nda.ac.jp/cc/users/okajima; Department of Applied Physics, National Defense Academy, 1-10-20 Hashirimizu, Yokosuka, Kanagawa 239-8686 JAPAN

Evaluating the 1931 CIE Color Matching Functions

Mark Shaw* and Mark D. Fairchild*
Munsell Color Science Laboratory, RIT

ABSTRACT

The use of colorimetry within industry has grown extensively in the last few decades. Central to many of today's instruments is the work of the CIE system, established in 1931. Many have questioned the validity of the assumptions made by Wright[1] and Guild[2], some suggesting that the 1931 color matching functions are not the best representation of the human visual system's cone responses. A computational analysis was performed to evaluate the CIE 1931 color matching functions against other responsivity functions using metameric data. An optimization was then performed to derive a new set of color matching functions using spectral data of visually matched metameric pairs.

1. INTRODUCTION

The 1931 Color Matching Functions were constructed from the relative color matching data of Wright[1] and Guild[2], with the assumption that they must be a linear combination of three functions including the 1924 CIE $V(\lambda)$ luminous efficiency function. Stockman and Sharpe[3] have suggested that the validity of the CIE 1924 luminous efficiency function $V(\lambda)$ is questionable, so too is the assumption that $V(\lambda)$ must be a linear combination of the Color Matching Functions. Stockman and Sharpe are not alone in their concerns, Stockman, MacLeod and Johnson[4], and others, have also questioned the validity of the assumptions made by Wright[1] and Guild[2].

The full implications of such questions are not known, is the concern purely one of theoretical rigor, bearing no significance to the application of the current technology? Or is the concern valid, one that may affect the whole of colorimetry as it stands to date?

If one is to assume that the CIE 1931 color matching functions are sufficient when they are not, then much of the work being done to build device models that minimize colorimetric error is attempting to attain an impossible goal. If the CIE 1931 color matching functions are not the ideal solution, would a new set of functions lead to better colorimetry? Or is the error within the bounds of statistical insignificance? These questions are of great importance to the color science community. Applications that assume that the CIE 1931 color matching functions are sufficient, if they are not, will operate in error.

Existing works clearly document some of the issues that cause concern when using the CIE color matching functions and demonstrate their effects on the color science community. Even so, little documented work has been done to compare the benefits of using the modified functions and sensitivities. The aim of this work was to evaluate the accuracy of the CIE 1931 color matching functions against more recent estimations and modifications, and determine whether the new cone fundamentals and color matching function derivations are truly optimal, or merely within the bounds of statistical insignificance. Six different sets of color matching functions and cone fundamentals were computationally analyzed using existing spectro-radiometric measurements of visually matched metameric pairs. The analysis indicates which set best approximated the observers' visual perception. A detailed documentation of the analysis can be found in Shaw[5].

2. METHODOLOGY

To save confusion between the differences of color matching functions and cone sensitivity functions, in this work both are called responsivity functions. Many different sets of responsivity functions have been published, each claiming to have its own benefits over the 1931 color matching functions. Some are merely linear transformations of the 1931 color matching functions into cone space to better predict the cone responses, while others include optimizations derived by the authors. In this study, a total of six sets were chosen to perform the computational analysis. The six sets included the work of the CIE in 1931, CIE in 1964, Stiles and Burch[6], Demarco, Smith and Pokorny[7], Stockman, MacLeod and Johnson[4], and Vos and Walraven[8].

Experimental Data

The work utilized experimental data from previous visual experiments by Alfvin[9], Shaw and Montag.[10,11] Alfvin and Fairchild[9] designed a visual experiment to permit observers to make critical color matches between prints or transparencies and a CRT display. Shaw and Montag[10,11] designed a visual experiment to allow observers to perform a color match between a gray card of Munsell N5 and an ACS VCS 10 additive mixing device. Further details of the experiments can be found in Shaw.[5]

Computational Analysis

One of the key underlying assumptions of this work is that an optimal set of responsivity functions will predict that the integrated response from a metameric pair are equal. Therefore, one can evaluate the performance of a set of responsivity functions using metameric data, by calculating the color difference over all the metameric pairs in that color space.

A problem arises when one wishes to compare the performance of different sets of responsivity functions. It is not sufficient to assume that one can use the CIELAB color space as the comparative space by just transforming the tristimulus values calculated by each set of color matching functions into CIELAB co-ordinates using the standard equations. One must find a common color space in which each set can be compared. One must therefore consider how to compare the different sets of responsivity functions. One approach would be to derive a new color space in which all of the responsivity functions can be compared, but this introduces a new quality metric that may bear no significance to existing standards. An alternative approach is to assume an existing color space as standard, and transform all other sets of responsivity functions into the closest linear approximation.

Thus the problem of disparate responsivity functions was overcome by assuming the common color space to be CIELAB, using the CIE 1931 standard observer. In order to evaluate the other sets of functions accurately, a linear transformation was calculated to transform each set into an approximate CIE representation. The method of calculating a 3x3 transformation matrix using least squares is shown in Equation 1. The transformed functions were then used to calculate a set of 'pseudo' tristimulus values for each set of functions.

$$\begin{bmatrix} x_{400} & y_{400} & z_{400} \\ \vdots & & \vdots \\ x_{700} & y_{700} & z_{700} \end{bmatrix} = \begin{bmatrix} r_{400} & g_{400} & b_{400} \\ \vdots & & \vdots \\ r_{700} & g_{700} & b_{700} \end{bmatrix} \cdot \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \quad (1)$$

$$XYZ = RGB \cdot A \qquad \text{where } pinv(W) = \left(W^T \cdot W\right)^{-1} W^T$$

$$A = pinv(RGB) \cdot XYZ$$

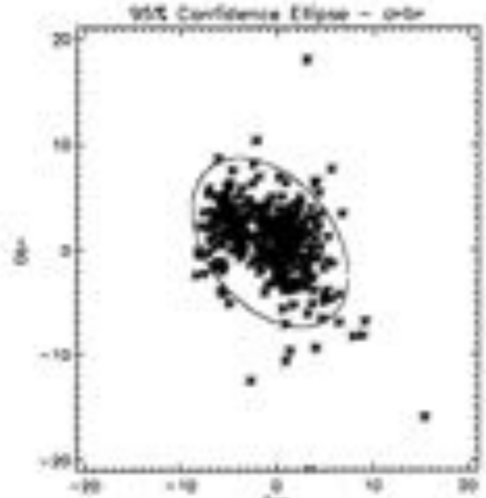


Figure 1. The 95% (outer ellipse) and mean (inner ellipse) confidence region for the sample distribution in the Δa Δb* plane of the sample data.*

By transforming each set into a CIE approximation, one is able use standard quality metrics, including CIE ΔE^*_{ab} and CIE ΔE^*_{94}. Although, the CIELAB color space is not optimized for the other color responsivity functions, but can be considered a consistent color space for comparison. Any systematic shifts introduced by the cube-root transformation, or Von-Kries type chromatic adaptation normalization will be consistent for all responsivity functions.

Tristimulus integration was used to calculate the tristimulus values for each of the metamer pairs from the spectral data. The 4nm interval spectral data was linearly resampled to 5nm data, and the wavelength range truncated to 400-700nm. The wavelength interval was chosen to correspond to that of the various sets of responsivity functions. Reference white tristimulus values for the measured radiance data were unknown. Therefore, since the gray patch in each data set had an L* of approximately 50 (20% reflectance), the reference white was approximated using the tristimulus values of the reflectance spectra scaled by five. CIELAB coordinates were calculated according to standard CIE methods, using each of the transformed sets of responsivity functions. CIE ΔL^*, Δa^*, Δb^*, ΔC^*, ΔH^*, ΔE^*_{ab} and ΔE^*_{94} values were calculated for each metameric pair.

Statistical Analysis

In order to evaluate the performance of each set of responsivity functions, two tailed t-tests were used. The t-test was used to compare the mean color difference vector (ΔL^*, Δa^*, or Δb^*) against a mean of zero. An ideal set of responsivity functions would yield a mean ΔL^*, Δa^*, Δb^* of zero, plus an offset for observer variance. A sample covariance matrix, S_{Lab}, was calculated for each set of responsivity functions.

Assuming a multivariate normal distribution, the inverse of the sample covariance matrix can be used to construct a 95% confidence region for the sample distribution of the CIE ΔL^*, Δa^*, and Δb^* multivariate data set[8]. An example of a Δa^*-Δb^* bivariate ellipse bound by a 95% confidence region for the sample distribution is shown in Figure 1, relative to the CIE 2° Standard Observer. If any one of the three confidence regions centering at the sample means of the Δa^*-Δb^*, ΔL^*-Δa^* or ΔL^*-Δb^* planes do not contain the theoretical mean match for a given standard observer, the mean color matches are considered to be statistically significantly different from zero[9].

3. RESULTS AND DISCUSSION

As well as the final six sets of responsivity functions chosen, a set of responsivity functions derived by Shaw and Fairchild in this work have been included in the results for ease of comparison. The derivation of the Shaw and Fairchild responsivity functions is documented below. This section shall only summarize the results of two of the analyses performed, the analysis of the Alfvin data set, and the analysis of all the data sets combined. The total Alfvin data set, containing all seven color centers, is comprised of 268 metamer pairs. A summary of the results can be found in Table I.

The results show that little difference can be found between the different sets of responsivity functions for the Alfvin Data. The CIE 1931 functions yield an average color difference of 4.4 ΔE^*_{ab}, 2.7 ΔE^*_{94}, with the best set of responsivity functions being that of Demarco, Smith and Pokorny[7], yielding an average color difference of 4.3 ΔE^*_{ab}, 2.7 ΔE^*_{94}. The Shaw and Fairchild responsivity functions derived by optimization yield an interesting result, the average color difference is the second highest. This indicates that the contribution of the Alfvin data set to the optimization may have been less significant than the other data sets, with the optimization minimum being found even though an increase in error in the Alfvin data set occurred.

The statistical tests performed on the data show some interesting features. A two tailed t-test of the means was applied on each of the ΔL^*, Δa^*, Δb^* values with the null hypothesis that the means are equal to zero. The results shown in Table II indicate that the CIE 1931 functions failed the test in both the Δa^* and Δb^* planes, showing that there are systematic deviations from a mean of zero, implying that the functions are not optimal. The results of the Shaw and Fairchild responsivity functions fail to reject the null hypothesis in all three dimensions, indicating that the mean cannot be shown to deviate from zero (p value > 0.025). When looking at the results of the entire dataset in Table III, it can be seen that the Shaw and Fairchild responsivity functions yield the lowest color difference, when averaged over all of the combined set of samples. But, it is clear that the difference between each of the sets of responsivity functions is only slight, ranging from 4.6 ΔE^*_{ab} at worst, to 3.9 ΔE^*_{ab} at best.

Color Difference	CIE 1931	CIE 1964	Stiles	Demarco	Stockman	Vos	Shaw
ΔE^*_{ab}	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ΔE^*_{94}	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table I : Average results of computational analysis for all color centers and observers in the Alfvin data set.

CIE 1931 Color Matching Functions

	Mean	Std Dev	Maximum	Minimum
DE :	4.384	3.468	22.300	0.220
DE 94 :	2.730	2.393	15.470	0.000
DL :	0.060	2.876	13.410	-13.100
Da :	0.471	2.876	15.440	-8.384
Db :	0.996	3.731	16.030	-21.000

	Critical Value	Test Statistic	P Value	Decision
DL :	1.969	0.371	0.356	Fail to Reject
Da :	1.969	2.653	0.004	Reject Null
Db :	1.969	3.016	0.001	Reject Null

(a)

Shaw and Fairchild Color Matching Functions

	Mean	Std Dev	Maximum	Minimum
DE :	4.563	3.602	24.360	0.404
DE 94 :	2.814	2.475	14.100	0.000
DL :	0.147	2.841	13.650	-15.170
Da :	0.248	2.841	13.600	-8.128
Db :	-0.152	3.819	17.130	-20.810

	Critical Value	Test Statistic	P Value	Decision
DL :	1.969	0.814	0.208	Fail to Reject
Da :	1.969	1.246	0.107	Fail to Reject
Db :	1.969	-0.565	0.286	Fail to Reject

(b)

Table II : Results of the statistical analysis of the Alfvin data set using the CIE 1931 (a), and Shaw and Fairchild (b) responsivity functions.

Color Difference	CIE 1931	CIE 1964	Stiles	Demarco	Stockman	Vos	Shaw
ΔE^*_{ab}	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ΔE^*_{94}	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table III : Average results for the computational analysis of all three data sets combined

The statistical analyses performed on the data show some interesting features. A two tailed t-test of the means was applied on each of the ΔL^*, Δa^*, Δb^* values with the null hypothesis that the means are equal to zero. The results shown in Table II indicate that the CIE 1931 functions failed the test in both the Δa^* and Δb^* planes, showing that there are systematic deviations from a mean of zero, implying that the functions are not optimal. The results of the Shaw and Fairchild responsivity functions fail to reject the null hypothesis in all three dimensions, indicating that the mean cannot be shown to deviate from zero. When looking at the results of the entire dataset in Table III, it can be seen that the Shaw and Fairchild responsivity functions yield the lowest color difference, when averaged over all of the combined set of samples. But, it is clear that the difference between each of the sets of responsivity functions is only slight, ranging from 4.6 ΔE^*_{ab} at worst, to 3.9 ΔE^*_{ab} at best.

Derivation of Optimized Responsivity Functions

The previous discussion documented the performance of the seven sets of responsivity functions. Of the seven sets, six were previously defined, and one was derived by the authors to satisfy the experimental objectives set forth in this work, the Shaw and Fairchild color matching functions. This section documents the approach taken in deriving the new set of color matching functions. It is possible to consider that an optimal set of responsivity functions can be derived from visual color matching data by a modification of an existing set of responsivity functions using the visual data to weight the adjustments.

Using the three combined metameric data sets, an optimization was performed to minimize the average color difference over all observations.

Of the thirteen approaches tried, optimization using a linear combination of existing sets of responsivity functions performed the best. The optimization function used the Levenberg-Marquardt technique, allowing constraints to be applied to different parameters in the optimization. The cost function and constraint applied are shown in Equation 2. Where $\bar{x}_i$ is the i^{th} weighting function under evaluation, ($\bar{x}$, $\bar{y}$, or $\bar{z}$), $w_{i,j}$ is the j^{th} weight for the i^{th} weighting function that scales C_j, the j^{th} responsivity function. The optimization was constrained such that the weights $w_{1..6}$ sum to one, and the solution being found when a set of weights ($w_{i,j}$) were found that minimized the average color difference between the reference and sample CIELAB values.

This approach did not yield the lowest color difference of all the techniques, but it did yield the most realistic set of weighting functions. The final set of functions can be seen in Figure 2, resulting in an average color difference of 3.9 ΔE^*_{ab} over all samples.

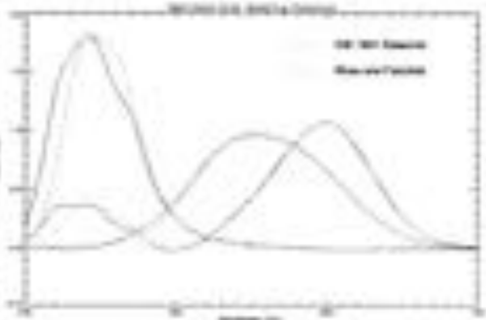


Figure 2 - Final selection of optimized color weighting functions

$$\bar{x}_{optimum} = \sum_{j=1}^{6} w_j C_j \longrightarrow w_j = \arg\min \Delta E_{mean}$$

where

$\bar{x}_{optimum}$ = Optimized weighting function (2)

w_j = j^{th} Weight

C_j = j^{th} Transformed Responsivity Function

constraint

$$w_1 = 1 - w_2 - w_3 - w_4 - w_5 - w_6$$

5. CONCLUSIONS

A computational analysis was performed to evaluate the 1931 color matching functions against other responsivity functions using metameric data. The underlying principle being was that an optimal set of responsivity functions will yield minimal tristimulus error between a pair of visually matched metamers. A common color space was used in order to compare the performance of the different responsivity functions, the color space used was CIELAB, based upon the CIE 1931 2° standard observer functions. Five other sets of responsivity functions were transformed into near-CIE approximations using a linear 3x3 matrix. Color differences were calculated between each pair of CIELAB coordinates for each metameric match using the standard ΔE^*_{ab} and ΔE^*_{94} color difference formulae. The differences between the average color differences found in the six sets of responsivity functions were small. The CIE 1931 2° color matching functions, on average, provided the largest color difference, 4.6 ΔE^*_{ab}. The best performance came from the CIE 1964 10° color matching functions, yielding an average color difference of 4.0 ΔE^*_{ab}.

An optimization was then performed using the responsivity functions based on the concept that color differences between metamers can be used to improve the prediction of color matching functions. Thirteen optimization techniques were derived, but only two were found that were capable of both maintaining the integrity of the color matching functions, and reducing the average color difference. The optimal solution, the 'Shaw and Fairchild' responsivity functions, were able to reduce the average color difference to 3.9 ΔE^*_{ab}, using a weighted combination of each of the different sets of responsivity functions.

REFERENCES

1. Wright W.D, (1928-29) A re-determination of the trichromatic coefficients of the spectral colours, Trans. Opt. Soc. 30, pp. 141-161
2. Guild J, (1931) The Colorimetric Properties of the Spectrum, Phil. Trans. Roy. Soc. (London), A 230, p. 149-187
3. Stockman A, Sharpe L.T, (1998) Human cone spectral sensitivities: a progress report, Vision Research, 38, 19, pp. 3193-3206
4. Stockman A, Macleod D.I.A and Johnson N.E, (1993) Spectral sensitivities of the human cones, Optical Society of America, 10, No 12, pp. 2491-2516
5. Shaw M.Q, (1999) Evaluating the CIE 1931 Color Matching Functions, MSc Thesis, Munsell Color Science Laboratory, Rochester Institute of Technology, Rochester, NY 14623 USA, http://www.cis.rit.edu/mcsl/ (see Publications - Student Research)
6. Stiles W.S. and Burch J.M, (1955) Interim report on the Commission Internationale de l'Eclairage, Zurich, on the National Physical Laboratory's investigation of Colour Matching, Optica Acta, 2, pp. 168
7. DeMarco, P., Pokorny, J., & Smith, V. C. (1992). Full spectrum cone sensitivity functions for X-chromosome linked anomalous trichromats. Journal of the Optical Society of America A, 9, 1465-1476.
8. Vos J.J and Walraven P.L, (1971) 'On the derivation of the foveal receptor primaries,' Vision Research, 11, pp. 799-818
9. Alfvin R, (1995) A computational analysis of observer metamerism in cross-media color matching, MSc Thesis, Munsell Color Science Laboratory, Rochester Institute of Technology, Rochester, NY 14623 USA
10. Shaw M.Q and Montag E.D, (1998) Analyzing Observer Metamerism, Color Measurement Laboratory Project, Munsell Color Science Laboratory, Rochester Institute of Technology, Rochester, NY 14623 USA.
11. Shaw M.Q and Montag E.D, (1999) Analyzing Observer Metamerism, Color Measurement Laboratory Project, Munsell Color Science Laboratory, Rochester Institute of Technology, Rochester, NY 14623 USA.

* Correspondence: Applied Science Fiction, 8920 Business Park Drive, Austin, TX 78759, USA. e-mail: mqshaw@hotmail.com

+ Correspondence: Munsell Color Science Laboratory, Rochester Institute of Technology, Rochester, NY 14623, USA. e-mail: mdf@cis.rit.edu

Transition between color contrast and assimilation by perceived size manipulation

Hiroyuki Shinoda, and Mitsuo Ikeda
Department of Photonics, Ritsumeikan University

The purpose of the present research is to show that color contrast can be also achieved by manipulation of perceived size and to generalize the idea that perceived size is more fundamental to color contrast and assimilation than retinal size of images. In the experiment we assessed color appearance of grating for three color combinations with four stripe widths from 4.6 to 18.6 min. at three vergence angles. Assimilative/contrastive color shift occurred when the vergence was larger/smaller and stripe appeared narrower/wider. Since both of stripe width of retinal image and subject's vergence affect perception of stripe width, we analyzed the size and direction of color shift in terms of perceived width. It was shown all color shifts were attributed to change in perceived width, which suggests perceived dimension is more fundamental than retinal dimension in color perception.

Keywords: Color appearance, color contrast, color assimilation, perceived size, retinal size, vergence

1. INTRODUCTION

Color appearance is affected by its contiguous area. Tough the direction of color shift is opposite in color contrast and assimilation, both can be observed with an identical pattern. A color grating made of two different color stripes shows both phenomena by changing its spatial frequency: color assimilation occurs at high spatial frequency and color contrast at low spatial frequency[1-4]. Our previous report showed that assimilation gets stronger when the vergence angle was larger and a color grating was perceived narrower without change in the spatial frequency[5]. The purpose of the present research is to show that color contrast can be also achieved by manipulation of perceived size and to generalize the idea that perceived size is more fundamental to both color contrast and assimilation than retinal size of images. In the experiment we measured the shift in color appearance of gratings for three different color combinations for various stripe widths and vergence angles. Since both of stripe width on the retina and vergence angle affect subject's perception of stripe width, we quantified the change in perceived size caused by vergence manipulation and analyzed the shift of color appearance in terms of perceived dimension.

2. MEASUREMENT FOR COLOR APPEARANCE OF GRATINGS

2.1 APPARATUS

We controlled a subject's vergence angle using a stereoscope-like apparatus shown in Figure 1. A subject fused two images presented on two CRTs (SONY GDM-2000TC) at the distance of 40 cm through the mirrors. Presentation of stimuli was controlled by Apple PowerMacintosh 7500/100. The screen size was 1280 x 1024 pixels (46.7 x 38.1 deg.), where a single pixel was 0.27 mm and subtended 2.3 min. of arc. Colors are controlled by input values of each phosphor (r, g, b) with 8 bit depth, namely 0 through 255. Identical stimuli were presented on the both screens but their positions were shifted horizontally and symmetrically so that subject's vergence angle could be varied with keeping the optical distance. The vergence was defined by this horizontal displacement, d (pixels), from the center. Its direction was defined positive as a left/right stimulus goes to the left/right. When d has a negative value, the vergence angle is larger and the vergence distance is closer than the optical distance like in Figure 1 and vice versa.

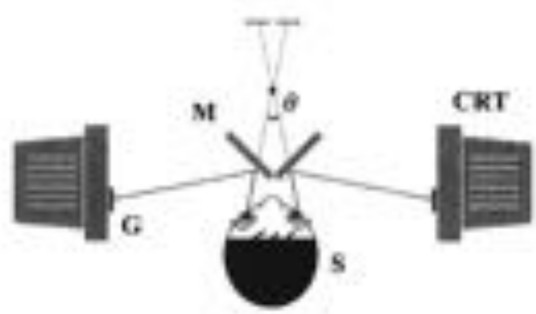


Figure 1. Apparatus. M, mirrors; S, subject; G, grating; θ, vergence angle.

2.2 STIMULI & CONDITIONS

Stimuli configuration of the left screen was shown in Figure 2. A color grating was composed of horizontal stripes of two different colors and presented on a white surround W. Both stripes had equal width. The four different stripe widths, 2, 3, 4, and 8 pixels (4.6, 7.0, 9.3, and 18.6 min. of arc.), were employed. The matching square was presented below the grating and its color was adjusted to the color of stripes by subjects. The size of both squares and their separation was changed so that the arrangement could be kept throughout all stripe widths. Every grating contained 27.5 cycles of stripes in themselves. The grating and matching square was, for instance, 220 pixels (8.49 deg.) and the separation was 60 pixels (2.32 deg.) for the 4 pixels (9.3 min.) of stripe width. Three color pairs were selected for grating, whose spatially averaged color would be a gray of (144, 144, 144) in (r, g, b). They were red-cyan (R-C), green-magenta (G-M), and blue-yellow (B-Y). They are specified in Table 1 with their input values (r, g, b) and the luminance Y cd/m^2 and $u'v'$ chromaticity and plotted on the CIE 1976 $u'v'$ chromaticity diagram of Figure 3. Thus the 12 color gratings (3 color pairs x 4 stripe widths) were employed. The each color of grating were matched with a color of the matching square, which was varied along the line going through two colors of stripes in the CIE 1931XYZ color space or in the rgb CRT space. Three vergence angles were employed: d = 76, 0, and -152 pixels (2, 0, -4 cm). They correspond to 2.9, 8.6, and 20.0 deg. in vergence angle or 120, 40, and 17 cm in vergence distance in the case of 6 cm interocular distance.

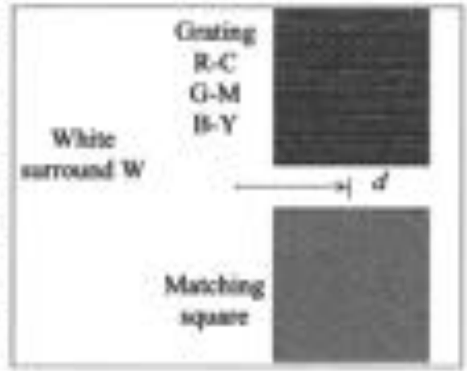


Figure 2. Stimulus configuration on the left screen.

Table 1. Input value, luminance and CIE1976$u'v'$ chromaticity of the gratings and the surround

Color	(r, g, b)	Y(cd/m^2)	u'	v'
R	(180, 126, 126)	18.36	0.256	0.488
C	(108, 162, 162)	21.18	0.158	0.468
G	(126, 180, 126)	26.77	0.160	0.515
M	(162, 108, 162)	14.23	0.246	0.426
B	(126, 126, 180)	14.66	0.190	0.406
Y	(162, 162, 108)	24.13	0.202	0.520
Gy	(144, 144, 144)	18.76	0.197	0.476
W	(255, 255, 255)	77.73	0.199	0.476

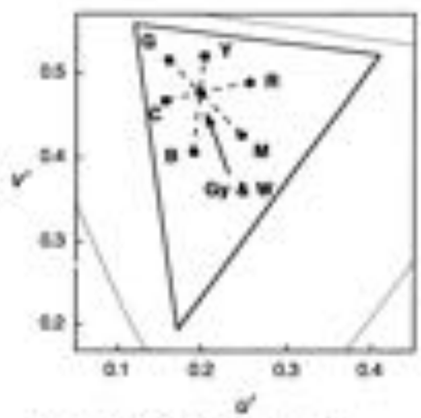


Figure 3. Colors of stripes on $u'v'$ chromaticity diagram. Three color gratings, R-C, G-M, and B-Y, were selected so that a spatially averaged color should be Gy. The specification are described in Table 1.

2.3 TASK, PROCEDURE & SUBJECTS

After a few minute dark adaptation the experimental session started. Subjects matched the color of the matching square to that of stripes by manipulating a trackball. Matching was done for both color stripes at three different vergences in succession. The grating was left presented on the screen until 6 matchings (2 colors x 3 vergences) have been completed; the grating was dragged from the current d to the next d. The order of the twelve gratings was random. One session was composed of 72 color matchings. A subject was required to confirm no blurry or double image before every adjustment. Three subjects, two graduate students and one of the authors, participated in the experiments. They are all color normal verified by Ishihara plate.

2.4 RESULTS

Results from subjects HS are shown separately for R-C, G-M, and B-Y in Figure 4. The abscissa shows the horizontal displacement d in pixels, where smaller d corresponds to larger vergence angle. The matching colors are described by one of the input values r, g, or b along the ordinate: value r for R-C grating, g for G-M, and b for B-Y. The three horizontal lines indicate the input values of original colors and the spatially averaged gray Gy. Error bars show standard

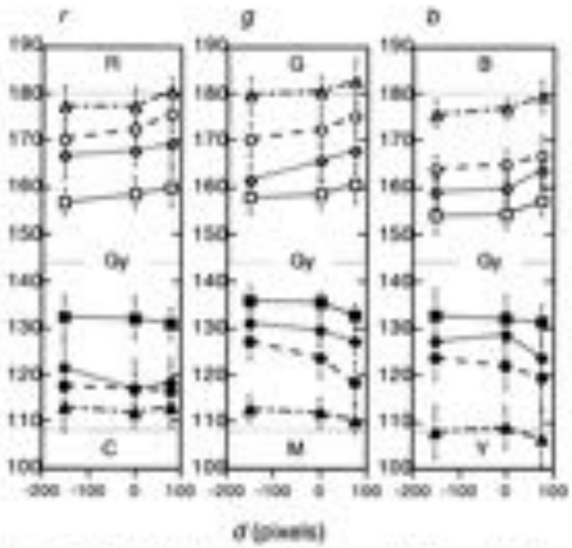


Figure 4. Matched color as a function of *d*. The matched color is described by one of input values *r*, *g*, and *b*. Open symbol shows stripe R, G,or B, and filled one C, M, or Y. Triangle, 8 pixel wide stripe; circl, 4 pixel wide; diamond, 3 pixel wide; square, 2 pixel wide.

deviations for 20 matchings. Most of the lines locate between the two horizontal lines at 180 and 108. It means colors of gratings appear less saturated than original colors. The difference between two lines of a single color pair gets smaller for narrower stripes, showing stronger assimilation occurred with narrower stripes. More importantly, all lines have slope. The slope indicates the effect of vergence angle on color appearance. At larger vergence angle two lines for color stripes come closer to Gy even if the retinal dimension of gratings is kept constant. On the other hand, decreasing vergence angle make two colors to appear more saturated, or bring stronger color contrast. The stripe G of 8 pixel wide appeared more greenish than the original at smaller vergence, such as d=0 and 76 pixels. The stripe Y of 8 pixel wide also appeared more yellowish than the original at d=76 pixels. Particularly at d=76 pixels, the difference of g for two colors of G-M grating and that of b for B-Y was larger than 72, the difference between 180 and 108 for the original. Thus both color contrast and assimilation can be obtained by vergence manipulation.

The shift of color appearance is shown in u'v' chromaticity diagram in Figure 5. The dots indicate the matched colors. The data points for same vergence are connected with lines but only shown for 8, 4, and 2 pixel wide stripes. The shift is biggest for 4 pixel wide stripes and rather small at 2 and 8 pixel wide. The stripes M show the largest shift and those of C smallest.

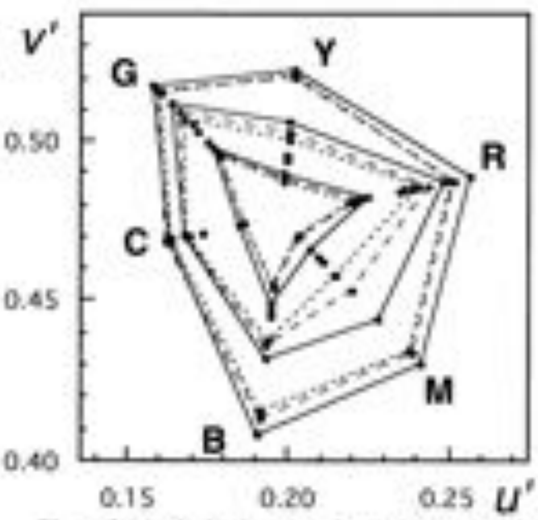


Figure 5. Matched color plotted on u'v' chromaticity diagram. The matched colors are shown by dots. The data points for stripes of 8, 4, and 2 pixels are connected by lines. Solid lines, d=76 pixels; dashed lines, d=0; dotted lines, d= -152.

Since accommodation normally co-varies with vergence, someone might claim that misaccommodation by conflict between vergence and optical distance could cause blur and averaging across patterns on retinal images. Our data reject the possibility of misaccommodation. If the optical averaging by misaccommodation caused the shift of color appearance, the difference in matched color for a pair should be largest at d=0 because of no conflict between vergence and accommodation there. However it was not the case as shown in Figure 4. Our results show color appearance of gratings changed depending on both stripe width on the retina and vergence angle. Since the retinal width and the vergence angle affect to the perceived width, the change in color appearance should be expressed as a function of perceived width of color stripes. For that purpose, the perceived size was quantified as a function of vergence in the next experiment.

3. MEASUREMENT OF PERCEIVED WIDTH

3.1 STIMULI & TASK

The apparatus was the same. Subjects' task was to adjust the horizontal displacement d (pixels) of a grating square so that its perceived size matches to that of a target square of various sizes presented at d=0. First, the target square of a certain size was presented in the center of screen, d=0. A subject memorized its perceived size and pressed a button beside the trackball. Immediately the target was replaced by a grating square and the subject adjusted its horizontal displacement d (pixels) using the trackball to replicate the perceived size for the target square. The same 12 gratings were used in this experiment. The color of the target square was Gy and its size was 0.7, 0.8, 0.9, 1.0, 1.1, or 1.2 times the size of each grating square. The grating and the size of the target square were randomly changed trial by trial. One session consisted of 72 trials of perceived size matching, 12 gratings x 6 sizes. The same subjects did three sessions of the experiment.

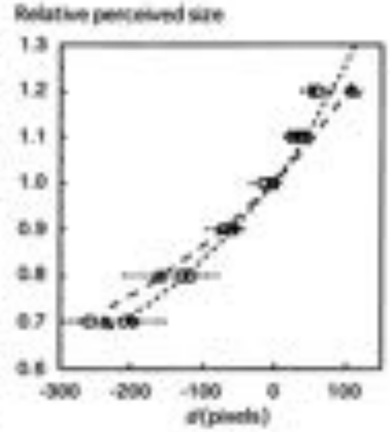


Figure 6. Horizontal displacement d required to replicate same perceived size of the target square presented at d=0. Same symbols are used as in Figure 4. Data were fitted by formula (1): dotted line, the grating of 8 pixel wide; dashed line, that for 4 pixel wide.

3.2 RESULTS

Results from subject HS are shown in Figure 6. The ordinate shows the relative size of the target square to the grating square. The abscissa shows the horizontal displacement d (pixels) required for replicating the perceived size of the target. Same symbols were used as in Figure 4 to signify the size of grating squares. Error bars show the standard deviations for 9 matchings. As expected, large/small d (small/large vergence angle) was required to bring large/small perceived size. The vergence distance is determined geometrically by the displacement d and the subject's interocular distance. Therefore, by assuming the relative perceived size to be proportional to the vergence distance, the data were fitted with the following formula containing one parameter α:

$$\textit{relative perceived size} = \frac{1}{1-\alpha \cdot d} \quad (1)$$

The two curves are shown in Figure 6, which were fitted to the data series for the grating of 8 pixel wide stripes and those for 4 pixel wide stripes.

4. DISCUSSION

The relative perceived width for each stripe was obtained by the fitted formulae as shown above. The data in Figure 4 were replotted against this perceived width of color stripe in Figure 7. The ordinate shows the input value r, g, or b of the matched color. The abscissa shows the relative perceived width or, in other words, the stripe width at d=0 which gives the same perceived width at other d. Each data series can be expressed by a single curve irrespective of what controls the perceived width, namely retinal width or vergence angle. It means the color appearance can be described as a function of perceived width. The perceived dimension is more fundamental than the retinal dimension in determining the color appearance of the repetitive patterns. The perceived size not retinal size determine which of assimilation or contrast occurs in repetitive color patterns.

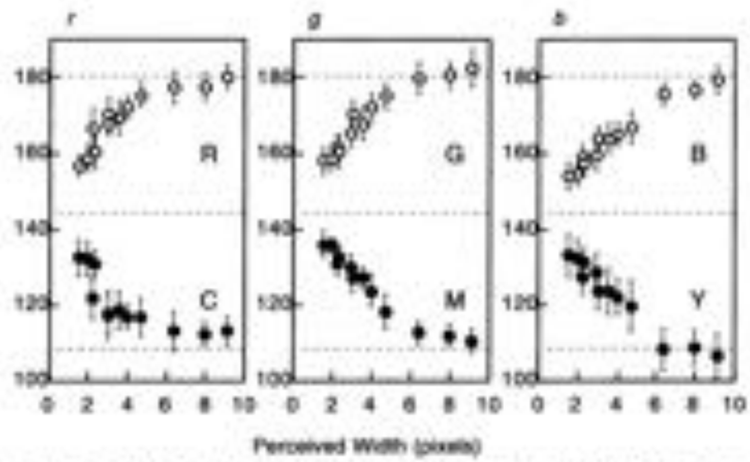


Figure 7. Matched color as a function of perceived width of color stripe. The relative perceived width was calculated using the formula (1) for each stripe width.

REFERENCES

1. H. Helson,"Studies of anomalous contrast and assimilation," *JOSA*, **53**, pp.179-184, 1963.
2. J. Beck,"Contrast and assimilation in lightness judgements," *Perc.&Psyc.*, **1**, pp.342-344, 1966.
3. J. Walker,"Brightness enhancement and the Talbot level in stationary gratings," *Perc.&Psyc.*, **23**, pp.356-359, 1978.
4. C. Fach & L. T. Sharpe,"Assimilative hue shifts in color gratings depend on bar width," *Perc.&Psyc.*, **40**, pp.412-418, 1986.
5. H. Shinoda & M. Ikeda,"Assimilative color shift introduced by change in perceived size," *Proc. AIC2000*, pp.43-46, 2000.

Rating of tinted ophthalmic lenses

Françoise Viénot*[a], Fatima Benhalima[b], Hans Brettel[c], Bernard Bourdoncle[d], Alain Colonna De Lega[d]
[a]Muséum National d'Histoire Naturelle, [b]INM-CNAM, France,
[c]CNRS & ENST, France, [d]Essilor, France

ABSTRACT

This study aims at establishing the relationship between the spectral transmission characteristics of tinted ophthalmic lenses and the visual percept of the observer looking through. We hypothesise that the rating of tinted lenses originates from what the observer sees rather than what the glass looks like. We develop a model for colour acceptance by calculating the colour distortions for a collection of coloured surfaces that are representative of the real environment using the spectral reflectance of the surfaces and the spectral transmittance of the lens. Then we apply the model to a collection of real tinted ophthalmic lenses and derive statistical indices that describes the global colour distortion induced by each lens. Preliminary results show a significant agreement between the subjective rating and the objective colour distortion index. We conclude that our model allows to predict the acceptance/rejection judgement of observers for a tinted ophthalmic lens of known spectral transmittance.

Keywords: Colour vision, Ophthalmic lens

1. INTRODUCTION

Illumination varies greatly in the environment. Although the visual system adapts to about 10 decades of illumination and from about 2 000 K to 10 000 K colour temperature, adaptation to the light environment can be facilitated by wearing tinted lenses. A large choice of tinted ophthalmic lenses is proposed to customers who make a buying decision on the basis of subjective criteria. The choice of the tinted lens is very often left to the wearer. However it is restricted within the range of glasses proposed by the manufacturer of spectacles which in turn is under the control of dye chemistry. We have noticed that already a slight colour change can cause tinted spectacles to be rejected. The question arises whether a tinted ophthalmic lens could be designed to better meet the wearer's needs and satisfaction.

We hypothesise that the acceptance/rejection of the colour of sunglasses originates from what the observer sees rather than from what the glass looks like, in other words that it is not the colour of the lens which is the basic parameter for the comfort of the wearer, but the colour of the environment as perceived through the lens. Therefore, while the manufacturer controls the spectral optical density of the glass, we look for a rating index that establishes the relationship between the spectral characteristics of the glass and the visual percept. As practically almost all the field of view of an individual wearing spectacles is subject to light filtering, the situation is very much like substituting a coloured light source for the natural light source.

In this study, we have developed a model for rating colour distortions produced by filtering light. Then, we have applied the model to a collection of real tinted ophthalmic lenses. At the end, we compare the objective colour distortion index with the acceptance/rejection judgement of observers.

2. MODELLING COLOUR ACCEPTANCE

The starting point of the model is the assumption that the observer judges the colour appearance of the panorama rather than the colour of the glass itself. Practically, wearing colour spectacles introduces colour modification of all the objects of the panorama. The phenomenon of chromatic adaptation compensates for most of the colour change. However, there are some residual distortions which are responsible for the degradation of the global colour appearance. Therefore, a method which accounts for chromatic adaptation and which allows estimation of residual distortions, such as the method to calculate the colour rendering index for light sources, should be suitable.

The method to calculate the colour rendering index establishes a relationship between a test source, a reference illuminant and a collection of colour surfaces. Illuminants are defined by their spectral power distribution (SPD) of energy. Samples are defined by their spectral reflectance. As suggested by CIE TC 1-33[1], we consider three illuminants: the test illuminant that corresponds to daylight as filtered by the tinted lens, a target illuminant that corresponds to daylight without filter, and the reference illuminant that corresponds to D65. Therefore, the colour specification of a sample is calculated using the filtered daylight and the unfiltered daylight, and these two colour specifications are transformed to the standard D65 based colour space.

Strictly, the target illuminant chromaticity should be near to the filtered test illuminant chromaticity leading to the possibility of calculating the correlated colour temperature for the test illuminant. However, in the case of tinted lenses, the colour of the illumination can change considerably, so we have to admit that the correction for chromatic adaptation proposed by TC 1-33 is still valid for large colour differences between the test illuminant and the target illuminant. Finally, for the sake of simplification, we assume that natural daylight is well described by D65.

The next step of modelling consists of choosing a data basis for representing the colour objects of the surrounding. In the absence of the spectral record of every surface included in the field of view of the observer, we have chosen a collection of spectral reflectance functions of coloured surfaces that are representative of real surfaces. The Munsell atlas collection comprehensively represents the hue, lightness and saturation gamut of colours that can be experienced by an observer. Although every sample is only defined by its colorimetric specification, spectral reflectance functions of one collection have been published and are available on the Internet[2].

Figure 1 illustrates the method that we use.

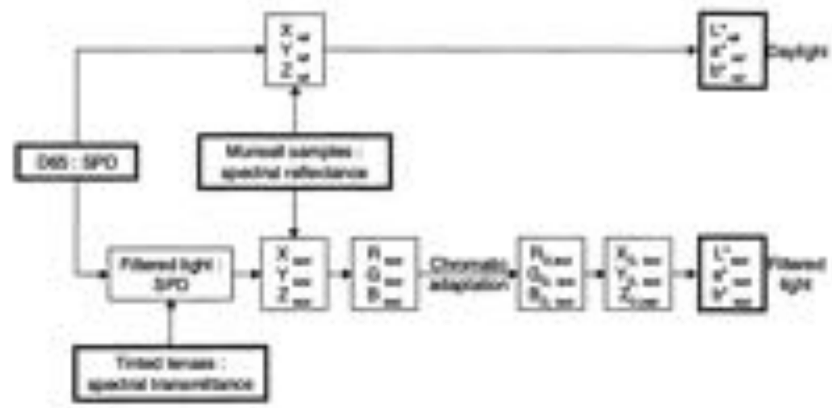


Figure 1. Schematic diagram of the model for predicting the acceptance of tinted ophthalmic lenses.

The last step of modelling consists of applying a chromatic adaptation transform to eliminate the overall colour change that the visual system compensates. We choose the chromatic adaptation transform that was introduced by CIE[3] in 1994. There, tristimulus values XYZ of every sample and of the test light source are first linearly transformed into RGB quantities analogous to cone responses. Then RGB quantities are adjusted to R_D G_D B_D equivalent quantities for D65 illumination using non linear relationships with empirically determined parameters which are similar for the R and G cone like signals and different for the B cone like signal. Finally, the R_D G_D B_D quantities adjusted for chromatic adaptation are reverse transformed to X_D Y_D Z_D tristimulus values. For the calculation, the illumination is supposed to be at 1000 lux and the background reflection factor at 0.20, as proposed by CIE TC 1-33.

All colour specifications are represented in CIELAB space using D65 as the neutral illuminant. For every sample, the colour distortion is graphically represented in the a* b* chromaticity diagram by a vector that originates at the colour of the sample seen under daylight and ends at the colour of the sample as seen through the tinted lens by a chromatically adapted observer. Graphically, all colour distortions are represented by a field of vectors [4].

Although the Munsell basis comprises 1269 sample spectral reflectance functions, a selection of one out of ten samples has been used for the graphical representation and for the statistics. Once all colour distortions for a collection of samples have been calculated, a statistical index can be derived, either from averaging the amplitude of the colour deviation vectors, or from calculating the standard deviation of the angle of the colour deviation vectors.

3. APPLICATION OF THE MODEL TO A SET OF REAL TINTED OPHTHALMIC LENSES

Using the method described in the previous section, the field of vectors representing the residual colour distortions after adjustment for chromatic adaptation has been drawn for every real tinted ophthalmic lens. Figure 3 shows the field of vectors in the a^* b^* chromaticity diagram for two tinted ophthalmic lenses.

Lens "D" is a green coloured lens to which observers easily adapt. Indeed, it only very little distorts the colour of the world. We can see that the chromaticity distortions are only about a few CIELAB units.

Lens "C" is also a green coloured lens but it originates from a different manufacturing process. It is often rejected by the wearer. Even though our model takes into account the chromatic adaptation, colours are severely distorted, up to about thirty CIELAB units. Moreover, the overall colour gamut is reduced and compressed along the b^* axis which means that while small colour differences that are based on red-green discrimination (a^* axis) remain visible, colours that are different along the blue-yellow dimension (b^* axis) might not be discriminated any more by the wearer.

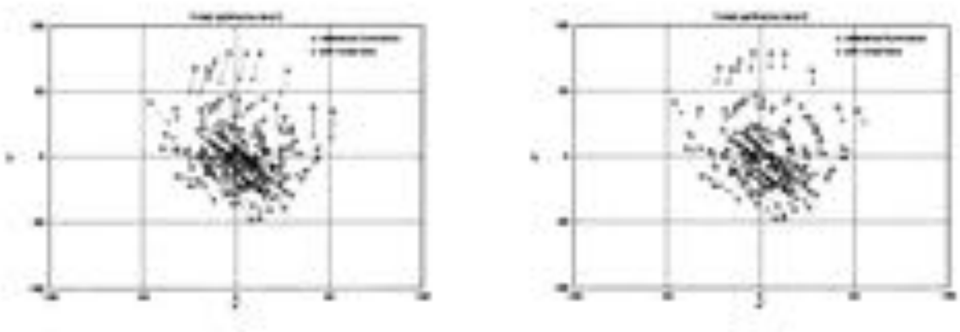


Figure 3. Colour distortion vectors for two tinted ophthalmic glasses in the a^* b^* chromaticity diagram.

So the comparison between the two lenses shows that lens "C" produces greater distortions than lens "D". Nevertheless, distortions follow a regular pattern.

Lens "E" is a blue coloured lens that has been developed and promoted for bicycle riders. Figure 4 shows that lens "E" not only produces large colour differences but also destroys colour classification. In the a^* b^* chromaticity diagram, the vector magnitudes are up to about thirty CIELAB units. Further, the vector field looks disorganised. There is no uniform pattern of colour change. Some colour specifications are displaced in any direction, even for samples that are nearby when seen under daylight illumination.

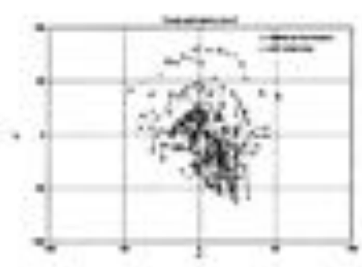


Figure 4. Colour distortion vectors for tinted ophthalmic lens "E" in the a^* b^* chromaticity diagram.

Two statistical indices "Norm" and "Disorder" have been calculated, refering to the module or to the angle of the vectors respectively (table I).

Table I. Statistical indices derived from the field of vector for 3 tinted lenses "D", "C" and "E" (Disorder = standard deviation of the angle of 127 vectors, in degrees).

Lens	Norm	Disorder
D	6.53	31.958
C	12.74	36.309
E	13.33	40.246

4. DISCUSSION

In the previous sections , we have shown that it is possible to represent in the CIELAB system, the colour distorsions produced by a tinted ophthalmic lens for a chromatically adapted observer.

Preliminary experiments have been performed with real observers in order to validate the colour distortion graphs. Thirty-two observers were asked to express their preference about the ophtalmic lenses, on the presentation of a photograph that represents natural surrounds (mountains). The experimental procedure is a two-alternative forced-choice procedure. At each trial, two filters are handled in succession in front of the projector, so that the observer has to choose the one he prefers when viewing the same image. Several tinted ophthalmic lenses have been proposed. Every possible pair of filters is presented to the observer during one session.

The aim of the experiment was to verify that the objective method of rating a tinted ophthalmic lens could predict the subjective judgement given by wearers. Actually, lens "D" has been ranked before lens "C" by 28 observers out of 32. Lens "E" has been ranked the last by 30 observers out of 32. Examination of the field of vectors plotted for each lens can explain the classification. For instance, lens "D" yields smaller distortions than lens "C", and the field of vector plotted for lens "E" shows a large amount of disorder. So results show a satisfying agreement between the subjective rating and the statistical index including the amplitude and the variability of the orientation of the distortion.

5. CONCLUSION

In conclusion, it seems possible to predict the rejection/acceptance judgment of observers about tinted ophthalmic lenses using a model, mostly based on a colour rendering scheme. In particular, the calculation of a statistical index has allowed to discriminate and classify two lenses that were originally aimed at the same colour but had been manufactured along different chemical processes. Already available, the calculation of the statistical index and the distortion plot could help the supplier to improve the manufacturing of coloured ophthalmic lenses. Indeed, this provides a rational and scientific method of design for tinted ophthalmic lenses, dedicated to the optimisation of the visual perception of the wearer, and making obsolete the usual subjective and disputable character of a colour choice exclusively based on persons preference.

REFERENCES

1. Commission Internationale de l'Eclairage, "Colour rendering (TC 1-33 closing remarks)", *CIE Collection in vision and colour and in physical measurement of light and radiation*, CIE Publ. 135-1999, pp. 10-22, 1999.
2. J.P.S. Parkkinen, J. Hallikainen J. and T. Jaaskelainen, "Characteristic spectra of Munsell colors", *J. Opt. Soc. Am*, **A, 6**, pp. 318-322, 1989. http://www.it.lut.fi/research/color/database/download.html
3. Commission Internationale de l'Eclairage, *A method of predicting corresponding colours under different chromatic and illuminance adaptations*, CIE Publ. 109-1994.
4. J. T. C. Van Kemenade , P. J. M. Van Der Burgt , "Towards a user oriented description of colour rendition of light sources". *CIE 119* - 1995 - 23rd Session, New Delhi, pp. 43-46, 1995.

* Correspondence: vienot@mnhn.fr; Muséum National d'Histoire Naturelle, Equipe Vision, Laboratoire de Photobiologie, 43 rue Cuvier, 75005 Paris, France

What determines unique yellow, L/M cone ratio or visual experience?

Yasuki Yamauchi[*a], David R. Williams[a], David H. Brainard[b], Austin Roorda[c], Joseph Carroll[d], Maureen Neitz[d], Jay Neitz[d], Jack B. Calderone[b], and Gerald H. Jacobs[b]
[a]University of Rochester, [b]University of California Santa Barbara,
[c]University of Houston, [d]Medical College of Wisconsin

ABSTRACT

Unique yellow is considered to represent the equilibrium point of the red-green opponent chromatic mechanism. There are several hypotheses that attempt to explain how this equilibrium point is established. The determinant for unique yellow, however, has not yet been clarified. Here we explored whether the L/M cone ratio or visual information determines unique yellow. If the former is the case, we expect that subjects with large differences in their L/M cone ratio would set different spectral lights to appear as unique yellow. The results of such an experiment, however, did not show a substantial difference in the value of unique yellow for two subjects with very different cone ratios. On the other hand, if the latter is the case, unique yellow should change when altering the chromaticity of the surrounding visual environment. To test this hypothesis, we conducted long-term adaptation experiments, in which subjects spent 8 to 12 hours in a chromatically altered environment. A significant shift of unique yellow was observed after spending time in such an environment for several days. These results indicate that the red-green opponent channel includes a plastic normalization mechanism that adjusts its balance point based on visual experience.

Keywords: color vision, unique yellow, long-term adaptation, chromatic, aftereffect, cone ratio, plasticity, normalization process

1. INTRODUCTION

What determines the perception of color?

The normal human eye has three classes of cones which differ in spectral sensitivity: long- (L-), middle- (M-), and short- (S-) wavelength sensitive cones. The perception of color is determined primarily by the relative magnitude of the signals from these cones. It has been recently reported that the relative number of the three cone classes in the retina varies from person to person.[1] This variability in cone ratio may affect the perception of color, but this remains controversial.[2,3]

If some mechanism in the visual system could compensate for these differences to stabilize color perception, it could account for the results reported by several studies which indicate that people have similar color perception. Such a mechanism could be either a plastic mechanism controlled by visual experience, or a hard-wired mechanism that acted during development.

To clarify what controls color perception, two experiments were conducted. We measured unique yellow as a method for assessing color perception. Unique yellow is the wavelength of light that appears neither reddish nor greenish. It is considered to express the equilibrium point of the red-green opponent color channel. In Experiment 1, spectral unique yellow was measured on subjects whose cone mosaics were characterized with an adaptive optics system. In Experiment 2, the effects of long-term chromatic adaptation were measured on unique yellow. Experiment 1 is reported in more detail elsewhere.[4]

2. EXPERIMENT 1: UNIQUE YELLOW OF SUBJECTS WITH KNOWN L/M RATIOS

2.1 Methods

Two male observers were used in this experiment. These observers were chosen because the relative numbers of L and M cones in their retinas had previously been established. The imaging procedure used to identify individual L, M, and S cones in the retinal mosaic combines high-resolution imaging and retinal densitometry. For each observer, the eye's wave aberration was measured with a Hartmann-Shack wavefront sensor and subsequently compensated for with a deformable mirror. This corrective procedure makes it possible to resolve the mosaic of cone photoreceptors. Identification of the type of each cone was done by comparison of the images acquired before and after selective bleaching of cone photopigment with 650- and 470-nm light. The two observers had a large difference in L/M cone ratio. AN had a L/M cone ratio of 1.15, while that of subject JW was 3.79.

The wavelength perceived as uniquely yellow was measured in a Maxwellian-view apparatus. Observers viewed a 0.52-deg circular spot with their right eye. The stimulus spot was located at 1 deg in the nasal retina, corresponding to the location where the L/M cone ratio had been established for both observers. The retinal illuminance was approximately 50 td. A small, dim spot served as a fixation point. The stimulus was viewed in an otherwise dark surround. The test stimulus was presented repeatedly for 0.5 sec with an interstimulus interval of 3.5 sec. Before starting a session the observer dark adapted for 1 min. During a session, 20 trials of each of five wavelengths were presented in a random order, for a total of 100 trials. On each trial, the observer made a forced-choice judgment as to whether the test flash appeared reddish or greenish. The five wavelengths used in the forced choice experiment with an interval of 1 nm were determined based on the preliminary measurement conducted using the method of adjustment, in which the observer set the wavelength of the test flash so it appeared to be neither reddish nor greenish.

For each session, the wavelength of unique yellow was determined as the 50% point of a psychometric function fit to the forced-choice data. This value was averaged over four sessions for observer AN and two sessions for observer JW to determine a mean value for each observer.

2.2 Results and discussion

The wavelength of unique yellow was 576.8 nm for AN (standard error, 0.6 nm) and 574.7 nm for JW (standard error: 0.7nm). Cicerone presented a simple additive model of how the wavelength of unique yellow could be expected to vary with the relative numbers of L and M cones[2]. This model is based on the ideas that (a) a stimulus appear as neither red nor green when the output of a linear red-green mechanism is zero and that (b) the contribution of L and M cones to the red-green mechanism varies in proportion to their relative numbers. This model may be expressed as

$$(N_L/N_M)L(\lambda_y) - k\,M(\lambda_y) = 0,$$

where λ_y is the wavelength of unique yellow, N_L/N_M is the L/M cone ratio, k is a constant that describes any neural factors that govern the relative contribution of L and M cones to the red-green mechanism, and the functions $L(\lambda)$ and $M(\lambda)$ represent the L and M cone spectral sensitivities. We set k here so that unique yellow for an observer having a relative cone ratio of two would be 580 nm.

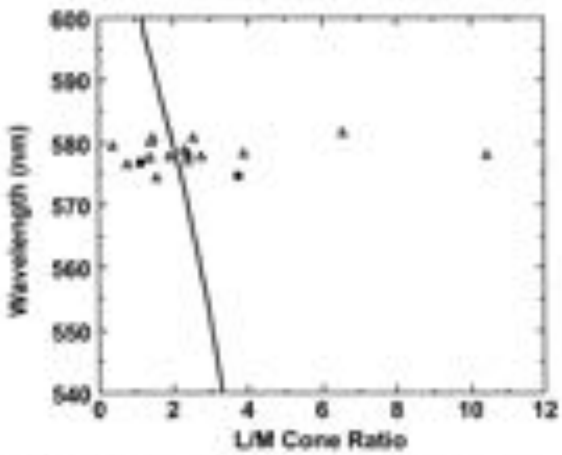


Fig. 1 Experimental data and predicted unique yellow by an additive model

Figure 1 shows both the experimental results (solid circles) and the theoretical prediction by the additive model described above (gray solid line). If unique yellow were solely determined by the relative cone ratio, the unique yellow of AN should be 602 nm, while that of JW should be 518 nm. Although the difference in unique yellow between two subjects is 2.1 nm and is in the right direction, it is smaller by a factor of 40 than the predicted difference. Shown also are unique yellow settings and ERG-derived L/M cone ratio estimates from 15 color normal males (open triangles).[3] There is no correlation between cone ratio and unique yellow settings. These results support the idea that the relative cone ratios are not primary determinant of the balance point of the red-green opponent channel.

3. EXPERIMENT 2: LONG-TERM CHROMATIC ADAPTATION

The first experiment showed that the balance point of the red-green opponent channel is not strongly influenced by the L and M cone ratio. This result suggests that color vision is either a hard-wired post-receptoral mechanism or an experience-based plastic mechanism that stabilizes unique yellow against changes in cone ratio. In both cases, individual differences in cone ratio would not be expected to influence color perception. However, to determine what the stabilizing mechanism is, we can simply alter the chromatic properties of a subject's visual environment. If the chromatic mechanism is plastic and driven by visual information, then unique yellow should show a shift after the eye has been exposed to such an altered environment. On the other hand, if a hard-wired mechanism is responsible for setting color perception, then altering the incoming visual information should not be expected to induce any long-term changes in color perception. We conducted a long-term chromatic adaptation experiment to determine which of these outcomes occurred.

3.1 Methods

In this experiment, the adult subjects spent a part of the day in an altered chromatic environment. Two male subjects and one naive female subject, all having normal color vision, were used in this experiment. We used tinted contact lenses to provide a chromatically altered environment. Contact lenses were tinted with a commercially available dye kit. Lenses were designed with similar transmission curves as Kodak Wratten filters 29 and 58 (red and green).

Before starting the experiment, the subject's unique yellow was collected for several days and served as a baseline. Once the adaptation started, the procedures were conducted on a daily schedule, as shown in Figure 2. Unique yellow was measured at the beginning of each day prior to being exposed to an altered chromatic environment. The subject then spent 8 or 12 hours in that condition. After adaptation, the subject spent the rest of the day in a normal environment. The activity of the subjects was not restricted at all during and after the adaptation. The interval between the termination of daily adaptation and the measurement of unique yellow the next day was about 12 to 16 hours. Since it is well known that the effects of short-term chromatic adaptation decay in minutes, 12 to 16 hours should be more than long enough for these short-lived aftereffects to fade away.

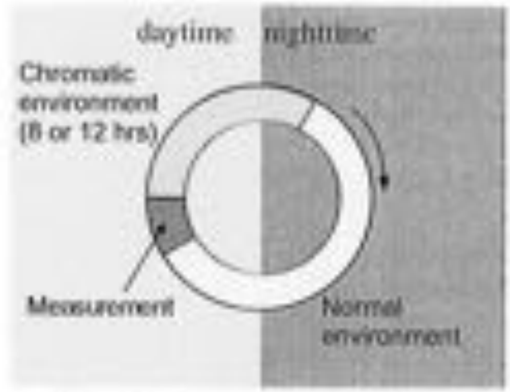


Fig. 2 Schematic representation of the daily schedule for the long-term adaptation experiment.

The same apparatus used in experiment 1 was employed to measure unique yellow. The method of adjustment was adopted in this experiment. The stimulus was presented to the fovea. Five trials were conducted in each session, after 5 minutes of dark adaptation. Each trial started with a monochromatic light that was clearly reddish or clearly greenish, and the subject adjusted the wavelength of this light until it appeared neither reddish nor greenish.

3.2 Results and discussion

Figure 3 shows the results obtained from two subjects, YY and EM. Subject YY adapted for 8 hours each day for more than 3 weeks, while subject EM adapted for 12 hours a day over a 10-day period. Open symbols correspond to data collected when the subjects were not exposed to an altered environment. Solid circles and squares represent data collected during the adaptation to the red and green environments, respectively.

When the subjects started the adaptation, unique yellow began to shift towards longer wavelengths even though the measurement of unique yellow was conducted 12 to 18 hours after the adaptation period. Unique yellow shifted so much that wavelengths previously called red now appeared green and vice versa. For approximately the first 30 minutes after immediately completing a daily adaptation of 8 or 12 hours, both subjects reported that the natural scene looked greenish or reddish, depending on which color adaptation was conducted. The shift of unique yellow, however, did not proceed in proportion to the period of adaptation. For YY, unique yellow did not show a further shift after a period of two weeks. EM's unique yellow also appeared to come to an asymptote after a week of adaptation. However, it is not clear if EM's unique yellow might have continued to shift if she had a longer adaptation period. After termination of the

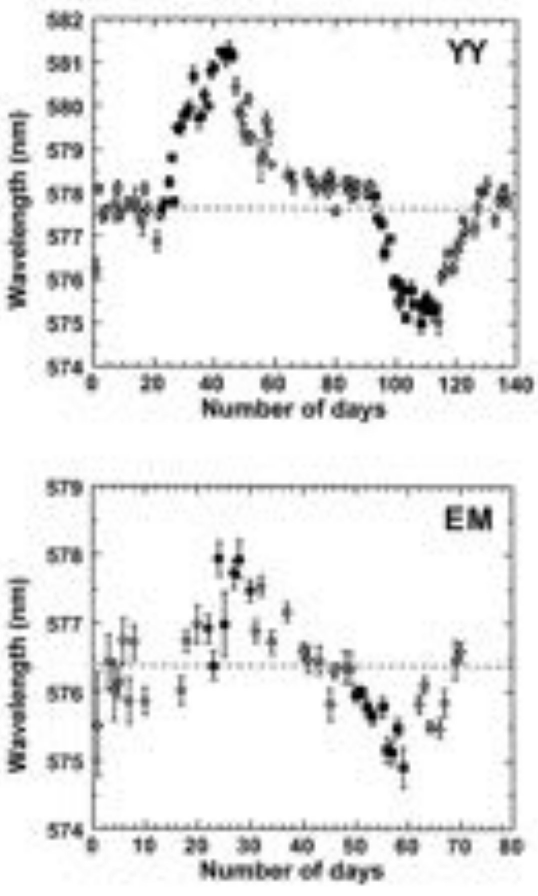


Fig. 3 The results obtained in the long-term adaptation experiment.

adaptation, unique yellow showed a steady recovery towards the baseline value and it took more than 2 weeks to come to an asymptote. For YY, a residual shift of unique yellow existed even a month after the adaptation. The third subject, whose results are not presented, showed the same trends when he conducted the red adaptation condition. Similar trends could also be observed in the green environment. For YY, unique yellow kept shifting for the first two weeks of adaptation and leveled off for the remainder of the test period, it then took almost two weeks to recover back to baseline. These results show that chromatic adaptation can cause a long-lasting effect on the perception of unique yellow, which differs in time course from the well-known, short-lived aftereffects of chromatic adaptation.[6,7]

4. DISCUSSION

In agreement with previous data on carriers of color vision defects[8,9], our results show that, in color normals, variation in unique yellow is not explained solely by the variation in L/M cone ratio. The lack of large variation of unique yellow can be accounted for if the opponent color channel adjusts its balance point based on visual experience. Our empirical results obtained in the long-term adaptation experiment support this hypothesis. Chromatic adaptation was shown to cause a long-lasting but reversible effect in the perception of unique yellow. The long-lasting effects suggest that color vision is mediated by a plastic normalization process, perhaps like that proposed by Pokorny and his colleagues, in which the mean chromaticity of the environment plays an important role in determining the equilibrium point of the red-green opponent mechanism.[10] This normalization mechanism may operate throughout the entire lifespan, as such plasticity could account for why there is little difference in perceived color appearance for observers of different ages, even though the optical quality of lens changes over time.[11] Our results indicate that it can take a long time to induce changes in color perception and that these changes can persist for weeks, even after returning to a natural, non-chromatically altered environment.

ACKNOWLEDGMENTS

This research is supported by NIH EY01319, EY02052, EY04367, EY09303, EY09620, EY10016, by Research to Prevent Blindness, and by The 2000 Satow's Research Fund for Behavioral Science (YY). We would like to thank Bausch & Lomb for providing the contact lenses used in these experiments.

REFERENCES

1. Roorda, A. and Williams, D.R., "The arrangement of the three cone classes in the living human eye", *Nature*, **397**, 520-522, 1999.
2. Cicerone, C.M., "Constraints placed on color vision models by the relative numbers of different cone classes in human fovea centralis", *Farbe*, **34**, 59-66, 1987.
3. Pokorny, J., Smith, V.C., and Wesner, M.F., "Variability in cone populations and implications", In *From Pigments to Perception*, Valberg A. and Lee B.B. (eds.), pp. 23-34, Plenum, New York, 1991.
4. Brainard, D.H., Roorda, A., Yamauchi, Y., Calderone, J.B., Metha, A., Neitz, M., Neitz, J., Williams, D.R., and Jacobs, G.H, "Functional consequences of the relative numbers of L and M cones", *Journal of the Optical Society of America A*, **17**, 607-614, 2000.
5. Yamauchi, Y., Williams, D.R., Carroll, J., Neitz, J., and Neitz, M., "Chromatic adaptation can cause long-term shifts in color appearance that arise in binocular visual pathways", *Investigative Ophthalmology and Visual Science*, **42**, S720, 2001.
6. Hayhoe, M. and Wenderoth, P., "Adaptation mechanisms in color and brightness", In *From Pigments to Perception*, Valberg A. and Lee B.B. (eds.), pp. 353-367, Plenum, New York, 1991.
7. Eisner, A. and Enoch, J.M., "Some effects of 1 week's monocular exposure to long-wavelength stimuli", *Perception and Psychophysics*, **31**, 169-174, 1982.
8. Jordan, G and Mollon, J.D., "Unique hues in heterozygotes for protan and deutan deficiencies", in *Colour Vision Deficiencies XIII*, Cavonius, C.R. (ed.), pp. 67-76, Kluwer Academic Publishers, Dordrecht, 1997.
9. Miyahara, E., Pokorny, J., Smith, V.C., Baron, R., and Baron, E., "Color vision in two observers with highly biased LWS/MWS cone ratios, Vision Research, **38**, 601-612, 1998.
10. Pokorny, J. and Smith, V.C., "Evaluation of single-pigment shift model of anomalous trichromacy", *Journal of the Optical Society of America*, **67**, 1196-1209, 1977.
11. Schefrin, B. E. and Werner, J. S., "Loci of spectral unique hues throughout the life span", *Journal of the Optical Society of America A*, **7**, 305-311, 1990.

Correspondence: yasuki@cvs.rochester.edu; phone 716-273-4998; fax 716-271-3043; Center for Visual Science, University of Rochester, 274 Meliora Hall, Rochester, NY 14627, USA.

Whiteness Perception in Japanese and Finnish under Cool and Warm Fluorescent Lamps

Miyoshi Ayama*, Marjukka Eloholma§, Mikko Hyvärinen§, Tetsuya Eda*, Daisuke Kon*,

Kenji Mukai‡, Saeko Kanaya†, Liisa Halonen§

* Dept. of Information Science, Utsunomiya University, Japan;
§ Lighting Laboratory, Helsinki University of Technology, Finland;
‡ Lighting Company, Matsushita Electric Industrial Co., Ltd., Japan;
† Dept. of Human Information Science, Kanazawa Institute of Technology, Japan;

ABSTRACT

In this study, we conducted the experiment to compare the whiteness perception of Finnish and Japanese observers. The rank order of perceived whiteness among seven nearly white Munsell chips (Value is 9.25 or 9.5, Chroma is 0, 0.5 or 1.0) under the fluorescent lamps of correlated color temperatures of 3000K, 5000K, and 6700K was determined. Observing condition employed in the two laboratories was exactly the same as well as the experimental procedure. In 3000K condition, the results of Japanese and Finnish observers agreed with each other quite well, while as the correlated color temperature becomes higher, the results from the two laboratories showed different tendencies. Negative correlation was found between the whiteness rank order and the metric chroma for all of the results.

Keywords: Whiteness perception, fluorescent lamp, correlated color temperature, Finnish observer, Japanese observer

1. INTRODUCTION

White surfaces are important in recognizing how the visual environment is illuminated because they give us a lot of information about the illuminant. However, property of white surface under different illuminants has not been paid attention, while several studies have been reported concerning on the achromatic points under different chromatic adaptation[1,2]. Akatsu et al. investigated the rank order of perceived whiteness among twelve whitish Munsell chips (V=9.25, C<=1.0) under the fluorescent lamps of various correlated color temperatures for Japanese observers[3]. The results showed that 3PB/9.25/1.0 was the whitest chip under all the illuminants except 6700K, and other charts were divided into two groups that the order of whiteness rank decreased or increased with correlated color temperature.

In this study, we conducted the same experiment in the laboratories in Japan and Finland in order to examine whether observers in the two countries where the illumination environments seem to be quite different show similar characteristics for whiteness perception under different illuminants.

2. EXPERIMENT

Two neutral (N9.5, N9.25), and five nearly white (4YR/9.25/0.5, 3G/9.25/0.5, 5B/9.25/0.5, 3PB/9.25/1.0, and 10PB/9.25/0.5) Munsell chips were selected and all the pair combinations among them (21 pairs) were prepared. A test card

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

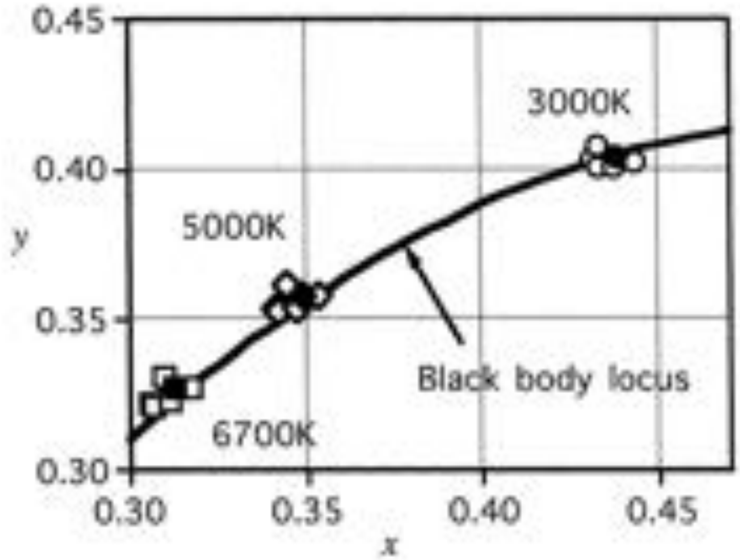


Figure 1. Chromaticities of the seven Munsell chips under the three different illuminants plotted on the CIE 1931 (x, y) chromaticity diagram. The filled symbol in each cluster denotes the point for N9.5 and N9.25.

was a 9.0° ×5.0° gray plate to which a pair of white chips, each was 3.5° ×3.5°, was attached. Viewing distance was 50 cm so that the visual angle of one Munsell chip in the observation was about 4° ×4°. Three different fluorescent lamps, of which correlated color temperatures are 3000K, 5000K, and 6700K were used. Figure 1 indicates the chromaticity coordinates of the Munsell chips under the three conditions plotted on the CIE1931 (x, y) chromaticity diagram. Similar viewing rooms larger than 2.2 m cubic were constructed in the laboratories, Utsunomiya University (UU) in Japan and Helsinki University of Technology (HUT) in Finland. The inside of them was finished in a neutral gray of about N7.5 and the floor was finished in a dark gray carpet. The test card was set on the table covered by a black cloth at the center of the room. Fluorescent lamps were equipped on the ceiling. The currency of each lamp was able be controlled by means of a dimmer circuit in order to adjust the illuminance level. The illuminance of the table surface was adjusted to 500 lx.

The observer entered the viewing room alone. After 5 minutes adaptation to a given lamp, he/she looked a test card obliquely set on the table with 45 degrees against the table surface. The observer was instructed to decide which one is whiter and which one is more preferable white in the pair. The experimenter was sitting outside the viewing room and recorded observer's oral answers. In one session, this task was repeated for all of the 21 test cards. For each of three illumination conditions, two sessions in which the same test card was presented in the right-left opposite way, were done for each observer. Eleven color normals participated in the experiment as observers in each of the two laboratories.

3. RESULTS

The results are given by "frequency of selection", which gives the number of times the observer selected that Munsell chip as whiter/preferable white in a given lighting condition. The maximum possible value for the frequency of selection is 12 and the minimum is 0. The two questions "which is whiter" and "which is more preferable (white)" were considered separately, and in this paper only the results of the former question is presented.

Figure 2 (a) and (b) show the average results of 11 observers in the UU (Japan) and HUT (Finland) under the 3000K warm and 6700K cool fluorescent lamps, respectively. Abscissa indicates Munsell hue notation of the chips. Ordinate represents the "frequency of selection". Note that since the frequency of selection reflects the rank order of perceptual whiteness within each illumination condition, it does not indicate absolute extent of whiteness over different conditions.

As shown in Figure 2 (a), under the 3000K lamp the results of UU and HUT agree with each other quite well whereas they show notable disagreement under the 6700K lamp. The results under the 5000K lamp indicated intermediate tendency between those of Fig. 2 (a) and (b) though not to be shown here to save space.

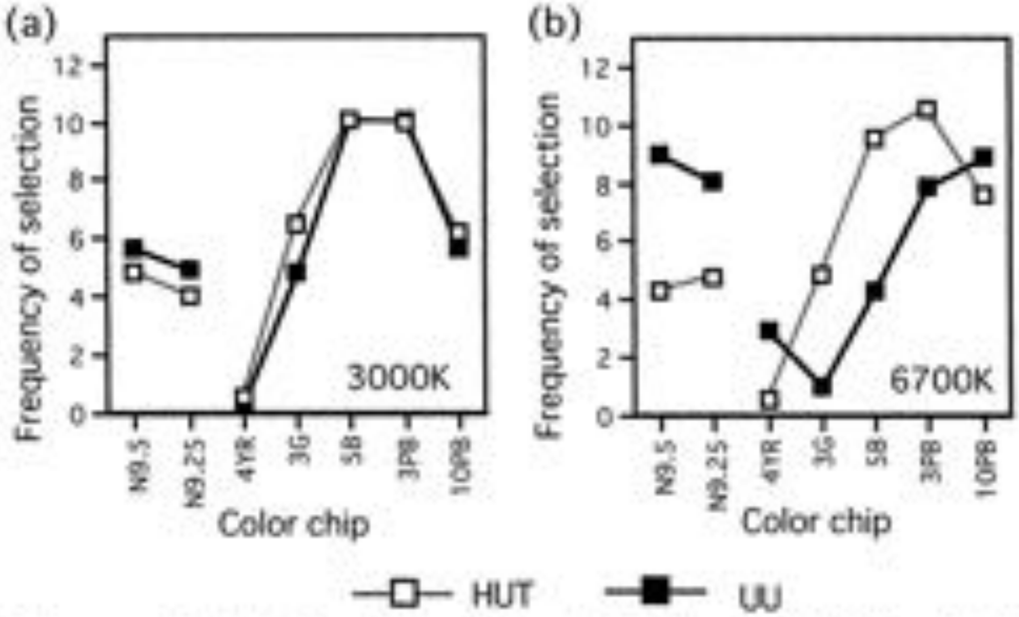


Figure 2. Frequency of selection of the seven Munsell chips under 3000K warm (a) and 6700K cool (b) fluorescent lamps. Open and filled symbols denote the results of UU(Japan) and HUT(Finland), respectively.

4. DISCUSSION

The frequency of selection represents the order of perceptual whiteness among the seven Munsell chips under the three lighting conditions. It is plausible to consider that the frequency of selection is inversely related to some kind of metric in color space that represents psychological distance from an ideal white. Here we compare our results with the metric chroma in the CIE 1976 $L^*a^*b^*$ (CIELAB) color space and the chroma in the CIE 1997 Interim Colour Appearance Model (CIECAM97s). Highly strong negative correlation was observed against both of the metrics in each of the illumination conditions examined in this study. Figure 3 shows the relation between the frequency of selection against the metric chroma for 3000K and 6700K lamps. It is suggested therefore that whiteness perception is determined by the same underlying mechanism whatever the illuminant is. Different results under different illuminants appeared in the rank order of the Munsell chips would merely reflect the effect of chromatic adaptation at some stages including the receptor level.

Concerning to the comparison of the results from UU and HUT, taken the differences of observers using different languages and having different cultural background into consideration, the agreement shown in the results of 3000K lamp is surprisingly good. From the results, we could argue that whiteness judgement is based on a common underlying mechanism of visual process independent of anthropological differences. On the other hand, the reason of the disagreement in the results of the 6700K lamp is unknown at present.

One possible explanation is difference of illumination conditions in the two countries. In Japan, fluorescent lamps of which correlated color temperature is higher than 5000K is mostly used in office rooms, public spaces, and private houses while incandescent lamps are sometimes used in restaurants and only occasionally in a living room of private houses. Fluorescent lamps of warm color, low correlated color temperature, is just recently begun to be used some places in Japan. On the other hand, in Finland, such fluorescent lamps of which correlated color temperature is about 3000K are most commonly used in office rooms and working environments while in home lighting, incandescent lamps are the ones mostly used. This means Finnish is more used to the illuminants of low correlated color temperature. Comparing the results in Figure 2 (a) and (b), the results of Finnish is less variant than those of Japanese indicating stronger color consistency. Five minutes light adaptation might not be sufficient to alter the higher level mechanism of perception constructed for decades of chromatic adaptation under warm color illumination.

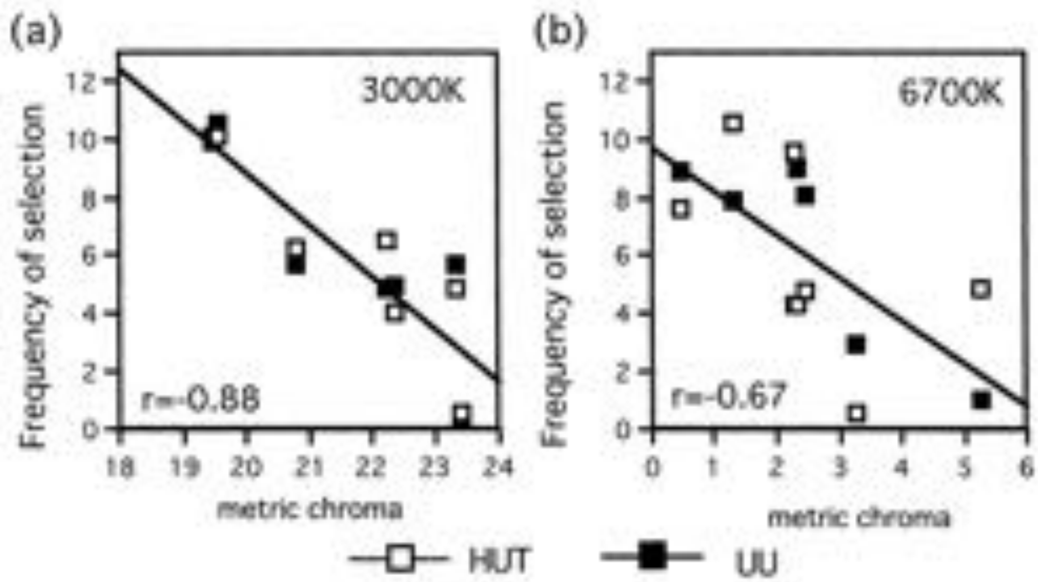


Figure 3. Relation between the frequency of selection and metric chroma in CIELAB color space.

ACKNOWLEDGEMENTS

We would like to thank E. Toriumi, T. Akatsu, and T. Takagi for their assistance in conducting and analyzing the experiments reported here.

REFERENCES

1. M. Fairchild, P. Lennie, "Chromatic adaptation to natural and incandescent illuminants," Vision Res., **32**, pp.2077-2085, 1992.
2. I. Kuriki, K. Uchikawa, "Adaptive shift of visual sensitivity balance under ambient illuminant change," J. Opt. Soc. Am. A, **15**, pp. 2263-2274, 1998.
3. T. Akatsu, E. Toriumi, M. Ayama, K. Mukai, and S. Kanaya, "Effects of color temperature of fluorescent lamp on the whiteness perception," CIE Proc. 24th Session Warsaw, pp.48-50, 1999.

Fluorescence thresholds for some reddish colours.

Osvaldo da Pos [*a], Michela Sponga [a]
[a] Dept. of General Psychology, Univ. of Padua - Italy

ABSTRACT

The extra-brightness which characterises fluorescent colours was adjusted to determine the luminance threshold dividing surface and fluorent colours for 7 zero-blackness reddish nuances (NCS notation) following three different psychophysical methods. Results are consistent with Evans' findings that threshold is always lower than surface-white luminance and decreases with chromaticness. When the same colours are observed over an achromatic Mondrian in a black viewing box fluorescence impression not only increases with the sample chromaticness, but also with the general illumination and the anchoring level of the Mondrian.

Keywords: fluorescence, greyness, blackness.

1. INTRODUCTION

The extra-brightness shown by properly lit fluorescent materials depends on their property of re-emitting in the visible part of the spectrum some of the absorbed UV radiation, with the consequence that the total amount of visible radiation sent to the observer's eye is larger from these materials than from non fluorescent ones. It became soon clear to Evans[1,2], who was probably the first to perform systematic research in this field, that fluorescent colours can also be perceived in absence of physical fluorescent processes. He then stressed the independence of the perceptual characterisation of fluorescence from the physical stimulus by calling these colours fluorent instead of fluorescent (and likewise fluorence instead of fluorescence).

According to Evans[3] the fluorent appearance of some colours belongs to a perceptual continuum, called brilliance, which is characterised by greyness when the luminance is lower to a certain threshold (called G_0, zero greyness) and by fluorence at higher luminance; beyond an upper threshold colours become luminous (perceptually self-luminous, i.e. they are perceived only emitting, but not reflecting light); luminance thresholds for fluorence is relative to the background luminance.

Most Evans[3] studies were performed by using the traditional disk-anulus display, in which the anulus luminance was kept constant and achromatic, and the disk luminance was varied from zero upward. It is worth to mention that Evans[2] greyness seems to be the same concept of blackness in the Natural Colour System. Colours at G_0, which show no greyness, lie on zero blackness lines in the NCS triangle and correspond to MacAdam "optimal colours". Lines of equal greyness plotted by Evans[2] (Fig. 11, 12, 13) in a Munsell hue chart, show the same inclination of the equal blackness lines in the NCS triangles.

Very few systematic studies (Petrov et al.)[4] followed the rather wide research by Evans[3] despite the theoretical importance of the topic, and we wanted to go into more detailed descriptions and measurements of the threshold dividing normal surface colours from fluorent ones. This intermediate mode of appearance between surface and luminous colours, as fluorescence would be according to Evans, was not described by Katz[5], and the problem arises whether fluorescent colours are just cases of a combination of light reflecting and light emitting appearances or they belong to an independent psychophysical category still dealing with surface colours but opposed to greyness, as suggested by Evans[3].

The work by Evans was quite general and a more precise determination of the threshold for perceptive fluorescence would offer a better understanding of the phenomenon, especially if supported by consistent reproducibility by different subjects and through different psychophysical procedures.

2 EXPERIMENTS

2.1 Experiment 1

Evans[3] studied many perceptive aspects of colour by using the very simple and traditional spatial arrangement of a disk-anulus display observed in an otherwise dark surround. However to reproduce the fluorescence effect he used a modified version of this setting by opening a 2° rectangular hole in the centre of a white 50x60 cm uniformly illuminated surround. When the hole was filled with colours of lower luminance than the background, it appeared like a normal reflecting surface.

but its luminance could be easily varied from behind until it reached the fluorescence appearance, while keeping all other variables constant. Evans[1] considered the data obtained in his work only as descriptively rather than quantitative accurate.

Our aim was to obtain more precise data on the lower luminance threshold of fluorescence and to study how it might depend on chromaticness. Although similar dimensions like saturation, chroma, and purity might also be used, chromaticness was chosen because it is defined inside the NCS[4] colour system, whose structure seems to fit well many relevant perceptive phenomena, fluorescence included. According to Evans[3] fluorescence, like greyness is a relational characteristics of colours, in that it can be perceived only when other colours are present in the environment and observed together. We wanted to increase the relational strength between many differently coloured areas by using a bi-dimensional chromatic Mondrian in which the luminance of an area could be adjusted independently of all other colour aspects. The colours surrounding the actual position of the hole in this Mondrian can influence the appearance of the colour perceived inside it: therefore a colour match was performed to determine the luminance at which the experimental colour (a NCS sample) located behind the hole appeared through it of the same colour of another piece of the same paper pasted in a different position of the uniformly lit Mondrian. We used colours of the lowest possible greyness, which correspond to colours belonging to the 00 blackness side of the NCS triangle. If the luminance of these colours is increased just beyond the level they have in an uniformly lit Mondrian, then they appear fluorescent, and this luminance level can be considered as the threshold between surface and fluorescent colours.

a. *Methods*. A Mondrian-shaped background (A4) made of 36 different nuances of the NCS Y70R hue and white grey black as well , was located at the end wall of a 2m x 1m black box and uniformly illuminated at about 180 lux by two Philips D65 simulators. Through a rectangular 2° hole opened in one of the Mondrian areas the observer could see a piece of paper, taken from a set of seven 00 blackness nuances (varying in chromaticness from 0030 to 0090) of the same Y90R hue, located behind the hole, and independently illuminated by a lamp of the same kind which could slide over a sledge so to vary the intensity of its illumination. In some phases of the experiment the position of this lamp could be directly adjusted by the subject by means of a couple of wires; in other phases the experimenter positioned the lamp so to obtain a predetermined level of illumination of the test colour. In front of the Mondrian a grey curtain (of the same average reflectance) with a fixation mark in its centre could be raised and lowered by the experimenter so to expose it for a predetermined time.

b. *Subjects*. The two authors performed all phases of the experiment, while two more subjects co-operated in some of them. All were colour normal.

c. *Procedure*. The experiment was divided into three parts: in the first phase the subject, seated at a distance of 1.5 m from the Mondrian, had to adjust the luminance of each 7 test colours until it matched that area of the Mondrian which was covered by the same coloured paper. The obtained luminance's served as a base-line against which the results of the following phases of the experiment had to be compared. In the second phase, by the psychophysical method of Average Error, all subjects had to vary, in a series of 6 ÷ 10 successive trials, the luminance of the test colour until it just appeared either a fluorescent colour or a normally reflecting surface. Lastly, by the method of Constant Stimuli, all subjects, after looking at the Mondrian for 1 sec, had to decide whether the test colours in the Mondrian, randomly presented at one of 5 equally spaced luminance levels, appeared fluorescent or not: the intervals between the 5 different luminances were determined for each subject on the basis of her-his previous adjustments.

d. *Results*. The luminance thresholds obtained by the average error procedure are plotted in Fig. 1 and compared with

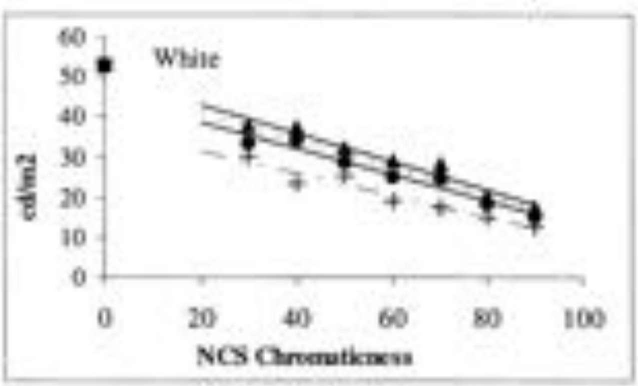


Fig. 1. Fluorence threshold for the 0030-0090 Y70R colours (method of Average Error). Triangles: upper border of the uncertainty interval; circles; lower border; crosses: surface colour reference luminance; square: surface white. (4 subjects)

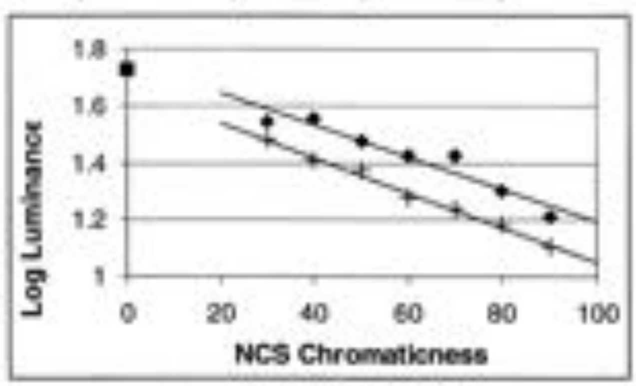


Fig. 2. Fluorence threshold for the same 0030-0090 Y70R colours (Constant Stimuli). Diamonds: fluorence thresholds; crosses: surface colour reference luminance; square: surface white. (4 subjects)

the surface colour luminance obtained in the matching phase. The average Log difference between fluorescence threshold and surface colour luminance is 0.125. In Fig. 2 the Log luminance thresholds obtained by the constant stimuli procedure are plotted and compared with the surface colour Log luminance obtained in the matching phase. Here too the average Log difference between fluorescence threshold and surface colour luminance is very similar (0.124). In general these results confirm the finding by Evans[1] that colours become fluorent at a lower luminance than the surface white; besides, more chromatic colours become fluorescent at lower luminance than less chromatic ones.

2.1 Experiment 2

In this experiment we used a very similar display as that employed by Evans[1], i.e. a uniform white background with a rectangular hole through which the colour underwent the same luminance variations as in the previous experiment. The six 0030-0080 Y70R NCS samples were examined and the psychophysical method of Limits was used instead of that of Constant Stimuli. The reference luminance of the surface colours was measured by putting the coloured samples over the white background under its illumination. One author and three different observers with normal colour vision served as subjects. Phase one of the exp. 1 was skipped because unnecessary, and for the rest all conditions were the same.

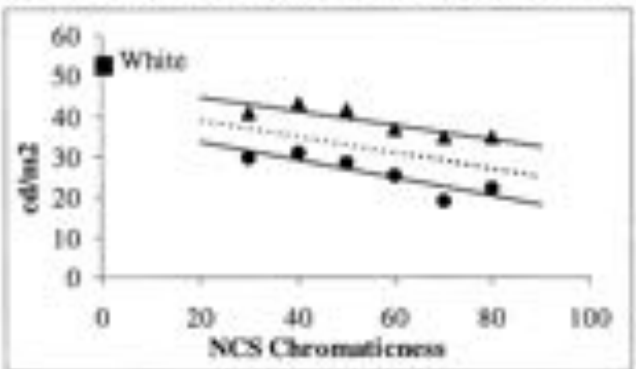


Fig. 3. Fluorence threshold for the 0030-0080 Y70R colours (method of Average Error). Triangles: upper border of the uncertainty interval; circles; lower border; square: surface white. (3 subjects)

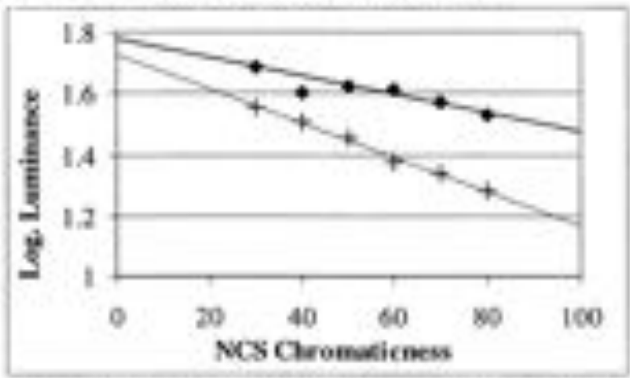


Fig. 4. Fluorence threshold for the same 0030-0080 Y70R colours (Method of Limits). Diamonds: fluorence thresholds; crosses: surface colour reference luminance; square: surface white. (4 subjects)

Results. The luminance thresholds obtained by means of the average error procedure are plotted in Fig. 3 and those obtained by the method of Limits in Fig. 4. Although the two regression lines of Fig.4 are not parallel, we calculated the average Log difference between the fluorence threshold and the surface colour luminance, which is 0.164, slightly higher than in the previous experiment. This can be explained by the higher average luminance of the white background in comparison with the coloured Mondrian, as both were equally illuminated. Also in this experiment all colours reached the fluorescent appearance at a luminance level below that of the surface white.

2.1 Experiment 3

The relation between lightness and brilliance is fixed for achromatic but not for chromatic colours: colours of the same lightness do not necessarily appear of the same greyness, as our and Evans' results show (Boswell Kohlrausch Helmholtz effect might play a role here). Therefore, on the basis of the anchor theory of lightness perception (Gilchrist et al.[3]), we wanted to see how fluorence threshold might depend on the range of reflectance factors of an achromatic Mondrian and on the general level of illumination. In a black box, at three illumination levels (900, 460, 3 lux) the observer (30 subjects with normal colour vision) had to look binocularly through a skin-diver mask at one coloured papers (0030 - 0050 - 0070 - 0090 Y70R, either 4x3 or 2.5x1.5 cm) located at distance of 37 cm over an achromatic A4 Mondrian (40 areas of equally spaced greys with either 92% or 40% reflectance factor for the highest luminance). Subjects had to evaluate how much the coloured paper appeared fluorescent or not by putting a mark on a correspondent position of a 20 cm line in which the left extreme denoted clearly not fluorent colours and the right extreme clearly fluorent ones (the middle therefore meant the threshold).

Results. Experimental evaluations, plotted in Fig. 5 and 6, show that fluorence appears stronger over the darker Mondrian, increases with chromaticness and illumination level (all differences are statistically significant). The first and second results were expected as they reflect luminance relationships already explored. The role of illumination does not seem to agree well with Petrov et al.[4] findings, as it not only interacts with reflectance but also with chromaticness. The sample size used were not relevant.

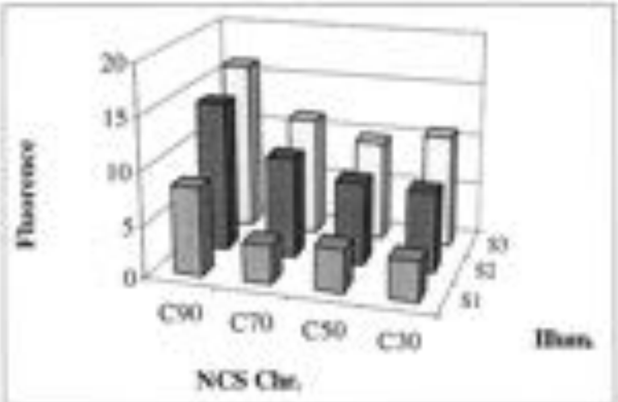


Fig. 5. Fluorence evaluations plotted as a function of chromaticness and illumination in Mondrian 1 (high luminance anchor). (10 = subjective threshold)

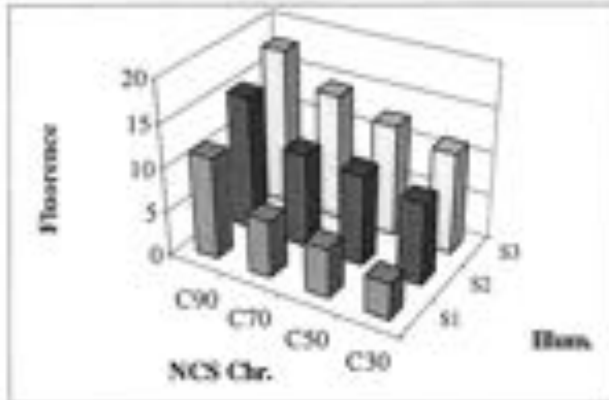


Fig. 6. Fluorence evaluations plotted as a function of chromaticness and illumination in Mondrian 2 (low luminance anchor). (10 = subjective threshold)

3 Conclusions

Fluorescence phenomenon can be reliably studied in different experimental conditions. The extra-brightness associated with fluorescence has been proven to depend on the object-colour lightness, chromaticness, illumination, and its relationship with the background. Essentially all Evans' findings were replicated, with the further result that higher luminance is needed when the background is uniformly white instead of a coloured Mondrian, and that the probability of perceiving fluorescence increases with the illumination level, keeping everything else constant. Evans' concept of grayness[2] is closer to NCS blackness than to what people normally consider by that term (Masin[8]) and therefore his claim that fluorescence can be considered as negative grains (i.e. blackness) should be questioned, as fluorescence seems to be also different from self-luminous appearance which is too opposed to blackness.

Acknowledgements

The authors wish to thank A. Gilchrist for the precious discussions and suggestions; they are grateful to Roberta Zorzi and Barbara Ciannavei who participated in the experiments. We acknowledge the support of National Ministry of University and Scientific Research, cofin. 1998.

References

1. R. M. Evans, "Fluorescence and gray content of surface colours" *Journal of the Optical Society of America*, **49**, 1049-1059, 1959.
2. R. M. Evans, "Variables of perceived colours" *Journal of the Optical Society of America*, **54**, 1467-1474, 1964.
3. R. M. Evans, *The perception of colour*. Wiley, New York, 1974.
4. A. P. Petrov, C. Y. Kim, I. S. Kweon, Y. S. Seo, "Perceived illumination measured" *Colour Research and Application*, **23**, 159-168, 1998.
5. D. Katz, *The world of colour*. Kegan, Paul, Trench, Trubner, London, 1935
6. Standardiseringen I Sverige SS 01 91 02, Scandinavian Colour Institute AB, Stockholm, Sweden, 1996.
7. A. Gilchrist, C. Kossyfidis, F. Bonato, T. Agostini, J. Cataliotti, X. Li, B. Spear, V. Annan, E. Economou, "An anchoring theory of lightness perception", *Psychological Review*, **106**, 795-834, 1999.
8. C. S. Masin, "Los componentes de la luminosidad subjectiva", *Revista Latinoamericana de Psicologia*, **19**, 393-399, 1987

*Correspondence: osvaldo.dapos@unipd.it; phone +39049 8276680; fax +39049 8276600; Dipartimento di Psicologia Generale, Via Venezia 8, 35133 Padova, Itlay

Control parameters for retinex

Brian Funt* and Florian Ciurea*
School of Computing Science, Simon Fraser University

ABSTRACT

The recently published Matlab implementation of the retinex algorithm[2] has free parameters for the user to specify. The parameters include the number of iterations to perform at each spatial scale, the viewing angle, image resolution, and the lookup table function (post-lut) to be applied upon completion of the main retinex computation. These parameters were specifically left unspecified in[2] since the previous descriptions of retinex upon which the new Matlab implementations were based do not define them. In this paper we determine values for these parameters based on a best fit to the experimental data provided by McCann et. al.[9]

Keywords: Retinex, color vision, human vision, color constancy.

1. INTRODUCTION

The retinex model for the computation of lightness was introduced by Land and McCann[7] in 1971. Land and his colleagues later described additional improvements to the original method[6,5,3,4,8]. These further refinements were mainly designed to improve computational efficiency while preserving the retinex principle of comparing pixel values from different spatial locations. Matlab code for two of the main retinex algorithms is provided in[2] by Funt et. al.

Even though the retinex algorithm is well documented, there are still many things which need to be specified before it can be used as a model of human color or lightness perception. In particular, there are parameters which are sensitive to both the spatial frequency and the dynamic range of the input image. We estimate values for these parameters based on fitting the experimental data obtained by McCann, McKee and Taylor.[9] We will refer to their study as the MMT (McCann-McKee-Taylor) experiment. A central part of the MMT experiment involves haploscopic matching of Munsell papers arranged in a Mondrian display[9]. Our procedure is to reconstruct digital images corresponding to the cone responses of the standard observer, and then run the retinex algorithm on that data while varying the algorithm's parameters to find those for which the program's output best matches the MMT corresponding color data.

2. PREPARING RETINEX INPUT DATA

Our goal is to determine the values of the free retinex parameters which make retinex work as accurately as possible as a model of color appearance in complex visual scenes. In the MMT experiment[9], subjects alternately viewed a Mondrian with one eye and a Munsell chip with the other eye. For each colored area in the Mondrian, the subjects chose a matching Munsell chip. The experiment was repeated under 5 different combinations of three narrowband illuminants. The results in[9] are reported in terms of the designators of the matching Munsell chips. In this paper we rely on the corresponding CIE tristimulus values estimated by Nayatani et. al.[10].

Our first step was to construct an LMS image of the Mondrian used in the MMT experiment as it would be under each of the 5 illuminants. The layout of the color patches in the Mondrian is given in MMT[9]. We convert the corresponding XYZ of each patch as estimated by Nayatani[10] to cone quanta catch values using the following transformation[4]:

$$
\begin{aligned}
L &= 0.38971\,X + 0.68898\,Y + 0.07868\,Z \\
M &= -0.22981\,X + 1.18340\,Y + 0.04641\,Z \\
S &= 1.00\,Z
\end{aligned}
\tag{1}
$$

Similarly, the XYZs of the matching Munsell chips are converted to LMS. The natural logarithm of each L, M, S value is then taken since the Matlab retinex implementations[2] require the logarithm of the image as input. Retinex is run on each of the L, M and S channels independently.

3. POST RETINEX PROCESSING

The post-retinex processing consists of four stages: exponentiation, scaling to white, conversion to Munsell Value scale, and compensation for differences in overall illumination intensity. Exponentiation of the retinex output simply compensates for the logarithm which was applied to the input data. Scaling to white is required because the retinex algorithm normalizes each of the LMS channels to 1. After retinex processing an ideal white patch will result in (1,1,1); however, the LMS value of the Munsell white (MMT area K) under the 'white' illumination in the MMT experiment is (92.55, 72.84, 49.23). Hence, we scaled the retinex output values to make the retinex white equal the MMT white. The three scaling factors, one for each channel, were then held constant across the 5 MMT illumination conditions.

The second post-retinex stage is to convert to Munsell Value scale, which is required because McCann et. al. compare the colors in the Mondrian to the matching Munsell chips using it. They convert integrated reflectance ρ (e.g., L/Lwhite) to Munsell Value using the approximation[3]:

$$V = 2.539\,\rho^{1/3} - 1.838 \text{ for } \rho > 0.384\% \qquad (2)$$

The third stage is to compensate for differences in overall illumination intensity between the test and match conditions based on the data in Figure 8 of MMT. McCann et. al. found that overall intensity affected subjects' matches. Hence, we incorporated their correction factor as a function of the ratio of overall illumination between the two scenes. By analyzing MMT Figure 8, we computed the correction to be added to the retinex output converted to Munsell Value, based on the scene radiances E at 630-nm, 530-nm and 450-nm as:

$$\begin{aligned}
\text{Correction}^{630} &= 1.53 \times \log_{10}(E^{630}_{Mondrian}/E^{630}_{Munsell}) + 0.04 \\
\text{Correction}^{530} &= 1.19 \times \log_{10}(E^{530}_{Mondrian}/E^{530}_{Munsell}) + 0.11 \\
\text{Correction}^{450} &= 0.93 \times \log_{10}(E^{450}_{Mondrian}/E^{450}_{Munsell}) + 0.01
\end{aligned} \qquad (3)$$

4. RESULTS

To establish the optimum choice for the number of retinex iterations, we ran retinex with the number of iterations (parameter nIterations in the Matlab implementation[2]) varying from 1 to 500. The post-retinex processing described above was then applied in each case. For each iteration setting, we computed the difference between the final retinex prediction and the matching Munsell chip data found in the MMT experiment. The image difference measure is the RMS over all pixels of the following single pixel difference measure:

$$d_3(R^c(i,j) - M^c(i,j)) = \sqrt{\sum_{c=L,M,S} (R^c(i,j) - M^c(i,j))^2} \qquad (4)$$

$R^c(i,j)$ denotes the pixel value at channel c for retinex output including post-processing; $M^c(i,j)$ denotes the pixel value at channel c for an image of the Mondrian made up of Munsell matching chips.

We found that for each of the five different MMT experimental setups—"gray", "red", "blue", "green" and "yellow"—different numbers of iterations were required to give the best match to the matching Munsell data. Although the number of iterations varied across the cases, 33 iterations gave the best overall result.

Image resolution is another variable which must be considered. To determine how the optimum number of iterations might be affected by image resolution, we constructed images of otherwise identical Mondrians at resolutions of 128×128, 256×256, 512×512 and 1024×1024. Contrary to what might be expected, we found almost no change in the optimum number of retinex iterations required as a function of image resolution.

The following graphs illustrate how the number of iterations affect the distance between the retinex prediction and the actual image as seen by the observers, for each experiment. For these tests we ran retinex with input images of 256x256 pixels.

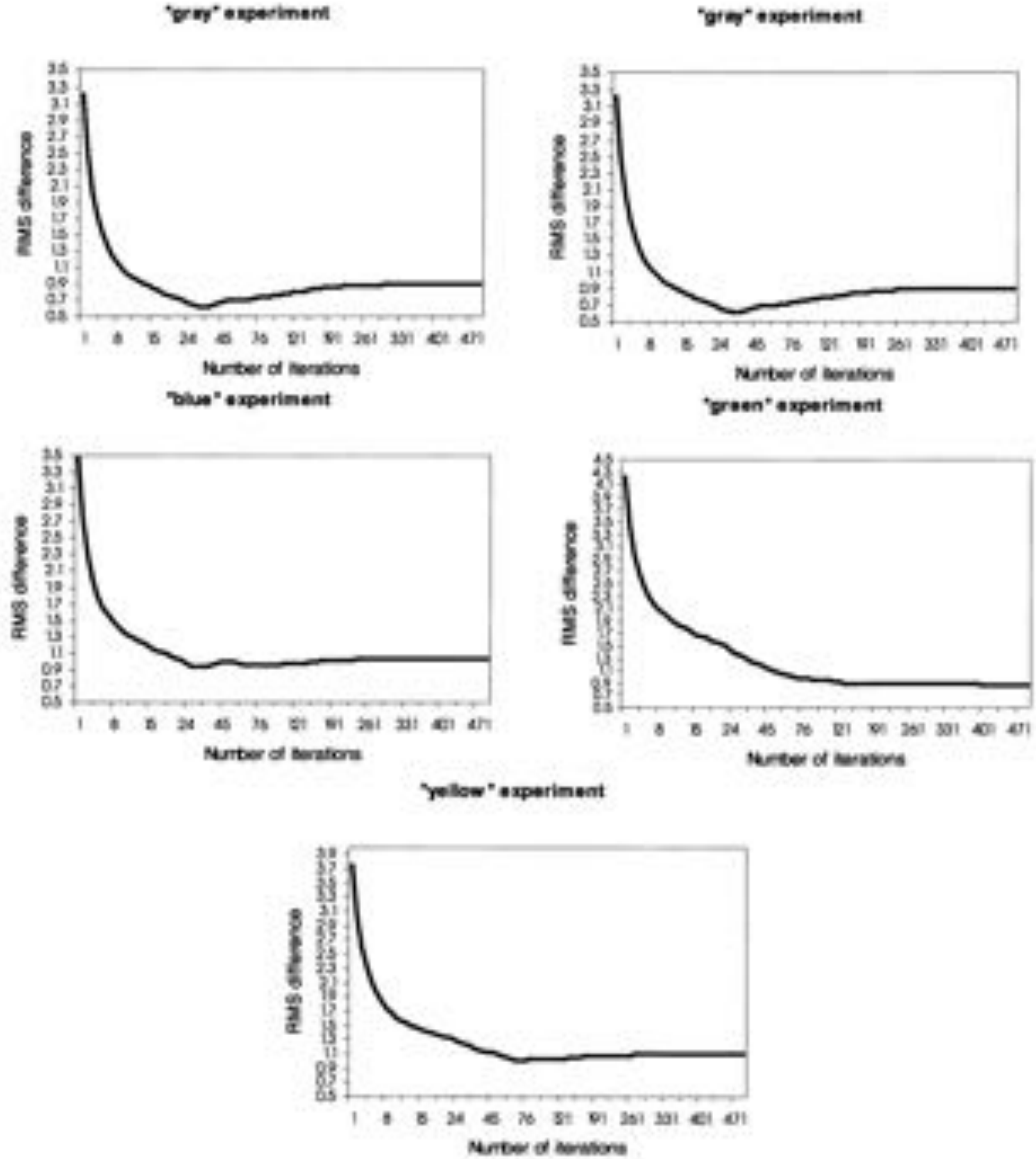


Figure 1: The accuracy of retinex as a model as measured by the RMS difference between the retinex output and the MMT corresponding color data as a function of the number of retinex parameter alterations[2].

CONCLUSIONS

For the MMT experiments we have been able to solve for the parameters needed in the retinex algorithm, based on a best fit with the experimental data. We have found that if we run either of the Matlab retinex algorithms[2], the optimum results can be obtained by choosing the number of iterations to be 33. An interesting finding was that the image resolution has very little effect on the accuracy of prediction. Details of the post-retinex processing step were also established. Although we have established parameters for the retinex computation based on the available MMT data, it would be helpful to have more extensive experimental data to improve the reliability of the results.

ACKNOWLEDGMENTS

We are grateful for the financial support of the Natural Sciences and Engineering Research Council of Canada.

REFERENCES

1. Frankle, J., and McCann, J.J., "Method and Apparatus for Lightness Imaging", *US Patent #4,384,336*, May 17, 1983.

2. Funt, B.V., Ciurea, F., and McCann, J.J., "Retinex in Matlab" *Proc. IS&T/SID Eighth Color Imaging Conference*, 112-121, Scottsdale 2000.

3. Glasser, L.G., McKinney, A.H., Reilly, C.D., and Schnelle, P.D. "Cube-root color coordinate system". J. Opt. Soc. Am. 48, 736-740, 1958.

4. Hunt, R.W.G., "Measuring Colour" (3rd edition), Fountain Press, p. 210,1998.

5. Land, E., "The Retinex Theory of Color Vision", *Scientific American*, 237, 108 - 128, 1977.

6. Land, E., "An alternative technique for the computation of the designator in the retinex theory of color vision", *Proc. of the National Academy of Science USA*, 83, 2078-3080, May 1986.

7. Land, E. and McCann, J.J., "Lightness and Retinex Theory", *Journal of the Optical Society of America*, 61(1), January 1971.

8. McCann, J.J., "Lessons Learned from Mondrians Applied to Real Images and Color Gamuts", *Proc. IS&T/SID Seventh Color Imaging Conference*, pp. 1-8, 1999.

9. McCann, J.J., McKee, S.P., and Taylor, T.H., "Quantitative Studies in Retinex Theory: A Comparison Between Theoretical Predictions and Observer Responses to the 'Color Mondrian' Experiments", *J. of Vision Res.* Vol. 16, 445 – 458, 1976.

10. Nayatani, Y., Takahama, K., Sobagaki, H., "Prediction of Color Appearance of Object Colors in a Complex Visual Field", *J. Light & Vis. Env.* Vol. 19, No. 1, 1995.

---

* Correspondence: funt@sfu.ca; phone 604-291-3126; fax 604-291-3045; http://css.sfu.ca/members/funt.html; School of Computing Science, Simon Fraser University, 8888 University Drive, Burnaby, B.C. Canada V5A 1S6

A uniform color space based on color vision mechanisms

Yasuhisa Nakano*, Ryuzo Yamashita, Yukinari Fukuda, Ken-ichiro Suehara, Takuo Yano
Dept. of Information Machines & Interfaces, Hiroshima City University

ABSTRACT

A uniform color space based on color vision mechanisms was proposed. The mechanisms considered to construct the uniform color space were, proportion of three types of cones, compressive response nonlinearity at receptor and post-receptor stages, constant noise or dark response added to the receptor response, and fractional expressions of opponent and S channel in the postreceptor stage. The present uniform color space explains, three dimensional color discrimination data, supra-threshold color differences such as Munsell color chips, and luminance dependence of the color differences.

Keywords: Uniform color space, color discrimination, color differences, color vision mechanisms

1. INTRODUCTION

Uniform color space is one of the important tools for colorimetry. CIE established two kinds of uniform color spaces, CIELUV and CIELAB in 1976. The CIELUV has an advantage in explaining small color differences such as MacAdam ellipses, and the CIELAB has an advantage in explaining supra-threshold color differences such as Munsell color chips. It was difficult to explain both kinds of color differences using only one uniform color space at that moment and that was the reason why two kinds of uniform color spaces were established. It is, however, difficult to know how to use these two spaces properly in practical applications, and it is convenient if there is such a uniform color space that can be used for any kinds of color differences. A purpose of this study is to find such a uniform color space.

Formulae in the CIELUV and the CIELAB spaces are rather empirical though some opponent mechanisms are suggested in the CIELAB space. Some modifications were made on the color difference formula based on the CIELAB space and resulted in the CIE94 color difference formula, but it is also empirical and rather complicated. Seim and Valberg (1986)[1] proposed a uniform color space based on physiological mechanisms and showed that color chips in Munsell and OSA color order systems are uniformly distributed in this space, but the threshold color differences were not tested. Guth (1991) [2] proposed comprehensive color vision model and explained both threshold and supra-threshold color differences, but different coordinates were used for each occasion. Though many study show that the threshold and the supra-threshold color differences are explained by different mechanisms (e.g. Kuehni, 2000[3]), it might be possible to find some compromise between them. We found such compromise based on some simple principles of color vision mechanisms.

2. CONSTRUCTION OF THE UNIFORM COLOR SPACE

2.1 COMPRESSIVE NONLINEAR FUNCTION

We used the following nonlinear function as a template applied to receptor and postreceptor responses.

$$f(x,\sigma) = \frac{\sigma}{114}\left[\left\{342\left(\frac{x}{\sigma}\right)+1\right\}^{\frac{1}{3}} - 1\right] \tag{1}$$

Parameter σ is the saturation constant. This function has the following features.

$$f(0,\sigma) = 0\,; \quad \left[\frac{d f(x,\sigma)}{d x}\right]_{x=0} = 1\,; \quad 19 f(x,100) = 116\left(\frac{x}{100}\right)^{\frac{1}{3}} - 16 \tag{2}$$

  · 0277-786X/02/$15.00

2.2 CONE RESPONSES

Smith and Pokorny cone fundamentals[4] were used with some modification so that responses of L, M and S cones were equalized for D65 daylight source. To account for Judd-Vos modification[5] for those samples that only have CIE 1931 xy-coordinates, conventional method was applied. After XYZ tristimulus values were converted into RGB tristimulus values, radiances of 700, 546.1 and 435.8nm monochromatic lights were obtained, and then Judd-Vos modified tristimulus values were calculated assuming the mixture of these monochromatic lights is equivalent to the original sample. This resulted in the following equation to calculate cone tristimulus values, l, m and s.

$$\begin{pmatrix} l \\ m \\ s \end{pmatrix} = \begin{pmatrix} 0.23036 & 0.83167 & -0.03938 \\ -0.43744 & 1.31887 & 0.10225 \\ -0.00020 & 0.00055 & 0.92331 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \tag{3}$$

Cone responses underwent nonlinear compression by Equation (1), then constant nose or dark response was added to each cone response. Proportion of the L, M and S cones were finally multiplied to the cone responses. L:M:S = 10:5:1 was used as the proportion. These effects resulted in the following cone responses,

$$\begin{aligned} l_c &= 0.6250 \{ f(l, 10000) + 4 \}, \\ m_c &= 0.3125 \{ f(m, 10000) + 4 \}, \\ s_c &= 0.0625 \{ f(s, 10000) + 4 \}, \end{aligned} \tag{4}$$

where the saturation constants for cones were $\sigma = 10000$, and the noise added was 4.

2.3 POSTRECEPTOR STAGES

Orthogonal axes of the uniform color space were expressed using the following formulae.

$$\begin{aligned} L^* &= 40 f(l+m, 100) \\ t^* &= 1500 \left\{ f\left(\frac{l_c - m_c + s_c}{l_c + m_c + s_c}, 30 \right) - f(0.3750, 30) \right\} \\ s^* &= 1500 \left\{ f(0.0625, 10) - f\left(\frac{s_c}{l_c + m_c + s_c}, 10 \right) \right\} \end{aligned} \tag{5}$$

Achromatic axis, L^*, had the similar function as the lightness function defined in the CIE system, that is, the function of luminance, $l+m$. Chromatic axes, t^* and s^*, were the function of fractional expressions that have the same denominators, $l_c+m_c+s_c$. Numerator of the one chromatic channel had opponent type of expression, $l_c - m_c + s_c$, and that of the other channel was expressed solely by s_c. All of these channels underwent nonlinear compression by Equation (1) but with different saturation constants. The saturation constant for the achromatic channel was $\sigma = 100$, that for the opponent channel was $\sigma = 30$, and that for the S channel was $\sigma = 10$. Constants were subtracted from responses of chromatic channels so that chromaticity coordinates became 0 for D65 white, and the sign of the S channel response was negated so that the direction of hue rotation became the same as the CIE system. Magnifying coefficient for each channel was also determined so as to resemble the CIE system.

3. RESULTS

Parameters such as saturation constants, noise and magnifying coefficients were determined using several data sets. First one is three dimensional color discrimination data collected in our laboratory[6]. Figure 1 shows three dimensional color discrimination ellipsoids plotted in the present uniform color space. Two plots in this figure are stereoscopic pair and can be fused with cross view condition. Color discrimination data was collected around 8 central colors at 3 luminance levels. Sizes of all the discrimination ellipses were close to each other and there was no extremely long or flat ellipsoid. This means that uniformity of this color space is fairly good.

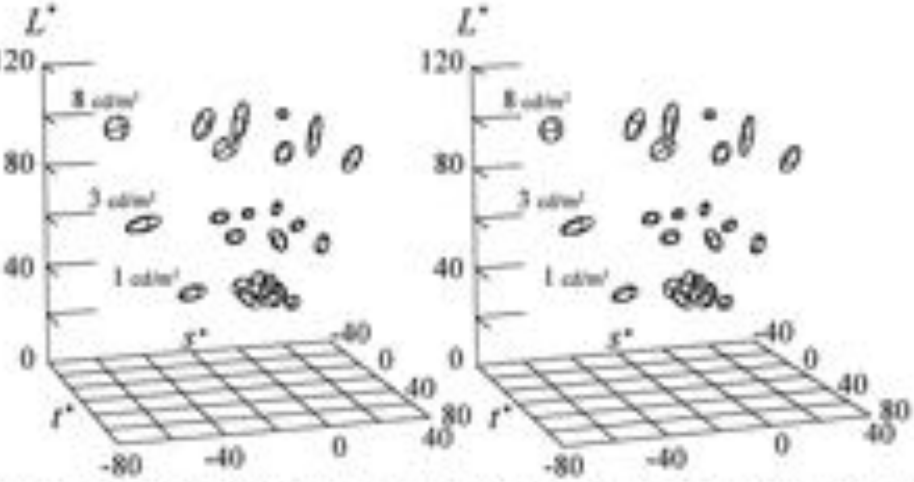


Figure1. Stereoscopic pair of color discrimination ellipsoids plotted in the present uniform color space. The plots can be fused by looking at the left plot by right eye and the right plot by left eye (cross view condition). The ellipsoids are plotted at 5 times their actual size.

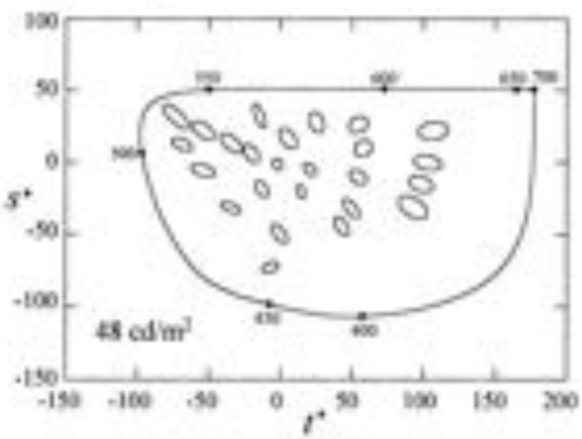


Figure 2. MacAdam ellipses in the t^*-s^* plain of the present uniform color space. The ellipses are plotted at 10 times their actual size.

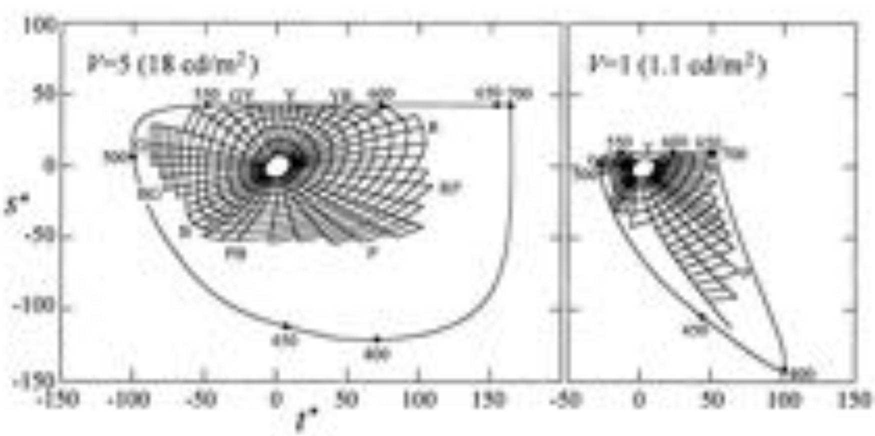


Figure 3. Constant hue and saturation loci of Munsell system plotted in the t^*-s^* plain of the present uniform color space. Left panel is for value 5 and right panel is for value 1.

Second data set is the MacAdam ellipses. Figure 2 shows the MacAdam ellipses plotted in the I^*-S^* plain of the present uniform color space. Luminance level was set to 48 cd/m^2 according to the condition of MacAdam's experiment. Spectral locus was also plotted in the figure.

Third data set is the Munsell color chips. Figure 3 shows constant hue and saturation loci of Munsell chips of value 5 and value 1 plotted in the I^*-S^* plain of the present uniform color space. Luminance level was set to 18 cd/m^2 for value 5, and set to 1.1 cd/m^2 for value 1, that corresponded to illuminance of about 300 lux.

4. DISCUSSION

Compressive nonlinear function of Equation (1) was designed so that it resembles the CIE lightness function. Disadvantage of the CIE function is that it requires exceptional treatment when luminance factor is close to zero because of negative value. It can not be applied to response nonlinearity because zero response frequently happens. The solution was found when we investigated the equation $\Delta\Phi = \Delta S/(a + bS)^{\frac{1}{2}}$ where $\Delta\Phi$ was sensation threshold and S and ΔS were stimulus and its threshold. Equation (1) was derived from this equation with the conditions of Equation (2).

Noise or dark response introduced in Equation (4) plays an important role in the present uniform color space. Spectral locus shrinks as luminance level decreases except for short wavelength region as shown in Figure 3. This feature is derived from this noise effect and it explains luminance dependence of color discrimination better than other systems such as CIELUV and CIELAB. Illuminance dependence of color discrimination can be also explained by the present system because it is luminance based system in contrast to the CIE systems these are luminance factor based system.

Fractional expressions in Equation (5) was derived by analyzing three dimensional color discrimination data obtained in our laboratory. We found that angles in the cone response space retain important information on color discrimination analogous to the study of Oleari (1991)[7], and resulted in such fractional expressions because they eliminate intensity information as angles do.

Parameters in the present uniform color space are not optimized by any mean. Such optimization and some more refinements will be needed to apply this system to the real problems.

ACKNOWLEDGMENTS

This study was supported by the Hiroshima City University Grant for Special Academic Research.

REFERENCES

1. T. Seim, and A. Valberg, "Towards a uniform colour space: a better fourmula to describe the Munsell and OSA colour scales," *Color Res. Appl.*, **11**, pp. 11-24, 1986
2. S. L. Guth "Model for color vision and light adaptation," *J. Opt. Soc. Am.*, **A8**, pp. 976-993, 1991
3. R. G. Kuehni, "Threshold color differences compared to supra-threshold color differences," *Color Res. Appl.*, **25**, pp. 226-229, 2000
4. V. C. Smith, and J. Pokorny, "Spectral sensitivity of the foveal cone photopigments between 400 nm and 500nm," *Vision Res.*, **15**, pp. 161-171, 1975
5. J. J. Vos, "Colorimetric and photometric properties of a 2° fundamental observer," *Color Res. Appl.*, **3**, pp. 125-128, 1986
6. Y. Nakano, R. Yamashita, K. Suehara, and T. Yano, "Measurement and analysis of color discrimination using color modulation threshold," *Special Issue to OPN (abstracts for the 1998 OSA Annual Meeting)*, **9**, No.8, p. 73, 1998.
7. C. Oleari, "Uniform-scale chromaticity diagram with angular coordinates in zero-curvature space," *J. Opt. Soc. Am.*, **A8**, pp. 415-421, 1991

---

* Correspondence: ynakano@bio.im.hiroshima-cu.ac.jp; fax +81-82-830-1605; Dept. of Information Machines & Interfaces, Hiroshima City University, 3-4-1 Ozukahigashi, Asaminami-ku, Hiroshima 731-3194, JAPAN.

Perceptual transparency

Caterina Ripamonti* and Stephen Westland
Colour & Imaging Institute, Derby University, Derby, UK

ABSTRACT

We suggest that colour constancy and perceptual transparency might be explained by the same underlying mechanism. For colour constancy, Foster and Nascimento (1994) found that cone-excitation ratios between surfaces seen under one illuminant and cone-excitation ratios between the same surfaces seen under a different illuminant were almost constant. In the case of perceptual transparency we also found that cone-excitation ratios between surfaces illuminated directly and cone-excitation ratios between the same surfaces seen through a transparent filter were almost invariant (Westland and Ripamonti, 2000). We compare the ability of the cone-excitation-ratio invariance model to predict perceptual transparency with an alternative model based on convergence in colour space (D'Zmura *et al.*, 1997). Psychophysical data are reported from experiments whereby subjects were asked to select which of two stimuli represented a Mondrian image partially covered by a homogenous transparent filter. One of the stimuli was generated from the convergence model and the other was a modified version of the first stimulus such that the cone-excitation ratios were perfectly invariant. Subjects consistently selected the invariant stimulus confirming our hypothesis that perception of transparency is predicted by the degree of deviation from an invariant ratio for the cone excitations.

Keywords: colour vision, colour constancy, perceptual transparency, spectral transmittance.

1. INTRODUCTION

The identification of surfaces is an important ability of our visual system which allows us to identify objects. Although features like shape and position play their role in the recognition task, it has been shown that the *colour* of a surface is also important. We easily recognise an object because we recognise its colour despite the fact that the colour signals for surfaces change depending upon the incident illumination. Our visual system seems to take into account this change and correctly recognises the same object when seen under a variety of different light sources (*colour constancy*). We have investigated a similar phenomenon whereby surfaces are partially covered by transparent filters. Although the spectral composition of the light reflected by the filtered surfaces is different from that of the surfaces themselves, our visual system seems to take into account this change and correctly recognises the filtered surfaces as the same surfaces seen in plain view (*perceptual transparency*). We suggest that colour constancy and perceptual transparency might be explained by the same underlying mechanism. For colour constancy, Foster and Nascimento[1] found that cone-excitation ratios (within a cone class) between surfaces seen under an illuminant and cone-excitation ratios between the same surfaces seen under a different illuminant were almost constant. In the perceptual transparency case we also found that cone-excitation ratios between surfaces illuminated directly and cone-excitation ratios between the same surfaces seen through transparent filters were almost invariant[2].

1.1 The convergence model

Early studies on perceptual transparency have focused their attention on figural and chromatic constraints as necessary conditions for perceiving transparency[3-5]. D'Zmura *et al.* [6] and Chen and D'Zmura[7] have suggested that a stimulus for which colours of opaque surfaces and their corresponding filtered surfaces converge in colour space will appear transparent. For example, if the tristimulus values of two opaque surfaces A and B are given by $\boldsymbol{x}_A$ and $\boldsymbol{x}_B$ respectively, the tristimulus values of the surfaces when covered by a single homogenous transparent filter would lie on lines passing through $\boldsymbol{x}_A$ and $\boldsymbol{g}$, and $\boldsymbol{x}_B$ and $\boldsymbol{g}$, where $\boldsymbol{g}$ defines the tristimulus values of the convergence point. The degree of convergence is measured by a factor α which represents the vector distance between the opaque surface colour and the filtered colour in the XYZ colour space. Thus, for $\alpha = 0$ the opaque surface colour and the filtered colour coincide. Whereas, for $\alpha = 1$ the opaque surface colour and the filtered colour are far apart and no transparency is perceived.

* For correspondence contact c.ripamonti@derby.ac.uk

1.2 The invariance of cone-excitation ratios model

The light reaching the eye when an illuminant strikes a surface is defined as the colour signal S. (The spectral power distribution of S is computed by multiplying the illuminant E at each wavelength by the corresponding value of the surface reflectance function R). If the surface is partially covered by a transparent filter (Figure 1), the colour signal S' from the filtered area is now different from the rest of the surface seen directly. The filtered or effective reflectance R' of the opaque surface can be expressed as a function of the spectral reflectance function R of the surface, the internal transmittance T that accounts for absorption of light by the filter, and the internal reflectance factor[8] of the filter b, such that

$$R'(\lambda) = R(\lambda)[T(\lambda)\,(1-b)^2]^2. \qquad (1)$$

The cone excitation $e_{i,j}$ of cone class i (where $i \in \{L, M, S\}$ denoting long-, medium-, and short-wavelength-sensitive cone classes) for a surface j seen directly is given by the integration of the product between the surface reflectance R, the illuminant E, and the cone sensitivity functions ϕ_i. Thus

$$e_{i,j} = \int E(\lambda)\, R(\lambda)\, \phi_i(\lambda)\, \delta\lambda. \qquad (2)$$

In Figure 1 two opaque surfaces ($e_{i,1}$ and $e_{i,2}$) are covered by a simulated homogeneous transparent filter and the cone excitations of the filtered patches are given by $e_{i,1}'$ and $e_{i,2}'$.

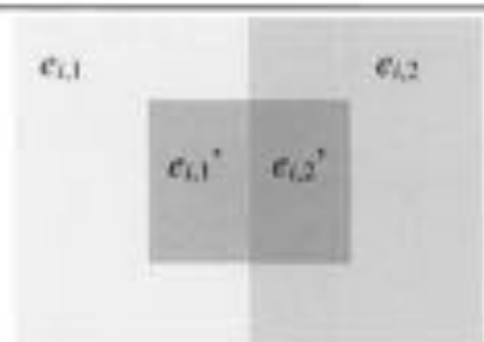


Figure 1: Cone excitations for two opaque surfaces seen directly and under a transparent filter.

The term $R(\lambda)$ can be replaced by $R'(\lambda)$ (Equation 1) in order to compute the cone excitation $e_{i,j}'$ for a surface j seen by cone class i through a filter defined by $T(\lambda)$ and b. A Monte Carlo simulation was carried out in a previous study[2] to compute the invariance of cone-excitation ratios for surfaces drawn randomly from the Munsell set[9] for filters defined by $T(\lambda)$ and b. Thus, explicitly, the equivalence

$$e_{i,1} \,/\, e_{i,2} \approx e_{i,1}' \,/\, e_{i,2}' \qquad (3)$$

was tested. Note that when $T(\lambda)$ is defined by a wavelength-invariant constant (denoting an achromatic filter) Equation 3 holds perfectly. For chromatic filters (defined by Gaussian-shaped transmission properties) the equivalence was found to hold approximately for many filter parameters[2].

1.3 Hypothesis

Both the cone-excitation-ratios invariance model and the convergence model define chromatic conditions under which transparency perception can occur. An important feature of our model, however, is that it can predict the degree of transparency perception. For each cone-excitation ratio it is possible to compute the degree of deviation from invariance for all the possible pairs of surfaces seen directly and under the filter displayed in each image. Our hypothesis is that the perception of transparency is correlated to this degree of deviation from an invariant ratio.

2. EXPERIMENTAL

The idea that the invariance of cone-excitation ratios may predict transparency perception has been tested in a set of psychophysical experiments whereby stimuli simulating filters generated using different values of α (from the convergence model) were compared with stimuli with perfectly invariant cone-excitation ratios .

2.1 Method

Stimuli contained Mondrian patterns (4.52 × 3.58 degrees of visual angle) composed of 12 surfaces displayed in a 12 x 6 arrangement and partially covered by simulated transparent filters (3.38 × 0.95 *deg*). The filters were generated using the convergence model. The parameter α was randomly selected from the values 0.1, 0.3, 0.5, 0.7 and 0.9 (the *convergent filter*) which was compared with Mondrian patterns partially covered by a simulated transparent filter whose cone-excitation ratios were systematically made invariant (the *invariant filter*). Five randomly selected *g* points were used. Figure 2 shows a schematic representation of the stimulus patterns.

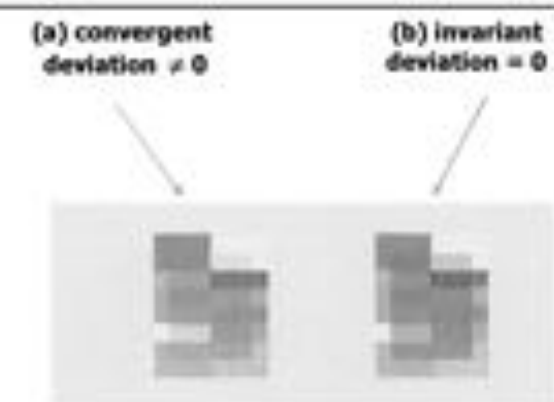


Figure 2: Schematic representation of stimulus patterns used in the experiment.

In each trial the two stimulus patterns (the one covered by the convergent filter and the one covered by the invariant filter) were presented simultaneously side by side (Figure 2). The invariant filter could randomly appear either on the left or on the right hand side. Six observers were asked which of the two stimulus patterns simulated a uniform transparent filter over opaque surfaces. Each trial was repeated 3 times for a total of 150 trials (3 (repetition) × 2 (left or right position of the invariant filter) × 5 (*α*) × 5 (*g*)).

3. RESULTS

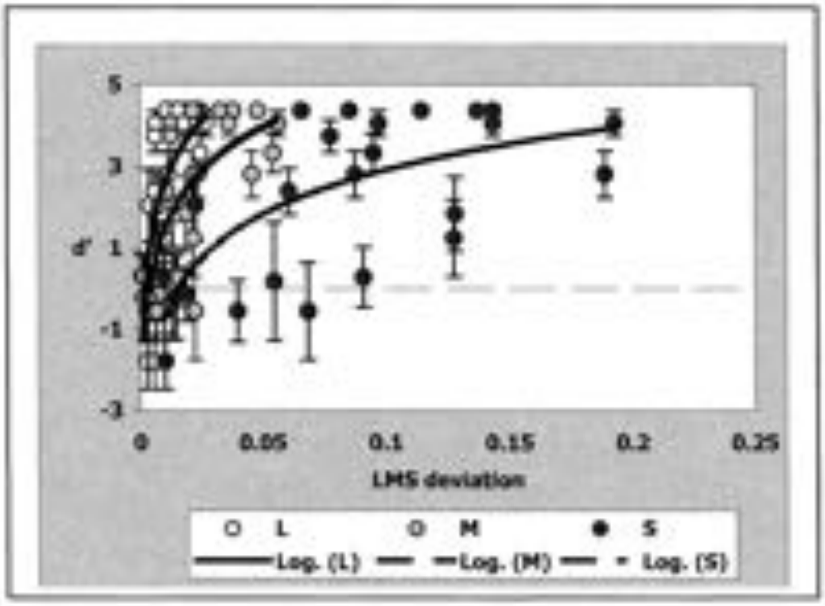
For each trial we calculated the degree of deviation from invariance in spatial cone-excitation ratios for all the possible pairs of surfaces seen directly and under the filter displayed in each image. The degree of deviation was equal to

$$\text{deviation} = 1 - r_i \qquad \text{if } r_i \leq 1$$
$$\text{deviation} = 1 - 1/r_i \qquad \text{if } r_i > 1 \qquad (4)$$

where r_i is the ratio of cone-excitation ratios defined as

$$r_i = (e_{i,1}/e_{i,2}) / (e_{i,1}'/e_{i,2}'). \qquad (5)$$

Note that for the invariant filters the deviations were always exactly zero whereas for the convergence filters the deviations varied between 0 and 0.2. Subjects' performance in the task was measured by *d prime* (*d'*) where positive values of *d'* indicate a preference for the invariant filter, negative values indicate a preference for the convergent filter, and chance performance is indicated by $d' = 0$. Figure 3 shows that observers generally preferred the invariant filter to the convergent filter (positive values of d'). However, we found no significant preference ($d' = 0$) when the convergence filter had deviations close to 0. Negative values of d' represent subjects' preference for the convergent filter; however, they were not significantly different from 0 (chance performance).



4. CONCLUSIONS

We suggest a simple computational method that the visual system could be implementing for perceiving transparency based on the invariance of cone-excitation ratios. The model we propose is consistent with previous work and its output leads to the same chromatic constraints defined by the convergence model. Our results show that the invariance of cone-excitation ratios can correctly predict perceptual transparency. Moreover, the degree of cone-excitation ratios invariance can predict the degree of transparency that will be perceived. Finally, we suggest that perceptual transparency and colour constancy may rely upon similar mechanisms – possibly even similar groups of neurones.

REFERENCES

1. D.H. Foster and S.M.C. Nascimento, "Relational colour constancy from invariant cone-excitation ratios" *Proceedings of the Royal Society, London, B*, **257**, pp. 115-121, 1994.
2. S. Westland and C. Ripamonti, "Invariant cone-excitation ratios may predict transparency" *Journal of Optical Society of America A*, **17**, pp. 255–264, 2000.
3. F. Metelli, "An algebraic development of the theory of perceptual transparency" *Ergonomics*, **13**, pp. 59-66, 1970.
4. F. Metelli, "The perception of transparency" *Scientific American*, **230**, pp. 90-98, 1974
5. P. Cavanagh, "Reconstructing the third dimension: Interactions between color, texture, motion, binocular disparity and shape" *Computer Vision, Graphics, and Image Processing*, **37**, pp. 171-195, 1987.
6. M. D'Zmura, P. Colantoni, K. Knoblauch and B. Laget, B, "Color transparency" *Perception*, **26**, pp. 471-492, 1997.
7. J.V. Chen and M. D'Zmura, "Test of a convergence model for color transparency perception" *Perception*, **27**, pp. 595-608, 1998.
8. G. Wyszecki and W.S. Stiles, Color Science: Concepts and Methods, Quantitative Data and Formulae", New York, Wiley, 1982.
9. J.P.S. Parkkinen, J. Hallikainen and T. Jaaskelainen, "Characteristic spectra of Munsell colors" *Journal of Optical Society of America A*, **6**, pp. 318-322, 1989.

Visual comfort evaluated by opponent colors

Ken Sagawa
National Institute of Advanced Industrial Science and Technology, Japan

ABSTRACT

This study aimed to evaluate psychological impression of visual comfort when we see an image of ordinary colored scene presented in a color display. Effects of opponent colors, i.e. red, green, yellow and blue component, on the subjective judgement on visual comfort to the image were investigated. Three kinds of psychological experiment were designed to see the effects and the results indicated that the red/green opponent color component was more affecting than the yellow-blue one, and red color in particular was the most affecting factor on visual comfort.

Keywords: Visual comfort, colored environment, opponent colors

1. INTRODUCTION

In order to evaluate colored visual environment, such as streets, buildings and interior rooms, an objective method to quantify the psychological impression of visual comfort to the colored environment is needed for a better use of color in our daily life. From our previous studies, it has been shown that the visual comfort was able to be evaluated by a mean saturation as defined by the CIE1976uv saturation averaged over an entire scene so that the higher the mean saturation the less comfort is felt when viewing the colored scene [1, 2]. Furthermore, it has been also shown that the number of basic colors contained in the image is an affecting factor on the visual comfort [3]. In the present study, in order to see the underlying mechanisms of these findings, effects of opponent color responses on the visual comfort were investigated [4].

2. EXPERIMENTS

2.1 VARIABLE RED/GREEN AND YELLOW/BLUE COMPONENT EXPERIMENT

A total of 40 colored images taken by a digital still camera (SONY DSC-F505K) from ordinary colored scenes in Tsukuba Science City in Japan were used as test images. These images were presented on a 20-inch CRT display, and by means of a specially developed software, opponent color components i.e. the r/g and the y/b component of each pixel of an image were varied continuously without changing the luminance. The changes are illustrated in Fig. 1(a). Chromaticity of each pixel

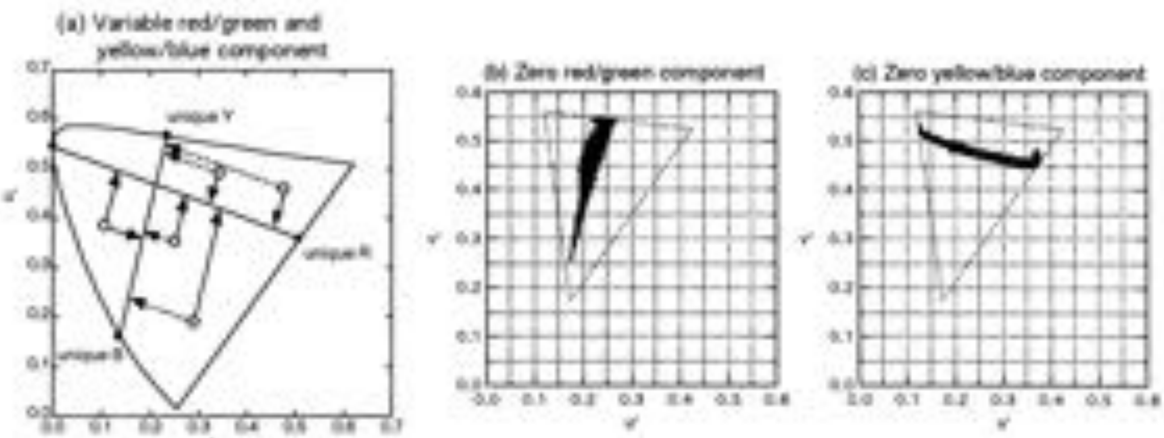


Figure 1: (a) Examples of chromaticity change of some pixels in an image in the variable r/g and y/b component experiment and (b) an example of pure y/b component image (zero r/g component) and (c) of pure r/g component image (zero y/b component).

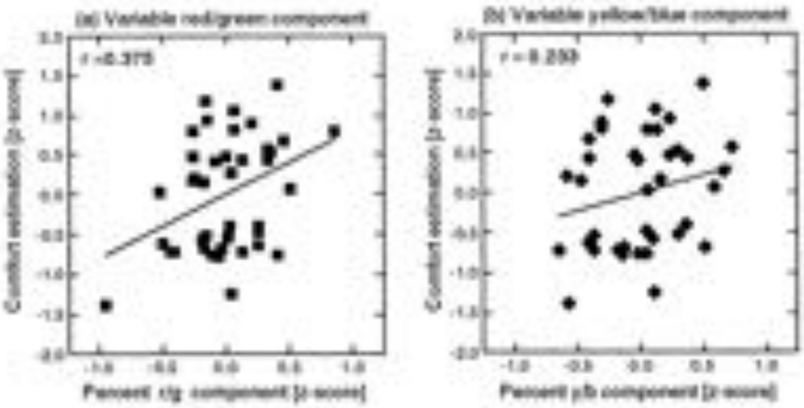


Figure 2: Correlation between direct estimation of visual comfort with (a) optimum percent r/g component and with (b) optimum percent y/b component.

shifted along with either of two unique hue lines of the r/g and y/b color mechanisms by a common change rate over the image as indicated in the figure. As shown in Figs. 1(b), at the zero percent of r/g component, the image was constructed only with the y/b component (just on the unique y/b line) , and on the other hand at the zero percent of y/b component the image was formed only by reddish or greenish colors (just on the unique r/g line).

The observer's task is to change the percentage of r/g (or y/b) component of each pixel of an entire image until he/she find a point where the most comfortable impression was felt for the image along with this changing. The point set by the observer was called optimum percent r/g (or y/b) component. This setting was carried out for all the 40 images twice in different days. At the same time, the observer was asked to directly judge the extent of visual comfort in 10 point scale from 0 (the most discomfort) to 9 (the most comfort) and the data was compared with the optimum percent r/g or y/b component.

The results are shown in Figs. 2(a) and 2(b). Correlations between direct estimation of visual comfort and the optimum percent r/g and y/b component are shown. As the range of data distribution is largely different for different observers, all the individual data were converted to so called z-score i.e. zero mean and a unit standard deviation. All the data hereafter are plotted in this z-score. Each point in the figures means data of each of 40 test images averaged over a total of 30 observers. Straight lines mean the linear regression lines and the numbers denoted as r are the correlation coefficients.

As shown in the figures, a trend is observed for the variable r/g component experiment (Fig. 2(a)) that the optimum percent r/g component is in a good positive correlation with the direct estimation of visual comfort. Similar positive correlation is obtained for the data of the variable y/b component experiment (Fig. 2(b)) but with a less extent. The fact that there exists a positive correlation between the comfort estimation and optimum percent r/g or y/b component means that the r/g or y/b component has an affecting factor on the visual comfort. The correlation coefficients indicate that the r/g component has a stronger effect on the visual comfort than the y/b one.

2.2 DIRECT ESTIMATION EXPERIMENT

In the second experiment, in order to see a direct relation between visual comfort and opponent colors, direct estimation on how much the image is colored by each of the opponent color components, was carried out. The observer was asked to estimate a total impression of redness, greenness, yellowness and blueness of the entire image by using 10 point scale. In addition the observer was also asked to judge the extent of visual comfort to the image and the data were compared with the opponent color estimation data. Another set of 30 test images was used and a total of 30 color normal observers participated in the experiments.

Figures 3(a) to 3(d) are the results of these experiments. The comfort estimation data is plotted as a function of the estimation of each of the four opponent colors averaged over the 30 observers (z-score). Each data point means the data for each of 30 test images and the straight lines are linear regression with correlation coefficients.

A clear negative correlation is seen for the visual comfort versus redness estimation, meaning that the more reddish the

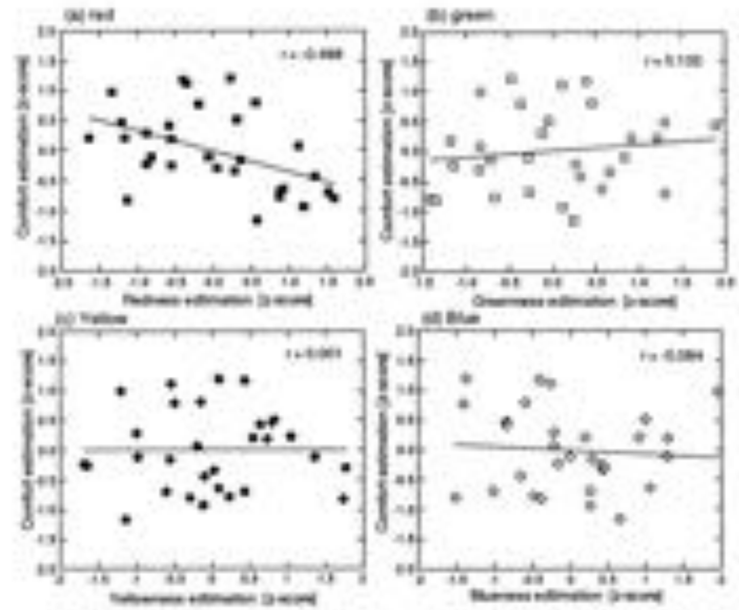


Figure 3: Correlations between the comfort estimation and the direct estimation of each of (a) redness, (b) greenness, (c) yellowness, and (d) blueness of the image.

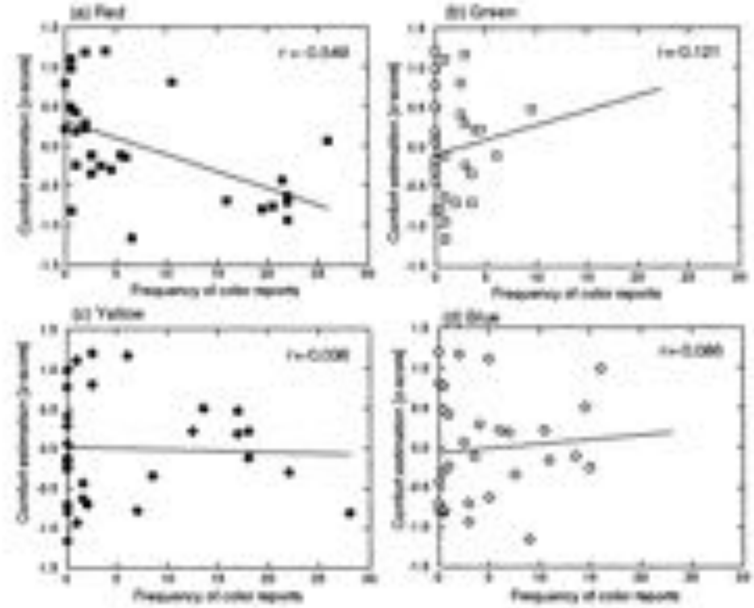
image appears the less comfort is felt to the image. A weak positive correlation is seen for the greenness estimation and almost no correlation is found for both the yellowness and blueness, indicating that the green component is a slightly positive for visual comfort. From these results, it can be said that red component is the most influencing factor among the opponent color components .

2.3 COLOR NAMING EXPERIMENT

In the third experiment, in order to find a primary color contained in an image and its relation to visual comfort, color naming experiment was done in which the subject was asked to report the colors he/she felt in the image after brief exposure of the image (5 sec) by using categorical color naming without any restriction on number of colors reported but in an order of the strength of the impression, i.e. most impressive color of the image comes first. From these color naming data, frequency of each of the opponent colors reported was counted and its relation to the comfort judgement was investigated.

The results are shown in Figs 4(a) to 4(d) where the comfort estimation was plotted against the frequency of the report for red, green, yellow and blue in each of four figures. Again, a clear negative correlation is seen for the red color and a slight positive for the green color. This means that the red color has a negative effect and a green is a slightly positive effect on the visual comfort.

From a series of these experiments, it was found that r/g component, in particular the red color, has a clear negative correlation with visual comfort, i.e. the more the red color is contained in an image the less comfort is felt when viewing the image. For other opponent colors such as green, yellow and blue, the effects are not so prominent, but slightly positive effect was found for green color.



3. CONCLUSION

Figure 4: Comfort estimation data plotted against the frequency of each of the opponent colors, (a) red , (b) green, (c) yellow, and (d) blue, reported by observers as most impressive in the image.

The present study has investigated the influence of opponent colors on the visual comfort of the images of ordinary scenes. The variable r/g component experiment showed that the r/g component has a negative effect on visual comfort, meaning that the more the r/g component is contained in an image the less comfort is felt for the image. A further direct estimation study showed that red color exhibits a negative effect on visual comfort rather than any other opponent colors such as green, yellow, and blue. This concludes that visual comfort can be evaluated primarily by the amount of red color contained in the image.

REFERENCES

1. K. Sagawa and Y. Shimizu, "Visual Comfort of a Colored Image Studied by Spatial Distribution of Colors," Proceedings of the 8th Congress of AIC, Vol. II, pp. 735-738, 1997.
2. K. Sagawa, "Visual Comfort to Colored Images Evaluated by Saturation Distribution," Color Research and Application, 24, pp. 313-321, 1999.
3. K. Sagawa, "Visual Comfort Evaluated by Number of Categorical Colors in a Colored Image, Color Research and Application, 25, pp.193-199, 2000.
4. K. Sagawa, "Opponent colors and visual comfort," Proceedings of 2000 AIC Meeting Seoul, pp.123-126, 2000.

* correspondence: sagawa-k@aist.go.jp; phone +81-298-61-6750; fax +81-298-61-6752; National Institute of Advanced Industrial Science and Technology, 1-1-1, Higashi, Tsukuba, Ibaraki 305-8566, Japan

ATD01 model for color appearances, color differences and chromatic adaptation

S. Lee Guth, Dept. of Psychology and School of Optometry, Indiana University

ABSTRACT

This paper reviews and critiques earlier version of the ATD model, and it describes a revised model, which differs mainly in its gain control function. The model is applied to recently published lightness, hue and colorfulness data.

Keywords: Color models, lightness, hue, colorfulness, chroma, saturation color differences, chromatic adaptation.

1. INTRODUCTION

In 1951, in a brilliant chapter on color vision, Judd[1] wrote, "By far, the most completely worked out of these stage theories is that of Mueller [from 1930]. It takes at least qualitative account of nearly every known [color] visual phenomenon …and … he has …made a start toward the solution of important problems that will eventually have to be faced by other theorists" (p. 836). Indeed, the ATD models for color perception and visual adaptation, which account for a very wide range of data of human color vision, suggest that Judd was correct in his judgment. That is, with some changes, the various versions of the ATD model that have been published during the past ten years[2] are quite similar to the Mueller model. Differences include, (i) changes of the receptor inputs to post-receptor mechanisms, (ii) addition of nonlinear gain control at the receptor level, (iii) changes of some post-receptor connections and weighting factors, and (iv) addition of other system nonlinearities.

The intent of this paper is to present an up-to-date version of the ATD model, to correct errors that were associated with prior publications, and to make explicit the formulations that should be used when applying ATD to current problems concerning color appearances. The paper will also emphasize the fact that the ATD models remain extremely powerful for solving the classical problems of color discriminations and chromatic adaptation.

2. DESCRIPTION OF THE MODEL, CHANGES, PRIOR ERRORS AND COMMENTS

Figure 1 schematizes the model. At the first level, the model uses generally accepted *LMS* receptors. Nonlinear (NL) signals from receptors are affected by nonlinear gain control mechanisms, which allow maximum neural information to flow at low light levels but help to prevent saturation at high levels. Gain control is also affected by neural activity from other retinal areas and from prior retinal stimulation. These gain control effects allow the prediction of simultaneous and successive chromatic adaptation data. The gain-controlled outputs of the receptors then feed a lower-level post receptor stage that consists of two "opponent" mechanisms (T_1 and D_1) and one additive nonopponent mechanism (A_1). (In ATD01, the value for c_3 is zero.) Neural activities from these three mechanisms are compressed nonlinearly and then define a three-dimensional Euclidian vector space. **The length of $A_1T_1D_1$ vectors in that space relate to the apparent brightnesses of light, and the distances between the vectors relate to discriminations between and among chromatic or achromatic lights or samples. The length of the A_1 vector alone is very nearly proportional to CIE luminance.** (Due to nonlinearities, A_1 looses strict proportionality as luminance increases, but note that changes in A_1 mimic level-dependent flicker-photometric spectral sensitivity functions that have been reported.) Outputs from the first post-receptor stage feed a second stage that is (after compression) a classical opponent colors stage. **The A_2 mechanism signals an achromatic percept, the T_2 mechanism signals redness ($+T_2$) or greenness ($-T_2$) and the D_2 mechanism signals yellowness ($+D_2$) or blueness ($-D_2$).**

The ATD01 model incorporates some changes that were made in earlier versions, but it also differs in several ways. (i) A slight and probably inconsequential change was made, and maintained here, in the equation for the *S* receptor. (ii) For ease of calculation, Judd's[3] "corrected" XYZ functions are not used (but, they should be used if one wants luminances to be based on the "corrected" spectral sensitivity function, and/or if near-spectral lights in short wavelengths are of concern). (iii) For suprathreshold predictions, receptor "dark light" or "noise" is neglected. (If noise is required, the *S* receptor's high noise in ATD95[2] should not be used, because it causes a severe shift in the model's white point at low levels.) (iv) To conform to common practice, the signs for yellow and blue are reversed relative to earlier models. (v) The various weighting coefficients are changed, and (vi) a new gain control equation is used. Items (v) and (vi) are discussed in the following paragraphs.

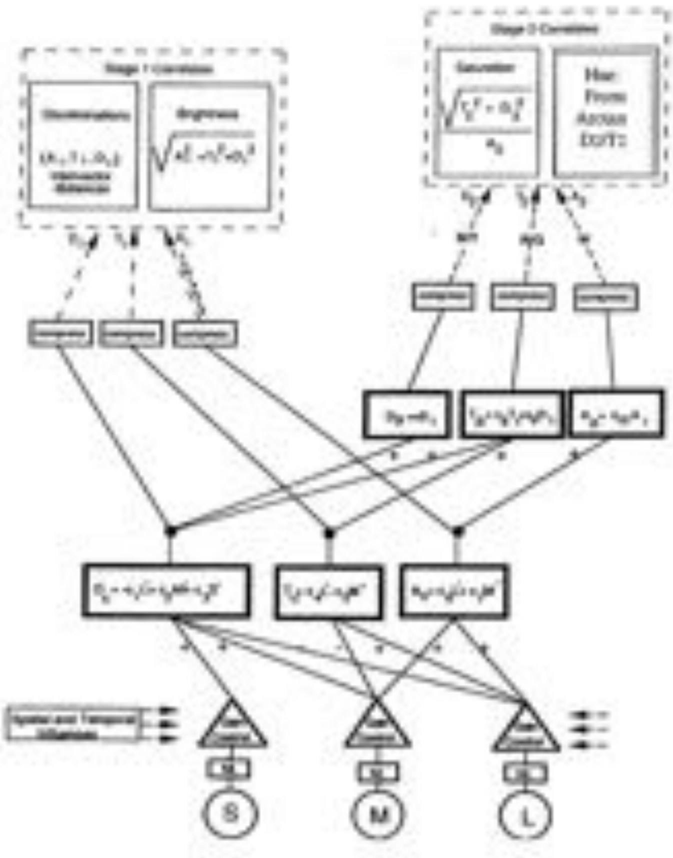


Figure 1. Diagram of ATD01

An explanation for the weighting coefficients in ATD01 raises profound issues regarding white-point normalization in color appearance experiments. The ATD models have been criticized, because they do not allow such normalization, but that is strength of the model. All other models, because of inherent limitations, must normalize white points, and experiments designed to test those models implicitly recognize the limitation by **defining** the neutral sample. However, ATD models make absolute, not relative predictions. An ATD model can be thought of as an "Average Observer," who has his/her own white point, but that theoretical observer cannot be persuaded that a non-neutral sample is really achromatic. **Within the framework of ATD, all experiments should be carried out without normalization of the neutral point. Other experimental data are now obsolete (at least for model competitions) because they were conceived within an incomplete theoretical framework.** Observers should be required to make their judgments just as they perceive the samples -- the model's gain control mechanism automatically adjusts for changes in adaptation produced by varying the illuminants, because **it is, by its very nature, a model for chromatic adaptation.** To apply ATD to appearance data its neutral point is moved by changing the weightings for the receptor inputs to the first opponent stage. However, this is not satisfactory, because the model will then "behave" as if it has that white point, whereas real observers will still judge most samples based upon their (the observers) true achromatic points. Therefore, after adjusting ATD's neutral point to conform to the normalization of a particular experiment, further fine-tuning of the receptor weights is required. **Note that ATD01 is not to be considered as a normative model for an Average Observer-- rather it is normalized and adjusted to conform of the normalization of the data being predicted. Previous models are closer to a normative Average Observer.**

2.1 The new gain control equation

The gain control equation for prior ATD models was inadequate for two reasons. As is true for ATD01, predictions of adaptation effects assume that receptor gain control is affected by adapting fields or lights of various sizes and durations, and the model includes an adjustable weighting factor for variations of those influences. For example, if a large red field exactly surrounds a white target, then the gain control effect of that red light might be multiplied by, perhaps, 50, and the resulting predictions of a strong dimming and greening of the target were excellent. A logical problem was that the same rule would apply if test and adaptation fields were identical, and this incorrectly implied large changes in target brightness, if the target's size were merely increased. A second problem concerned the fact that a given adapting field will not have the same proportional effect on a slightly dimmer field than on a much dimmer field. A model should not suggest that the attenuating effect of an adapting field can be expressed as a multiplicative reduction factor. Note that this has nothing to do with the nonlinearities in the system -- the problem exists no matter what nonlinearities lead to the attenuating factor. This problem existed in prior ATD models, and it meant that ATD could not possibly have predicted much of the Werner and Walraven[8] data. Indeed, an extremely unlikely combination of two programming errors made impossible predictions look very good (and this author very bad). Both problems suggest that **gain control must depend not only on a receptor's own activity (self adaptation) but also on the difference between receptor activities for a target light and an adaptation light**. The following gain control equation (for *L* as an example) incorporates this idea. (*L* is for the target and *La* for the adapting light.)

Attenuation Factor = $\sigma/[\sigma + L + k(La - L)]$, only if $La > L$, otherwise $(La - L) = 0$

The value for σ is fixed in the model, and k depends upon the size and duration of adapting lights or fields. This equation reduces to self adaptation when the adapting receptor activity is equal to, or less than, receptor activity from the target, and it means that, for a given adaptation light, the attenuation factor increases as the target light dims.

3. ATD01 EQUATIONS

It is assumed that *XYZ* tristimulus values, **with *Y* in photopic trolands**, are specified for a given "target" light or sample. Also specified must be the adaptation values, X_a, Y_a and Z_a, which might be based on some weighted combination of all prevailing adapting fields. The problem is to derive the final values for A_1, T_1 and D_1, and A_2, T_2 and D_2. [Note that, if Y_t is luminance in trolands, and if Y_c is in cd/m^2, then $Y_t = (18)\, Y_c^{0.8}$

(3.1) Calculate responses in *LMS* channels for both "target" (*L*, *M*, and *S*) and adapting field (L_a, M_a and S_a).

$L = (0.16X + 0.56Y - 0.034Z)]^{0.70}$, $\quad M = (-0.40X + 1.16Y + 0.084Z)]^{0.70}$ and $\quad S = (0.017Y + 0.27Z)]^{0.70}$

$L_a = (0.16X_a + 0.56Y_a - 0.034Z_a)]^{0.70}$, $\quad M_a = (-0.40X_a + 1.16Y_a + 0.084\,Z_a)]^{0.70}$ and $\quad S_a = (0.017Y_a + 0.27Z_a)]^{0.70}$

(3.2) Calculate L_g, M_g and S_g, which are receptor responses after gain control. The *LMS* receptor signals, are multiplied by their respective attenuation factors, $\sigma/[\sigma+L+k(L_a-L)]$ or $\sigma/[\sigma+M+k(M_a-M)]$ or $\sigma/[\sigma+S+k(S_a-S)]$, where $\sigma = 220$ and $k=5.5$, and only if $(L_a>L)$ or $(M_a>M)$ or $(S_a>S)$. Otherwise, (L_a-L) or (M_a-M) or $(S_a-S) = 0$.

$L_g = L[200/(200+L+5.5(La-L)]$, $M_g = M[200/(200+M+5.5(Ma-M)]$, $S_g = S[200/(200+S+5.5(Sa-S)$. (La-L, etc as **3.2** above)

(3.3) Calculate the initial (subscript i) uncompressed responses for the stage 1 mechanisms, and the initial (subscript i) uncompressed responses for the stage 2 mechanisms.

$A_{1i} = 3.57L_g + 2.64\,M_g$ $\qquad T_{1i} = 6.90\,L_g - 6.90\,M_g$ $\qquad D_{1i} = -0.83\,L_g + 1.00\,S_g$

$A_{2i} = 0.09\,A_{1i}$ $\qquad T_{2i} = 0.60\,T_{1i} + 0.75\,D_{1i}$ $\qquad D_{2i} = -D_{1i}$

(3.4) Calculate the final (compressed) responses *for* $A_1T_1D_1$ and for $A_2T_2D_2$.

$A_1 = A_{1i} / (200 + |A_{1i}|)$ $\qquad T_1 = T_{1i} / (200 + |T_{1i}|)$; $\qquad D_1 = D_{1i} / (200 + |D_{1i}|)$;

$A_2 = A_{2i} / (200 + |A_{2i}|)$, $\qquad T_2 = T_{2i} / (200 + |T_{2i}|)$, $\qquad D_2 = D_{2i} / (200 + |D_{2i}|)$.

4. CALCULATE SUMMARY MEASURES FOR COLOR APPEARANCES AND COLOR DIFFERENCES

(i) The **Brightness** (*Br*) of a sample is proportional to its vector length, and the **Lightness** (*Li*) of a test sample (t) is its brightness relative to the brightness of a reference (ro) scaled to 100. (ii) Tentatively, a sample's **Colorfulness** (*Co*), **Chroma** (*C*) and **Saturation** (*Sa*) are all predicted using the ratio of its chromatic to achromatic signals. (iii) The correlate of **Hue** (*H*) for a sample is its angular position in T_2D_2 space, with quadrants 1-4 being Red/Yellow, Yellow/Green, Green/Blue, and Blue/Red.

$\mathbf{Br} = (A_1^2 + T_1^2 + D_1^2)^{0.50}$, $\qquad \mathbf{Li}_t = [Br_t / Br_{ro}]\, 100$, $\qquad \mathbf{Co} = \mathbf{C} = \mathbf{Sa} = (T_2^2 + D_2^2)^{0.50} / A_2$ and

$\mathbf{H} = \text{Arctan}\,(D_2 / T_2)$, (From zero to 360 degrees, with attention to the quadrant in which the ratio falls.)

Regarding color differences, if A_1, T_1, and D_1 values are determined for two lights, with Δ being the difference between corresponding ATD values, then the discriminability between the two lights is inferred by calculating the intervector distance, which is the **small-step color difference, ΔE_s** The difference required for discrimination depends, of course, on many factors. A $\Delta E_s = 0.002$ would be approximately correct for predicting MacAdam's ellipses, whereas $\Delta E_s = 0.005$ has been found to be more appropriate for predicting a wide variety of other discrimination and detection results. Judgments of **large color differences, ΔE_L** are directly related to intervector distances in $A_2T_2D_2$ space.

$$\Delta E_s = (\Delta A_1^2 + \Delta T_1^2 + \Delta D_1^2)^{0.50} \quad \text{and} \quad \Delta E_L = (\Delta A_2^2 + \Delta T_2^2 + \Delta D_2^2)^{0.50}.$$

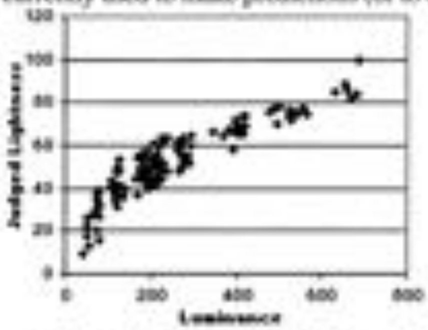
5. CHROMATIC ADAPTATION

By their very natures, all ATD models have been chromatic adaptation models, but ATD01 makes that fact even more obvious. If the input values, X_a, Y_a and Z_a are for a chromatic adapting light or field, then ATD01 will predict chromatic adaptation (with an appropriate choice of ***k***). Space limitations prevent illustrations here, but important predictions are shown in previous articles.

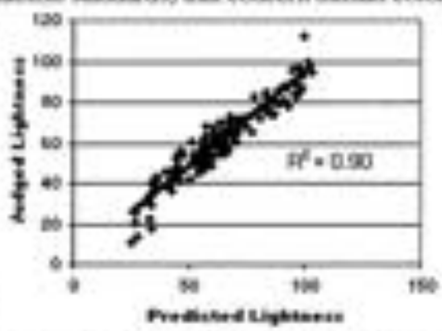
6. PREDICTIONS, DISCUSSION AND SUMMARY

Juan[3] obtained lightness, hue, colorfulness and saturation judgments of 132 reflecting samples. The adapting *XYZ*'s used for ATD01 predictions were, ***Xa=232, Ya=276***, and ***Za=121***, with ***Ya*** in trolands. For the predictions, final $A_1T_1D_1$ and $A_2T_2D_2$ values were calculated for each sample using equations from sections 3.1 to 3.4, above. Figure 2 shows Juan's obtained lightness judgments as a function of luminance. Note that the upper right point is not a data point, but rather it represents the defined lightness of the reference sample. For some reason, samples of the same luminance, or essentially the same luminance, as the reference were judged less light than the reference; therefore, for prediction purposes, the sample judged to have maximum lightness was the reference. Figure 2 shows the predictions. Figure 3 shows hue angle predictions, which can be grossly deceiving when even miniscule deviations are either across the 0°- 360° boundary, or around the origin. Fig. 4 shows colorfulness predictions. It might be surprising that the **best** colorfulness predictions were made using what is defined as saturation within ATD models, and what others might call chroma. That is, for predictions, ATD01 forms the ratios of samples' chromatic signals to their achromatic signals, and, because the achromatic signals are proportional to luminance, this is equivalent to comparing the samples to equal luminance white references. (For carefully considered reasons, CIE definitions are rejected here.) Although not shown, ATD01's saturation correlate also predicted colorfulness judgments from the only set of LUTCHI data (R-HL, phase 1) that was examined. Figure 5 shows more about the saturation-colorfulness-chroma question. It compares the observers' colorfulness and saturation judgments. Note that many samples (which were all dark samples) with near-zero colorfulness were judged to have almost maximum saturation. This did not seem reasonable, especially because many of the high saturation samples were near-neutral. Therefore 30 samples with luminances below 20 (max = 100) were eliminated from the comparison, and Fig. 6 shows the result. Because what others call "chroma" made the best predictions of the colorfulness data, and because of the correspondence between colorfulness and saturation shown in Fig. 6, it appears that judgments of colorfulness, saturation and chroma all depend upon the ratio of the chromatic to achromatic components of an observer's percept.

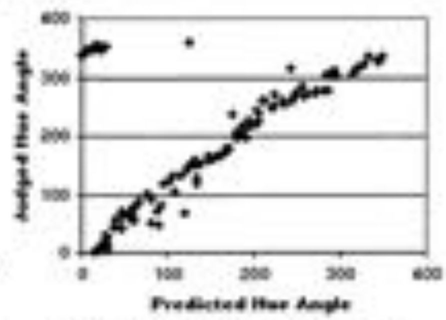
In conclusion, consider that ATD is not a model in the usual sense. It is best described as a quantitative theory of color vision that builds on and validates the theoretical ideas of our greatest contributors, including Helmholtz, Hering, von Kries, and Mueller. It is very powerful, and it should now be seriously considered by the vision community as a replacement for all models that are currently used to make predictions (or to establish standards) that concern human color perception.



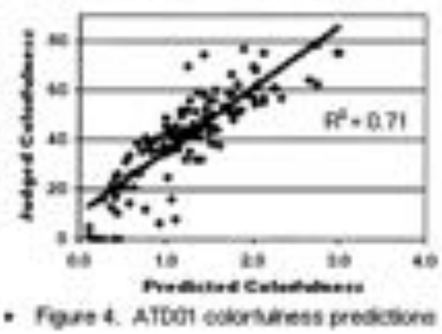
• Figure 1. Luminance vs lightness



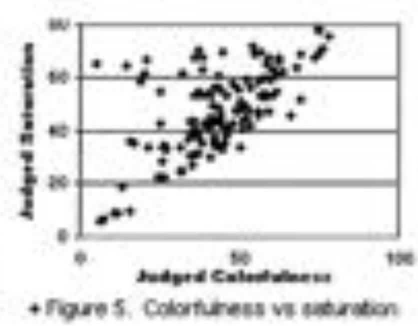
• Figure 2. ATD01 lightness predictions



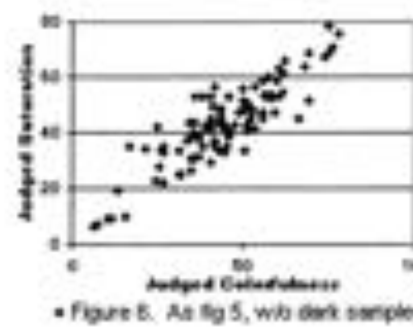
• Figure 3. ATD01 hue predictions



• Figure 4. ATD01 colorfulness predictions



• Figure 5. Colorfulness vs saturation



• Figure 6. As fig 5, w/o dark samples

7. REFERENCES

1. D. Judd, "Correlates of the visual stimulus," In Stevens, *Handbook of Experimental Psychology*, Wiley, New York, 1951.
2. S. Guth. See references in three articles reprinted in R. Eschbach and K.Braun, *Recent Progress in Color Science*, Society for Imaging Science and Technology, Springfield, Virginia, 1997.
3. D. Judd, "Colorimetry and artificial daylight," *Proc. CIE*, part 7, p. 11, Paris, 1951.
4. J. Werner and J. Walraven, "Effect of chromatic adaptation …background color," *Vision Res.* **22**, pp. 929-943, 1982.
5. G. Juan, *Verification of Colour Appearance Models Using Magnitude Estimation Data*, Ph.D. thesis, University of Derby, Derby, UK, 2000.

* Correspondence: email *guth@indiana.edu* for information or current address.

Floating phenomenon and mode of color appearance

Hironobu Aoki, Hiroyuki Shinoda and Mitsuo Ikeda
Dept. of Photonics, Ritsumeikan University

ABSTRACT

We found an interesting phenomenon concerning the motion perception and the mode of color appearance. We suppose you are holding a stiff sheet of picture and move it laterally to and fro in front of the eye. Though the picture and all items in it move physically altogether with your hand, your perception is not always so. But when the picture that is a figure appears light-source color mode and a background of object color, a figure appears to slip on a background. We call this a "floating phenomenon". We predicted the occurrence of floating phenomenon depends on whether the color is perceived to belong to an object or not. To examine the relation between the floating phenomenon and the mode of color appearance, we measured the luminance threshold of floating phenomenon and the transition luminance between two color modes by constant stimulus method to use a mondrian. Our results show the floating never occurred when the target appeared as object color mode. The floating phenomenon may be caused by the separation of the light-source color from an object or week-belonging.

Keywords: light-source color mode, object color mode, motion perception, fluttering heart

1. INTRODUCTION

In the present paper we will report about an interesting phenomenon concerning the motion perception and the mode of color appearance. Let us suppose you are holding a stiff sheet of picture and move it laterally to and fro in front of the eye. Though the picture and all items in it move physically altogether with your hand, your perception is not always so. When a certain color pattern, for instance, that made of a vivid red figure and a vivid blue surround is moved to right and left, the red figure appears to move asynchronously with respect to its blue background. This phenomenon, called the "fluttering heart", is observed under dim illumination and normally accounted by different temporal characteristics between rod and cone systems[1, 2]. We found a similar phenomenon but occur with a figure of light-source color or aperture color mode. A figure of light-source color appears to slip on a background of object color. We call this a "floating phenomenon" and distinguish it from the normal fluttering heart.

Colors are normally classified into two different modes by their appearance not by physical conditions. When a color appears as a surface of an object, it is called the object color, or surface color. On the other hand, a color that appears to be emitting light from itself is called the light-source color, or aperture color[3, 4]. You cannot see any textures in the light-source color or aperture color and sometimes you feel difficult in localizing the light-source color in depth direction. The object color is bound to an object's surface but the light-source color is not. This week binding force onto an object might cause the floating or the slipping of the light-source color.

To examine the relation between the floating phenomenon and the mode of color appearance, we measured the luminance threshold of floating phenomenon and the transition luminance between two color modes by constant stimulus method. In the experiment, subjects were asked to move a sheet of the mondrian pattern by hand and to judge whether a small target in the center appear to slip or not, at various target luminances. If the occurrence of floating phenomenon depends on whether the color is perceived to belong to an object or not, the luminance thresholds for the floating and the transition luminance should agree with each other.

2. EXPERIMENT

2.1 STIMULUS AND APPARATUS

A mondrian pattern was made of ten pieces of color chip pasted on a stiff board of 30 cm x 40 cm square. Figure1 shows the arrangement of ten color chips in the mondrian pattern and their Munsell color notation. In the center there was a small hole of 0.4 cm, which was lit by a backlight through a red color filter (FUJI SP-3) to provide the small red target, as shown in Figure2.

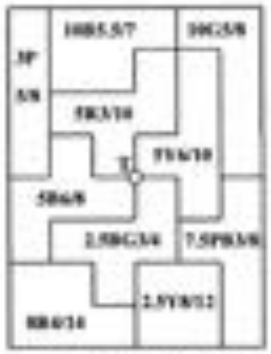


Figure1. The arrangement of ten color chips in the mondrian pattern and their Munsell color notation: T,target.

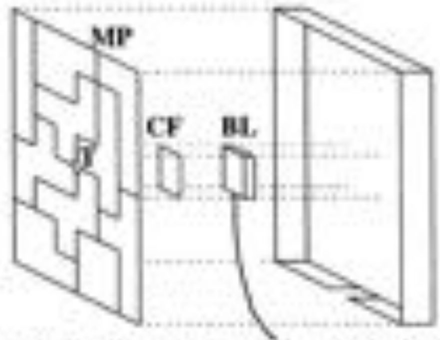


Figure2. The object to move: MP, mondrian pattern; T, target; CF, red color filter (FUJI SP-3); BL, backlight.

Figure3 shows the experimental setting. The mondrian pattern was put uprightly, supported by two horizontal guiderails. The pattern was slid by subject along the guiderails. A subject sat in front of the pattern and slide the pattern right and left by hand when judging if the target appears to slip or not. The scale of 5 cm step on the upper guiderail was used to specify amplitude of horizontal oscillation. The viewing distance was 42 cm. The mondrian pattern subtended 39 deg. horizontally and 51 deg. vertically from that distance. The size of the target was 0.5 deg. The illumination of the backlight was provided by a halogen lamp through fiber optics. Its intensity was varied through a light controller. The experimental booth was lined with black cloth and illuminated by fluorescent lamps on the ceiling. The intensity of the ceiling light was being monitored by measuring its vertical illuminance with an illuminance meter beside the mondrian pattern.

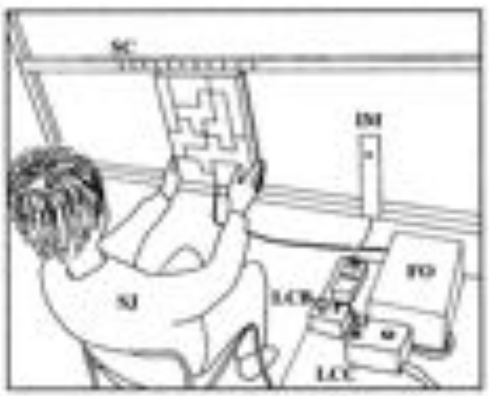


Figure3. The experimental setting: SJ,Subject; SC,Scale; IM, Illuminance meter (MINOLTA T-1M); FO, Fiber optics (Fiber Lite PL-800); LCB, Light controller of the backlight; LCC, Light controller of the ceiling light.

2.2 TASK, CONDITIONS, AND SUBJECTS

Two different experiments were conducted, FLOATING and MODE experiment. In FLOATING experiment, the luminance threshold for the floating was measured. In MODE experiment, the luminance threshold for the light-source color mode was measured. The both thresholds were obtained at 3 different illuminance levels, 2, 8, and 32 lx.

A subject's task in FLOATING experiment was to move the mondrian pattern right and left and judge whether the target appears to move synchronously or asynchronously with respect to the mondrian background. The subject was required to judge within 20 oscillations. The amplitude of oscillation was about 5 cm and its speed was about 24 cm/sec. A subject trained to keep the constant operation at the beginning of every session. In a single session, the room illuminance was kept constant either at 2, 8, or 32 lx. The luminance of the target was randomly selected from 14 levels ranging from 0.14 to 39 cd/m^2 at the illuminance of 2 lx, 13 levels from 0.6 to 36 cd/m^2 at 8 lx, and 14 levels from 1.4 to 107 cd/m^2 at 32 lx. 4judgements were collected for each target luminance level in a single session. Each subject run 15 sessions in total and 20 judgements were obtained for each luminance level of the target.

A subject's task in MODE experiment was to report the appearance mode of the target. Besides "object color" and "light-source color", we employed another category "unnatural surface color" to describe an intermediate appearance between object and light-source color when the target looks too bright as an object's surface but does not appear as a light-source. The procedure was the same as in the FLOATING experiment. In one session, responses were collected for each luminance level of the target. Ten mode judgements were obtained for each luminance level from 2 sessions.

Four subjects with normal color vision, HS (35, male), HY (23, male), HH (24, male), and HA (22, male), participated in the both experiment.

3.RESULTS AND DISCUSSION

A probability for floating perception (Pf) was calculated from 20judgements in FLOATING experiment. Both probabilities for object color perception (Po) and that of light-source color perception (Pl) were calculated from 10 judgements in MODE experiment. These three probabilities from subject HA are shown for each luminance in Figure4. The abscissa indicates the target luminance (cd/m^2) and the ordinate indicates probability. Abscissa is scaled logarithmically. Square symbols stand for Po, triangle symbols for Pl, and diamond symbols for Pf.

In every chart, Po is unity at low target luminance levels. When the backlight intensity was low, the target appeared as though the small red patch was pasted on the mondrian background. Interestingly, though it was emitting light physically, the target appeared as a light-reflecting surface. As target luminance increases, Po gradually goes down and finally reaches zero. While Po is decreasing, Pl still stays at zero. Around these luminance levels, the target starts to appear as a fluorescent surface, but not appears to emit light yet. With further increase in target luminance, Pl goes up and finally reaches unity. When Pl goes up, Pf also goes up with target luminance. That means the floating phenomenon starts to occur where the mode of appearance shifts to the light-source color mode. It should be noted that the floating phenomenon never occurred while the target looked as an object's surface.

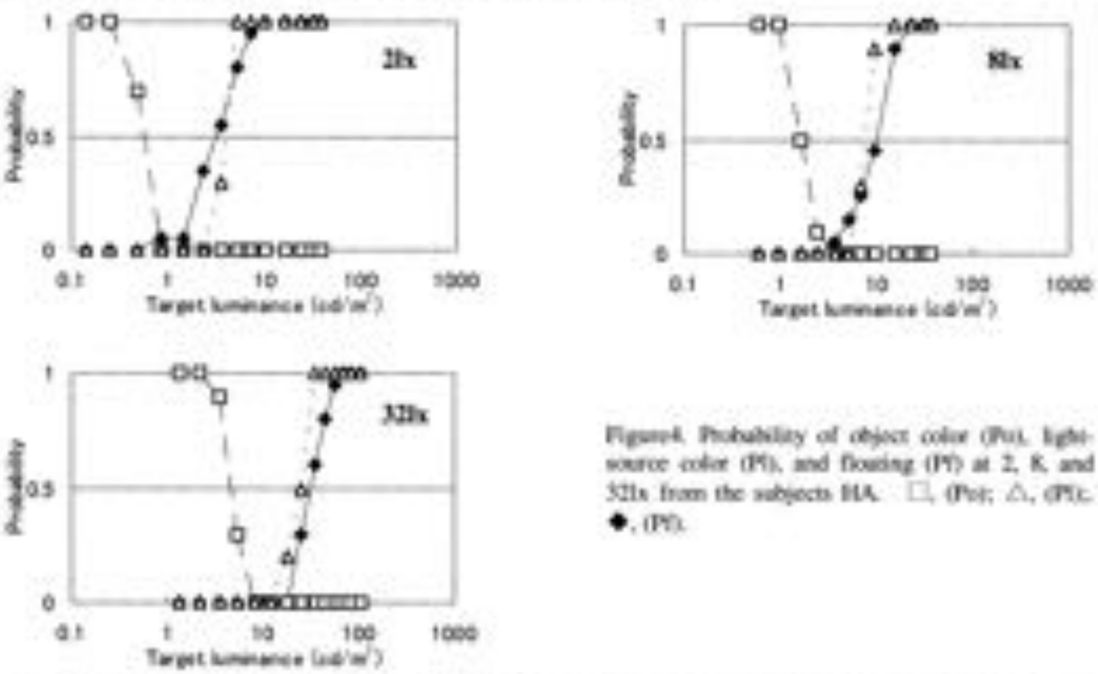


Figure4. Probability of object color (Po), light-source color (Pl), and floating (Pf) at 2, 8, and 32lx from the subjects HA. □, (Po); △, (Pl); ◆, (Pf).

Three luminance thresholds for object color mode (Lo), light-source color mode (Ll), and floating phenomenon (Lf) were defined respectively as the target luminances that gave 0.5 probability of Po, Pl, and Pf. Three arrows indicate Lo, Ll, and Lf in each chart of Figure.4. Luminance thresholds, Lo, Ll, and Lf, are all shown as functions of illuminance level in Figure5. The luminance thresholds from subject HA and those from subject HS are shown as examples. The abscissa indicates illuminance (lx) and the ordinate indicates the target luminance (cd/m^2). Both axes are scaled logarithmically. The symbol notations are the same as in Figure4.

Three luminance thresholds increase lineally with illuminance level. Area of every chart can be divided into three different areas corresponding to appearance modes: an area below the line of Lo stands for the object color, that between the lines of Lo and Ll is for the unnatural surface color, and that above Ll is for the light-source color. The chart area can be also divided in terms of the floating perception: an area above the line of Lf shows the floating occurs. The area for the light-source color mode and that for the floating phenomenon overlap with each other, as was expected.

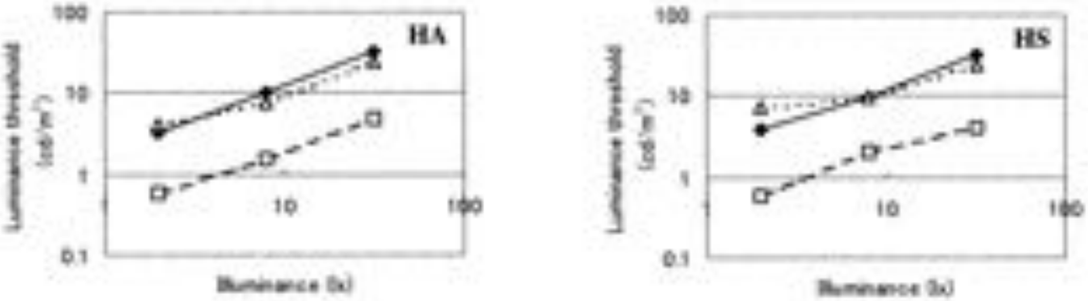


Figure5. Results of luminance thresholds for object color (Lo), light source color (Ll), and floating (Lf) at 2, 8, and 32lx from the subjects HA and HS. □, (Lo); △, (Ll); ◆, (Lf).

It should be noted that the floating phenomenon occurred even at 32 lx. The fluttering heart phenomenon is normally accounted by the difference in spatio-temporal characteristics between rod and cone systems. The cone system is fast and the rod's dull. If the floating phenomenon were also caused by the same mechanism, the floating would have never occurred in the photopic vision. This was not the case, it occurred even at 32 lx. The subjects likely pursued the target when they try to judge the slip. That means the target was always fell onto the fovea, say a rod free area. This may also reject the account by the difference between rod and cone systems. When the target appeared to move asynchronously with the background, all subjects reported it appeared to lag behind the background at turning point of oscillatory movement. This also opposes to the rod-cone account. In conclusion, the floating phenomenon is different from the fluttering heart. Coincidence of occurrence of the floating and the light-source color suggests that the floating phenomenon may be caused by the separation of the light-source color from an object or week-belonging.

4.REFRENCES

1. Michael W.von Grunau, "The Fluttering Heart and spatio-temporal characteristics of color processing- I ", Vision Research, 15, pp431-436 (1975)
2. Michael W.von Grunau, "The Fluttering Heart and spatio-temporal characteristics of color processing- II ", Vision Research, 15, pp437-440 (1975)
3. H.Yamaguchi, H.Shinoda and M.Ikeda, "Determinant of the size of recognized visual space of illumination in a natural environment", AIC Midterm Proceedings, (2000)
4. M.Ikeda, H.Shinoda and Y.Mizokami, "Three dimensionality of the recognized visual space of illumination proved by hidden illumination", OPTICAL REVIEW, 5-3, pp200-205 (1998)

---

* Correspondence: ro000971@se.ritsumei.ac.jp; phone +81-77-566-1111 (ex.8552); fax +81-77-561-2663; Dept. of Photonics, Faculty of Science and Engineering, Ritsumeikan Univ., 1-1-1, Nojihigashi, Kusatsu, Shiga, 525-8577 JAPAN

The effect of the luminous of the peripheral visual field on the binocular vision

~Aspects of three-dimensional seeing on the different color stimulus observation with stereoscope on CRT display

Yumi AWANO
Tokyo Zokei University

ABSTRACT

The purpose of this study is to investigate the characteristics of color in more detail, especially on the perception of depth, to verify the order of the color coordination that amplify the perceptual depth on the computer mediated drawing. It can draw interesting achievements to valid expression in the new method of three-dimensional presentation.

On CRT display, in the case of the stimuli that different wavelength set with luminance difference and the other case of the stimuli that different wavelength set with same luminance on the bright peripheral visual field (white) were discussed in the previous report[2]. In this paper, I reported the results of some observation on the dark peripheral visual field, gray (some luminous as the stimulus) and black, in the same manner to discuss the luminous effect of the peripheral visual field on the basis of comparison with the results of the blight peripheral visual field.In the results,the influence of the luminance of the peripheral visual field to the perception of the superiority or inferiority and occurrence of the qualitative change are recognized.Almost of those phenomenon seems quite probable that occurred results in the contrast of the luminance factor including the characteristics of each dominant wavelength.

keywords: stereopsis,stereoscope, binocular fusion or rivalry, color mixture, advancing or receding color, CRT display

1.INTRODUCTION

As a clue to elucidate above order, I extracted the phase of color advancing and receding from the seeing of binocular vision on CRT display with stereoscope. The outline of the experimental method is as follow; when the different wavelength and figure stimuli are given to each eyes, binocular rivalry or binocular fusion or binocular color mixture has percepted. It stand for the characteristics of color as dominantive or repressive. The dominance color order and the transparency color order were derived from the experimental results. The following point was pointed out as a result of the experiment A,the experiments performed on white background.

1)The affecting factors are luminance,hue,a dominant eye,form and position
2)Perception of color mixture on binocular fusion accompanying phenomenon of transparency are generaly related with the phase of subtractive color mixture.
3)The phase of additive color mixture are recognizwd in some cases.

1.1. difinision for valuation

In those analyzing, 'dominance' defined as hiding to the other. This definition including also the condition of the perfect hiding on the apparent phase of binocular rivalry imperfect hiding on the uncertain phase of binocular rivalry or fusion[1]. Deep and clear condition is not always analyzing as 'dominance', and condition like translucent firm shown the behind color is not always analyzing 'repression'. According to the definition, some case of the judgement of dominance accompanying the transparence tendency. And 'transparency' defined as the condition of imperfect fusion (the retreating stimulus color peep out from the hole on the advancing stimulus surface, perfect fusion that percept the mixture color) or perception the stimulus color as volume color. The phase of translucent overlapping which appear color mixture seems to be a worthwhile subject to continue the investigation to reach out the sufficient explanation about which factor make us to judge the spatial order of color and how the spectral energy distribution of each stimulus effect. Further more, the stimuli without luminance

* awano@zokei.ac.jp ; http//www.zokei.ac.jp/ ; Tokyo zokei university ; phone +81-426-37-8111 ; fax +81-426-37-8110 ; media design course(Interface design section),1556 Utsuki-cho,Hachioji,Tokyo,#192-0992,

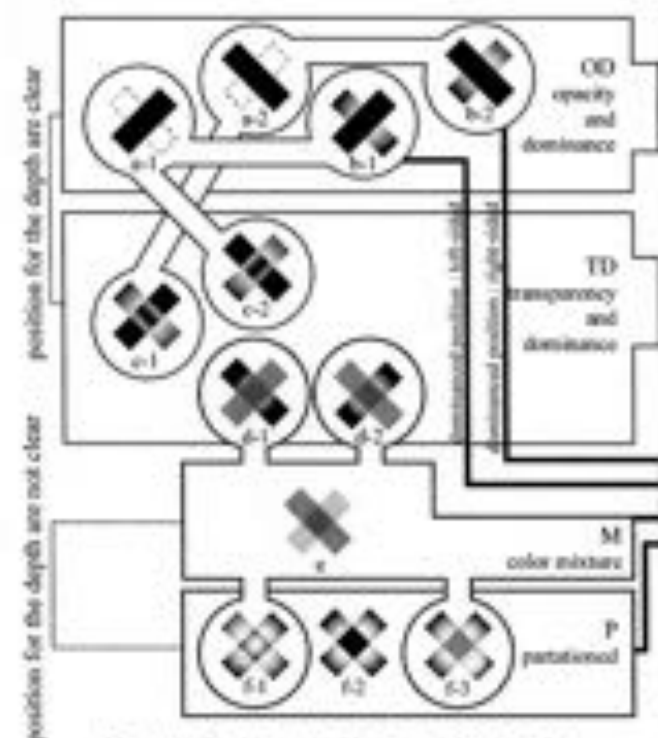


Figure 1. The 12 types of index and the valuation

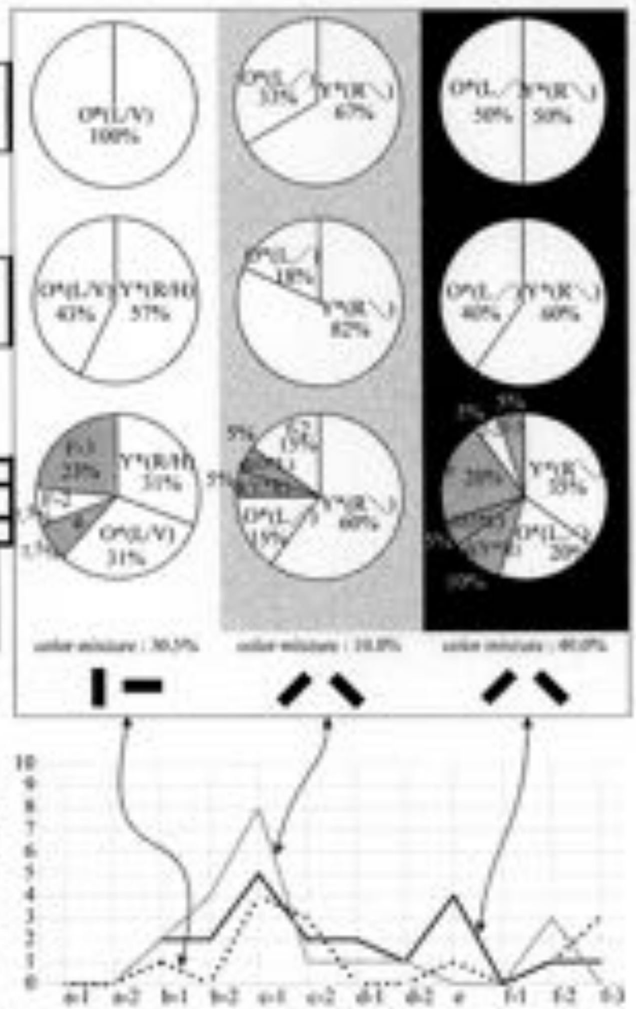


Figure 2. Orange vs. Yellow(*17.5cd/m^2 each)

Figure 3. The variation of index f-2

difference or the stimuli with only wavelength difference have been considered to be repression occurring the binocular rivalry[2,3]. Regarding the participation in the seeing of stimulus color, the dark peripheral visual field has been considered to be assist occurring the binocular fusion. On CRT display, in the case of the stimuli that different wavelength set with luminance difference and the other case of the stimuli that different wavelength set with same luminance on the bright peripheral visual field (white) were discussed in the previous report. In this time, I report the results of some observation on the dark peripheral visual field(gray as same luminance as the stimulus) and black, in the same manner to discuss the luminous effect of the peripheral visual field on the basis of comparison with the results of the blight peripheral visual field.

1.2. View point of these experiments

The influence of the luminous of the peripheral visual field on the perception of the superiority or inferiority and occurrence of the qualitative change(for example transparencization, filmization and color mixture) is the main theme of this paper.

I will discuss the theme under the following topics in the light of the results of these experiments as a whole.

1)The validity to the occurrence of binocular fusion by the long time presentation of the stimulus
2)The validity to the occurrence of binocular fusion by the dark periphery of visual field
3)The validity to the occurrence of binocular fusion by the small binocular color difference
4)The opponent-color pairs(for example red vs. green, yellow vs. blue) stimulus are fail in binocular fusion
5)The middle wave length area is dominant to the long or short wave length area.
6)Theory of additive color mixture can not adapted to the color mixture of binocular fusion.

2.EXPERIMENTAL PROCEDURES

Experiment-B (gray background which luminous maintained as same as the stimulus ,17cd/m^2) and experiment-C (black background) performed with 6 hues which luminous maintained as same as the experiment-A-3, 17cd/m2. 5 persons participated in the experiment. Each experiment are performed on other day for each person to exclude an influence of eye fatigue. The condition of these experiments are changed as the following.

1)To exclude an influence by the arrangement of vertical and holizontal ,the figure of the stimulus are leaned at 45° from the experiment-A. Subjects percept the cross which leaned at 45° .

2)The length of time for observation is 60 seconds by 1 pair as standard and the subjects asked to report the phase of view enough.

3) Without replacing the arrangement of the same color combination to right and left, the results about 15 sets of the colors are reported in this paper.

3.RESULTS

3.1.Valuation

Type OD shows a tendency to perceive the frequently replacing of superior and repression(binocular rivalry)at the time of the initial stage of the observation.On the other hand, the qualitative change (transparencization) of the stimulus perceived with type TD, M, P.It indicates the binocular fusion because of they shows a tendency to approach stability a little. A little replacing to the position of the depth are recognized often even type P. It is due to just a few color inclination in the intersection toward the one side color to make perceive the replacing. The typical condition of binocular fusion is index-e with filmization and occur the color mixture that shows a tendency of becoming stable.Besides,not as the hue change, the impression as one side color become deeper or brighter or whitish were recognized.These are not the pahse of color mixture.

3.2.Experimental results

The ranking order of the dominance color which selected on experiment-A,-B,-C are as following(the number means the selected count). So the result of the experiment A was re-totaled in accordance with the 15 sets of the stimulus combination and the judging regulation of the experiment B&C that the ranking order is different from the previous report.

- The number of times that is superior regardless of the qualitative aspect of the superiority stimulus(a+ b+ c+ d)

experiment-A (white) R(46)>O(41)>Y(27)>G(25)>B(23)>P(10)
experiment-B (gray) R(62)> O(52)>G(40)>P(38)=Y(38)>B(28)
experiment-C (black) O(56)>R(48)=P(48)>Y(39)>G(38)>B(37)

- The number of times with the qualitative change (c, d, e, f as transparencization, filmization, color mixture,). But, because superiority or inferiority relations were not clear, e&f were counted to both. As for the color which got adjacent numerical value, we should take into consideration of the possibility that order replacing caused by the increase in the observation data from now on.

experiment-A (white) O(44)> R(34)>G(29) > B(28)>Y(21)> P(17)
experiment-B (gray) G(38)>Y(36)>O(36)> P(32)>B(30)>R(20)
experiment-C (black) Y(47)>G(41)>R(39)>O(30)>B(24)>P(23)

The total selected number of times of each index by each phase of view about the pair of yellow and orange are shown as an example in Figure.2. since the characteristics about superiority,occurrence of the qualitative change and occurrence of the color mixture were admitted on Y through the experiment A. The circular graph of the upper step shows the ratio of opacity and dominance (type OD),the middle step shows the ratio of transparency and dominance (type TD) and the lower step shows the ratio of occurrence of the qualitative change(the shading in the circle). The line graph of the bottom step shows the selected number of times of each index.

- The order of the combination that occurs the impression of color mixture easily in the white background
O-Y(30.5%)>Y-G(25.0%)>Y-P(16.0%)>Y-R(12.0%)>Y-B(0.0%)
- The order of the combination that occurs the impression of color mixture easily in the gray background
Y-G(25.0%)>Y-B(16.5%)=Y-B(16.5%)>Y-R(10.0%)=O-Y(10.0%)
- The order of the combination that occurs the impression of color mixture easily in the black background,
Y-G(60%)>O-Y(40%)>Y-R(33%)>Y-B(16.5%)>Y-P(0.0%)

· When it is compared synthetically, it becomes the following order.
Y-G(60%,bk)>O-Y(40%,bk)>Y-R(33%,bk)>O-Y(30.5%,w)>Y-G(25.0%,w)=Y-G(25.0%,g)>Y-B(16.5%,g)=Y-B(16.5%,g)> Y-B(16.5%, bk)> Y-R(12.0%,w)> Y-R(10.0%,g)=O-Y(10.0%,g)> Y-P(0.0%,bk)= Y-B(0.0%,w)

4.DISCUSSIONS

4.1.The validity to the occurrence of binocular fusion by the long time presentation of the stimulus, and by the dark periphery of visual field

Though the perception of type OD decrease follows in the progress of the observation time, there are many combinations which continue the binocular rivalry slowly with changing in the type TD type. In the combination which occur the color mixture easily, the seeing of binocular fusion perceived since the early stage of the observation time.Though the long time presentation of the stimulus becomes the factor that restrained the seeing of binocular rivalry, it is assumed that the factor of the main wavelengh area has a stronger influence when there is a color condition in the stimulus. Futhermore,it is assumed that the dark peripheral visual field effectively in the binocular fusion from the selected number of times of c~f increasing in the case of the black and gray background against the case of the white background(Figure.2.).

4.2.The validity to the occurrence of binocular fusion by the small binocular color difference and the verification about the the opponent-color pairs(for example red vs. green) stimulus are fail in binocular fusion

The perception of color mixture easily occurred with the combination which dominant wavelength are closely both on the white or the black background.But in the case of on the gray background, the perception of color mixture were hardly occurred.Generally,it is clear that the dark peripheral visual field is effective for the occurrence of the color mixture and the order also accordance with the distance between each dominant wavelength.

4.3.Theory of additive color mixture can not adapted to the color mixture of binocular fusion.

When the the third color occurred in the intersection of the cross,almost their impression became muddy or darker than the presented colors.It would be suggested to occur as the subtractive mixture. Though the phenomenon which I paid attention to with experiment-A (index f-1) did not recognized,in the case of a few combinations of colors occurred pinkish. It can be seen in the additive color mixture.

4.4.The qualitative change

It recognized that some variation of index f-2(Figure.3.). About transparencization and the color unevenness ,the color unevenness is the first characteristics of transparencization..About filmization,the wing extended in all directions from intersection of the cross often can be impressed as a transparent layer due to looks through the background.

5.CONCLUSIONS

In conclusion,the luminance of the peripheral visual field influenced the perception of the superiority or inferiority and occurrence of the qualitative change in above. Almost of those phenomenon seems quite probable that occurred results in the contrast of the luminance factor including the characteristics of each dominant wavelength.

As for the interesting point in the results of this research,one is the point that 2-D CG bring third dimensions due to the perception of the qualitetive change,and other,the perception of the movement in the depth direction along with the conflict of the information disparity for each eye.Although the phase of the binocular color mixture and qualitative change are too complicated to be examined in detail here,more research regarding about the qualitative change is required.

REFERENCES

1.Y.Awno"*Study on the binocular vision by the different color stimulus on CRT with stereoscope*"*Internet Imaging,proceedings of SPIE volume3964*,pp175-185,SPIE,USA,2000

2. I.P.Howard&B.J.Rogers edit,*Binocular Vision and stereopsis*,pp313-348,oxford university press,New York,1995

3. Y.Wada,T.Ohyama&S.Imai edit,*sense and perceptional psycology handbook new edition*,pp424-425,pp737-767,pp773-776,Seishin-shobou,Tokyo,1994

Tetrachromacy of Human Vision: Spectral Channels and Primary Colors

Vitali V. GAVRIK, Ludwig-Gies-Str.18, 50769 Cologne, Germany. E-mail: gavrik@metronet.de

ABSTRACT

Full-color imaging requires four channels as, in contrast to a colorimeter, can add no primary to matched scene colors themselves. An ideal imaging channel should have the same spectral sensitivity of scene recording as a retinal receptor and evoke the same primary color sensation. The alternating matching functions of a triad of real primaries are inconsistent with the three cones but explicable of two pairs of independent opponent receptors with their alternating blue-yellow and green-red chromatic axes in the color space. Much other controversy of trichromatic approach can also be explained with the recently proposed intra-receptor processes in the photopic rod and cone, respectively. Each of their four primary sensations, unmixed around 465, 495, 575, and 650 nm, is evoked within a different spectral region. The current trichromatic photographic systems have been found separately to approximate the blue and red receptors, as well as their spectral opponency against the respective yellow and blue-green receptors simulated with a single middle-wave imaging channel. The channel sensitivities are delimited by the neutral points of rod and cone and cannot simulate the necessary overlap of non-opponent channels for properly to render some mixed colors. The yellow and cyan positive dyes closely control the brightness of blue and red sensations, respectively. Those red and blue respectively to control the yellow and blue-green sensations on brightness scales are replaced by magenta dye, controlling them together. Accurate rendering of natural saturation, metameric colors, problematic blue-green, purple-red, and low-illumination colors requires to replace the hybrid 'green' channel with the blue-green and yellow channels.

Keywords: photoreceptors, tetrachromacy, color opponencies, primary colors, spectral sensitivity, rod colors, cone colors

1. NON-NEGATIVE COLOR MATCHING IS TETRACHROMATIC

The point of departure of the trichromatic principle that a weighted *sum* of three 'principal colours' supposedly reproduced every other color allowed Thomas Young to suggest the 'red, yellow, and blue' sensitive 'particles' in the retina.[1] Now everybody believes in the trichromacy even if knows that any triad of real primaries (even if the standard RGB triad of spectral colors of maximum saturation) has its own irreproducible moiety of colors within the negative ranges of matching functions. Instead of actual reproduction, a strong desaturation is observed after the addition of respective primary to the test color itself. Also the three cones has never been unequivocally proved. The 'L- and M-cones cannot be distinguished by their shapes or other anatomical means.'[2] Even if signals from some cones were 'transmitted by special types of bipolar and ganglion cells', there was no evidence for them to be just the S-cones and not to detect, say, object boundaries. The trichromatic prejudice, ignoring experimental inconsistences, starts increasingly to mislead technical and medical applications.

'How Thomas Young would have smiled if he had realized the endless controversy to which his suggestion would lead!'[3] The color science has not avoided the controversy hitherto. No stable visual pigment, except for rhodopsin and iodopsin, was isolated from the retinas of ground vertebrates.[1] Genetic variations in color deficients, a priory assumed as 'photopigment genes', gave no independent evidence for the three cones. The M-pigment, biochemically produced together with L-pigment,[4] could be its long-living photochemical intermediate. No M-pigment was sythesized with using opsins from a protanope. Photoelectrical potentials of the single light-sensitive outer segments, OS, of human photoreceptor cells demonstrated only the rhodopsin sensitivity (~500 nm max.) of rod[5] and the iodopsin sensitivity (~560 nm) of L-cone[6] at moderate illumination. A sole 'M-cone' found had the same spectral maximum as the multiple L-cones. No S-cone was found at all and no curve explained the 610-nm hump of foveal sensitivity. The differential light reflection from living retinas at a strong photopic illumination could not be satisfactory explained with the three cone pigments and suggested long-living photoproducts accumulated within photoreceptor cells at photopic illumination.[7] The photo-labile intermediates,[8] living for minutes at physiological conditiom, could be additionally stabilized with using chromatographic techniques. Their significant presence 'in vivo suggests a functional role, since otherwise their formation would operationally interfere with biochemical regeneration' of photopigment.[9] The spectral absorption curves of most cone OS were close to that of iodopsin (~560 nm, 'L-cone').[10] The curves often implied two-pigment mixtures[11] and 'were rejected from precise computations of absorbance spectra' on the base of a single-pigment template.[10] The portion of M-cones (530 nm) increased with surgical illumination and their averaged spectral absorption had a hump at 560 nm. Although Brown and Wald[8] found the M-pigment to be 'bleached' with a light out of its spectral absorption range, the random mixtures of iodopsin and its intermediate are usually considered as the M- and L-cones.[12] The poorly reproducible S-pigment curves (420-460 nm), mainly found until after-surgery keeping of retinas improved,[13] could be assigned[8] to some products of thermal decay of iodopsin.

The opponent color phenomena discovered by E. Hering has become a common knowledge after the green-red and blue-yellow processes were seemingly reduced to interactions of the L-, M-, and S-cones.[1] A difference of M and L-responses was assumed to produce the green-red opponency, and that between the S- and (L+M)-responses to determine the blue-yellow opponency. Potential responses, alternating within definite spectral ranges, were recorded from various cells along the neural pathways.[14] In fact, the opponent tetrachromacy is spectrally inconsistent with the trichromatic principle. Already the first opponent responses, recorded from strongly illuminated *single photoreceptor cells*,[15] showed the long-wave sensitivity limit of red-green mechanism to lie by about 50 nm further than that of blue-yellow mechanism.

A tritanope and a normal central fovea see the primary red (after 650 nm) and complementary blue-yellow (~495 nm), which strongly differ from the sensitivity maxima of L- and M-cones. Protanopes and deuteranopes who supposedly have no L- or M-cones, respectively, see solely the complementary blue (460 nm) and yellow (575 nm) hues as the unilaterally dichromatic subjects report.[16] Their green-red pair is absent although elimination of red component from a neutral sensation leads to a blue-green sensation, and vice versa, in the normal and tritanopic colorimetry. A normal external retinal periphery with solely the rods produces the blue and yellow sensations.[17] The so called 'S-cone monochromats' and some protanopes[18] possess neither L- nor M-cones but see the opponent blue and yellow with their 'rhodopsin receptors.'[19] Absence of the green and red cone responses at mesopic illumination does not prevent from seeing the yellow and blue.[20] The yellow sensation disappears around 650 nm, after the rhodopsin sensitivity limit, whereas the red only after 700 nm.[21] Saturating at high photopic illumination,[22] the rod responses 'may continue to function over a greater range of intensities than is generally accepted.'[23] The Purkinje transition from the scotopic rod vision to the 'cone vision', requires 'surprisingly high intensities before the photopic curve was approached.' The spectral shift, not seldom deduced from accumulation of rhodopsin intermediates within the rod, is absent in tritanopes, which have no blue-yellow sensations, and in rod-monochromats. The photopic activity of rod was repeatedly suggested to take part in producing the blue and yellow sensations.[17,22,24]

2. OPPONENT RECEPTORS IN THE PHOTOPIC ROD AND CONE

The intra-receptor optical mechanism of opponent color separation[25,26] obviates the inconsistencies. The OS of rod or cone consists of two structural parts that differ in growth mechanism, structure, and electrical contact to the cell membrane. 'In the basal third of cone OS and in the basal twentieth of rod OS, the membrane of the <light-sensitive> sacs was frequently seen to be continuous with the cell membrane, but the points of continuance fell off sharply above these levels'.[27] Mathematical simulation[25] detected two dichromatic opponencies: a green-red iodopsin-based process in the cone and a yellow-blue rhodopsin-based process in the rod after the long-living intermediates had accumulated enough at photopic illumination. The spectral sensitivity difference in the rod OS changes its sign at 495 nm, the neutral point of protanope, and the difference in the cone OS changes its sign around 570 and 460 nm, the neutral points of tritanope (Fig. 1).

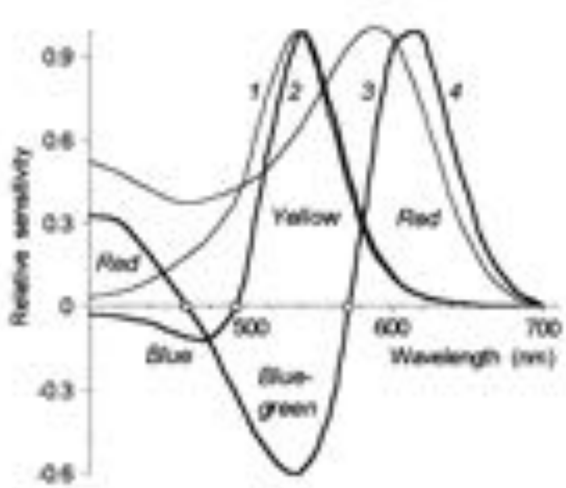


Fig. 1. Normalized spectral sensitivities of photopic rod (*1*) and cone (*3*) and sensitivity differences of the basal and distal parts of outer segment in the rod (*2*) and cone (*4*). The circles denote the neutral points.

The two differential receptors in the rod and two in the cone produce four primary color sensations (blue *B*, blue-green *BG*, yellow *Y*, and red *R*, unmixed at the neutral points and after the 650-nm rod sensitivity limit) within four different spectral regions.[26] The curves do not vary with the length and diameter of outer segment at a constant length ratio of its basal and distal parts. Orders of magnitude photochemical decay of visual pigments, say 10 to 0.01%, as well as 20% shedding of distal part in a renewing OS has almost no effect.[25] The logarithmic dependence of photoelectrical response[25] explains the stability of primary sensations over orders of magnitude decrease in the absolute content of residual vision pigment. The brightness sensation could be the sum of entire OS responses of the rods and cones whose maxima (Fig. 1, curves 1 and 3) coincide with the 530-nm and 610-nm maxima of the increment threshold sensitivity curve of human retina.[28]

3. FOUR CHANNELS FOR FULL-COLOR IMAGING

Even in the best trichromatic systems, a monochromatic spectral hue strongly differs from its wide-band metameric analogues.[29] Also the lowered saturation especially of the 'difficult-to-create' blue-greens (~500 nm) and purple-reds cannot be improved without desaturation of primaries until a fourth channel is involved even in part.[30,31] For every triad of real primaries, there are colors which cannot be reproduced with their sum. The irreproducible colors take in the standard XYZ chromaticity diagram about as much area as the RGB triangle area of reproducible colors. Many colors require addition to an RGB mixture a fourth, complementary blue-green color instead of the R-primary added to the test colors themselves and desaturated them. The desaturation appears to be residual of that in the 'lovely' multicolor images obtained by E. Land with mixing not three but only two colors. The colors of low-illuminated scenes are also hardly to reproduce.[31] Even if a single hue (say that of especial psychological or psychophysical importance such as flesh or diffuse-white[32]) is matched with a combination of three imaging primaries, other subject colors remain more or less distorted. A recently pictured image frequently dissatisfies consumers since the scene colors are still in memory or can be directly compared with the original (like in the mass video or digital photography, or the art reproduction[29]), or are of especial personal importance, e.g., the textiles in a woman portrait.[26]

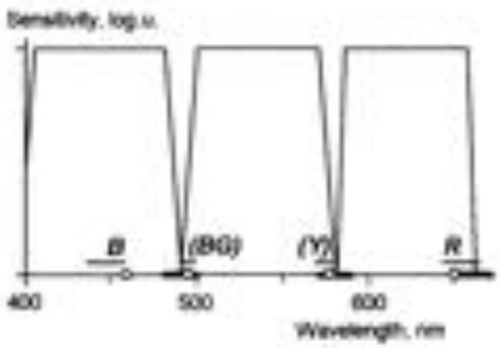


Fig. 2. Color primaries (circles) and sensitivity ranges of vision receptors as represented in photographic systems. The spread of sensitivity limits (black bars) and absorption maxima (thin bars) of the yellow and cyan positive dyes to control the *B* and *R* primaries on a brightness scales. The brightness of *Y* and *BG* in their mixtures is not independently controlled with using the same magenta dye.

Ideal imaging requires the spectra of every image detail to affect the four vision receptors like a respective scene detail does. Imaging channels should simulate the receptors, record the four spectral ranges of every subject, and represent them with the four primary colors of vision.[26] In an additive system (television, virtual reality) a partial positive image should give rise one of the primary vision sensations: 460 (*B*), 495 (*BG*), 575 (*Y*), or 650 nm (*R*). A partial image should be recorded within the spectral sensitivity range of respective differential vision receptor. In particular, the channel to control the red primary sensation must have an extra sensitivity range in the short-wave region of spectrum. A subtractive four-channel reproduction in photography, polygraphy, reprography, or digital printing should independently simulate the same sensitivity ranges: below 495 nm (*B*), 495-650 nm (*Y*), 460-575 nm (*BG*), also 400-460 and 575-700 nm (*R*), with the ranges of an opponent pair not to overlap each other. A positive dye should give rise a primary vision sensation on a saturation scale, as well as its gradual subtraction from a neutral four-dye combination should control the same sensation on a brightness scale. The shapes of channel sensitivity curves have a secondary effect and widely vary in the photographic systems of different speed. Preliminary estimations showed that the unmixed vision primaries around the neutral points of another receptor are close to their maximum saturation and the choice can scarcely affect the hue and saturation of mixed colors.

After a century of technological development with permanent mass consumer testing, the absorption maxima of dyes in the state-of-art trichromatic photographic papers and reversal films lie at 445, 545 and 655 ± 10 nm. The first and third dyes control practically the *B* and *R* vision primaries on brightness scales, and the complementary *Y* and *BG* sensations on saturation scales (Fig. 2, thin bars). The magenta dye replaces the absent 495 and 575-nm dyes. The inaccuracy violates the necessary independence of respective primaries in their mixtures[30] on saturation and brightness scales. The spectral sensitivity ranges (Fig. 2, curves) of the three channels in negative and reversal films abruptly decrease down to a tenth of maximum around the rod 495-nm and cone 575-nm neutral points, as well as the long-wave sensitivity limit of rod at 655 ± 10 nm. The blue-controlling channel and yellow-controlling sum of two other channels are delimited at 490 ±10 nm. The red- and green-controlling channels are delimited at 580 ± 15 nm. The absence of fourth channel hinders the sensitivities of non-opponent channels from the necessary overlap (Fig. 1) and distorts the respective mixed colors. Lacking in the sensitivity ranges, 400 to 460 and 650 to 700 nm, of respective vision receptor, the red imaging channel cannot properly render the problematic[30,31] violet, crimson, and wine-red colors. Lacking in the sensitivity range from 460 to 495 nm of respective vision channel, the green imaging channel cannot properly render the 'teal-greens' and other 'difficult-to-create various green colors.[30,31]

REFERENCES

1. P.K. Kaiser and R.M. Boynton, *Human Color Vision*, OSA, Washington, 1996; R.M. Boynton, " History and current status of a physiologically based system of photometry and colorimetry," *J.Opt.Soc.Am.* **A13**, pp. 1609-1621, 1996.
2. H. Wässle, "A patchwork of cones", *Nature* **397**, pp. 473-475, 1999.
3. W.D. Wright, "The present status of the trichromatic theory," *Docum. Ophthalm. ('s Gravenage)* **3**, pp. 10-23, 1949.
4. S. Merbs and J. Nathans, "Absorption spectra of human cone pigments," *Nature* **356**, pp. 433-435, 1992; A.B. Asenjo, J. Rim, and D.D. Oprian, "Molecular determinants of human red/green color discrimination," *Neuron* **12**, pp.1131-1138, 1994.
5. D.A. Baylor, T.D. Lamb, and K.-W. Yau, "The membrane current of single rod outer segments," *J.Physiol.* **288**, pp. 589-611, 1979.
6. J.L. Schnapf, T.W. Kraft, and D.A. Baylor, "Spectral sensitivity of human cone photoreceptors," *Nature* **325**, pp. 439-441, 1987.
7. H. Ripps and R.A.Weale, "Photo-labile changes and the directional sensitivity of the human fovea," *J.Physiol.* **173**, pp. 57-64,1964.
8. P.K. Brown and G. Wald, "Visual pigments in human and monkey retinas," *Nature* **200**, pp. 37-43, 1963.
9. J.W. Lewis, F.J.G.M. van Kuijk, J.A. Carruthers, and D.S. Kliger, "Metarhodopsin III formation and decay kinetics: Comparison of bovine and human rhodopsin," *Vision Res.* **37**, pp.1-8, 1997.
10. J.K. Bowmaker and H.J.A.Dartnall, "Visual pigments of rods and cones in a human retina," *J. Physiol.* **298**, pp. 501-511, 1980; H.J.A. Dartnall, J.K. Bowmaker, and J.D. Mollon, "Human visual pigments," *Proc.Roy.Soc. Lond.* **B220**, pp. 115-130, 1983; J.K. Bowmaker e.a., "Photosensitive and photostable pigments in the retinae of old world monkeys," *J. exp. Biol.* **156**, pp. 1-19, 1991.
11. T. Hanaoka and K. Fujimoto, "Absorption spectrum of a single cone in carp retina," *Jap. J. Physiol.* **7**, pp. 276-285, 1957; W.B. Marks, W.H. Dobele, and E.F. MacNichol, "Visual pigments of single primate cones," *Science* **143**, pp. 1181-1182, 1964.
12. A. Roorda and D.R. Williams, "The arrangement of the three cone classes in the living human eye," *Nature* **397**, pp.520-522, 1999.
13. E.F. MacNichol e.a., "Microspectrophotometry of visual pigments in primate photoreceptors," in: *Colour Vision*, Eds. J.D. Mollon and L.T. Sharpe, London, pp.13-38, 1983.
14. F. Ratliff, *Mach Bands: Quantitative Studies on Neuronal Networks in the Retina*, 1965; B.D.Drujan and M. Laufer, *The S-Potential*, 1982.
15. G. Svaetichin, "Spectral response curves from single cones," *Acta Physiol. Scand.* **39**, Sup.134, pp. 17-46, 1956.
16. D.B. Judd, "Color perception of deuteranopic and protanopic observers," *J. Res. Natl. Bur. Stand.* **41**, pp. 247-271, 1948.
17. E.N. Willmer, "Human colour vision and the perception of blue," *J. Theor. Biol.* **2**, pp.141-179, 1961.
18. W.A.H. Rushton, "Rhodopsin measurement and dark-adaptation in a subject deficient in cone vision," *J. Physiol.* **156**, pp. 193-205, 1961.
19. K.H. Ruddock, "Psychophysics of inherited colour vision deficiencies," In: *Inherited and acquired colour vision deficiencies: fundamental aspects and clinical studies.* Ed.: D.H. Foster, Macmillan: Houndmills, pp. 4-37, 1991.
20. B. Stabell and U. Stabell, "Bezold-Brücke phenomenon of the far peripheral retina," *Vision Res.* **22**, pp. 845-849, 1982.
21. J.S. Werner and B.R. Wooten, "Opponent chromatic mechanisms: relation to photopigments and hue naming," *J.Opt. Soc. Am.* **69**, pp. 422-434, 1979; Th. Knottenberg and H.Scheibner, "Berücksichtigung des Abney-Effekts im Rahmen der linearen Gegenfarbentheorie," *Ophthalmologe* **90**, pp. 155-160, 1993.
22. M. Aguilar and W.S. Stiles, "Saturation of the rod mechanism of the retina at high levels of stimulation," *Opt. Acta* **1**, 59-65, 1954; P. Gouras, "Color vision," *Prog. Ret. Eye Res.* **3**, pp. 227-261, 1984.
23. H.V. Walters and W.D. Wright, "The spectral sensitivity of the fovea and extrafovea in the Purkinje range," *Proc. Roy. Soc. Lond.* **131B**, pp.340-361, 1943.
24. P.W. Trezona, "Rod participation in the 'blue' mechanism and its effect on colour matching," *Vision Res.* **10**, pp. 317-332, 1970; S.L. Buck e.a., "Opponent-color models and the influence of rod signals on the loci of unique hues", *ibid.* **40**, pp. 3333-3344, 2000.
25. V.V. Gavrik, "Opponent rhodopsin receptor in rod and opponent iodopsin receptor in cone underlie the human colour perception," *Perception* **27S** (ECVP, Oxford), p.171, 1998; "A mechanism for single-pigment color opponency in a photoreceptor cell," *Proc. Intl. Joint Conf. Neural Networks*, Washington, IEEE, pp. 174-177, 1999.
26. V.V. Gavrik, "On the spectral dimensionality of subject colors," *15th Intl. Symp. Digital Print. Technol.*, IS&T, pp. 331-333, 1999; "Four Spectral Channels for Natural Imaging of Scene Colors," *16th Intl. Conf. Digital Printing Technologies*, IS&T, pp. 560-565, 2000.
27. A.I. Cohen, "The fine structure of the extrafoveal receptors of the Rhesus monkey," *Exp. Eye Res.* **1**, pp.128-136, 1961; R.H. Steinberg, S.K. Fisher and D.H. Anderson, "Disc morphogenesis in vertebrate photoreceptors," *J. Comp.Neurol.* **190**, pp. 501-518, 1980.
28. H. Krastel e.a., "Systematics of human photopic spectral sensitivity," In: *Colour Vision Deficiencies X*, Eds.: B. Drum, J.D. Moreland, and A. Serra, pp. 323-339, 1991.
29. B. Hill, "Multispectral color technology: A way towards high definition color image scanning and encoding," *Proc.SPIE* **3409**, pp.2-13, 1998; R.S. Berns e.a., "Multi-spectral-based color reproduction research at the Munsell Color Science Laboratory," *ibid.*, pp. 14-25.
30. H. Ikeki, "Design of color reproduction required for portrait photography," *Intl.Cong.Imag.Sci.*, IS&T, pp. 212-213, 1998.
31. T. Tani, "Progress and future prospects of silver halide photography compared with digital imaging," *J.Imag.Sci.Tech.* **42**, pp.1-10, 1998; Fuji Photo Co., Fujicolor Superia 200. Data Sheet, 1998.
32. V.V. Gavrik, "Economical subject-selective metrics of perceptual color image quality," *Proc. SPIE* **3409**, pp. 52-63, 1998.

THE HVC COLOR VISION SKILL TEST : A TECHNICAL UPDATE

Louis A. Graham *(retired), Lisa Thieme, Colorcurve Systems, Inc.

ABSTRACT

Since 1991 the HVC Color Vision Skill Test has been available worldwide. Initial technical information was published in 1993. Further data allow additional conclusions with regard to sex and experience of observers. However, the conclusions reported in 1993 have been revalidated and remain unchanged. No essential difference in scores show up in the comparisons of male and female observers. Workplace experience comparisons for those who deal surface colors and those working with CRTs favor surface color in the limited data reported.

1. INTRODUCTION

Originated and initially manufactured by Lou Graham & Associates, the HVC Test rights have been obtained by Colorcurve Systems, Inc. . Although minor mechanical changes were made, the basic concept is retained in the Colorcurve Edition. The background of color vision testing was reviewed in an AIC 93 Budapest paper, and are not repeated here.

The need for this type of color vision skill test has been reemphasized by interest shown from the global color community, particularly since the ISO 9000 certifications. The antiseptic, though effective, mathematical color measurement and control (spread by the computer) must be finally subjected to human eye color evaluation by the ultimate consumer. Any technique that assists in this relationship is welcome.

1.1 Background

The HVC Test requires 36 color choices distributed over four hues. (The general arrangement is shown in Fig. 1 of Ref 1.) The tolerances for the green chip set are given in Table 1. During the manufacture of the LGA set of colors three different types of spectrophotometers were to triple check the actual colorimetric measurements of the Dorn Color Co. The colors for the Colorcurve Edition were made under industrial quality control standards established by that company. The colorants used by Colorcurve are slightly different from those used by Dorn, resulting in a small amount of metamerism between the two color sets.

1.2 Testing Procedure

Each observer is required to select from 36 loose chips, each taken one time only, the appropriate match of his or her choice to a mounted chip. "Exact" matches have a value of "3", less precise matches are valued from "2" to "1" to "0". Maximum score is 100.

Industrial observers take the HVC Test under the conditions they normally use for color evaluation. This is frequently, but not restricted to, artificial light close to the D65 standard. Other observers are tested under natutal daylight or the closest artificial lighting available.

2. RESULTS

The cumulative scores collected are shown in Figure 1. These include results from Brazil and Mexico as well as the USA. It has proven difficult to obtain similar numbers for "naïve" observers, that is, persons with no color training. The elementary school children previously reported are still included. These data are for the LGA Edition of the Test.

Distribution of observer ages is shown in Figure 2. Distribution of scores by sex are shown in Figure 3. There are not sufficent new data for times to take the Test to expand the results shown in the AIC 93 Budapest paper.

One new result is that shown in Figure 4 for two small populations. Group A represents scores for persons working with luminous colors on CRTs only. Group B represents scores for persons working exclusively with surface colors. It may be seen that there is a large difference in the scores obtained with no overlap.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

A few of the ten year old color sheets from the LGA HVC color production have been remeasured. Although the hue groups have shifted together in overall color somewhat, the individual colors still fall around the the center values within the typical tolerances given in Table 1.

The Colorcurve Edition of the HVC Test has been available for a short time , and the number of scores obtained to date are insufficient to report . Data so far collected are divided between trained color matchers and a few college level art students.

3. CONCLUSIONS

The value of color vision testing is reaffirmed. The HVC Test data confirm the conclusions of the AIC Color 93 paper with these additional comments:

3.1 Sex Comparisons There is little difference to report between the sexes, provided that results for males exclude those below a score of 37. The number of males in this category is about ten percent, roughly corresponding to the percentage of known color defective males in the general population. Unfortunately separate testing for color defects is not available for the majority of HVC observers; the few tested tend to confirm lower HVC scores. The number of female HVC observers with scores below 37 are much fewer. However, it is be remembered that the HVC Test itself was not intended as a check for color vision defects. Other known tests are available for this specific purpose.

3.2 Experience and Training Experience and training in making color discriminations of paired samples continues to show up in the data. This is best illustrated by the two groups in Figure 4. The limited data from the new Colorcurve Edition show those regularly making commercial color choices score higher.

3.3 HVC Color Change with Time Although age deterioration certainly effects any & all colors used for color vision tests, HVC color groupings appear to hold up reasonably well. Nevertheless any color vision test showing dirt, wear and tear should be replaced.

REFERENCES

1. **Graham, Louis A.** *A New Color Vision Skill Test,* Die Farbe, **39** (1993) 1/6p. 89-98 (from AIC Color 93 Budapest)
2. **Colorcurve Systems, Inc.** *HVC Color Vision Skill Test – Users Manual,* 1998

Table 1. HVC Color Vision Skill Test : Colorimetric Tolerances

1. The four nominal hue centers in Munsell Renotation terms are: Blue 2.5PB/5/5 Red 7.5RP/5/5 Green 5.0 BG/5/5 Yellow 7.5 YR/5/5
2. Around each of the four hue centers the eight color variants are specified as CIE L,a,b points. The color reproduction limits around the center and each variant in a, b are circles proscribed by 0.3 delta a, 0.3 delta b as radii around the specified centers. The delta L limits are below.
3. For the GREEN colors arranged around the center established when the nominal 5.0 BG/5/5 is reproduced, the center points and lightness tolerances are:

Position	Green Center Points	Delta L
1	a= 0.0 b= 0.0 L=0	+ or – 0.2
2	a= -1.55 b= -0.35 L=0	same
3	a= 0.35 b= -1.20 L=0	"
4	a= 1.55 b= 0.35 L=0	"
5	a= -0.35 b= 1.20 L=0	"
6	a= -0.80 b= -0.20 L=0	"
7	a= 1.30 b= -0.65 L=0	"
8	a= 0.00 b= 0.00 L= 1.00	"
9	a= 0.00 b= 0.00 L= 1.00	"

*Louis a. Graham, 501 Dakota Drive, Temple, TX 76504 USA, Lisa Thiema, Colwell Industries, Inc, 2065 Marion Drive, Kendallville,IN 46755 USA

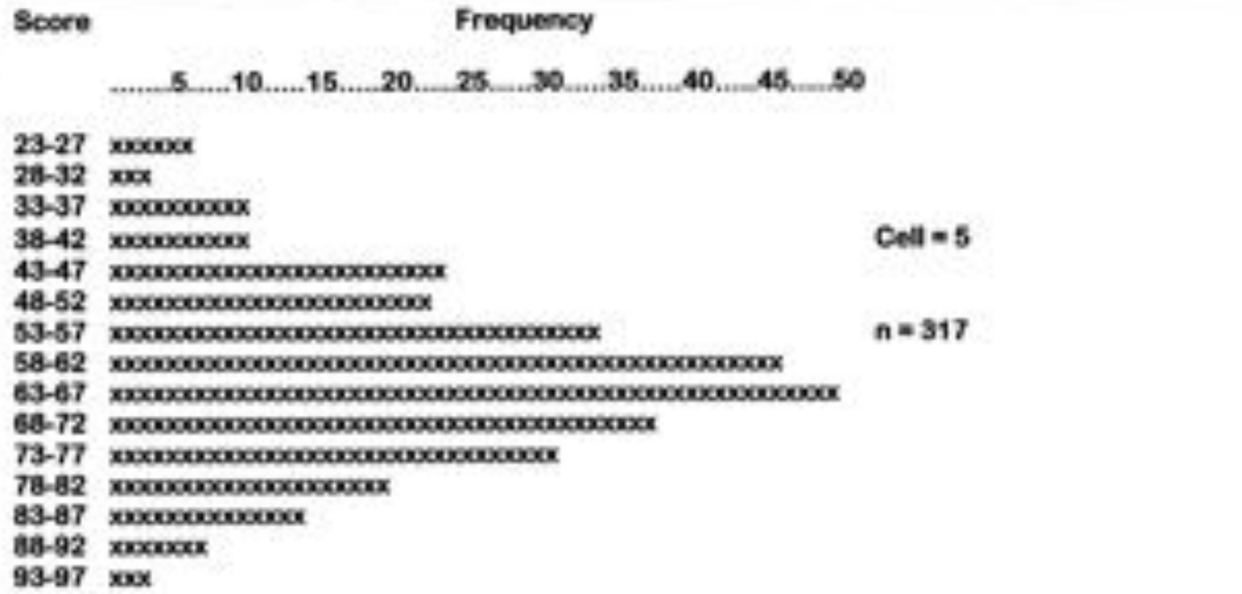


Fig. 1 HVC COLOR VISION SKILL TEST/ LGA : GENERAL DISTRIBUTION OF SCORES

Fig. 2 Distribution of Observer Ages for HVC Test/LGA

*L. A. Graham, 501 Dakota Drive, Temple, TX 76504 USA; Lisa Thieme, Colwell Industries, Inc., 2065 Marion Dr., Kendallville,IN 46755

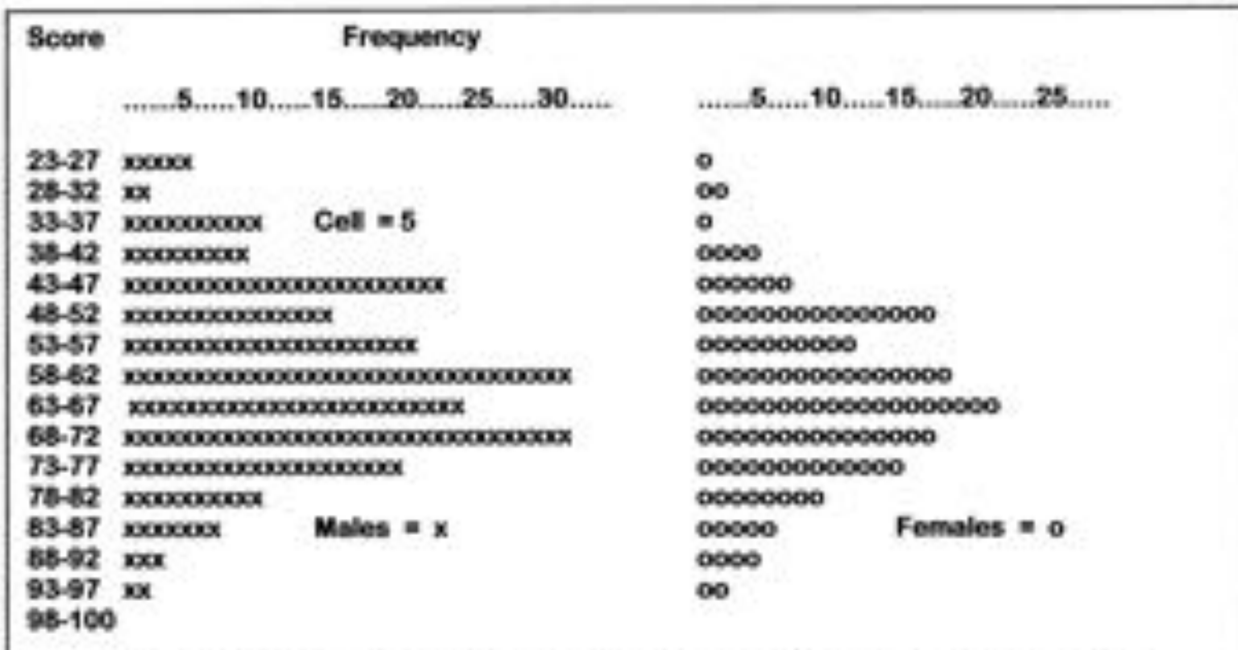


Fig. 3 HVC COLOR VISION SKILL TEST/LGA : SCORE DISTRIBUTION BY SEX

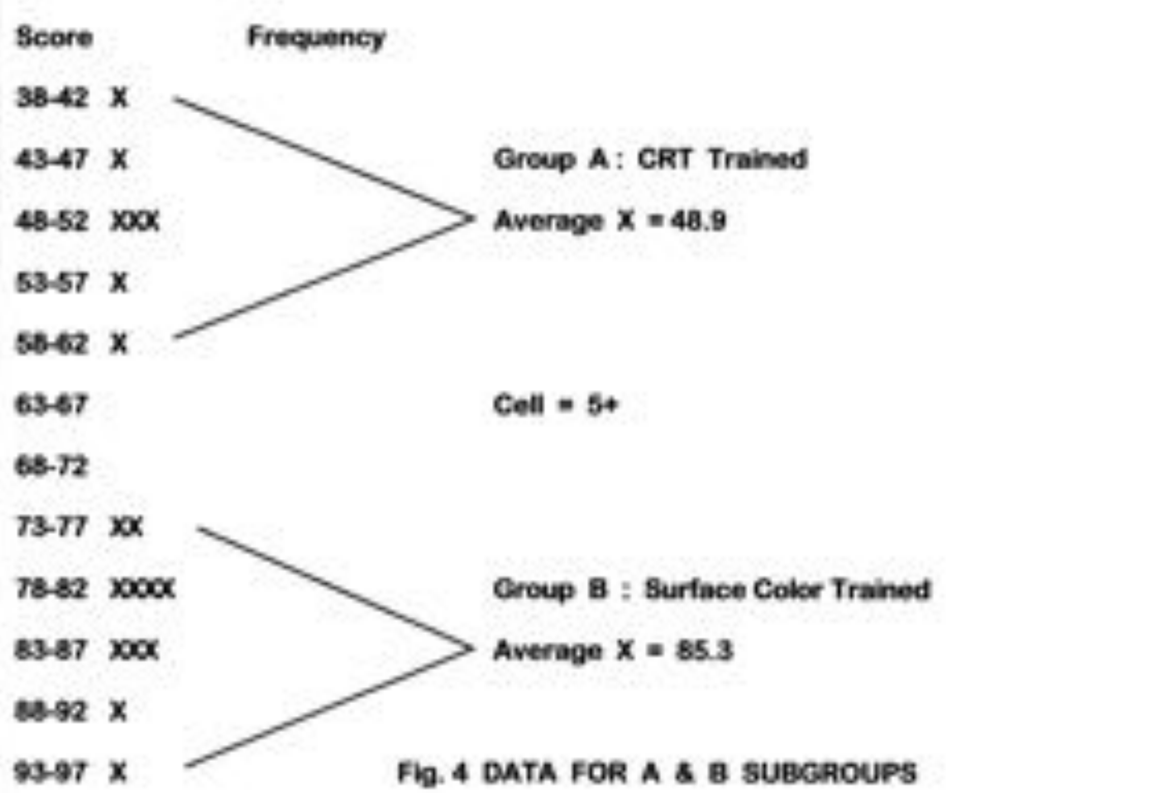


Fig. 4 DATA FOR A & B SUBGROUPS

Field Trials of Three Tests for Colour Vision and Colour Aptitude

Robert Hirschler*, Jennifer Gay** and Danielle Ferreira de Oliveira***
SENAI/CETIQT, Rio de Janeiro, Brazil

ABSTRACT

253 visual observers, at the average level of between "unselected" (inexperienced) and "in-plant applicants" have been tested under controlled industrial conditions using the Ishihara or T.M.C. (Murakami) pseudoisochromatic plates, the Farnworth-Munsell 100 Hue Test (FM), the HVC Color Vision Skill Test (HVC) and the Japanese Color Aptitude Test (JCAT). There is only loose correlation between the FM and the HVC tests. The FM scores do not improve significantly by retesting, while the HVC scores can be improved through training, e.g. by using the JCAT. We found practically no correlation between the performance in visual pass/fail decisions and the FM or the HVC scores. Three different editions (3 copies from 1991, 3 from 1997 and two from 1998) of the HVC test were measured and analysed. They showed good, in the latest edition very good, intra-edition repeatability and good inter-edition reproducibility.

Keywords: colour vision, colour aptitude, colour vision tests, visual observers, Farnworth-Munsell, HVC, JCAT

1. INTRODUCTION

Colour vision and colour aptitude tests have been performed for over 50 years now, but only recently have they become indispensable tools in industry and commerce, mainly as an answer to the requirements of the ISO 9000 - type quality systems. The ASTM Guide[1] covers practically all of the currently available tests for colour vision (pseudoisochromatic plates, colour rules, FM), visual acuity and discrimination (FM, JCAT triangle, HVC) and magnitude scaling (JCAT Color Estimation).

Since its foundation in 1989 the SENAI/CETIQT Applied Colorimetry Laboratory has provided visual testing services for a number of companies in the textile, fibre, chemical, paint, glass, automotive and other colour using industries, screening over 250 visual observers using the Ishihara / Tokyo Medical College (Murakami) pseudoisochromatic plates, the FM, the HVC and the (JCAT). These screenings serve two purposes: to provide qualitative and quantitative proof that the observers making the visual judgements (pass/fail decisions) have the necessary level of colour discrimination, visual acuity and aptitude as defined by the ASTM Guide, and in many cases also to select a panel of the best 6 to 10 observers to make the large number of pass/fail evaluations necessary for the establishment of instrumental tolerance limits for their company.

2. INDUSTRIAL RESULTS OF COLOUR VISION AND APTITUDE TESTS

1. General conditions

The factories selected their observers from among the employees whose work was related - directly or indirectly - to colour QC. In some cases only the potential colour matchers (pass/fail evaluators) were tested, in other cases the panel of pass/fail evaluators was selected from a group of 50-60, by applying the tests. The tested population thus was a mixture of laypersons, technical and design professionals (some of them with more, others with relatively little experience in colour judgements), and in each factory a number of experienced colourist.

All the tests were performed under well-controlled industrial conditions, according to the recommendations in the respective manuals[2-4]. The illumination was provided by D65 simulators, either utilising the visual booths of the companies themselves, or one of our portable Judge II (GretagMacbeth) cabinets. The observers were always asked not to wear coloured clothing, and they used neutral grey cotton or plastic gloves to prevent directly touching the samples. We have detected 4 deutans by the Ishihara resp. T.M.C. (Murakami) tests; their FM scores confirmed this finding. These observers didn't participate in further tests and their results are excluded from the overall scores.

2. Farnworth-Munsell 100-Hue Test

Figure 1. shows the overall performance of the 249 colour-normal persons tested (*CETIQT 1st*) and retested (*CETIQT repeat*). The score of the first test falls between that of "unselected" persons and "in-plant applicants" as defined by Farnsworth[3], the retest (recommended by Farnsworth *when a more precise diagnosis is needed*) shows overall improvement, putting our population nearly exactly to the class of "in-plant applicants".

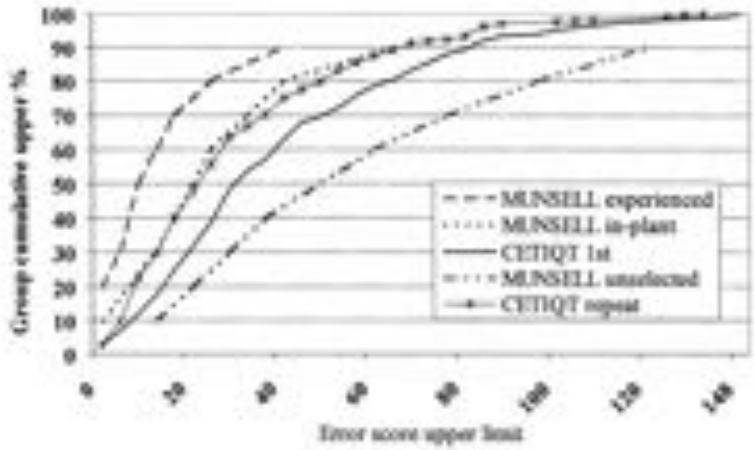


Figure 1. Distribution of total error scores by percentiles in the FM tests. *MUNSELL* data based on Ref.[3]

This test was designed to *separate persons with normal colour vision into classes of superior, average and low colour discrimination* and *not intended to distinguish fine degrees of differences between persons of superior aptitude*[3]. However, as in each factory only few of the observers had superior scores, and we needed a group of at least 8-10 for the pass/fail panel, we decided to sub-divide the "average" category into **A+** (score of 20-44), **A** (48-72) and **A-** (76-100) (Figure 2.) and selected into the pass/fail panel those with superior or A+ score.

	% of observers in each category			
	Scale 1 to 3		Scale 1 to 5	
Category	Test	Retest	Test	Retest
Inferior	4.8	2.4	4.8	2.4
Average-			9.6	5.6
Average	70.3	57.4	17.7	14.5
Average+			43.0	37.3
Superior	24.9	40.2	24.9	40.2

Figure 2. Test-retest results for 249 observers for the FM test. The "average" group was sub-divided into A-, A and A+.

The increase in the relative number of "superior" observers is quite significant for the group (from 24.9 to 40.2%), but it isn't quite unambiguous when looking at the performance of individual observers. Figure 3. shows that while 41.7% of the observers improved their scores by 1, 2 or 3 categories, 12.4% of them impaired by 1 (e.g. from A to A-) and 2.8% by 2 categories, and there was even one person, whose first score was 28 (A+) and at the retest scored 108 (I). Using the original 3-level scale 26.5% of the scores improved and 8.8% deteriorated.

Change in category	3	2	1	0	-1	-2	-3
Scale 1 to 5	2.4	6.4	32.9	42.6	12.4	2.8	0.4
Scale 1 to 3			26.5	64.7	8.8		

Figure 3. Change in category (+ improved, - impaired) by re-applying the FM test

3. The HVC Color Vision Skill Test

The HVC, first published in 1991, was devised and produced by Lou Graham and Associates, and its characteristics and differences as compared to the older ISCC Color Aptitude Test are well documented[1-8], so we shall limit our discussion to the results obtained with our 249 colour-normal industrial observers. Figure 4. compares the distribution of the observers according to the FM and the HVC categories. In the FM around 68% of the selected observers fell into the 2 top categories: 5 (superior) and 4 (average+), but in the HVC test - which requires much more experience, than the FM - only 34% fell into the 5 (excellent) and 4 (good) categories. In order to have enough observers for the pass/fail work in each company we decided to include also those whose score was "average" in the HVC test.

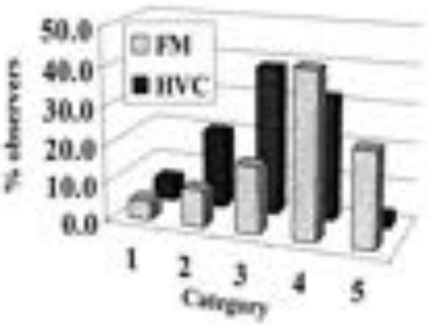


Figure 4. Distribution of 249 colour normal observers according to the 5-scale FM and the HVC categories

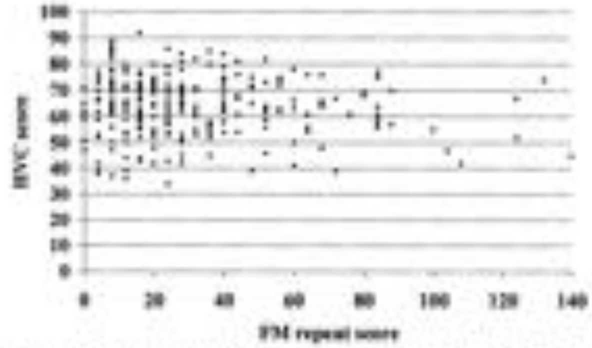


Figure 5. Average HVC scores as a function of the FM repeat scores of the same persons

Figure 5. shows the very poor correlation between the FM and the HVC, confirming previous observations[10] obtained between the ISCC CAT and the FM tests, and recent results by Park, Fernandez and Taplin[12]. The 4 deutans, eliminated from the group of observers, were also tested just to see how they would perform in a much more complex test. Somewhat to our surprise their scores (33, 36, 44, 57) were not lower than those of some colour normals.

4. Japanese Color Aptitude Test (JCAT)

The new JCAT[8] consists of three tests: the *Triangle Test* detecting the presence of small colour differences; the *Colour-Attribute Discrimination Test* determining the attributes of small colour differences (whether they are in hue, value or chroma); and the *Magnitude Scaling Test* measuring the ability to identify the degree of colour differences. The JCAT is much more complex than even the HVC test: to score well it is not enough to have good colour acuity and even to have experience in colour matching; the observer has to be quite familiar with the concepts of hue, value and chroma, and the ability and practice to scale colour differences in these attributes.

The first two tests come in two levels of difficulty, for beginners and for senior workers, but for the majority of our observers even the beginner level proved to be too difficult. As our task was not only to find a panel of qualified observers in each factory, but also to motivate them to later perform hundreds of visual judgements under controlled conditions, we decided to apply the JCAT not as a test, but as a training tool. In those cases where the company required not only the screening, but also the training of the observers, significant improvement could be achieved in the HVC test after a few days training using a combination of the MUNSELL Student sets and the JCAT, as shown in Figure 6.

HVC score	Poor	Regular	Average	Good	Excellent
First test	4	16	20	5	0
Repeated test	1	10	19	13	2

Figure 6. HVC scores for 45 industrial observers before and after training with the MUNSELL student set and JCAT

As would be expected, the FM test applied for the third time showed little improvement, the average score of 35 observers increased from 4.1 to 4.4 (on a scale from 1 to 5).

3. VISUAL TESTS AND TEXTILE PASS/FAIL PERFORMANCE

The main aim of our tests was selecting panels of 6-10 industrial observers in each factory, who would be capable of evaluating hundreds of standard-sample pairs, and pass a judgement on the commercial *acceptability* of the colour differences presented. The results of these judgements and their utilisation in establishing instrumental tolerance limits is reported in another paper[12]. The results obtained with 62 observers in 5 factories and a laboratory are summarised in Figure 7. Only those observers were selected into the pass/fail panel whose repeated FM score was at least A+, and HVC at least *good*. There is little correlation between the results, indicating that industrial pass/fail (*acceptability*) judgements are based not only on colour discrimination, but other (e.g. commercial) considerations as well.

Company	1	2	3	4	5	6
% RVA	85.9	83.8	82.4	80.9	74.8	74.1
Repeated FM score	A+	A+	A+	A+	A+	S
HVC score	A	G	G	A	A	A

Figure 7. Average % of *right visual assessments* (RVA) of individual observers as compared to the panel judgement, and the FM and HVC scores for the same group in 6 companies

4. COLORIMETRIC PROPERTIES OF THE COLOUR VISION TEST SETS

The colorimetric properties of the coloured paper chips used in the FM test were already described by Nickerson and Granville[13] and Farnsworth[14], and, according to Graham and Carlson[7] no changes have been made since the original test came out in about 1943. The manual of JCAT gives the nominal (tristimulus and CIELAB) values of all the chips, but there are no specifications given for the tolerance around these. Park, Fernandez and Taplin[11] recently investigated the colorimetric properties of the new edition of the HVC test.

We have made a detailed colorimetric analysis of 6 "original" (i.e. Lou Graham) and 2 new, Colorcurve sets. The repeatability of the chips among sets of the same batch is very good for the new edition (< 0.15 $CMC_{2:1}$), there are differences in the order of one $CMC_{2:1}$ unit between the corresponding chips of the "old" and the "new" sets. The colour differences between the fixed and the corresponding unattached chips follow very closely the intended graduations. More details of this analysis will be published shortly.

REFERENCES

1. ASTM, *Standard Guide for Selection, Evaluation, and Training of Observers*, E 1499-97
2. Ishihara's *Tests for Colour-Blindness*, 24 Plates Edition, Kanehara & Co., Tokyo: 1992
3. Tokyo Medical College *Color Vision Test*, First Edition, Murakami Color Research Laboratory, Tokyo: 1957
4. D. Farnsworth, *The Farnsworth-Munsell 100-Hue Test*, Manual, 1957
   New edition: Munsell Color, GretagMacbeth, *Quick Guide to Operation FM Test*, May 1997
5. Colorcurve Systems Inc. *HVC Color Vision Skill Test - User's Manual*, 1998
6. Japan Color Research Institute *Japanese Color Aptitude Test - manual*. December, 1994
7. L. A. Graham and D. R. Carlson, *Review and Comparison of Three Old and One New Color Vision Screening Test for Normal Observers*, Book of Papers, 1991 National Technical Conference, AATCC, pp.133-138
8. L. A. Graham, *A New Color Vision Skill Test*, Die Farbe, 39 (1993) 1/6 p. 89-98
9. L. A. Graham and L. Thieme, *The HVS Color Vision Skill Test: A Technical Update*, AIC 2001, Rochester
10. A. C. Little, *The Measurement of Color Discrimination Ability*, Color Engineering, **5**, 48-53 (May-June 1967)
11. S. J. Park, S. R. Fernandez, and L.Taplin, *Evaluation and Correlation of Color Discrimination Abilities*, Munsell Color Science Laboratory (Internal) Technical Report, http://www.cis.rit.edu/mcsl/research/reports.shtml
12. J. Gay and R. Hirschler, *Determination of Industrial Colour Tolerance Limits*, AIC 2001, Rochester
13. D. Nickerson and W. C. Granville, *Hue Sensibility to Dominant Wavelength Change*. JOSA, **30** 159-162 (1940)
14. D. Farnsworth, *The F-M 100 Hue and Dichotomous Tests for Color Vision*. JOSA, **33**, 568-578 (1943)

Correspondence: SENAI/CETIQT Applied Colorimetry Laboratory, Rua Dr. Manuel Cotrim, 195, Riachuelo, Rio de Janeiro, 20961-040, Brazil, Fax: 55-21-2410495, *rhirschler@unido.org, phone 55-21-582-1029, **jgay@cetiqt.senai.br, phone: 55-21-582-1017

The difference between seeing a random colour dot picture and reading shapes from the same colour dot picture in the Ishihara pseudoisochromatic plates

-Artistic research of coloured picture using functional MRI-

Yasuyo G. Ichihara[1], Satoshi Nakadomari [2,4], Hiroaki Takeuchi[2], Satoru Miyauchi[3], Kenji Kitahara[4]
Dept. of Arts and Design, Hosen Gakuen College/Tokyo[1], Kanagawa Rehabilitation Hospital[2], Communications Research Laboratory[3], The Jikei University School of Medicine[4]

ABSTRACT

When we are viewing coloured pictures, what is the difference in our brain between a random Colour dot picture and a digit figure pattern picture seen through its coloured dots? We created 3 patterns that are a functional magnetic resonance imaging version of the Ishihara plate patterns to test multiple color-sensitive areas in human ventral occipitotemporal cortex. The results showed that area V4 is activated by the stimulus of reading shapes from its colour dots in the Ishihara pseudoisochromatic plates but not by the stimulus of seeing a random colour dot picture.
We suggest that area V4 is activated not by colour processing but by segregation.

Keywords: the human colour centre, V4, segregation, colored picture stimulus, functional magnetic resonance imaging; Human Color Vision, ISHIHARA pseudoisochromatic plates,

1. INTRODUCTION

One of the main roles in colour vision is the detection of contours through colour.
We can see countless colours in the world but we can not read figures without the detection of contour through its colours. To detect contour, it is necessary for there to be some difference between the colour of the figure and the background colour. A link in our brain between seeing a colour and finding a shape was proposed over a century ago. Evidence from many studies of cerebral dyschromatopia [1,2] support the conclusion that the ventral occipitotemporal cortex is crucial for human colour perception. A lesion on the ventral occipitotemporal cortex causes cerebral dyschromatopia. In such cases, patients complained that his/her colour vision was impaired - even brightly colored objects appeared monotone.

Even when the colour is not different, we know it is possible to find the shape from only the difference in brightness. However, is it possible to perceive only colour, without any figure, shape, or form?
Seeing that patients with an impaired cortex area have the feeling of a monotone world, could we suggest that the area impaired is the colour centre?
Our experience does not allow us to determine that colour processing and figure processing are areas that are perfectly independent from each other.

More recently, imaging data using functional MRI [3,4,5] has shown that multiple sites in the ventral cortex are important for processing colour. In which areas and by what pathways in our brain is colour involved with figures?
This is our question and the main subject of our research.
The pseudoisochromatic test is strongly concerned with this question and the Ishihara pseudoisochromatic test is the most widely used screening test for red-green color deficiency.The test pattern can be distinguished from the background, only by its colour. We reported that in the Ishihara test, brightness has no connection with the perceptual segregation by color.[6]

For this research, we created three patterns that are a functional magnetic resonance imaging version of the Ishihara plate patterns to test multiple color-sensitive areas in human ventral occipitotemporal cortex.
Firstly, the "RC" pattern is like a pseudoisochromatic plate that is a Readable-Coloured digit pattern distinguished from its dappled background only by its colour. Secondly, the "NC" pattern is a Non-readable Coloured digit pattern, using the same colour as the "RC" pattern. It is non-readable because its pattern is composed of the random dot pattern. Thirdly, the "NM" pattern is a Non-readable Monotone pattern that is an achromatic version of "RC" and "NC".

In this study, we describe the activation in the occipitotemporal lobe when shown these visual stimuli. Then, we consider the implication for our understanding of cortical color and figure processing.

2. METHODS

2.1 THE MEASUREMENTS OF ISHIHARA PLATES

We measured the 38-plate version of the Ishihara plates. Its best feature is the segregated figure-background differentiation through color in all the Pseudoisochromatic Plates. The new Minolta 2D-colorimeter system, CL1040i that can define all pixels in a 4cm×4cm square, was used to take measurements. This colorimeter is used to measure complex colors such as picture drawings. From the results of the measurements[6], we could choose 4 colors that are suitable for the following visual stimulation.

2.2 VISUAL STIMULATION

From the result of the measurements of the Ishihara plates, we created three patterns that are a functional magnetic resonance imaging version of the Ishihara plate patterns to test multiple color-sensitive areas in the human ventral occipitotemporal cortex.
The three patterns created as the visual stimulation were named "RC", "NC" and "NM "(see fig.1 on the last page).
"RC" is a Readable-Coloured digit pattern distinguished from its dappled background only by its colour.
"NC" pattern is a Non-readable Coloured digit pattern, using the same colour as "RC" . It is non-readable because its pattern is composed of the random dot pattern. "NM" pattern is a Non-readable Monotone pattern that is an achromatic version of "RC" and "NC"

For "RC" and "NC" pattern, we used 4 colors (see fig.2 on the last page and in table 1) – the choices from the measurements of Ishihara plates.

		Lv	x	y
		cd/m²	–	–
1	coral red	34.69	0.3817	0.3588
2	bluish green	37.38	0.3153	0.4071
3	Japanese green tea	28.40	0.3714	0.3903
4	Chinese orange tea	30.84	0.3999	0.3765

Table 1

The 4 colours are coral red orange, bluish green, Japanese green tea color, and Chinese orange tea color.
The 4 colors come into 2 categories. Normal trichromats can see 2 categorical colors; one category (red-orange) included coral red orange and Chinese orange tea color, and the other category (blue-green) included bluish green and Japanese green tea color. For red-green colour deficiency people, Japanese green tea color and Chinese orange tea color can be seen closer than the other 2 colours.
The visual stimuli were generated on a personal computer, the output of which was fed to an acryl plate screen. The stimuli were projected onto the translucent screen and the subjects viewed the stimuli via a 45° angled mirror. (see fig. 3)
The size of the visual field was subtended 9° × 9° .

2.3 SUBJECTS

7 volunteers, with no colour vision deficiencies, were used in this experiment, 5 of whom were male and 2 female (aged between 27 and 40 years old). All subjects gave their informed consent and this experiment was carried out at the Kanagawa Rehabilitation Hospital in Japan.

2.4. FUNCTIONAL MRI EXPERIMENTS

The apparatus was Simens Magnetom Vision using a 1.5 T scanner with a repetition time (TR) of 2000 ms, an echo time (TE) of 66 ms, a flip angle of 90° , a matrix of 64 ×64, a fov of 192mm, thickness 3mm.
Our detailed method of fMRI datasets has been published elsewhere [7].
For the analysis of the fMRI datasets, we used Statistical Parametric Mapping 99 (SPM 99) and Image Calculator version 0.43 that is our customized software.

3. RESULT

3.1 THE 4 COLOURS SELECTED FROM THE MEASUREMENTS OF ISHIHARA PLATES

We have reported the detail of data from the measurements of Ishihara plates in reference [6].
From the result, the important and structural 4 colours on Ishihara plates were selected for the visual stimulation.
Table 1 shows the 4 colours: coral red, bluish green, Japanese green tea color, and Chinese dark orange tea colour.

3.2 FUNCTIONAL MRI DATA RC-NM AND NC-NM: ACTIVE BRAIN AREAS

7 subjects performed the fMRI using the chromatic stimulations of RC, NC and their achromatic version NM. For 3 subjects, no well-circumscribed activation foci was found in any region of their brain. In these 3 subjects, during fMRI experiment their brains moved more than 3 mm from the correct position so we could not use their data.
As shown in Fig. 4, one subject, who is typical of the major activation patterns among the 4 remaining subjects, was revealed by the comparison of chromatic versus achromatic stimulation. The SPM data is shown on sagittal, coronal and transverse.
The left figure was elicited by the comparison of the chromatic RC (Reading a digit from its colour) versus achromatic NM, and the right figure was NC (non-readable random colour dot) versus NM.
In RC-NM, the figure shows a unilateral activation in the ventral occipitotemporal cortex (left area V4). In NC-NM, no area of the ventral occipitotemporal cortex was activated. In both datasets, the primary visual cortex (area V1) of the area surrounding the posterior calcarine fissure was activated. The V1 activation almost certainly involved V2 but the difficultly of seeing borders between V1 and V2 in our scan meant we could not determine this.

4.DISCUSSION

Activation of area V1 and (probably)V2 is a colour-selective area but characterized by retinotopic organization because lesion toV1 typically leaves patients cortically blind and unaware of specific colour deficits.
V4 has been considered to be important as the colour centre in many colour vision studies [3) 4) 5)].
But in this study, we were surprised that V4 was not activated by NC-NM in spite of NC being in the same area and the same colors as RC. The difference between NC and RC is only the position of the colour dots. V4 was activated by RC-NM. We suggest that the detection of contours from its colour is vitally important for the activation of V4. More work, however, is needed to research how contour, shape and figures are involved with its colour. For now, it is clear that colour processing is linked in some way with figure processing on the pathways in our brain.

REFERENCES

1. MS Beauchamp, JV Haxvy, JE Jennings, EA DeYoe: An fMRI version of the farnsworth-Munsell 100-hue test reveals multiple color-sensitive areas in human ventral occipitotemporal cortex. Cerebral Cortex 9: 257-263, 1999
2. Michael S. Beauchamp, James V. Haxby, Allyson C. Rosen, Edgar A. DeYoe :A functional MRI case study of acquired cerebral Dyschromatopsia, Neuropsychologia 38 (2000) 1170-1179
3. S.Zeki & Ludovica Martini:Three cortical stages of colour processing in the human brain. Brain 121:p.1669-1685,1998
4. A.Bartels & S.Zeki:The architecture of the colour centre in the human visual brain, European Journal of Neuroscience, vol.12, pp.172-193,2000.Zeki:The visual image in mind and brain,Scientific American, September, 1992
5. D. J. McKeefry and S. Zeki :The position and topography of the human colour centre as revealed by functional magnetic resonance imaging ,*Brain* (1997), 120, 2229–2242
6. Ichihara, Y.G. : What do you see in a digital color dot picture such as the Ishihara pseudoisochromatic plates? -Web Accessibility palette (WAP)-,Internet Imaging II Proceeding of SPIE, Vol. 4311, pp. 419-426, 2001
7. Kunihiro Asakawa, Satoshi Nakadomari, Yasuyo Ichihara, Atsushi Kandatu, Hiroaki Takeuchi, Satoru Miyauchi, Jun Okamoto, Kenji Kitahara: The ventral cortical activities in occipito- temporal lobe associated with continuous pictorial stimulation, Journal of Kanagawa Rehabilitation Hospital, now printing.
8. Brazis PW, Graff-Radford NR, Newman NJ, Lee AG. Ishihara color plates as a test for simultanagnosia. Am J Ophthalmol 1998; 126 (6) : 850-1.

Send correspondence to Hosen College, E-mail: ichihara@po2.hosen.ac.jp,hbb01114.nifty.com, Tel&Fax:+81(3)3370.4022

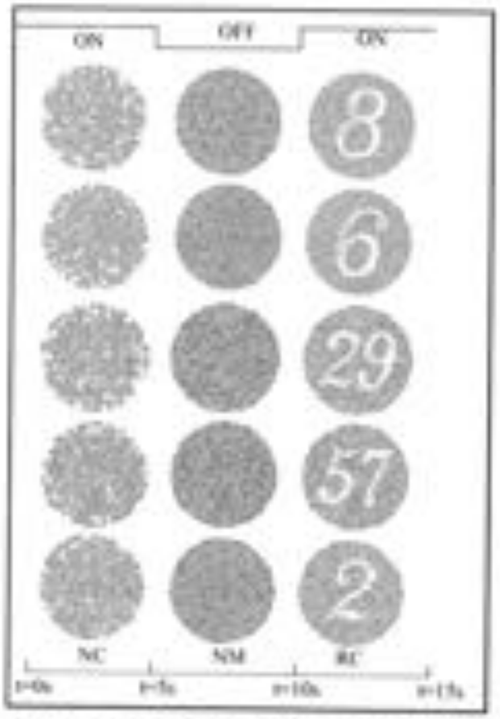


Fig.1 Visual stimulation: RC and NC are chromatic stimuli, and NM is its an achromatic version.

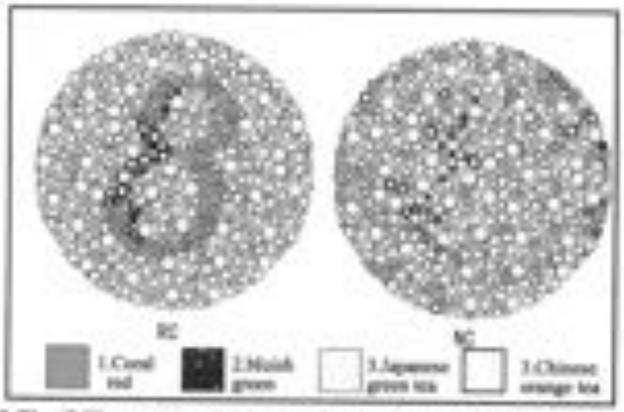


Fig.2 The "RC" pattern is a Readable Coloured digit pattern distinguished from its dappled background only by its colour. The "NC" pattern is a Non-readable Coloured digit pattern, using the same colour as "RC" because its pattern is composed of a random dot pattern. The "NM" pattern is a Non-readable Monotone pattern that is an achromatic version of "RC" and "NC"

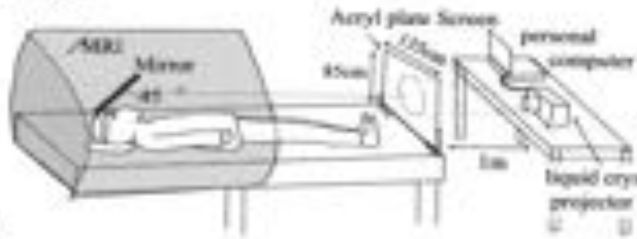


Fig.3 The apparatus of fMRI

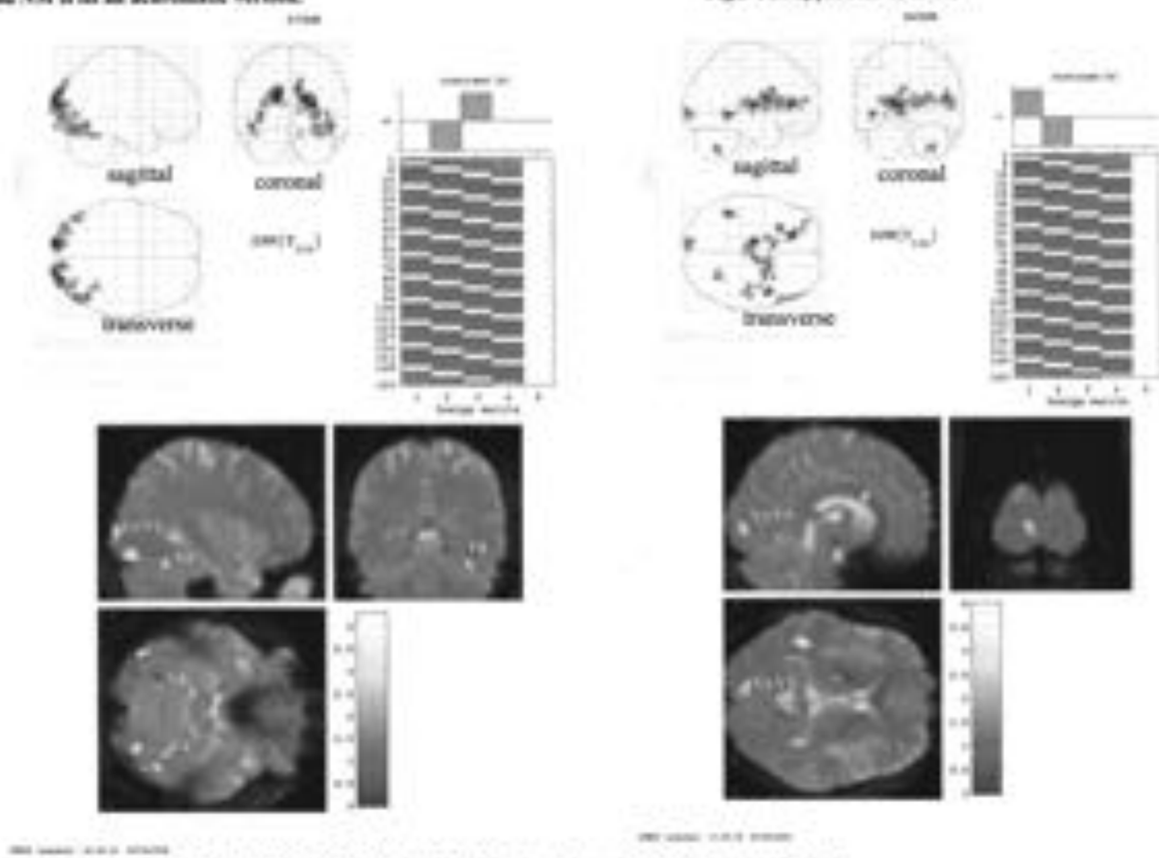


Fig. 4 a subject who is typical of the major activation patterns revealed by the comparison of chromatic (left RC right RM) versus achromatic(NM) stimulation. The SPM data is shown on sagittal, coronal and transverse.

A phenomenal observation on transparency and layer of depth

Sashiko Kawai
Seian College of Art and Design,

ABSTRACT

Brightness differences between an overlapping area of two figures and a surrounding area as a background effected to bring apparent transparency at the area.

Regarding this phenomenon of a sense of transparency, there were two kinds of a sense being related to either depth or interposition. In this paper we analyzed conditions of a figure-background brightness relation in terms of contrast and assimilation evoked these two senses of transparency at the area.

A sense of transparency of the area located apparently in a space of three dimensions produced a sense of depth by a brightness contrast effect between the crossing area of two figures and its surrounding background. On the other hand a sense of transparency of the crossing area of two figures as seen in a space of two dimensions produced a sense of interposition when assimilation occurred between the area and its surrounding background.
Keywords: transparency, layer of depth, contrast, assimilation

1. INTRODUCTION

Transparency is perceived when the surface of a figure is seen through a transparent medium. The phenomenon of a sense of transparency is perceived when the brightness of an interposition area of two figures is set nearer to one of the figures, which will then appear to be above the other figure. The brightness condition of the interposition area defines the medium between the two figures.

Separating the two figures into upper and lower layers is explained not only by the laws of similarity but also by the factor of good continuation from the Gestalt perception theory, as the upper layer seems to be of similar quality in brightness assimilation (Morinaga, 1952).

The lower layer is similar to the background and continues to have changeable elements while under the upper layer, which has a shade more than the upper layer. The effects of shape recognition and the interposition of figures on the phenomenon of transparency was studied in relation to the upper layer and depth and in connection with subjective contour (Coren, 1972). The effect of depth between the two figures is due to the brightness contrast and the response to the opposite colors (Goda et al. 1997). The differences in brightness between an overlapping area of two figures and the background produced transparency in that area. When a sense of depth in the phenomenon of transparency is perceived, the overlapping area was affected by the background brightness in terms of contrast (Kawai, 1997).

When the surface of a figure is perceived through a transparent figure, layer of depth is created by the recognition of space between the two figures which are interposed or separated in depth.

In this paper we use the phenomenon of the sense of transparency and layer of depth with three factors: figure-background brightness, linear perspective, and the attitude of observation .

2. METHODOLOGY

2-1. Stimulus figures

Two different kinds of stimulus figures (linear and non-linear perspective) were employed, the one was consisted of a large rectangle and a small trapezoid, and the other two rectangles of large and small.

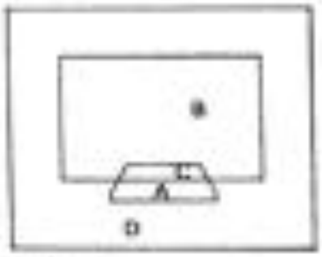


Figure 1. A stimulus having linear perspective.
A vertical board ,B, and a horizontal stand ,A, in linear perspective.
The A is 84.2 cd/m² and looks like being a front part of the stand divided by the board. The B is 23.0 cd/m². A crossing part of the A and the B, C, is a back part of the stand divided by the board, and the luminances of the C are changed from 5.8 to 84.2 cd/m².
A background of the figures, D, is either a white with 123.4 cd/m²
Or a black with 5.8 cd/m². A width = 4° & 3.1°. A height = 0.3° & 0.5°. C width = 3.1° & 2.3°. C height = 0.6°.
B = 6.9° x 4.5°. D = 13.3° x 10°.

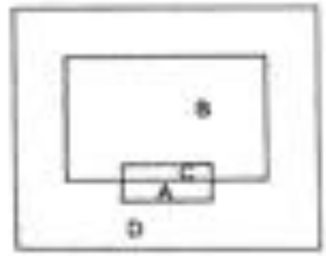


Figure 2. Stimulus figures having a non-linear perspective.
A combination of two rectangles, large one (B+C) and small one (A+C). Width x height : A = 3.1° x 0.8°.
C = 3.1° x 0.6°. B = 6.9° x 4.5°. D = 13.3° x 10°.
(B and D are same size as Figure 1)

2-2. Experiments

2-2-1 Instruction

Two different instruction, which described below as (a) and (b), were used, being intended the same stimulus figure to perceive specially different in either the 3- or 2-dimention.

(a) The figure you look at shows a large rectangle wide board (B) vertically elected on a small base (A) drawing as a trapezoid with a partially crossing (overlapping) area (C) of the two things.
Press the button either No.1 when the large board looks transparent, or No.2 when it doesn't.

(b) The figure you look at shows a large rectangle (B) and a small one (A) placed together having a partially crossing area (C) of the two shapes.
Press the button either No.1 when the large square looks transparent, or No.2 when it doesn't.

Therefore the experiment was executed for four conditions: two stimulus figures times two instructions.

2-2-2 Subjects

Five subjects for each of four conditions, then 20 subjects in total were participated in the study.

2-2-3 Procedure

The independent variable was the luminance of the area C which was changed in seven steps of luminous intensity.
The response of transparency of the area B was the dependent variable. Ten responses for each of seven luminances were required and the total of 70 stimulus were presented randomly.
Two background luminous intensities, black (D) and white(W), were introduced as parameter.

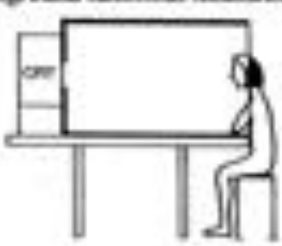


Figure 3. Experiment equipment (a sectional box), computer HD is Power Mac 7100 by Apple, CRT display is Flex Scan 56TS by NANAO. Inside width and height of the dark-box is 75 cm, depth 138 cm; covered by wall velvet.

3. RESULTS

Averages of transparency responses obtained from 5 subjects with standard deviations were calculated for each of luminance conditions of the area C with each of background luminances.
The results were shown in Figure 4 which the frequency rate of transparency of B was plotted as a function of the luminance of the crossing area, C.
The luminance of C when__is compared with the luminance of A and B.

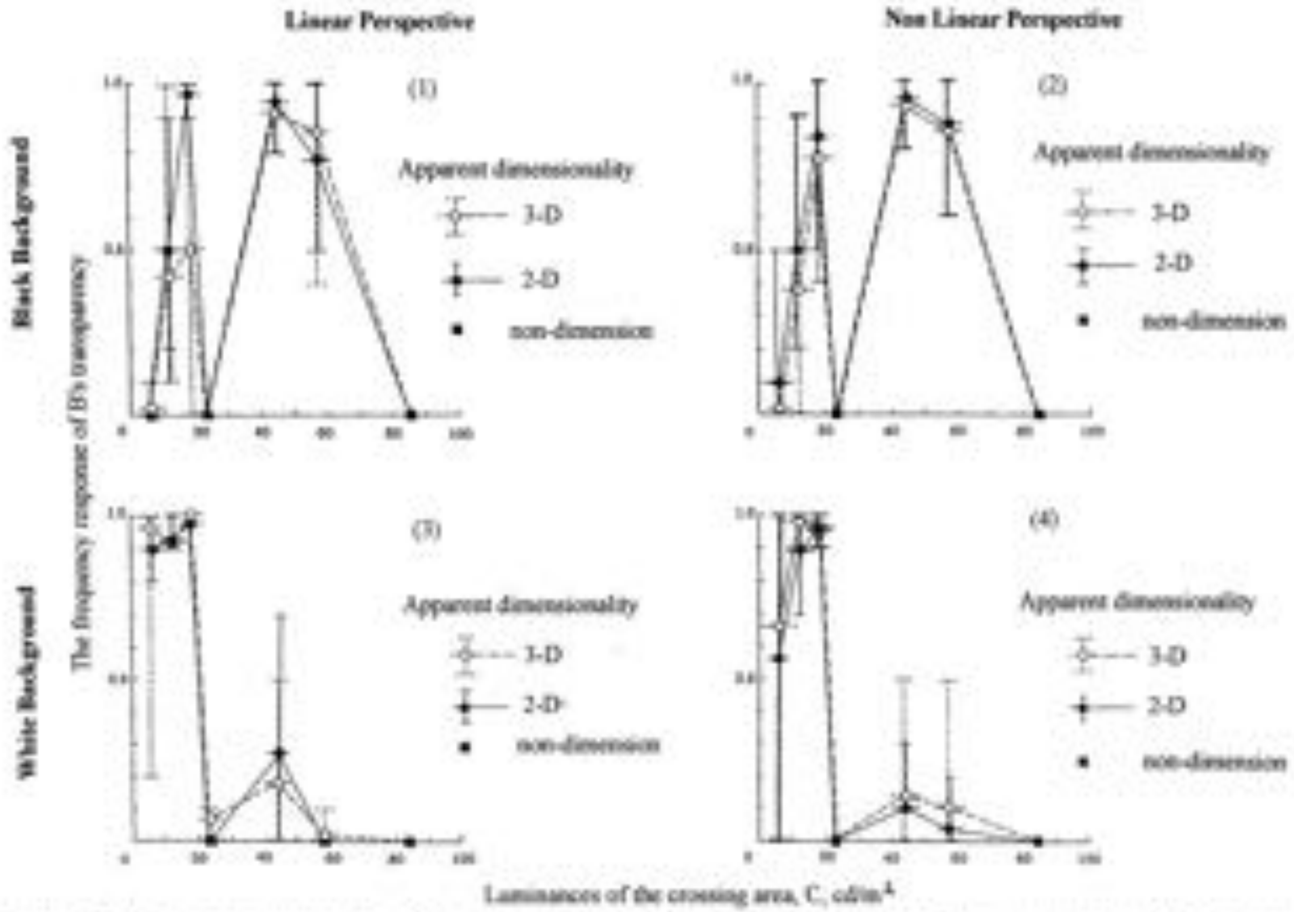


Figure 4. The frequency response rate of B's transparency as a function of luminances of the crossing area, C, with apparent dimensionalities, 2-D or 3-D, as a parameter. Whether a figure shown in Figures 1 or 2 perceives as 2-D or 3-D is controlled by the instruction (a) or (b), respectively.

The brightness C when an apparent transparency of the B shows the highest rate of frequency is compared with the luminance A and B. The following results in terms of the luminance order of three parts, A, B and C are obtained.
The order obtained from Figure 4-(1) which is apparent dimensionality 3-D controlled by the instruction for a linear perspective with a black background condition is A > C > B > D that means the area B seems look the most transparent when C is much brighter than the black background, D, brighter than B and darker than A, and which is apparent dimensionality 2-D controlled by the instruction for a linear perspective with a black background condition, the order of luminance is A > B > C > D that means the area B seems to look the most transparent when C is much darker than A, darker than B and brighter than the black background, D.
From Figure 4-(2) which is apparent dimensionality 3-D and also 2-D for a non-linear perspective with a black background, the order of luminance is A > C > B > D that means the area B seems to look the most transparent when C is much brighter than the black background, D, brighter than B and darker than A.
From Figure 4-(3) which is apparent dimensionality 3-D and also 2-D for a linear perspective with a white background (W) condition, the order of luminance is W > A > B > C that means the area B seems to look the most transparent when C is the darkest than the white background, W, much darker than A and darker than B.
From Figure 4-(4) which is apparent dimensionality 3-D and also 2-D for a non-linear perspective with a white background condition, the order of luminance is W > A > B > C that is the almost same results as Figure 4-(3), but C for apparent dimensionality 3-D is darker than C for 2-D.

4. DISCUSSIONS

(1) A sense of depth
For a phenomenon of transparency resulting from a sense of depth for figures drawn in linear perspective, the condition of brightness contrast is more efficient than that of form. On a white background especially, the shade effect seems to promote the recognition of a sense of depth under normal conditions.

Many subjects perceived brithness on transparency in a sense of depth, that the surface of transparent layer seemed to be clear and strongly contrasted. When the surface of the transparent layer seems clear and deep, the impression of depths in a space of transparent surface is perceived as depth.

(2) A sense of interposition
A sense of transparency in the crossing area of two figures, upper and lower, as seen in a space of 2 dimensions is observed as a sense of interposition when assimilation occurs between the crossing area its surrounding background. And also in creating a sense of interposition for the stimulus figures, a condition of form with & without a linear perspective is influenced by a condition of brightness assimilation or contrast between the crossing area and its surrounding.

In the case of a stimulus figure with non-linear perspective (Figure 2.), it is important to consider the brightness contrast effect because the sense of interposition needs a little sense of depth between the crossing area of two figures and its surrounding background. In the case of a stimulus figure with linear perspective (Figure 1.), a depth effect of a stimulus figure in 3 dimensions takes brightness assimilation.

A sense of interposition of the phenomenon of transparency is affected by brightness contrast and assimilation or depth effect in the linear perspective way.
As mentioned above it is necessary to perceive the meaning of a sense of interposition from touched figures to two separated figures for layer of a depth.
The surface of the layer that seems to appear as transparent with a sense of interposition is little turbid as mud glass or unclear as a soft lace.

5. CONCLUSIONS

(1) The differences between a sense of interposition and a sense of depth come from the differences in space recognition: the one based on sensing lower and upper layer; the other on supposition of a three dimensional space.

(2) When a phenomenon of transparency has resulted in evoking a sense of depth, the conditions of brightness contrast play a greater role than the condition of form in space of three dimensions. A sense of interposition is created by some sense of depth, which is affected by brightness contrast or linear perspective.

(3) In a phenomenal transparency the attitude of observation in experiment plays an important role, besides factors of brightness and linear perspective construction. The brightness in relation to the crossing area of two figures in a space of three dimensions and its surrounding background is especially important. Contrast and assimilation are brought from differences in the attitude of observation, whether to recognize space as two dimensional or three dimensional.

(4) In a phenomenal transparency, transparency with a sense of depth shows more clarity than one with a sense of interposition. The difference of clearness is a cue to recognition of space as of two dimensions or of three dimensions.

ACKNOWLEDGMENTS

I am grateful to Munehira Akita for his direction of this paper.

PREFERENCES

Coren S.: Subjective Contours and Apparent Depth, Psychological Review **79(4)** 359-367, 1972.
Kanizsa, G.: Organization in Vision, New York, Praeger, 1979.
Metelli, F.: The PTerception of Tranceparency, Scientific American **230 (4)** 90-98, 1974a.
Shevelle, S. K., Holliday, L. & Whittle, P.: Two separate neural mechanisms of brightness induction, Vision Research **32** 2331-2340, 1992.
Morinaga S.: Law of Similarity & Organization of Visual Field Organizational Structure, Pr. Chiwa Annual Articles, 9-15 (written in Japanese), 1952.
Goda, Takahashi, Ejima : Luminance and Color cue perceptual transparency, Perception **26**, 131, 1997.
Kawai S.: A phenomenal observation on the perception of transparency and the sense of depth, Proceedings of The Color Science Association of Japan **28**, 46 (written in Japanese), 1997.
Kawai S.: A phenomenal observation on transparency and layer of depth, Color Forum JAPAN '99, 127-130 (written in Japanese), 1999.

Movement and colour: independent or complementary channels?

Maria L. F de Mattiello*, Maria M. Chague and Susana Buglione
Laboratorio de Investigaciones Visuales. CONICET.

ABSTRACT

We analyzed how much motion coherence was needed to detect a target group of three moving dots in a dynamic visual noise background and how the addition of color helps to achieve this coherence. In order to do this, 171 different situations were analyzed: the amount of noise dots, three different organizations of the samples, and different achromatic and chromatic situations both in the backgrounds and in the samples. The results indicate that: collinear targets are easily recognizable; in an achromatic situation the increase of noise dot produces a sharp decrease in recognition; color of the dots, particularly if the color is in opponence to the background color, re-establishes this loss. The results also indicate that movement and form regularity do not appear to be additive but are interactive.

Keywords: Coherent motion, dots, color, chromatic opponence, grouping; spatial facilitation

1. INTRODUCTION

During the 70s and the beginning of the 80s specific stimuli were believed to be processed by independent channels. This hypothesis coincided with the discoveries of Hubel & Wiesel[1] on cortical specificity. Around the same time, Estévez and Spekreijse[2] published a paper – which in our opinion is paradigmatic – on the "silent substitution" which takes place between cones and rods when the intensity of light or the location of the stimulus on the retina vary. An idea underlying this study was that receptors, even when they present specific characteristics and fulfil different functions, are related and are not independent channels of information.

Other papers[3-5] followed to support this idea, with the result that today we can debate that although the brain is organized on the basis of parallel processes, these would appear to present complementary characteristics. So, the mechanisms which would allow a channel to compute a set of properties, would also prevent it from computing properties of its complementary channels. A well-known example of this is the red-green opponent which is indisputable in post-images. Consequently, every channel would seem to present capacities and weaknesses which seek to balance each other in order to adapt to the conditions of the physical world, a world which also presents its own complementarities, such as green ivy leaves which become deep red in autumn without actually modifying their molecular structure.

The same thing occurs with the Visual System (VS): after the retina, visual information passes to the Lateral Geniculate Nucleus which, as we know, is made up of two cellular systems: the parvo, which culminates in the infero-temporal region, and the magno in the parietal region. The former processes colour and *orientation*, while the magno system -which is blind to colour- processes *direction* of movement. These two systems are not as separable as originally thought, and may be considered complementary since the action of one balances the action of the other. For example, some P cells can respond to high rates of flicker, up to 30 Hz[6] and many M neurons show some colour selectivity[7,8]. So, due to the fact that colour is captured by the parvo system, and movement is captured by the magno[9], it is to be expected that colour acts as a complement of movement and, in consequence, the threshold of human observers' detection of targets in movement should improve significantly when the targets are presented in colour. If this occurs, the experiments would seem to indicate certain spatial facilitation[10] and new assumptions on perceptual phenomena such as spatial grouping [11,12].

This paper seeks to reveal this property by way of the recognition of chromatic and achromatic dots, with equal direction of movement, which are presented on a set of dynamic random-dot stimuli. Let us agree that an image or object in movement is a set of boundaries of different *orientation*, which move in the same *direction*, that is perpendicular to the *orientation*. The brain reorders this information grouping equal or similar *orientations*, *directions* and *speeds*, thus achieving a precise perception of objects in movement, even if they are partially occluded.

2. METHODS

With this experimental framework in mind, a total of 171 different situations were devised. They were grouped into three subgroups. The first presented a variable number of black dots (20, 15 & 10) with random movement on a gray background, and another 3 black dots with the same direction placed colinearly (A), and on the vertices of two different virtual triangles (B, C), all of which are the sample to consider. See Figure 1. The second group used the same background but the samples were red or green, with colorimetric purity equal to 0.06, 0.12 and 0.18. The third group was similar to the former and considered red or green backgrounds of 0.12 purity, acting in opponence to the color of the samples. The stimuli were presented on a PC monitor with a resolution of 640 x 350 pixels. The display was positioned 110 cm from the observer's eyes, and at this viewing distance the test region subtended 10° of visual angle. During the experiments, 15 frames per second were used, but only after it had been clearly demonstrated that samples could be recognized at this speed. Ten observers with normal color vision took part in the different experimental sessions. They were university students with ages ranging from 22 to 26 years. In a previous experiment, the 171 possibilities were arranged according to degree of difficulty, in such a way as to prevent learning; the experiment was suspended as soon as the observers recognized the samples. The lifetime of the target group of dots was 1500 ms. Firstly, in two consecutive intervals of time, the groups of dots with random movement were presented. In the following interval, the three dots which were the sample to be considered, were added to the background and these were presented twice. The target group of dots always started at a random position. The task of the observer was to detect in which of the four intervals the target appeared.

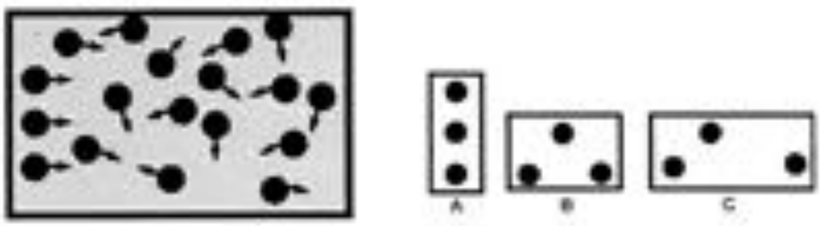


Figure 1. Diagram of the stimuli used

3. RESULTS AND DISCUSSION

Figures 2 to 4 summarize the results obtained. Figure 2 indicates the average of the total number of estimations according to the type of samples and gives an idea of the pregnancy of sample A with regard to B and C, showing the strong interaction that exists between spatial and temporal factors in figure-ground segregation[17]. The contribution of color to the discrimination of the samples in movement also was observed since its use reduced the effect of the perception of movement of the background dots, thus diminishing its distracting effect.

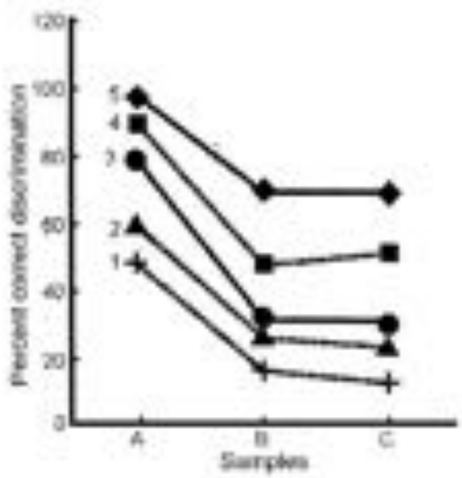


Figure 2 Percentage of recognition according to the type of samples (A, B and C) for five different situations: gray background and black sample (1), gray background and red sample (2) and green sample (3), green background and red sample (4); red background and green sample (5).

Figure 3 indicates the influence of saturation. Numbers 1 to 3 only indicate the growth of purity that was of 0.06, 0.12 and 0.16 for red and green samples. The backgrounds exhibited purities equal to 0.12. The percentage of recognition grow with the increase in the saturation of the sample and with the addition of a color opponent to the sample in the background. If we consider the two lower curves (gray background) with respect to the two upper ones (opponent chromatic background) we can notice that in the first case recognition increases with the increase in saturation. However, in the case of the two upper curves, recognition becomes stable at a purity level of 0.12.

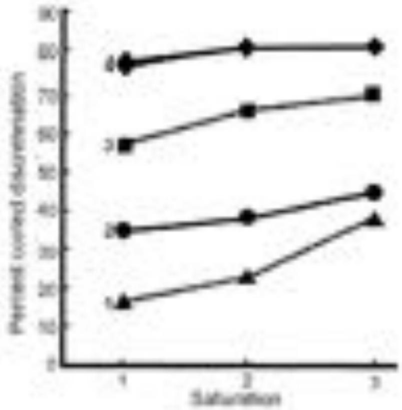


Figure 3. Recognition accordig to saturation of the samples and backgrounds. (1) shows a red sample with a gray background, (2) shows a green samples whit gray background, (3) shows a green background with a red sample, and (4) a red background with a green sample. Numbers 1 to 3 only indicate the growth of purity that was of 0.06, 0.12 and 0.16 for red and green samples. The backgrounds exhibited purities equal to 0.12.

Figure 4 analyzes the influence of the number of dots distributed with random movement in the background. The dotted curves indicate only the samples A and B in achromatic situation, since C could not be recognized in this experimental condition. Leaving aside the achromatic situation, included for the sake of comparison, three well defined levels of recognition can be observed. With around 100% recognition, we can only find sample A with backgrounds of color opponent to that of the samples. At 50% of recognition are sample A with chromatic dots and gray background, and samples B and C with color in opponence with the background. Finally, around 15% of recognition belong to color samples B and C with gray background. If we observe the figure carefully, it is evident that the increase of the dots in the background significantly reduces the possibility of recognition in achromatic situation and in the case of samples with smaller pregnance. These results show also, that chromatic and achromatic mechanisms are independent at threshold but appear to interact in suprathreshold processes such as visual marking[14].

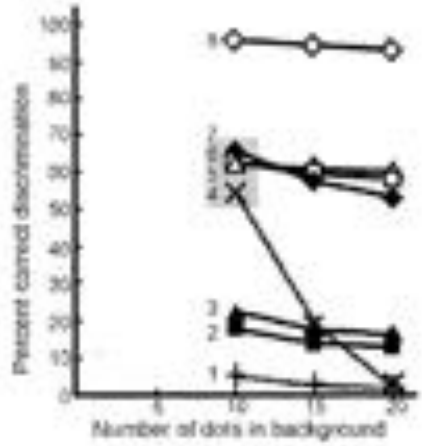


Figure 4. Percentage of recognition according to the number of dots in the background. The numbers indicate (1) black samples A and B (2) on a gray background; color samples C (3) and B (4) on a gray background, color samples C (5) and B (6) on a opponent chromatic background; (7) color sample A on a gray background, (8) color sample A with opponent chromatic background. The gray rectangle indicate the cases with similar detection.

These data reveal that: 1) in those cases in which color did not intervene, the recognition of the samples could not be carried out when there were more than 20 dots on the backgrounds; 2) in the cases of non-recognition the aggregate of color to the sample made recognition easier; 3) the use of backgrounds of a complementary color to that of the samples, increased recognition while detection times fell; 4) the direction of movement assisted recognition of the sample and, in the case of collinear points -where the perpendicularity of direction in relation to movement was very evident- it assisted recognition even more; 5) the distancing of the sample dots in sample C has a negative impact on recognition. The evidence for this is consistent with neurophysiological data showing that the response characteristics of visual cortical cells change with the context in which a trigger-stimulus is presented[15].

In summary, the observed complementarities were: a) achromatic versus chromatic channels; b) opponent colours; c) movement versus colour; d) orientation versus direction of movement. Let us say that complementarity possibly allows the VS to transmit greater information in less time, and in consequence the illusions – both in color and in movement – are probably due to the fact that in certain situations, information channels could not anticipate the computing of properties of their associated channels. The general conclusion is that inducers defined by color contrast produce spatial facilitation in the same way as inducers by luminance contrast. Therefore, the visual detection of a target object can be facilitated or suppressed by nearby objects, spatial location, orientation, contrast intensity or color contrast.

REFERENCES

1. D.H. Hubel, and T.N. Wiesel TN, "Functional architecture of macaque monkey visual cortex," *Proc. Royal. Soc. Lond., B* **198**, pp. 1-59, 1977.
2. O. Estévez, and H. Spekreijse, "The silent substitution method in visual research," *Vision Res.* **22**, pp. 681-691, 1982.
3. H. Egusa, "Effects of brightness, hue and saturation on perceived depth between adjacent regions in the visual field," *Perception* **12**, pp. 167-175, 1983.
4. J. Faubert and M. von Grunau, " The influence of two spatially distinct primers and attribute priming on motion Induction", *Vision Res.* **35**, pp. 3119-3130, 1995.
5. H.S. Smallman, and S.P. McKee, "A contrast ratio constraint on stereo matching," *Proc. Royal Soc. Lond., B* **260**, pp. 265-271, 1995.
6. W.H. Merigan, and T. A. Eskin, "Spatio-temporal vision of macaques with severe loss of PB retinal ganglion cells," *Vision Res.* **26**, pp. 1751-1761, 1986.
7. M. S. Livingstone, M.S. and D. H. Hubel, "Segregation of form, color, movement, and depth: anatomy, physiology, and perception," *Science*, **140**, pp. 740-749, 1988.
8. P.H. Schiller, N.K. Logothetis, and E.R. Charles, "Functions of the color-opponent and broad-band channels of the visual system," *Nature*, **343**, pp. 68-70.
9. E.A. DeYoe and D.C van Essen, "Concurrent processing streams in monkey visual cortex," *Trends in Neurosci.* **11**, pp. 219-226, 1988
10. C. Yu, and D.M. Levi, "Spatial facilitation predicted with end-stopped spatial filters," *Vision Res*, **37**, pp. 3117-3127, 1997.
11. U. Polat, and D. Sagi, "The architecture of perceptual spatial interactions," *Vision Res.* **28**, pp. 115-132, 1994.
12. C. Werhahn, and B. Dresp, "Detection facilitation by collinear stimuli in humans: Dependence on strength and sign of contrast," *Vision Res*, **38**, pp. 423-428, 1998
13. S-H. Lee, and R. Blake, "Detection of temporal structure depends on spatial structure," *Vision Res.* **19**, pp. 3033-3048, 1999.
14. J.J. Kulikowski, "Spatial and temporal properties of chromatic processing: separation of colour from chromatic pattern mechanism," in C. M. Dickinson, I. J. Murray, and D.Carden, *John Dalton's colour vision legacy*, pp. 133-146. London: Taylor and Francis.

15- C.D. Gilbert, and E.N. Wiesel, " The influence of contextual stimuli on the orientation selectivity of cells in the primary visual cortex of the cat", *Vision Res.*, **30**, pp. 1689-1701, 1990

* Departamento de Fisica-Matemática, Facultad de Farmacia y Bioquímica, Universidad de Buenos Aires, Junín 956 (1113) Ciudad de Buenos Aires, Argentina. Mail: lzvia@ffyb uba ar

On the transfer of visual data from the laboratory to the real world

Lucia R. Ronchi*
* Associazione Ottica Italiana, 1 vua Suor Maria Celeste, 50125 Florence, Italy

ABSTRACT

After a brief report on the gap existing between the visual functionality assessed in the constrained laboratory conditions and its applications in the complex, multidimensional, real world, two examples concerning color appearance are described. In the former experiment we wonder why a colotimetrically uniform, 10° diam. test field has a uniform color appearance, in spite of the eccentricity dependence of the color naming for a 1° diam exploring spot. It is as if the underlying gradient of responsiveness of the underlying array of photoreceptrs were discounted.. But this does not tell us what is the actual color appearance. Less distal mechanisms resulting in assimilation or filling-in are to be called into play. In the second experiment we consider as test objects the modern, expensive, flashy cars. Although coated uniformly, under natural outdoor lighting they appear as a complex set of segmented "regions" differing in lightness and even in hue. However, simultaneously and effortlessly, we perceive a coexisting idealized uniform surface color, probably reconstructed as if the perturbation due to natural lighting, responsible for the segregation into regions, and the gloss responsible for intra-region textures were discounted.

Keywords: color appearance, perceptual constancy, apparent uniformity

1. INTRODUCTION

Entering the 3rd millennium implies amplifying the horizon, by going beyond the quantitative assessment of visual laws, and considering on a wider scale the appearance, the perceptual organization, the role of attention, etc, passing from local to global, from short- to long- range interactions, from contrast to context, from simple to complex, and so on. This imposes to abandone the aseptic conditions of the traditional visual laboratory, where several variables are "frosted", to face the observer with experimental situations involving the environmental multidimensionality. Nowadays, while the Cognition experts raise the question "how our brain is functionally organized to achieve an adaptive behavior in a changing world", in specialized laboratories[1] novel research methods are planned to assess the qualities of real objects, by identifying the aspects of the stimulus that are likely candidates as "cues" for the perception of the attributes of various materials (e.g. non-lambertian surfaces with a marked highlight), Moreover, novel structured stimulation conditions and novel psychophysical methods are planned, to assess the systematic and surpisingly large deviations of the "optical space" from the physical space.
In parallel with the explosion of advanced attitudes on the part of the investigators, an important problem deserves attention: what results obtained by the laboratory research can be directlyutilized, how they may be transferred to the real practice, and what are their limitations. The list of examples would be very long, out of the allowed space. Let us limit ourselves to consider the problem of apparent uniformity, by describing two experiments having the flavor of "exercises"

2. THE FIRST "EXERCISE"

This experiment started by using as test objects a cap of the F-M 100-Hue Test, subtending at the eye 1° diam, presented on a middle gray background (L = 20 cd / sq.m), lit by an incandescent source. Its color appearance, in foveal vision, is assessed by the color naming technique. The frequency distributions of the responses, in terms of the four unique hues, are shown in the plot at the top of Fig.1, where each point represents the average of the responses of three normal young adults, taking part in three sessions each.
Now, let us compare the foveal response to the same cap, placed at 5° from the fovea, up, on the vertical meridian. By calculating the difference R(0° - 5°) of the responses, for every cap, after averaging across sessions and across observers,, we obtain the data shown in the lower plot in Fig.1. The shift in color appearance, when passing from the fovea to the parafovea is practically "as expected". However, the fact that a greater blueness is reported in foveal vision deserves some attention. This fact was confirmed by other three obserevrs, by using the Hahn Double 15 Hue Test.

This effect might be accounter for by considering, a), that according to a recent suggestion the concept of synthetization of uniform percepts may be extended to an undersampled retinal region such a the central fovea, sparsely populated by S-cones; b), that the desaturating contribution of rods is favoured by large stimuli, as the 10° diam test field is.
In the second part of the experiment we compared the appearance of a test field, 1° diam, to that of a large test field, both being cut from the same surface material (colored cardboard). The samples were presented on a black (or dark grey) backgtound, the inter-centre distance being about of 10°. The adaptation strategy was carefully controlled. The color appearance was assessed by the use of [4+1] color naming technique, to take into account that the larger field appeared rather desaturated, compared to the smaller one. Now, it is as if we were comparing an 1° diam test field, on a black backgtound, of 10° diam., to the same 1° field on an equiluminous, isochromatic backgtound of 10° diam. This latter is the critical "crispening" condition, which is known to be minimized by the presence of a frame surrounding the test field (for this reason, the findings obtained with above said caps can be only indirectly applied)
Now, depending on the hue of the considered material, the 1° field, on the black background, appears more-or less different from the 10° field, which appears quite uniform both in lightness and hue. It is as if we were in the presence of an assimilation effect, which might be also referred to other possible facts, such as l filling-in, a centripetal spreading, flanking the discount of the underlying gradient of retinal responsiveness, M-scaling, integration of building blocks, association fields, and so on.
Ler us limit ourselves to report about the appearance of the sample for which the said difference is large at most, that us, the green bluish sample (which marches the NCS S 20 60 B90G). The blueness of the foveally viewed 1° field is found to be significantly superior to that of the 10° field (which, in addition, appears desaturated). This fact agrees with Fuld's suggestion[2] Working with monochromatic stimuli, at low levels of purity, in the range 480 – 500 nm, this author noted the difficulty in detecting hue, "when it is present as a small proportion of the total color".
At last, looking for the proof that the reduced apparent blueness is the parafovea is due to rod intrusion, we performed some observations out of the laboratory, under natural illumination. As Table I shows, the expectation is fulfilled. As the luminance L of the test field increases, the percent difference (b1° - b10°) between the frequency of occurrence of the color name "blue" for the small (1°) and for the large (10°) test field decreases. In turn, the ratio (A10° - A1°) between the relative achromatic contents of either test field decreases also.
For the sake of reference, these same quantities recorded in the laboratory, averaged over three observers,are also displayed, at the bottom of Table I.

3. THE SECOND "EXERCISE"

The test objects are now the expensive, modern, glossy and flashy cars, seen outdoos, under natural lighting, in a serene or not too cloudy day. Let the car be uniformly coated, hence, colorimetrically uniform. In spite of it, the appearance is highly complex, for various reasons. On a gross scale, because of the distribution of curvatures, in addition to various slow and sharp gradients, it appears as a set of segmented "regions", differing in brightness / lightess and somehow also in hue. On a fine scale, various regions appear "textured", because of various grain / gloss interaction, depending on being the surface of the car metallic pigmented, or opalescent with mica pearl pigment, possibly resulting in the high lustre "Flip-Flop" due to goniochromatic color shifts of "effect pigments".
The question arises whether perceptual constancy for brightness and color should occur or not. However, it is difficult to be predicted, because of the interplay of contradictory facts.
In favour of constancy there is the fact that illumination is "natural", both diffuse (by the sky) and direct (by the sun), and its effects on the appearance of the lit objects are well known, either "learned" or even inborn. In turn, a car, per sé, it is known and bilaterally symmetric.
On the other hand, militate against the constancy, a), the intrinsic complexity of the lit pattern, going far beyond the presence of the slow gradients (classically favouring constancy); b), the tremendous variability of the interplay of specular and diffuse reflections, depending on the direction of observation and of the incidence of illumination, on both the gross and the fine scales, aggravated by and depending on the speed of the car, when moning.
The reply to the above question was given by a sample of ten observers, taking part in an experiment performed partly in the laboratory, looking at pictures of cars, partly outdoor, looking at real cars. Their responses were based on visual scaling : a ten point subjective scale for brightness / lightness, color naming (categorical and / or intracategorical) for hue.
Their responses were simultaneously in favour of either alterantive, although mutually contradictory (it seems legitimate, as asserted by de Valois et al.[3])

The failure of constancy is patently shown, because the observers perceive the inhomogeneous regions on the surface of the car.

The occurrence of constancy may be found in a number of facts: a), the observers' response is immediate and effortless; b) he identifies without hesitation the brightness / lightness, by making reference to his personal scale; moreover, he names the color, rather than in terms of basic categorical naming, by easily"navigating" within the categories . It is as if they were referring to an idealized, uniform, representation.

In terms of modelling, we might refer to the so-called "feature models": the various regiones imaged on the retina would be processed in parallel and pre-attentively, by assigning a "weight" to each of them; from the integration of various building blocks, a reconstruction emerges, probably based on the maximum weight, after having discounted the gradients of retinal responsivity, and after having combined the "frames" captured during the fixations allowed by the stragery of visual perlustration.

4. CONCLUSION

It is not easy and immediate to explain why we perceive surfaces of uniform brightness / lightness and hue, both when the surface is colorimetrically uniform and when it is not. Perceptual constancy, a typical characteristic of natural, familiar environments, has to be caller into play, by going out of the laboratory (really or through appropriate simulations), invoking the help of cognitive science, and often waiting for the future findings of advanced research.

REFERENCES

1. J.J.Koenderink, " The structure of optical space under free viewing conditions", *CVNet Project description*, 23 Feb., 2001.
2. K. Fuld, "The contribution of chromatic and achromatic valence to spectral saturation", *Vision Res.* **31**, pp. 237 – 246, 1991.
3. R.L. de Valois, M.A. Webster, K.K. de Valois and B. Lingelbach, "Temporal properties of brightness Induction ", *Vision Res.* **26**, pp.887 - 897, 1986.

TABLE 1

Outcome of color naming, for a small (1°) foveally viewed test field, and for a large (10° diam) test field, both cut from the same green bluish cardboard, matching the NCS sample S 20 60 B90G.

Upper portion: data obtained under natural ioutdoor lighting. First column, log test field luminance. Second column, the fvveal excess of blueness in foveal vision, compared to an eccentricity of 5°. Third column, the greater achromatic component of the large field, compared to the small one. Averages and Standard deviation of data from ten observers.

Lower portion:data recorded in the laboratory, under incandescent anf fluorescent sourced (x,y, chromaticity coordinates)

Range of log L (cd / sq.m)	(b 1° - b 10°) %	(A 10° / A 1°)
		outdoor, natural daylight
0 - 1.0	39 +- 11	8.9 +-1.7
1.0 - 1.7	34 +- 15	5.9 +-1.4
1.7 - 2.0	20 +- 6	3.9 +- 0.7
2.0 - 2.7	14 +- 5	2.3 +- 0.8
2.7 - 3.0	10 +- 7	1.8 +- 0.8
3.0 - 3.2	5 +- 8	1.1 + 0.4
	Incandescent source	(x = 0.475; y = 0.415)
0.90	44 +- 11	4.9 +- 1.4
	Fluorescent source	(x = 0.388; y = 0.397)
1.28	35 +- 12	4.3 +- 1.1

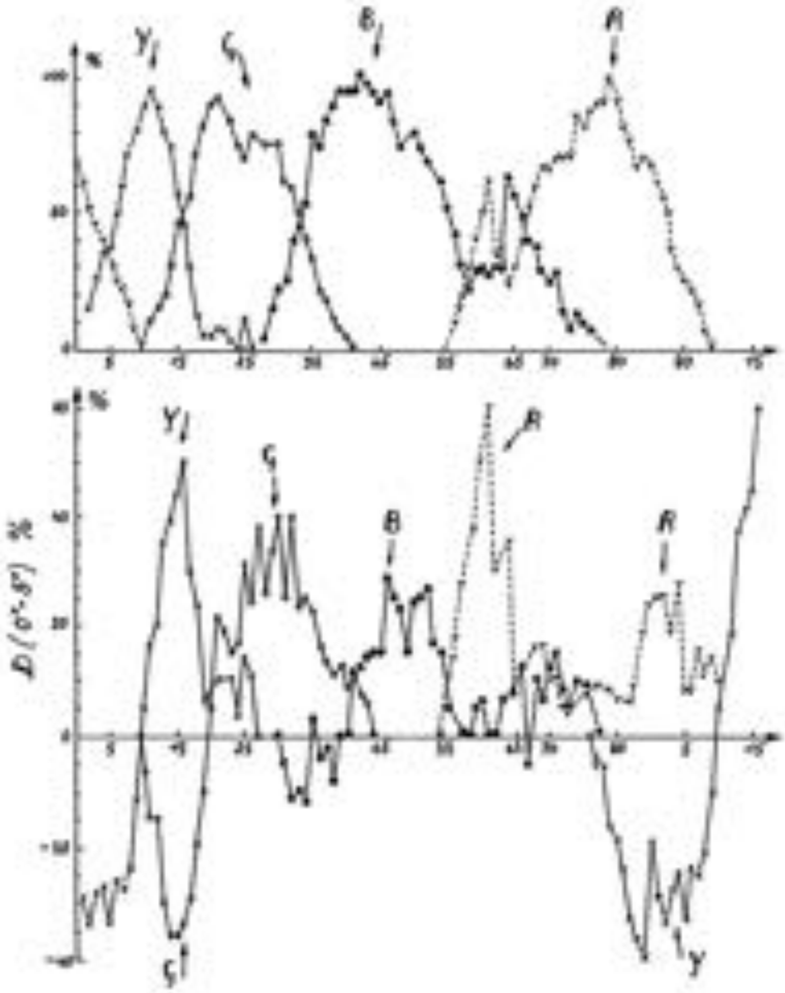


Fig. 1 – Abscissae : the order number of the caps of the F-M- 100-Hue

Ordinates, top : frequency of occurrence of the color naming responses corresponding to the four unique hues, in foveal vision

Ordinates, bottom: the percent difference between the responses in the fovea and at an eccentricity of 5°.

Colour also decides motion direction.

Katsuaki Sakata*
Joshibi University

ABSTRACT

However many research suggest that chromatic information is not used to perceived motion, some reports suggest the possibility of effect of colour on motion perception. The correct ratio of motion direction judgment was measured in this experiment in which isoluminant stimuli were presented. The results suggest that colour may have some effects to motion direction judgment.

Keywords: colour, motion, isoluminance

1. INTRODUCTION

Colour information that are conveyed by P-path way were not used to some kind of perception such as stereovision of which information used M-path way (Livingstone and Hubel, 1984). The difference of these pathway obstruct to use information each other, and some demonstration shows that lack of luminance information that use M-path way interfaces to perceive some kind of perception. In these demonstrations isoluminant stimuli are used to show the lack of luminance, i.e. luminance is same while chromaticity is different. Using this type of stimuli, shadings and highlights are difficult to see and they perceived flat, two dimensional stimulus. Lens accommodation is also interfered without luminance information (Wolf and Owens, 1981).

Motion perception is also independent from colour information, and it is often said that it is impossible to see motion with isoluminant visual stimuli. However many demonstration tell us that motion perception is caused only by luminance difference of stimuli, some researcher reported the possibility of working of chromatic information mechanisms when we see some kind of motion stimuli. In direction judgment of apparent motion, chromatic values of stimuli show better fit to data, while luminance values show less fit (Sakata, 1999). Further, activation of V4, which are observed by f-MRI during watching chromatic motion stimuli, is reported. These reports suggest that chromatic cue has effects somewhat to motion perception mechanisms which is, at least, first order motion, however the effects are small. Then the correct choice ratio of isoluminant stimuli are measured in order to know the effect of colour in perception of apparent motion direction. If colour information has no effect in motion direction judgment, and only luminance cue affects the judgment, the correct ratio should be chance level in any chromaticity. On the other hand, if chromatic information affects apparent motion mechanisms, the correct ratio will not be chance level, and the evidence of colour assist will be available.

2. EXPERIMENTAL

2.1 luminance

At first, subjects tuned the isoluminant stimulus value that decided the physical luminance of stimuli used in following session. Each subject tuned her isoluminant green to given red by minimum flicker photometry method, after ten minutes adaptation to experimental booth condition. The subjective same luminance for each subject was measured ten times and

* sakata@joshibi.ac.jp http://www.joshibi.ac.jp Joshibi University, 1900 Asamizodai, Sagamihara 228-8538, Japan

these mean values were used.

2.2 Stimulus

Each stimuli involved start figure and end figure both of which were red or green circle. Start stimulus fall from top of experimental field, then separate into two ways at the midway of the field (Fig. 1). Start stimulus was red or green, and one of end stimuli was red and the other was green (Fig.2). These green were isoluminant with red stimulus as subjects tuned. The motion of stimuli was apparent motion, and the size of each circle was approximately two degrees, and total size of stimulus was almost eighteen degrees. The stimuli were presented on CRT display of which refresh rate were 120 Hz, and these stimuli were presented in a dark booth.

2.3 Method

Subjects were asked to see the fixation point which was shown middle of display by hair cross, and they were asked to choice the direction in which start stimulus went. Start stimulus fall by mouse click by subject, and then they were asked to choose right or left by mouse click (2AFC). Velocity of stimuli motion was three levels, and changed randomly at each trial. Colour of start stimulus and direction of correct response (right or left) also changed randomly.

2.4 Subjects

Eight female students who have normal colour vision joined this experiment.

3. RESULTS

3.1 Isoluminance

Fig.3 shows the average of green L* which were adjusted by eight subjects, and L* of red stimulus which was constant in this experiment. And it was significant between Ascendant and Descendant ($p=.05$).

Many subject told that it was easy to tune minimum flicker in talking after experiment, and they thought that they achieved exactly.

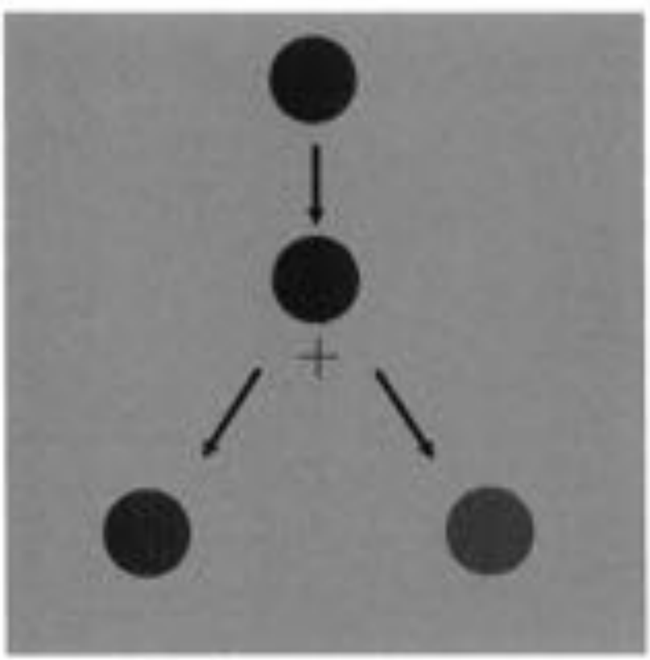


Fig.1 Stimuli layout on the display.

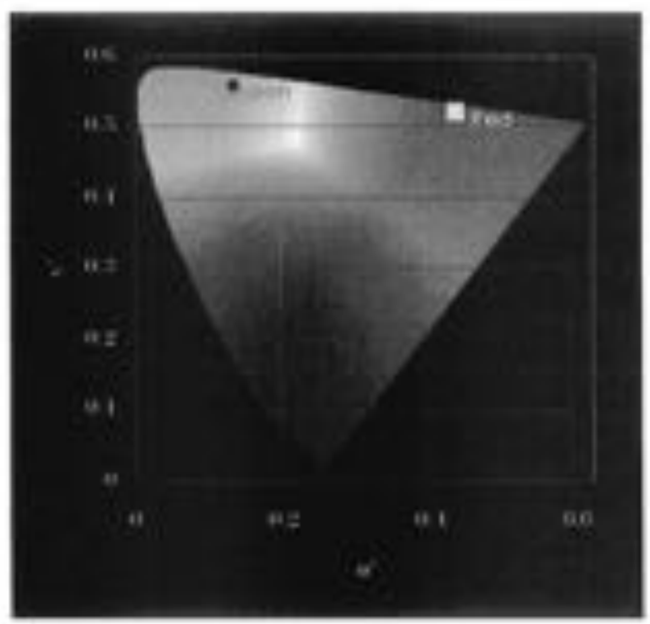


Fig.2 Red and Green location on u' v' diagram.

3-2. Motion direction judgment

Fig.4 shows each correct response ratio of colour and velocity. Green-Fast is less than chance level, while Red-Middle is more than 80% correct. Fig.5 shows mean correct ratio of each velocity. There is no significant difference between each velocity. But colour affected correct ratio of motion direction judgment as shown in Fig.6. The difference between correct ratio of red stimuli and that of green stimuli were significant by ANOVA (p=.01), however interaction between colour and velocity were not significant.

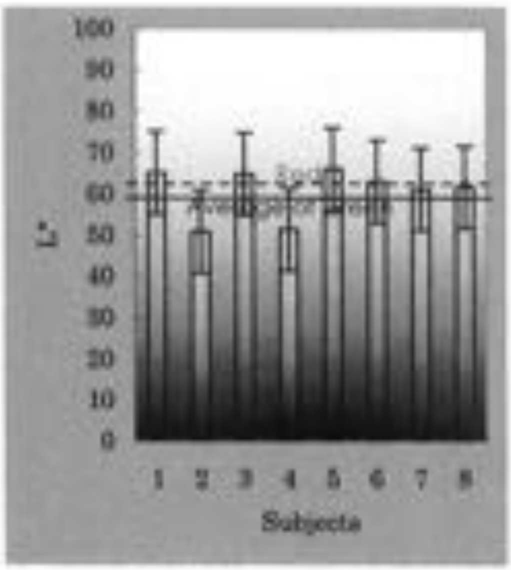


Fig.3 L* of mean green and L* of red.

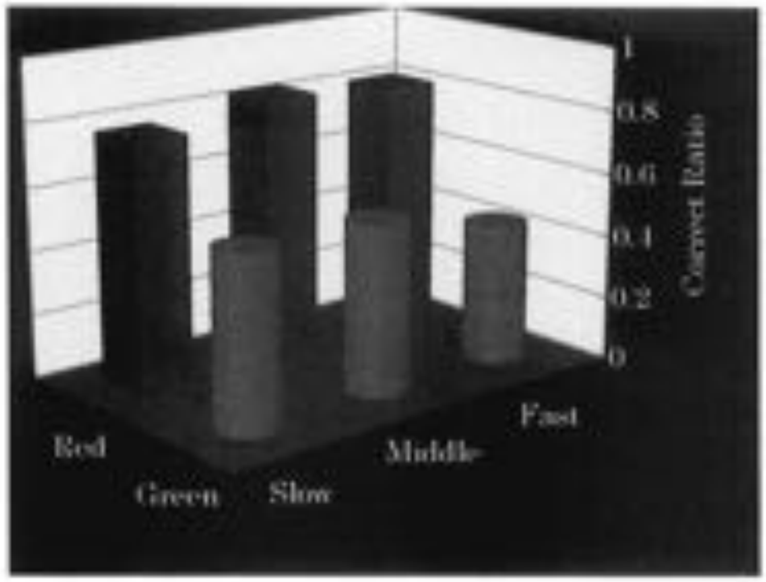


Fig.4 Correct ratio of each colour and vejlocity

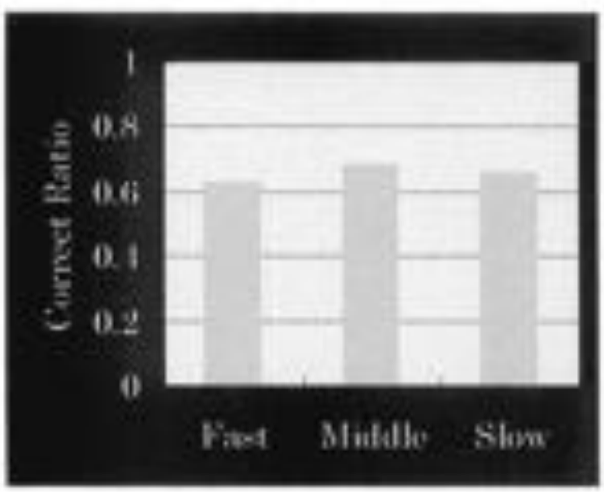


Fig.5 Mean correct ratio of each velocity.

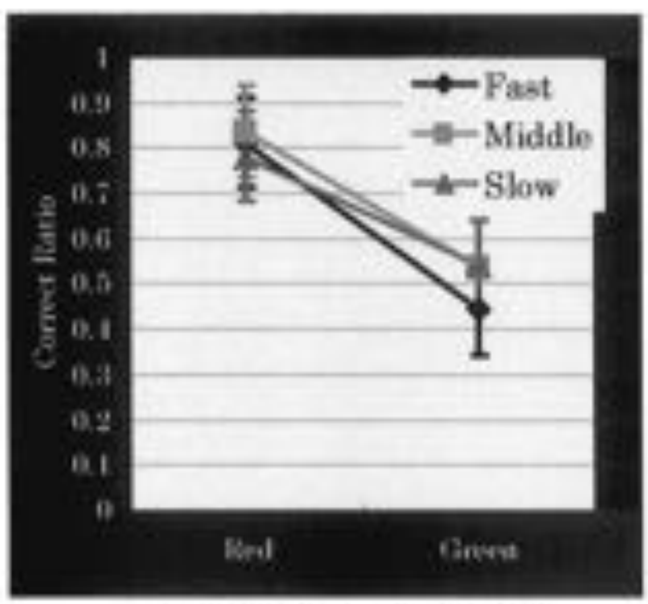


Fig.6 Mean correct ratio of each colour.

4. DISCUSSION

L* of isoluminant green by minimum flicker photometry had small variance, and also had small difference from L* of red. This suggest that the validity of L* has sufficient reliability. Correct ratio of isoluminant stimuli were not chance level nevertheless many research suggest. The difference of correct ratio between red and green suggests that chromatic information affect the judgment of motion direction decision.But why red stimuli shows such high correct ratio? Red stimulus has little bit high saturation than Green one. If saturation affects motion perception, strength of colour, such as saturation or brightness or similarity to elementary colour, may have some effect to motion perception. And this leads that colour and motion may be integrated in higher stage.

REFERENCES

1. M. S. Livingstone and D. H. Hubel, Anatomy and physiology of a color system in the primate visual cortex. *The Journal of Neuroscience*, Vol.4, No.1, 309-356, 1984.
2. J. M. Wolf and D. A. Owens, Accommodation colorblind? Focusing chromatic contours. *Perception*, Vol.10, 53-62, 1981.
3. K. Sakata, Colour affects motion. European Conference on Visual Perception (ECVP) proceedings, *Perception, supplement*, 1999.

Size of Recognized Visual space of Illumination Influenced by Color Scheme of Interior

Hideki Yamaguchi, Hiroyuki Shinoda and Mitsuo Ikeda
Department of Photonics, Ritsumeikan University

ABSTRACT

Understanding of illumination performs an important role in perceiving the color and brightness of object's surface. Especially, we can evaluate observer's perception about intensity of illumination by the concept of the brightness size of recognized visual space of illumination, RVSI. Our previous work[1] showed that the RVSI size is determined by the luminance of a highest-lightness object and it's normally proportional to the illuminance. In the present experiment, we measured the border luminance between object color and unnatural object color in two rooms differently furnished, to examine the effect of color scheme of interior on the brightness size. In spite of the same illuminance, the border luminance was a half of that in normal environment when the room was furnished with only objects whose Munsell Value were 5 or less. The measurement of the border luminance was not affected by local illuminance or immediate background. It indicates the RVSI is unique for a room: only one measurement is enough. It can be a great advantage when the measurement is applied for real and complex environments. The RVSI size may be a useful and easy measure for evaluation of the adaptation level of the visual system in practical and complex environments.

Keywords: brightness size of recognized visual space of illumination, color appearance mode, color scheme

1. INTRODUCTION

In our everyday circumstances, understanding of illumination, for example bright or dim, and white or reddish, is necessary for the perception of color and brightness of object's surface. This situation is expressed as that the recognized visual space of illumination, RVSI, for the room was constructed in a person's brain. Especially, we use a term 'brightness size' of RVSI to describe an observer's perception about intensity of illumination. When an observer recognized a room is illuminated brightly/dimly, we say the brightness size of RVSI is large/small. We use a circle to describe the RVSI schematically, as shown in Fig.1. The radius indicates the brightness size of RVSI. When we consider an object in the room, it is expressed by a certain point in the circle, as shown by a filled square in Fig.1. The apparent lightness of its surface is determined in relation to the brightness size of RVSI. In other words, it is determined by the relative distance between the point and the center to the radius. When the luminance of its surface is increased, for instance by a spotlight, its surface is getting brighter, and finally, at certain luminance, it begins to appear unnaturally bright as an object in this environment. This particular luminance is called 'border luminance' and defines the brightness size of RVSI.

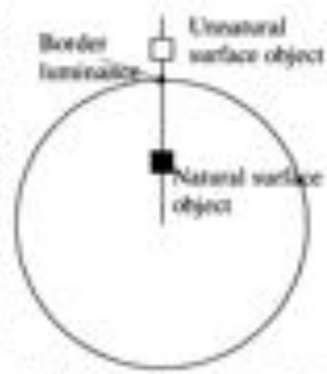


Fig. 1 Schematic representation of RVSI and the border

One of the most important and difficult tasks in evaluation of perceived brightness in everyday circumstances is to assess what level the visual system adapts to. In particular, this is an inevitable process when putting the new photometric systems into practice[2]. We can already assess the state of color adaptation even in any complex environments, by measuring chromaticity of a stimulus that appears achromatic. On the other hand, we have neither definition nor measure of adaptation level with general consent that is usable for complex visual environments. Measurement of the brightness size of RVSI is thought to be a useful method for assessment of the adaptation level in complex visual environments. Although the brightness size of RVSI is not a sort of sensory adaptation, but a cognitive understanding for light filled in a space, it may be predominant in the brightness perception in everyday experiences rather than the sensory adaptation mechanism.

Our previous study[1)] showed that the brightness size of RVSI was proportional to the room illuminance. Interestingly the border luminance was not affected by the luminance of the light source color but rather almost corresponded to the highest luminance of object in a room. Normally in a room, there are many objects of various lightness ranging from black to white. The luminance of a white surface is normally the highest and changes with room's illuminance. We, human, are likely to use the luminance of an object of highest lightness to know the illumination intensity. Therefore the brightness size of RVSI is expected to change depending on how a room is furnished, that is color scheme of interior. In the present experiment, we measured the border luminance in two rooms differently furnished. One room was furnished with white walls and various lightness objects from black to white (W-room). The other was furnished with black walls and objects of low lightness (B-room). We also compared the border luminance obtained at three different positions in a room, to investigate the effects of the local illuminance and the luminance of immediate background.

2. METHODS

2.1 Experimental room

An experiment was done in a real living room as shown in Fig.2. The room was 3.6m wide, 2.7m deep, and 2.2m high. The room was illuminated by fluorescent lamps (daylight type, FL) on the ceiling. The intensity of FL was variable and the horizontal illuminance (room illuminance, I_R) was monitored with an illuminance meter placed on the table (Tb) in the center of the room. We measured the border luminance with a test stimulus (T), a N5 gray patch of 6x6cm that had a mat surface. A test stimulus was put on a rod at a height of 1.0 m and inclined at 45 deg. from vertical. Its surface was hardly illuminated by the ceiling light but, instead, spotlighted by a slide projector (PB). We controlled the luminance of the test by the neutral density wedge filter inserted in the light path. The distance between an observer and the test stimulus was 2.0m.

Fig. 2 Scene of the experimental room. A small square noted as T is the test stimulus. The labels attached to objects are shown in Table1.

2.2 Conditions

Two different environments were prepared to examine the effect of color scheme of interior on the brightness size of RVSI. In one environment, the room was furnished with white walls and many objects of various lightness levels, say from black to white (W-room). Luminance at the points indicated by item labels in Fig.2 were measured with MINOLTA CS-100 under the illuminance of 300 lx. Munsell notations were obtained by visual matching with the book of Munsell color chips. The measured luminance and the Munsell notation for items are shown in Table1. The lightness of the magazine (M_2) was the highest and its Munsell Value was 9.5. The luminance of the white flower was the highest except the ceiling light and 43.3 cd/m^2. In the other environment, the room was furnished with black walls and objects of low lightness (B-room). The lightness of the low board (LB) was the highest and its Munsell Value was 5. The luminance of the table (Tb) was the highest and 12.0 cd/m^2.

Table 1 Munsell notation and luminance of objects at the room illuminance of 300 lx

		W-room		B-room	
Label	Items	HVC	Y (cd/m^2)	HVC	Y (cd/m^2)
Wl	Wall	5Y9/1	41.0	N2	1.76
Fl	Floor	2.5Y4/6	6.15	2.5Y4/6	4.38
Tb	Table	10YR4/3	13.7	10YR4/3	12.0
LB	Low board	10YR5/4	11.3	10YR5/4	6.33
Cu	Curtain	5PB7/4	25.7	7.5PB2/6	2.16
Co	Coat	N2	0.98	N2	0.68
CH	Coat hanger	7.5YR4/6	5.68	7.5YR4/6	3.63
PB	Projector box	N2.5	3.59	N2.5	2.87
M_1	Magazine1	5R4/14	5.06	5R4/14	3.33
M_2	Magazine2	N9.5	21.0		
MR	Magazine rack	5PB3/8	1.91	5PB3/8	1.97
L_1	Leaf1	7.5GY3/3	7.54	7.5GY3/3	6.57
L_2	Leaf2	7.5GY4/6	9.52	7.5GY4/6	7.06
Tr	Trunk	2.5Y7/6	13.4	10YR3/2	4.03
Pt	Pot	2.5YR3/2	1.57	2.5YR3/2	1.18
FV	Flower vase	5YR2/1	1.07	5YR2/1	0.47
Fw	Flowers	10Y9/2	43.3	5R3/10	2.07
	Flowers	5R4/14	10.4	2.5P5/4	6.91
	Flowers	5Y9/6	51.3		
	Flowers (stem)	5GY5/4	5.86	5GY5/4	2.64

The border luminance was measured under five illuminance levels, 3, 10, 30, 100, and 300 lx to examine the effect of room illuminance on the brightness size of RVSI. We also employed four different measuring positions, P1, P2, P3, and P4, to examine two other effects from the local illuminance around the test stimulus (I_T) and the luminance of immediate background (L_{BG}). The horizontal illuminance at the position of the test (I_T) is shown for each position and for each room in Table2. The luminance of immediate background (L_{BG}) is shown in Table3. The immediate background was the same back wall (Wl) for position P1 and P2. But the position P1 was closer to the observer to get higher illuminance, 400 lx, which was two times higher than that at P2, 200 lx. The local illuminance at P3 and P4 were the same as that at P1, but the immediate background were different: the background for P3 was the black coat (BC) and that for P4 was the curtain (Cu). If the brightness size of RVSI was influenced by I_T and L_{BG}, the border luminance should change depending on the position even though the room illuminance (I_R) was the same.

Table 2 The local illuminance (I_T) for each room illuminance levels (I_R).

Room Type	W-room			B-room		
Position	P1	P2	P3	P1	P2	P4
I_R=3 (lx)	4	2	4	4	2	4
10	13	7	13	13	7	13
30	40	20	40	40	20	40
100	130	70	130	130	70	130
300	400	200	400	400	200	400

(lx)

2.3 Procedures

The observer's task was to adjust the luminance of the test stimulus where it starts to look unnatural as an object under the illumination. The observers were instructed to look around the entire room rather than to gaze at the test stimulus only. One experimental session was composed of 25 adjustments, five successive adjustments for each five room illuminance levels. We carried out three sessions for all 6 conditions, 2 rooms x 3 positions. Three male observers, HY, HS and HH were participated in the experiment.

Table 3 The luminance of immediate background (L_{BG}) for each room illuminance levels (I_R).

Room Type	W-room			B-room		
Position	P1	P2	P3	P1	P2	P4
I_R=3 (lx)	0.36	0.36	0.01	0.02	0.02	0.03
10	1.20	1.20	0.04	0.06	0.06	0.10
30	3.60	3.60	0.11	0.18	0.18	0.32
100	12.0	12.0	0.53	0.59	0.59	1.06
300	36.1	36.1	1.80	1.76	1.76	3.20

(cd/m²)

3. RESULTS AND DISCUSSION

The result from observer HY is shown in Fig.3 as an example since the result from other observers showed the same trend. The ordinate indicates the border luminance and the abscissa indicates the room illuminance (I_R). Circle symbols show the border luminance at P1, square symbols at P2 and triangle symbols at P3 or P4. The error bars indicate the standard deviation across 15 adjustments. The thick lines show the highest luminance in the scene, the luminance of the white flower (Fw) in W-room, and that of the table (Tb) in B-room. All the border luminances were proportional to the room illuminance (I_R). In the both charts, the border luminances were almost the same in spite of their positions. It means that the room illuminance is dominant in the determination of the brightness size of RVSI, and the effects of I_T and L_{BG} on the border luminance are relatively small. When you compare these two charts, you can notice the border luminance in W-room was higher than that in B-room. For instance, the border luminance at P1 under the I_R of 300 lx was 51.8 cd/m^2 in W-room but 20.3 cd/m^2 in B-room and so on. The ratio of the border luminance (W-room/B-room) was 2.5 at P1, and 1.9 at P2. The impression of observers also supported the result, that is, they felt the W-room brighter than the B-room. This result shows that the border luminance is changed by color scheme of interior, even if the room illuminance (I_R) was the same. In W-room, all the border luminances are close to the highest luminance, which agrees with our previous report[1] where the border was equal to the highest luminance except the light-source. On the other hand, in B-room, all the border luminances are plotted above the highest luminance in the scene. The border luminance in B-room was lower than that in W-room, but no lower than the highest luminance.

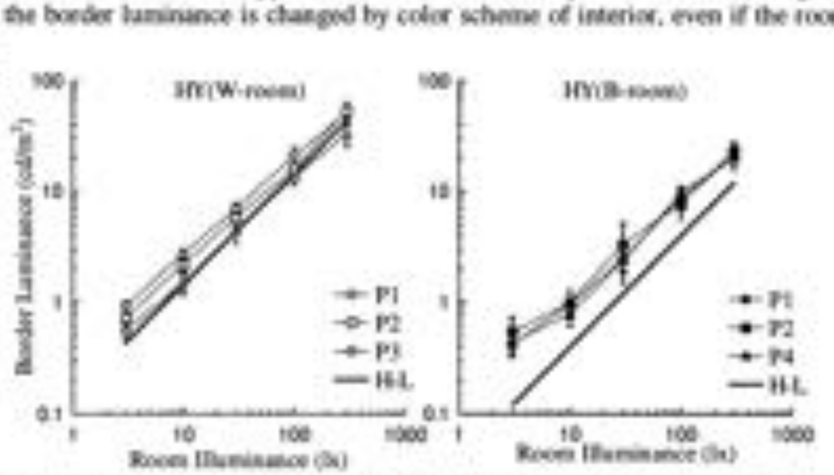


Fig. 3 The border luminance as a function of illuminance from observer HY, left chart in W-room, right chart in B-room. The thick lines show the highest luminance in the scene.

In normal environments, like in W-room, there are many objects with various lightnesses ranging from black to white and, therefore, the border luminance almost coincides to the highest luminance. The highest luminance is usually given by a white surface. On the other hand, in B-room where only low-lightness-objects are placed, the border luminance was much higher than the highest luminance of object. Since, in the case of B-room, the highest luminance was given by the table with Munsell Value 4, subjects are unlikely to adjust the border luminance to that of the table. Rather, they may adjust it to that of a white surface, which was not in the room actually. To see if this prediction was true or not, we converted the border luminance to the corresponding lightness by measuring luminance of N9-white and N5-gray patches put uprightly at each position P1, P2, and so on. The corresponding lightness from subject HY and HS are shown in Fig.4. The ordinate indicates the corresponding lightness of the border luminance and the abscissa indicates the room illuminance (I_R). Data for both room are plotted altogether in the chart. Symbols are the same as used in the Fig.3. Horizontal lines show the highest lightness in each room, the lightness of 95 for the magazine (M_2) in W-room and that of 50 for the low board (LB) in B-room. In the left chart, the corresponding lightnesses for all conditions in W-room were plotted around 95, but those for B-room were around 70 except at I_R of 3 lx. In the right chart, the corresponding lightnesses were distributed in a range from 80 to 100 and those for B-room were around 65. For both observer, the corresponding lightness for the border was around the lightness of a white surface, namely 95, in W-room but that in B-room was somewhere between white and the highest lightness 50.

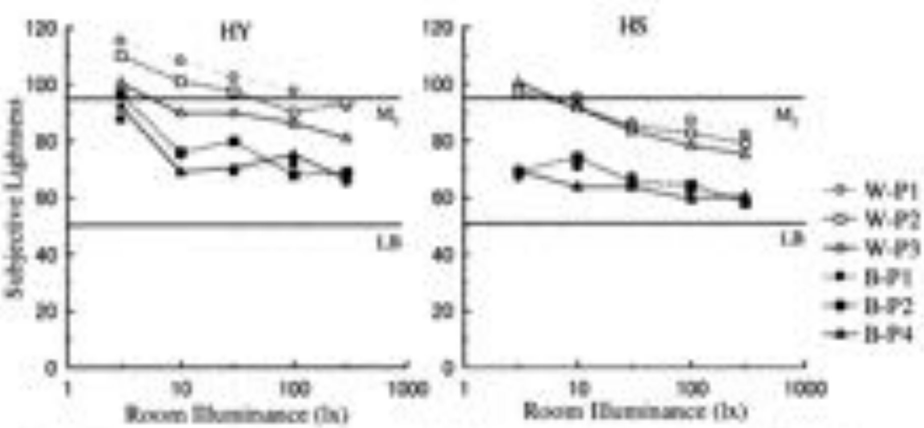


Fig. 4 The corresponding lightness converted from the border luminance, left chart from observer HY, and right chart from HS. Horizontal lines show the highest lightness in each room, the magazine in W-room and the low board in B-room.

To conclude, when the room is furnished with objects with various lightness from black to white, the border luminance is equal to the luminance of the white surface. On the other hand, when the room is furnished with low-lightness-objects, the border luminance is lowered but not reduced to the luminance of the highest lightness. Thus the brightness size of RVSI is mainly determined by the room illuminance but also affected by the color scheme of interior, in particular the highest lightness in a room. In addition, the border luminance was unique for a room and independent of the local illuminance and the immediate background. It means only one measurement of the border luminance is enough to assess the perceived brightness of a room, the observer's estimate of illumination intensity, and further, the adaptation level of an observer. This nature may be advantageous in practical usage. The measure of the border luminane is very easy and corresponds well to the impression of observer. Therefore the border luminance can be recommended as a useful measure for evaluation of the perceived brightness of a room and the adaptation level of the visual system to complex environments.

REFERENCES

1. H. Yamaguchi, H. Shinoda and M. Ikeda: Determinant of the Size of Recognized Visual Space of Illumination in a Natural Environment, Proceedings of 2000 AIC Meeting Seoul, pp.228-232 (2000)
2. H. Shinoda: Visual Adaptation to Complex Luminance Distribution, CIE 133/5, pp.44-49 (1999)

Correspondence: ro012962@se.ritsumei.ac.jp; phone +81-77-566-1111(ex.8552); fax +81-77-561-2663; Department of Photonics, Faculty of Science and Engineering, Ritsumeikan University, 1-1-1, Nojihigashi, Kusatsu, Shiga, 525-8577, Japan

Colour and luminance contrast sensitivity function of people with anomalous colour vision

Kristian Samu*, Klara Wenzel*, Karoly Ladunga*

1. INTRODUCTION

The experience of a colored picture is formed of the multitude of spots of different colors and shapes projected on the retina of the eye. The more spots we can distinguish the more details we can see and the more information we can get. It can be observed that people of anomalous color vision are at a disadvantage not only from the point of view of the correct recognition of colors but also from that of seeing less detailed than do that of normal trichromats.

It is rather difficult to measure the detail of colored pictures formed by seeing. It is practical to carry out the measuring with simplified geometry and in limited colors. The most simple test picture is the grating and it is best to limit the colors to two and to their additive mixtures respectively.

The color contrast sensitivity function (CCFS) can be well used to prove that people of anomalous color vision can distinguish less details than those of normal trichromats. Besides this the effect improving color vision (e.g. by color vision correction filters) can also be proved.

Several examinations can be made by gratings created with two colors and by changing their various parameters [1,2]. We have got appreciable data by changing space frequency and contrast, and redefining colored gratings to the CCSF already known in the examination of sight testing. Thereby we succeeded in demonstrating the difference between normal and anomalous trichromats.

Keywords: Colour contrast, contrast sensitivity function, defective colour vision

2. LUMINANCE AND COLOUR CONTRAST

The subject of our examination was the contrast sensitivity function (CSF). We can determine this function and its curve respectively by gratings which seem to be grey at a given space frequency of the grating under a certain contrast threshold [3]. The calculation of the contrast of the grating is done on the basis of the definition of brightness contrast:

$$K = \left| \frac{I_1 - I_2}{I_1 + I_2} \right| \qquad (1)$$

where K is the contrast

I_1 and I_2 are the different brightness of two pixels or grid lines marked 1 and 2

The measured curves of spatial frequency-contrast sensitivity of neutral color are U-shaped f4].

The definition of the contrast of colored gratings on the basis of formula (1) is made more difficult by the fact that gratings of different colors but of identical brightness are still resolved by the retina but in such cases the contrast according to the definition is 0. Thus if we want to extend the contrast to colored gratings too, we must find a definition which makes the color contrast measurable.

For measuring the CSF it is necessary to change the contrast of colored gratings on different spatial frequencies. The contrast modulation of colored gratings can be carried out in three ways with the help of two grating colors. If the color coordinates of one grating color controlled on the CRT monitor by computer are R_1, G_1, B_1 and that of the other are R_2, G_2, B_2, then we can modulate the color contrast in the ways given in Table 1.

	Bar 1 and 2 color at K=0..1	Bar 1 and 2 color at K=0..1	Bar 1 and 2 color at K=0..1
color contrast modulation I	R_1, G_1, B_1 R_2, G_2, B_2	$M_R = max(R_1, R_2)$ $M_G = max(G_1, G_2)$ $M_B = max(B_1, B_2)$	$R_{1,2} = R_{1,2} + (M_R - R_{1,2})(1-K)$ $G_{1,2} = G_{1,2} + (M_G - G_{1,2})(1-K)$ $B_{1,2} = B_{1,2} + (M_B - B_{1,2})(1-K)$
color contrast modulation II	R_1, G_1, B_1 R_2, G_2, B_2	$M_R = (R_2 + R_1)/2$ $M_G = (G_2 + G_1)/2$ $M_B = (B_2 + B_1)/2$	$R_{1,2} = R_{1,2} + (1-K) M_R$ $G_{1,2} = G_{1,2} + (1-K) M_G$ $B_{1,2} = B_{1,2} + (1-K) M_B$
color contrast modulation III	R_1, G_1, B_1 R_2, G_2, B_2	$M_R = 0$ $M_G = 0$ $M_B = 0$	$R_{1,2} = K\,R_{1,2}$ $G_{1,2} = K\,G_{1,2}$ $B_{1,2} = K\,B_{1,2}$

Table 1. Methods of color contrast modulation

At modulation type II the maximum contrast grating number 1 contains only one of the starting colors of the two neighboring grating colors while the two colors belonging to the 0 contrast consists of mixtures of the starting colors of identical intensity. The modulation of the color contrast made in this way suits well the method measuring the CIE L*a*b* color difference as the calculated color difference between the two grating colors defines the color contrast sensitivity. White and black are the grating colors belonging to contrast 1 of the modulation types I and III. In the course of contrast changing at these modulations the identity of the brightness of the grid lines does not exists, and the values calculated by the methods of color differences are not correlated with the decreasing contrast values, so the modulation types I and III have not been used.

The color contrast sensitivity curve CCSF is measurable by the modulation described in method II, which shows the threshold of color contrast sensitivity expressed in the CIE La*b* system is given in the function of spatial frequency.

3. METHODS

We have made the contrast and spatial frequency modulation of the red and green gratings by a computer controlled CRT monitor with a software made for this purpose. The computer was a PI MMX-200, the calibrated monitor was a GS Studioworks 57I, and the display adapter was a Matrox Millennium.

We have made the examinations with a group consisting of 10 normal trichromats and 10 anomalous trichromats, by dividing them into three subgroups. Normal trichromats belong to the first subgroup while anomalous trichromats and corrected anomalous trichromats belong to the second and third subgroups. The glasses used for color vision correction contained general correcting filters for protanomalous trichromats developed using tinting technology in Coloryte Hungary. For the choosing of anomalous trichromats we applied Ishihara plates and for choosing the protanomalous people from the anomalous trichromats Heidelberg anomaloscope.

The brightness sensitivity of anomalous and normal trichromats are not identical because the spectrally shifted L and M receptors of the anomalous trichromats [5]. Therefore anomalous trichromats can recognize the given contrast of colored gratings on the basis of the brightness difference without sensing the color difference. As this was not our aim, before the measuring of the CSF curves we carried out heterochromatic brightness matching as well between red and green primaries of the monitor. After this the software carrying out the measuring generates the gratings according to the CRT primary rations [6].
The gratings consist of red and green lines because the CSF differences between the protanomalous and the normal subgroups can be best demonstrated with these colors. For the background of the gratings we used the color belonging to the 0 contrast, the brightness of which is identical with the colors of the grating lines. The gratings were modulated sinusoidal and besides this in order to avoid the contrast appearing at the edges were shaded into the background.

4. MEASUREMENTS

The measurements were made in a dark room, the CCSF measuring software uses the gamma-corrected brightness rations of the primaries R and G got by heterochromatic brightness matching for creating gratings of identical brightness but different contrast.

The CSSF measuring were carried out on 1, 2, 4, 6, 8, 12, 20 [period/°] spatial frequencies generally used in CSF measuring. The viewing angle of the test pictures was 1.5°, and the observation distance was 4 meters.

In the curse of the measuring the color contrasts were increased to the point of the given space frequency at which the person concerned could recognize the grating. As in the curse of the contrast changing the gratings randomly appeared horizontally and vertically respectively, the task of the person concerned was to determine the direction. We accepted and registered the result of the just resolved contrast made at three measurement from both directions. We measured both CCSF and CSF curves at all the three subgroups and besides this we carried out three series of repeated measurements at one normal trichromat to confirm the reliability of the examination.

5. RESULTS

In the curse of the evaluation we determined the brightness contrast (at the CSF) and the color difference in CIE L*a*b* (at the CCSF) on the basis of the monitor emission and the gamma curves of the monitor primaries.

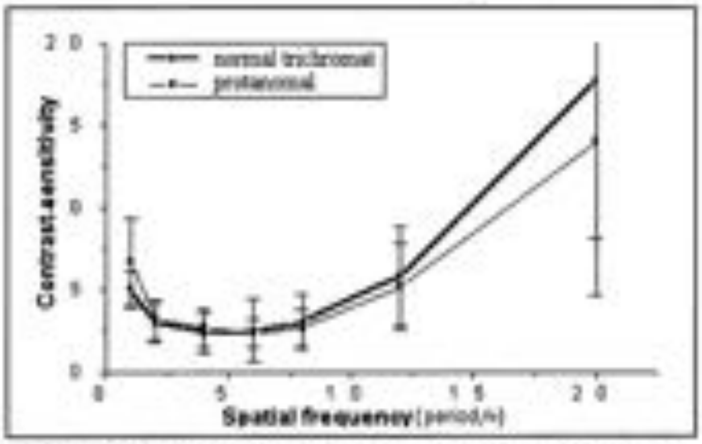


Fig. 1. CSF diagram of normal and anomalous trichromats

The statistical tests carried out and demonstrated on Fig. 1. prove that the neutral CSF measuring has not shown any significant difference between the anomalous and the normal trichromats. The cause of this is that in the development of the sensation of neutral colors, all the three (L, M, S) receptors take part identically disregarding the fact whether the sensitivity of a receptor is spectrally shifted or not. In this case the stimulus contains mainly intensity information (and not spectral information) and thus it can be established that the contrast sensitivity of an anomalous and a normal trichromat does not differ significantly from each other.

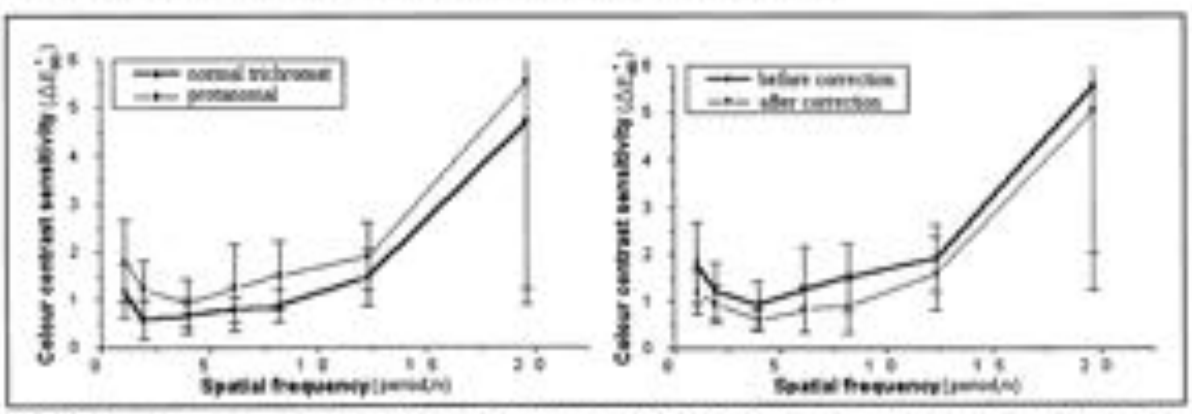


Fig. 2/a CCSF curves of normal and protanomalous trichromats 2/b CCSF curves of corrected and not corrected anomalous trichromats

The significant difference between normal and anomalous trichromats can be seen on Fig. 2/a. as well as the fact that the character of the CCSF curves is similar to those of the CSF ones. The results confirm the observed fact that the details seen by the anomalous trichromats in case of the red and the green colors are worse than those of normal trichromats.

The CCSF curves formed on the basis of Fig. 2/b by corrected and uncorrected anomalous trichromats show a difference that proves that we succeeded in demonstrating the improving effect of the glasses. Moreover if we compare the values of corrected anomalous trichromats it can also be established that by the glasses we succeeded in bringing the color contrast sensitivity to the normal value. Thus by the use of glasses the anomalous trichromats produced about the same contrast sensitivity as those of normal trichromats.

The standard deviation experienced at repeatability measurements is under 10% of the average value proving the reliability of our measurements.

6. CONCLUSION

On the basis of neutral CSF measuring carried out on 10 normal and anomalous trichromats each, we have established that the contrast sensitivity threshold of normal trichromats is identical with that of the protanomalous ones.

In the case of colored gratings the same examination show the difference between the two groups according to which the red-green contrast sensitivity of protanomalous trichromats is worse than that of the normal trichromats, but with the help of color correction glasses used by protanomals they could produce the CCSF results of normal trichromats.

- The results verified our method for contrast modulation;
- The results confirmed the correctness of our definition for CCSF;
- Finally the results verified the color vision correction method.

ACNOWLEDGEMENTS

We wish to express our thanks to Coloryte Hungary for providing the technical conditions.

REFERENCES

[1] Bernt Christian Skottun: The magnocellular deficit theory of dyslexia: the evidence from contrast sensitivity. Vision Research, 40, 111/127, 2000.
[2] Jin, Phil Q.; Pokorny, Joel; Smith, Vivianne C.: Effect of spatial frequency on chromatic induction. 3rd Color Imaging Conference: Color Science, Systems, and Applications (Springfield), 11/14, 1995.
[3] Peter G. J. Barten: Contrast Sensitivity of the human eye, SPIE Opt. Eng. Press, Bellingham, 1999.
[4] Lovegrove W., Bowling A., Badcock D., Blackwood M.:Specific reading disability differences in contrast sensitivity as a function of spatial frequency. Science, 210, 439/440, 1980
[5] K. Wenzel, K. Ladunga, Gy. Abraham, G. Kovacs, I. Kucsera, K. Samu: Measuring Colour Resolution of the Eye by Using Colour Monitor, Colour 2000. 3.-14. April ,Derby. 2000..
[6] R. Jackson, L. MacDonald, K. Freeman: Computer Generated Colour, John Wiley & Sons, Chichester, 1993.

* wenzel@fot.bme.hu; http://fot.bme./hu;phone: +36-1 463 2602; Technical University of Budapest, Department of Precision Mechanics and Optics, Building E III.1., H-1521 Budapest, HUNGARY

A study on color conspicuity at the Purkinje shift

Ayako Mochizuki*, Tooru Yoshioka*, Tomomi Suzuki*, Shigeru Ichihara**
*Otsuma Women's University, **Tokyo Metropolitan University

ABSUTRACT

We used the samples prepared by letting the background stimulus color change so that the size of contrast will differ from the test stimulus color in various ways, studied the relation between contrast and advancing color in the three directions of value, chroma, and hue, also let the illuminance level change, and examined the influence of Purkinje shift. As a result, we found in the value contrast and chroma contrast that in any hue, as the contrast with the background becomes higher, the stimulus looks closer, and we could not observe any influence of Purkinje shift. However, in an experiment in which only the hue is different at the same values of the value and chroma between the test stimuli, we could observe the influence of Purkinje shift in that, when only the background stimuli is N1, a blue color looked most advancing in the mesopic vision, whereas a red color looked most advancing and the blue color did not look advancing in the photopic vision.

Keywords: Purkinje sift, advancing color, mesopic vision, contrast,

1. INTRODUCTION

The increasing number of cars has so far caused very many traffic accidents. Therefore, it is urgently necessary to take preventive measures against such accidents. One candidate might be color that is possibly an effective means of identifying objects. With this in mind, if there were any quantitative evaluation data concerning the advancing color that could be perceived closer than the actual distance, the elderly, infants, etc could utilize them for preventing possible accidents. Nevertheless, a variety of colors intermingle in the environment where we live and we also wear colorful clothes, and accordingly it is difficult to determine simply which colors look advanced and which colors look receded among a world of different colors. Furthermore, visual characteristics vary depending on the illuminated environment, and therefore Purkinje shift occurs when the viewing shifts from a photopic vision to a mesopic vision, also attributing to the difference in the spectral sensitivity of cones and rods. Under the circumstances, a red color looking bright in the daytime looks dark in the evening dim light, and on the contrary, a blue color that looks dark in the daytime appears bright in the evening. This study, therefore, was aimed at finding the influence of illuminance level on the visibility of the advancing color and receding color according to the difference of background stimulus colors in order to obtain the basic data for designing safety clothing.

2. EXPERIMENTAL

Concerning the visibility of color according to the change of illuminance level, we also experimented to find the influence of difference among (1) value contrast, (2) chroma contrast, and (3) hue. We switched off all the lights in the room during the experiment so that we could eliminate the influence of light other than that of the standard light source. We showed stimuli to the subjects after a 5-minute dark adaptation and asked them to answer which of the left and right test stimuli looked closer (advancing color). The experiment was performed placing the left and the right stimuli the other way around to counter-balance the positional effect of the test stimuli. Moreover, we adopted in experiment (3) a method to prioritize the order in which the 4 test stimuli looked advanced in ranks.
There are 40 sheets of samples in total that were used in the experiment and we composed the stimuli mentioned in Munsell value as mentioned below. In the experiment by the value difference (1), we adopted an achromatic color to observe the influence of the value contrast, we changed only the value, and used the 9 colors of samples in total; N1, N2, N3, N4, N5, N6, N7, N8, and N9, on which test stimuli N3 and N7 were juxtaposed respectively. In the experiment by chroma difference (2), we employed hues 5R, 5Y, 5G, and 5B taking into consideration the four primaries of colored psychology, three primaries of colored light, and three primaries of colorants, and regarding the value, we chose a stage that could produce the highest chroma among respective hues. To check the influence of the chroma contrast, we fixed the value for each hue and changed only the chroma. And, we used the samples of 7 colors in total; background stimuli 5R4/2, 5R4/4, 5R4/6, 5R4/8, 5R4/10, 5R4/12, and 5R/14 for R, on which test stimuli 5R4/4 and 5R4/12 were juxtaposed, 6 colors in total; background stimuli 5Y8/2, 5Y8/4, 5Y8/6, 5Y8/8, 5Y8/10, and 5Y8/12 for Y, on which test stimuli 5Y8/6 and 5Y8/10 were

juxtaposed, 5 colors in total; background stimuli 5G5/2, 5G5/4, 5G5/6, 5G5/8, and 5G5/10 for G, on which test stimuli 5G5/4 and 5G5/8 were juxtaposed, and 5 colors in total; background stimuli 5B4/2, 5B4/4, 5B4/6, 5B4/8, and 5B4/10 for B, on which test stimuli 5B4/4 and 5B4/8 were juxtaposed respectively. For these test stimuli, we also prepared the samples juxtaposed in the same combination respectively on the background stimulus N5.5. In the experiment by hue difference (3), we fixed the value and chroma of test stimuli to check the influence by the difference of the hues, and changed only the hues. Then, we used the samples N1, N5.5, and N9 on which 4 colors of test stimuli; 5R5/10, 5Y5/10, 5G5/10, and 5B5/10, were placed respectively. The sample test stimulus is a regular square with a 5o visual angle and the interval of the two test stimuli was composed in 6o (Fig. 1). We used the glossy colored paper made by Nihon Shikisai Kenkyujo (Japan Color Research Institute). Here, the subjects were 30 females at the age of early 20's.

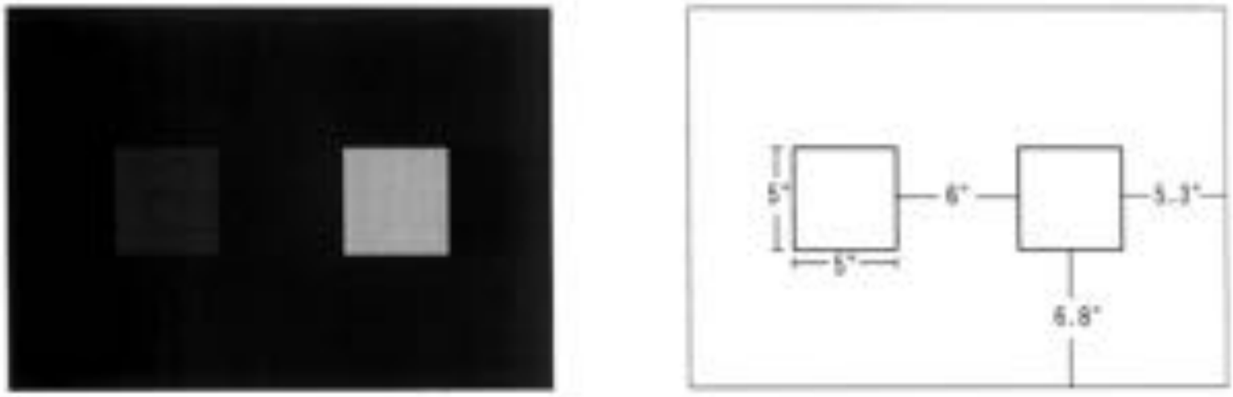


Figure 1: Samples used in experiment

3. RESULTS

We attempted to find an answer to the question of [which test stimulus looked advanced] in a ratio, and established it as an advancing rate. In value contrast test (1), the advancing rate of test stimulus with low value was high on the background stimulus with high value and, on the contrary, the advancing rate of test stimulus with high value was high on the background stimulus with low value. In chroma contrast test (2), we were able to obtain a consistent result that the test stimulus with low chroma advanced on the background stimulus with high chroma of background stimulus and test stimulus with high chroma looked advanced on the background stimulus with low chroma in all the cases of hues 5R, 5Y, 5G, and 5B.
From this result, we can say that the test stimulus with high background and chroma contrast looks advanced in any hue. What's more, when the contrast with the background stimulus is in the same degree with the two test stimuli in both experiment (1) and (2) (e.g. the location of background stimulus N5 in Fig. 2 and Fig.3), no clear difference is exhibited in the advancing and receding visibilities, but the one with higher value in an achromatic color and the one with higher chroma in a chromatic color looked advanced albeit slightly. Nonetheless, in a yellow color, the test stimulus with low chroma showed a higher advancing rate unlike other chromatic colors. In addition, in the experiment where the test stimulus used in (1) and (2) were placed in the same combination on experiment (1) and (2) of background stimulus N5.5, the chromatic color of the test stimulus with higher chroma looked advanced. Pertaining to the illuminance level difference, we could not observe any outstanding difference in the result at 2000lx and 5lx in both experiment (1) and (2).
In experiment (3), we gave points to the test stimuli selected in order of advance visibility; that is, 4 points to first, 3 points to second, 2 points to third, and 1 point to fourth for calculation, establishing an advance evaluation score. In background stimulus N1 (Refer to Fig. 4), we obtained the result of 5R>5G>5B>5Y in order of high advance evaluation score at 2000lx and 5B>5G>5R>5Y at 5lx. Although 5R looked most advanced at 2000lx, the advance evaluation score of 5R dwindled when exposed to 5lx, and on the contrary, the score of 5B increased, clearly exhibiting the effect of Purkinje shift. In background stimulus N5.5, it came in order of high advance evaluation score 5B>5R>5Y>5G at 2000lx and 5B>5R>5G>5Y at 5lx. Also with background stimulus N9, a similar tendency appeared, and practically no change was observed in the advance visibility by the illuminance level difference. Besides, with background stimulus N5.5 and N9, 5B looked most advanced in whichever illuminance level, resulting in the negation of generalizations that a warm color is an advancing color and a cold color is a receding color. Also, 5Y - medium frequency modulated light - scarcely looked advanced in any background stimuli and at any illuminance level.

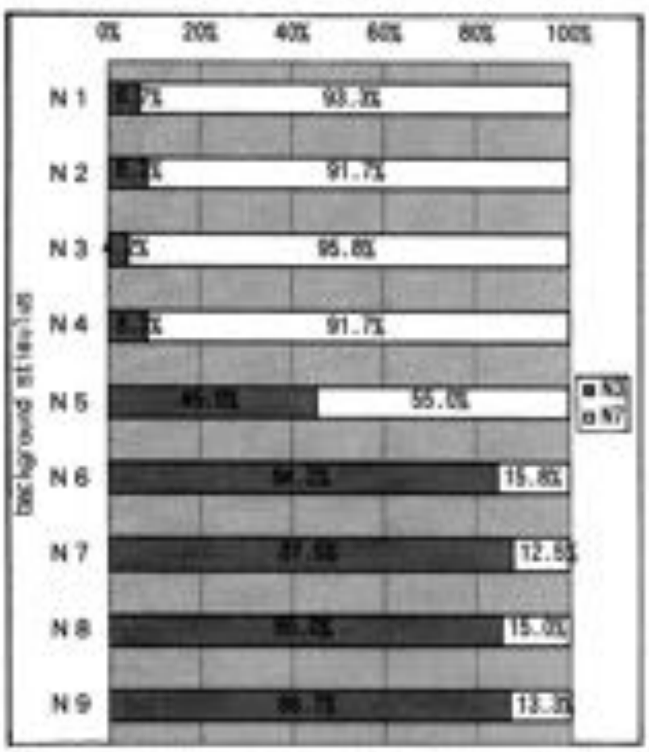


Figure 2: Advance rate of test stimuli at 2000lx, experiment (1)

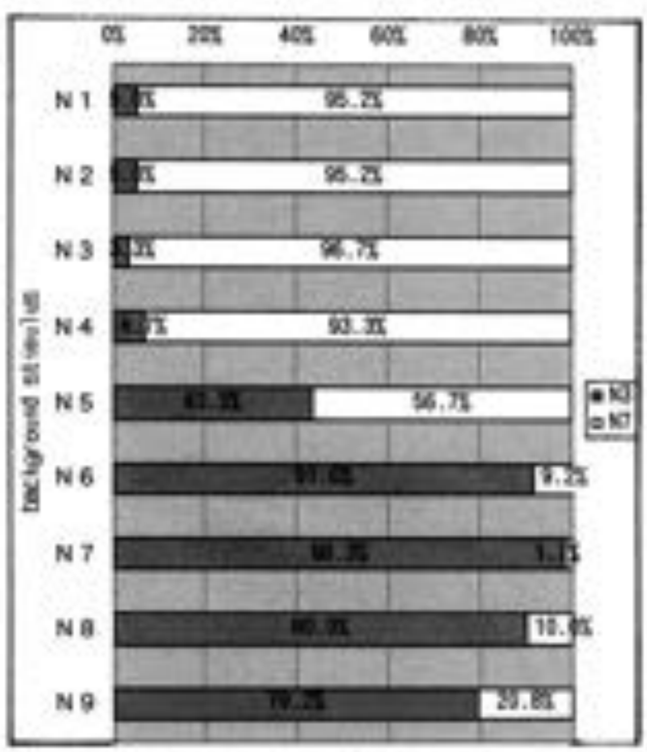


Figure 3: Advance rate of test stimuli at 5lx, experiment (1)

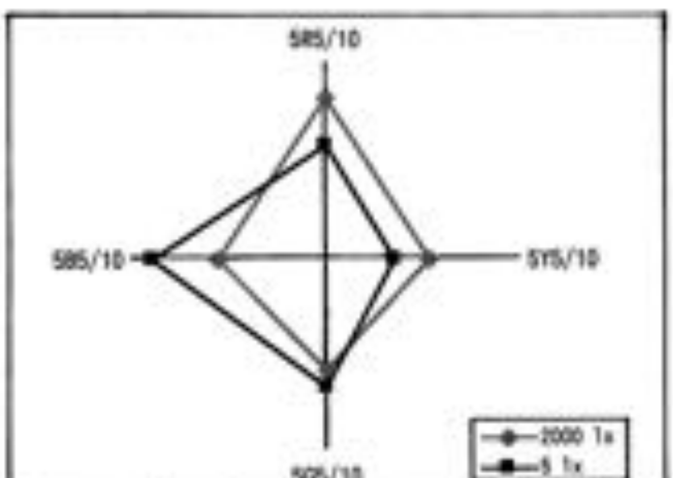


Figure 4: Influence of illuminance level to advance evaluation score in background stimulus N1, experiment (3)

4. CONCLUSION

From the above-mentioned result, it is feasible to explain the visibility of advancing/receding colors through the value contrast/chroma contrast. Further, we found from the result of experiment (1) and (2) that even in a state of the mesopic vision, the value/chroma contrast can function as a factor of advancing/receding perceptions. For this reason, we feel that it is possible to employ a color scheme utilizing the value/chroma contrast as the basic data to design safety clothing. When the hue alone was changed keeping the value and chroma fixed between test stimuli in experiment (3), we checked which hue looked most advanced, but we observed a considerable amount of non-uniformities unlike in cases of experiment (1) and (2), and we subsequently discovered that the hue is weak to function as a factor of advancing/receding perceptions. We also noticed that the advance perception changes as influenced by the illuminance level only when the background is black. In other words, the influence of Purkinje shift apparently came out in that a red color looked advanced in a bright spot, and as it got darker, a blue color appeared advanced. Notwithstanding, such phenomena cannot be observed on the gray or white background, and we would like to study why such a phenomenon takes place as a subject of our future experiment.

ACKNOWLEDGMENTS

We asked for cooperation from many people to accomplish the present study. We would like to express our deep appreciation here. Also, we wish to extend our sincere appreciation to the students of the clothing science department, Otsuma Women's University, who kindly volunteered to become test subjects.

REFERENCES

1. H. Egusa, "Effects of brightness, hue, and saturation on perceived depth between adjacent rejoins in the visual field," *Perception*, **12**, 167-175, 1983.
2. R. P. O'Shea, S. G. Blackburn, and H. Ono, "Contrast as a Depth Cue," *Vision research*, **34**, 1595-1604, 1994.
3. S. Ashizawa and M. Ikeda, "Change of Conspicuity for Various Illuminance Levels" *J. Illum. Engng. Inst. Jpn.*, **71**, 612-617, 1987
4. J. Davidoff, *Cognition through color*, Massachusetts Institute of Technology, Cambridge, 1991
5. ED by The Color Science Association of Japan, *Handbook of Color Science [second edition]*, University of Tokyo Press, Tokyo, 1998

* Correspondence: yoshioka@otsuma.ac.jp; Department of Clothing Science, Otsuma Women's University, 12 Sanbancho, Chiyoda-ku, Tokyo 102-8357, Japan

Daylight spectral power distribution recovery through a linear model and few filters

Javier Hernández-Andrés*, Javier Romero and Juan L. Nieves.
Departamento de Óptica, Universidad de Granada, Granada, SPAIN

ABSTRACT

We study here the feasibility of a spectral daylight recovering algorithm using a linear model that takes advantage of the strong correlation among daylight curves. To test the algorithm we use the daylight eigenvectors obtained by a principal-value decomposition over 2600 daylight spectra recorded over a period of two years. A binary search, performed here, found the optimal spectral positions of a set of few narrow-band filters. We analyze, over the set of 2600 daylight curves, the algorithm accuracy when using three to six narrow filters, obtaining that such an daylight algorithm is not sufficiently accurate in comparison with similar linear models that recover objects spectral reflectances proposed in artificial-vision.

Keywords: daylight, spectral recovery, linear models, artificial-vision.

1. INTRODUCTION

Ideally the spectral power distribution (SPD) of daylight is measured in different spectral bands with a carefully calibrated dispersive device such as a grating. However in many tasks there are economical, operating, and/or maintaining reasons that impede to have these complex and expensive instruments. Therefore it is essential to propose simple but accurate algorithms that enable the estimation of spectral data. Different techniques for estimating spectral reflectance curves[1-3] or spectral distribution of solar radiation[4,5] has been presented. They all have in common the use of methods for estimating a continuous function by a small number of that function's samples. Here we analyze the spectral and colorimetric accuracy of a simple linear model that has been frequently proposed on artificial-vision algorithms for recognizing and identifying colors.

2. DAYLIGHT SPECTRAL CORRELATION AND LINEAR MODELS

To develop the algorithm we require prior rigorous mathematical analysis of the daylight SPDs; in fact we need to determine the smallest dimension for our linear daylight models that lets us reconstruct the original $E(\lambda)$ to within some specified accuracy. Over the last five decades the strong spectral correlation among daylight curves has been reported by several authors in several countries[6-10]. Yet before a previous paper by the authors[10] suitably large databases of daylight spectra were not readily available.

Within a linear model, frequently used on artificial-vision algorithms[11,12], if $E_E(\lambda)$ is a measured daylight spectrum, then we can approximate it by using p eigenvectors in $E_R(\lambda)=\sum_{i=1}^{p}\langle E_E(\lambda)|V_i(\lambda)\rangle V_i(\lambda)$ where $E_R(\lambda)$ is the reconstructed spectrum, $V_i(\lambda)$ is the i-th eigenvector, and $\langle\,|\,\rangle$ denotes the inner product. To reconstruct a curve of N points exactly, in principle we need N eigenvectors. In practice, however, daylight correlation mean that we can set $p \ll N$ without losing any meaningful spectral information. One of the Judd *et al.*'s results[6], supported by later works by other authors[7-10], is that most daylight SPDs can be accurately estimated by linearly combining three fixed basis functions. Although our collection of daylight spectra is the largest measured to date with 2600 daylight spectra, we require only a few $V_i(\lambda)$ to account for nearly all its variance in the visible[10]. Unlike earlier researchers, we find that the first five $V_i(\lambda)$ account for 99.991% of the observed variance between 380-780 nm. Indeed we need $p > 5$ for accurate $E_R(\lambda)$ in the visible region of the spectrum (380-780 nm), even though CIE recommendations for reconstructing daylight SPDs from chromaticities in effect call only for $p = 3$. As the CIE recommends[13], we showed that $p = 3$ will produce $E_R(\lambda)$ that are *colorimetrically* indistinguishable from the corresponding $E_E(\lambda)$ for most observers.

All these results are obtained when the spectral curves are estimated using the daylight eigenvectors obtained from a principal-value decomposition over 2600 daylight spectra recorded over a period of two years[10]. Unfortunately it is impossible to have sensors with the same spectral transmittance as the eigenvectors obtained from a principal-value decomposition (eigenvectors have negative values, as shown on Figure 1). This is only a mathematical approach to the problem. Then daylight recovery algorithm must be implemented through the use of a particular set of well chosen filters with physical existence.

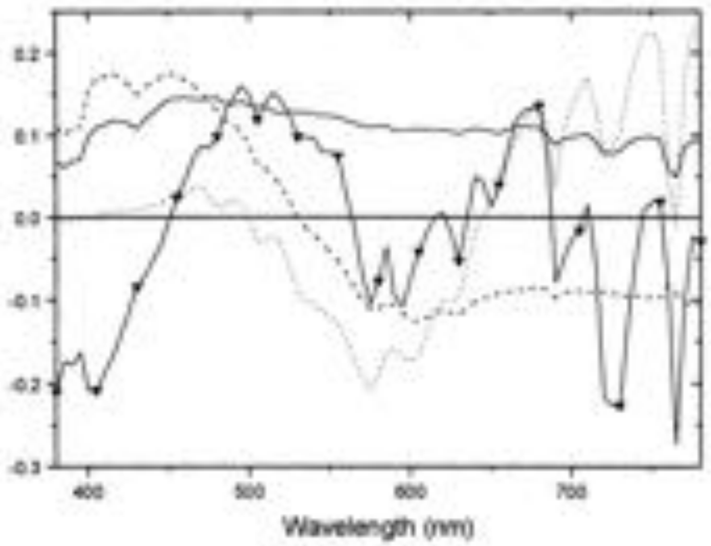


Figure 1.- Spectral distribution of eigenvectors $V_1(\lambda)$,$V_2(\lambda)$,$V_3(\lambda)$ and $V_4(\lambda)$ for our 2600 daylight measurements. Solid curve: $V_1(\lambda)$; dashed curve: $V_2(\lambda)$; dotted curve: $V_3(\lambda)$; solid line with triangles: $V_4(\lambda)$.

For a daylight spectrum $E_E(\lambda)$ a sensor with a spectral sensitivity $R_k(\lambda)$ will give the response $\rho_k = \sum_{n=1}^{N} E_E(\lambda_n) R_k(\lambda_n)$.

Let $\bar{\rho}$ be the matrix of the p sensors responses. Then $\bar{\rho} = \bar{\Lambda}\bar{\sigma}$ where $(\Lambda)_{kj} = \sum_{n=1}^{N} V_j(\lambda) R_k(\lambda)$ and $(\sigma)_j = \langle E_E(\lambda) | V_j(\lambda) \rangle$.

Solving the equation $\bar{\rho} = \bar{\Lambda}\bar{\sigma}$ for σ we obtain the reconstructed daylight spectrum as $E_R(\lambda) = \sum_{j=1}^{p} (\sigma)_j V_j(\lambda)$.

3. OPTIMAL FILTER POSITIONS

Here we check up, using a binary search, the suitability of such algorithm over the visible spectrum (380-780 nm with a spectral resolution of 5 nm) with a set of three to six narrow-band interference filters (FWMH ~ 10 nm). Our binary search considers all the possible filter spectral positions over all the visible spectrum, providing us the optimal spectral positions.

While the binary search was being performed, we simultaneously tested the similarity between the daylight SPD received by filters $E_E(\lambda)$ and the reconstructed daylight SPD $E_R(\lambda)$, by the evaluation of three different parameters. First, a goodness of fit coefficient (GFC)[14,15], based on the inequality of Schwartz, to test the spectral quality. The GFC is the multiple correlation coefficient R, the square root of $E_R(\lambda)$'s spectral variance with respect to the original $E_E(\lambda)$; GFC ranges from 0 to 1, where 1 indicates a perfect reconstruction. Second, the Euclidean distance between the CIE 1931 chromaticity coordinates x and y for the original and the reconstructed daylight. Third, the relative error between integrated irradiances (both original and reconstructed) over the visible spectrum (380-780 nm).

4. RESULTS AND DISCUSSION

Our binary search gives an unexpected result: the optimal filter positions are different when we seek the maximum mean GFC, the minimum mean colorimetric distance and the minimum mean integrated irradiance error. This unexpected result seems to disagree with the logical sense: a good colorimetric quality should be followed by a good spectral agreement and also by a good integrated irradiance similarity. However this is not true due to metamerism; not only colorimetric metamerism, but also global irradiance "*metamerism*" (two well different SPDs with the same integrated irradiance).

To avoid any "metamerism" we find the best filter positions that improve the three qualities simultaneously, obtaining the results shown in table 1. These results are not as good as those obtained by us using a similar algorithm and filters for the recovery of spectral reflectances of natural objects[1]. Although spectral correlation is significantly lower for these reflectances their spectral distributions are remarkably smoother. The reason for this discordance rest on the complex and rough daylight spectral profile; whereas daylight is essentially achromatic, many factors (*e.g.*, solar elevation, site altitude, atmospheric conditions, pollution, detector orientation, etc.) can affect its spectral composition and thus its color. An accurate spectral daylight recovery demand a correct specification in the spectral location of the absorption bands (*e.g.* water vapor, oxygen, ozone, aerosols) and the strength of these bands depends on the day and even on the time of the day.

Moreover, an increase on the number of sensors used on the algorithm does not improve the reconstruction quality. In fact the best quality is obtained when four sensors are used instead of six. However if we analyze the variance accounted for by each eigenvector we observe that the fifth eigenvector only increase the variance accounted for on 0.018%, an the sixth eigenvector on 0.003%. Thus we are introducing "noise" instead of improving the recovery algorithm when including eigenvectors with little contribution to the variance.

Number of sensors	Optimal filter central peak wavelengths (nm)	Maximum mean GFC	Minimum mean colorimetric Euclidean distance	Minimum mean integrated irradiance relative error
3	410, 440, 535,	0.99236 (0.0096)	0.0269 (0.0133)	2.91 (3.56)
4	405, 530, 580, 605	0.98544 (0.01061)	0.0218 (0.014)	2.45 (3.2)
5	510, 525, 585, 610, 675	0.97352 (0.01103)	0.0231 (0.0238)	5.13 (6.25)
6	505, 525, 585, 610, 745, 750	0.98049 (0.01692)	0.0353 (0.0274)	5.92 (6.75)

Table 1. Best global results obtained with the binary search. Standard deviations between brackets.

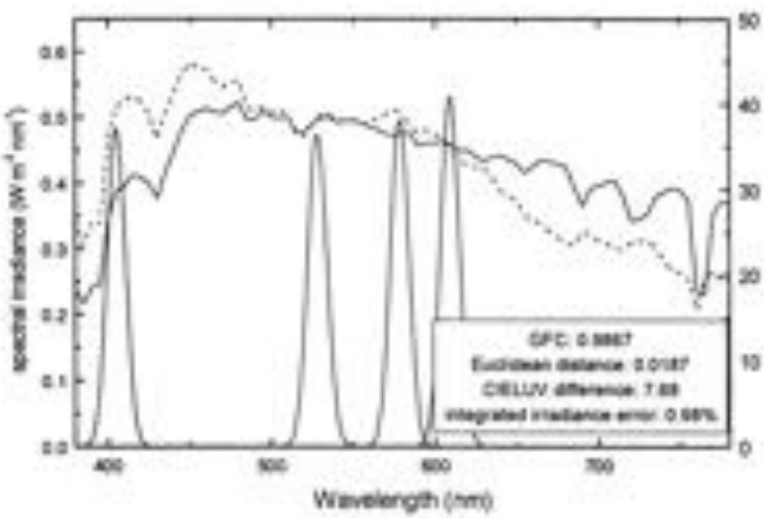


Figure 2. Example of a reconstruction using four filters.

5. CONCLUSIONS

Research on artificial-vision algorithms for recognizing and identifying colors have repeatedly assumed that linear models are accurate enough to recover not only spectral reflectances but also spectral illumination[11-12]. We have tested the accuracy of a daylight spectral estimation algorithm that use a linear model and a set of few carefully chosen narrow-band filters. From the response of these filters to a daylight SPD the linear model gives us the estimation of the daylight. We have analyzed the quality of the daylight estimation from a spectral, colorimetric and integrated irradiance points of view, obtaining that a linear model is not sufficiently accurate when we intend to reconstruct roughly daylight spectral curves. Daylight spectrum is not a smoothly varying function in opposite of spectral reflectance of natural objects, and this is especially pronounced in the near-IR where water vapor and molecular oxygen have strong absorption bands.

This paper is a first step in determining whether the physical implementation of linear models is appropriate or not on artificial-vision algorithms. Because the sensors choice is critical on the results our future intention is to extend this work to different kind of sensors.

ACKNOWLEDGEMENTS

This research was supported by Spain's Comisión Interministerial de Ciencia y Tecnología (CICYT) under research grant BFM 2000-1473 and by the CICYT-European Commission FEDER grant R-IFD97-1534-CO2-01.

REFERENCES

1. S. K. Park and F. O. Huck, "Estimation of spectral reflectance curves from multispectral image data," *Appl. Opt.* **16**, pp. 3107-3114, 1977.
2. D. H. Brainard and W. T. Freeman, "Bayesian method for recovering surface and iluminant properties from photosensor responses," in *Human Vision, Visual Processing and Display V*, Rogowitz B.E., Allebach J.P., eds., Proc. SPIE **2179**, pp. 364-376, 1994.
3. A. García-Beltrán, J. L. Nieves, J. Hernández-Andrés, and J. Romero, "Spectral reflectance recovering through linear model and narrow-band filters", *OSA Annual Meeting*, Portland, Oregon, Proceedings, p. 132, 1995.
4. J. J. Michalsky and E. W. Kleckner, "Estimation of continuous solar spectral distributions from discrete filter measurements," *Sol. Energy* **33**, pp. 57-64, 1984.
5. J. J. Michalsky, "Estimation of continuous solar spectral distributions from discrete filter measurements: II. A demonstration of practicability," *Sol. Energy* **34**, pp. 439-445, 1985.
6. D. B. Judd, D. L. MacAdam, and G. Wyszecki, "Spectral distribution of typical daylight as a function of correlated colour temperature," *J. Opt. Soc. Am.* **54**, pp. 1031-1041, 1964.
7. V. D. P. Sastri and S. R. Das, "Typical spectral distributions and colour for tropical daylight," *J. Opt. Soc. Am.* **58**, pp. 391-398, 1968.
8. A. W. S. Tarrant, "The spectral power distribution of daylight," *Trans. Illum. Eng. Soc.* **33**, pp. 75-82, 1968.
9. E. R. Dixon, "Spectral distribution of Australian daylight," *J. Opt. Soc. Am.* **68**, pp. 437-450, 1978.
10. J. Hernández-Andrés, J. Romero, J. L. Nieves, and R. L. Lee, Jr., "Color and spectral analysis of daylight in southern Europe," *J. Opt. Soc. Am. A* **18**, pp. 1325-1335, 2001.
11. L. T. Maloney and B. A. Wandell, "Color constancy: a method for recovering surface spectral reflectance," *J. Opt. Soc. Am. A* **3**, pp. 29-33, 1986.
12. D. H. Marimont and B. A. Wandell, "Linear models of surface and illuminant spectra," *J. Opt. Soc. Am. A* **9**, pp. 1905-1913, 1992.
13. G. Wyszecki and W. S. Stiles, *Color Science: Concepts and Methods, Quantitative Data and Formulae*, Wiley, New York, 1982.
14. J. Hernández-Andrés, J. Romero, A. García-Beltrán, and J.L. Nieves, "Testing linear models on spectral daylight measurements," *Appl. Opt.* **37**, pp. 971-977, 1998.
15. J. Hernández-Andrés, J. Romero and R. L. Lee, Jr., "Colorimetric and spectroradiometric characteristics of narrow-field-of-view clear skylight in Granada, Spain," *J. Opt. Soc. Am. A* **18**, pp. 412-420, 2001.

* Correspondence: javierha@ugr.es; phone 34-958-246165; fax 34-958-248533; http://www.ugr.es/~geoptica/; Departamento de Óptica, Facultad de Ciencias, Campus Fuentenueva, Universidad Granada, 18071-Granada, SPAIN

From Mean Diffuse External Reflectance to Color and Visual Appearance Representation

Patrick Callet
Ecole Centrale Paris, grande voie des vignes 92290, Châtenay-Malabry, France
callet@pl.ecp.fr http://virtual.pl.ecp.fr/ callet
Robert Sève
Centre Français de la Couleur, 15 passage de la Main d'Or, 75011 Paris, France
robert.seve@free.fr http://www.cf-couleur.org

ABSTRACT

Color and visual appearance of materials are presented within the general framework of their optical properties, described with the unique notion of complex index of refraction. We limit our investigation to materials described as homogeneous and forming a *continuum* at a macroscopic scale of observation, though there exist some methods for extracting optical data from spectral curves. Previous works due to John W.T. Walsh in 1926 are recalled and generalized with the help of the 3D computer simulation of the *Surface of Whole Reflectivities*.

Keywords: Transparency; gloss ; opacity ; reflectivity ; physically based modelling ; image synthesis; colorimetry; roughness; electronic plasma; BRDF ; Fresnel factor; color rendering ; metals ; alloys ; dielectrics.

1. INTRODUCTION

Color and visual appearance of materials are presented within the general framework of their optical properties. Metallic aspect, characterized by a high reflectivity (over the whole visible spectrum and more) and opacity of conductive substances are explained by plasma physics. Transparency is a property of homogeneous dielectric substances and is mainly described with the refractive index notion. Colored materials such as glasses, ceramics or resins are mainly translucent and have generally a very low electric conductivity while their optical conductivity is described by a spectral function. In our real world, pure metals or perfect dielectrics are abstractions or ideal matters associated with the notion of great purity. The distinction between these two opposite states of matter for the visible light behavior is relevant from band theory. It appears that any real material, however homogeneous and isotropic, can be described with the help of some notions such as complex dielectric function (or complex refractive index) and geometrical parameters such as roughness at an optical scale and undulation at a mesoscopic scale. Though this notion is not completely new, it is not enough employed. The main reason lies in the fact that the data are often missing or not sufficient.[8]

2. PERTINENT DATA EXTRACTION OR MEASUREMENT

At a more fundamental level, the real part of the index of refraction is linked to the valence band of the material while the imaginary part is linked to its conduction band. There exists, in optics fields, some methods for extrating optical constants from reflection or transmission spectra. Among these methods, the Kramers-Krönig analysis is currently used, fast and very efficient. Using spectral data consisting in real and imaginary part of the complex refractive index and not directly spectra, it is possible to anticipate the angular and spectral behavior of light when interacting with materials.[3] Some optical data, as needs spectral rendering of color phenomena, have been placed in our web pages and concern about 30 elements of the periodic table. The goniospectrophotometric records defined as BRDFs (Bidirectional Reflectance Distribution Function) can be modeled applying the laws of optics and, by this way, can help in visualizing real optical properties in a design process. Instead of the use of BRDFs, that can only help in the replication of an optical aspect of a real body but visualized with different illumination conditions, we calculate and compute the BRDFs from optical data [complex refractive index (n,k)]. This approach is very rich when textured materials, either natural or man made, are involved since goniospectrophotometric measurements are not pertinent.

2.1. Importance of the index of refraction

As previously mentioned, the complex refractive notion appears to be more important for modelling than spectra. Our arguments for a good knowledge of the way we are walking in, are founded on the following observations :

- opacity and very high reflectivity of metals are characterized by a very important absorption index k, while the real part of the refractive index can be less than unity (evanescent wave) e.g. noble metals.
- semi-transparency in thin slabs and a high reflectivity of semi-metals are characterized by an absorption index k weaker.
- transparency and translucency are characterized by either a completely real refractive index associated with a very weak spectral absorption index k.

2.2. Some inherent limitations

In many cases where the notion of index of refraction does not apply is often employed the alternative notion of *effective complex index of refraction*. Formally it is easy to understand that this index can always be extracted from reflection or transmission spectra. There is no place here to discuss about this and the reader is invited to the reading of some treatise on optics of composite materials.

3. THE MEAN DIFFUSE EXTERNAL REFLECTANCE OF A SMOOTH HOMOGENEOUS MATERIAL SURFACE

Thus, any calculation and model must be sufficiently general to include all possible cases of optical behavior. Following a first historical approach conducted by Walsh[3] in 1926, we apply an analytical or computational representation of reflectance (or transmittance) expressed by the "Surface of Whole Reflectivities". This surface is obtained by numerical integration of the Fresnel reflectance formulae when n ranges in [1 ; 6] and k in [0 ; 10] and including an attenuation due to roughness (gaussian microfacets distribution) influence*. The integration concerns the complete half space delimited by the local mean tangent plane to a real material surface. For this purpose the illumination is considered as uniformly diffuse over the illuminated real surface and thus does not participate by the mean of a real indicatrix surface to the angular computation. The obtained results completely include the experimental results published by Judd in 1942 (for a real index of refraction) and confirmed by Mandelis[5] and col. in 1990 when they studied the reflectivity of large powders. This generalization by the use of the computer capabilities exhibit within the same representation the possibility of accessing to color, transparency and gloss for a given surface state. The radiance of a specular surface lited by a diffuse (isotropic) natural or unpolarized light source depends on the calculation of the following angular integrals :

$$K_1(\hat{n}) = 2\int_0^{\frac{\pi}{2}} \mathcal{F}[\theta_1, \hat{n}(\lambda)] \sin 2\theta_1 d\theta_1 \quad K_2(\hat{n}) = 1 - \sin^2\theta_1^\ell + 2\int_0^{\theta_1^\ell} \mathcal{F}[\theta_1, \hat{n}(\lambda)] \sin\theta_1 \cos\theta_1 d\theta_1 \tag{1}$$

$K_1(\hat{n})$ describes a propagation starting from a weakly dense medium (optically) and crossing the material interface toward a denser medium. $K_2(\hat{n})$ describes the opposite crossing of the material interface and involves the limit angle of reflection θ_1^ℓ so that, using the writing of Born and Wolf[7] :

$$\hat{n}(\lambda) = n(\lambda) + ik(\lambda) = n(\lambda)[1 + i\kappa(\lambda)] \qquad \sin\theta_1^\ell = \frac{1}{n} \tag{2}$$

For dielectric materials (when n is a pure real number) these integrals have been calculated.[5] The angular representation of the directional reflectance is then :

$$\mathcal{F}[\theta_1, \hat{n}(\lambda)] = \frac{1}{2}\left[\frac{\sin^2(\theta_1 - \theta_t)}{\sin^2(\theta_1 + \theta_t)} + \frac{\tan^2(\theta_1 - \theta_t)}{\tan^2(\theta_1 + \theta_t)}\right] \tag{3}$$

where θ_t is the angle of refraction.

The two angles θ_1 and θ_t beeing linked by the Snell-Descartes law $\sin\theta_1 = n \sin\theta_t$. The details of the calculation is also given in our book.[4] There exists an analytical answer to the problem of the determination of the radiance

*A homogeneous and isotropic roughness[1] distribution only results in an amplitude shift of the reflectance surface of a specular non-absorbing surface (perfectly dielectric material). For metallic materials, the previous calculation is so complicated as the refractive index is complex number so that a numerical expression seems to be preferable. It has previously been mentioned[5] that the integral $K_1(n)$ was evaluated by Walsh.[8] We verified this model in 1998.[4] As some results appeared to be contradictory we decided to use a numerical integration which is reported in Fig. 2. $K_1(n)$ and $K_2(n)$ are then computed for n values ranging between 1 and 4. Mandelis[5] pointed out that the difference between the numerical integration and the exact calculation was so weak (within the framework of our aplications) so that the use of the numerical integration process is reasonable when studying dielectric materials. The Walsh's relationship is recalled herafter :

$$R_d = 0.5 + \frac{(n-1)(3n+1)}{6(n+1)^2} - \frac{2n^3(n^2+2n-1)}{(n^2+1)^2(n^2-1)} + \frac{n^2(n^2-1)^2}{(n^2+1)^3}\ln\left(\frac{n-1}{n+1}\right) + \frac{8n^4(n^4+1)}{(n^2+1)^3(n^2-1)^2}\ln(n) \quad (4)$$

Experimental results were published by Judd in 1942 ; they lead to a remarkable correspondence with the theoretical predictions of Walsh. These results obtained by Judd are reproduced in Fig. 1. Considering these previous attempts in modeling the mean internal or external angular reflectances, we decided to use a numerical integration process.

For metals or semi-metals a greater complexity is then introduce by the imaginary part of the refractive index, as it is not negligible at all. Thus, numerical integration is the only reasonable way of evaluation. The results are presented in Fig. 3 and 4. Using this numerical process we have computed these mean values of the angular reflectances either internal or external for about 30 elements (from light elements as Li, Na to noble elements as Cu, Ag, Au and semi-metals as Si, Ge, Zr, Hf and for more "exotic" elements as Ho, Gd, Tb). Many of them are visible on the authors' web sites.) with a diffuse isotropic lighting in natural light (mean polarization of light). These data are used in the ray-tracing rendering process as an accurate approximation for the ambient light contribution and as diffuse reflection spectra.

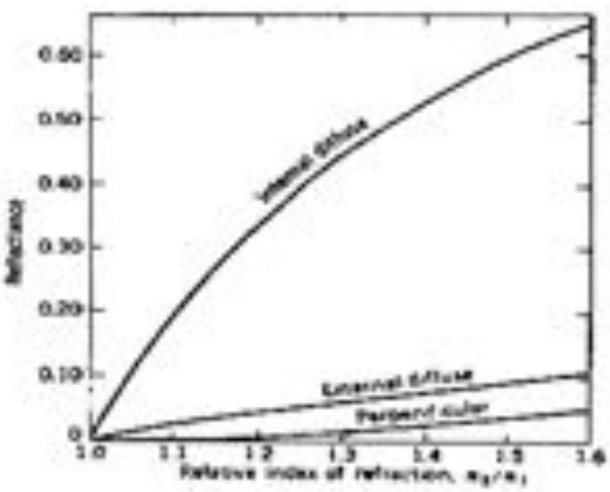


Figure 1. Experimental results obtained by Judd in 1942 for the mean external and internal reflectances $K_1(n)$ and $K_2(n)$. Notice the interval of variation for the real number n.

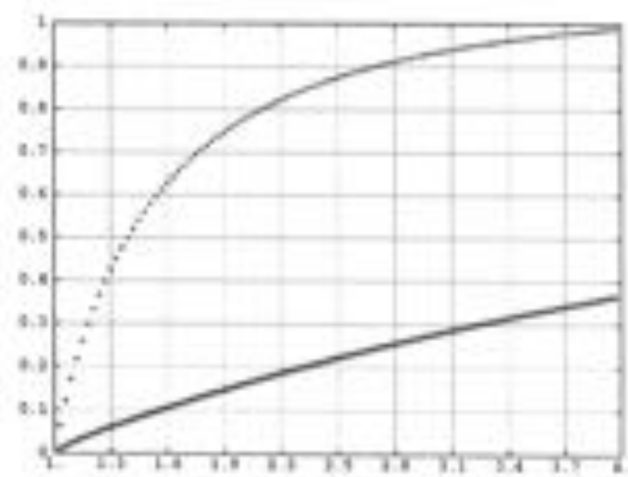


Figure 2. 2D Plot of the mean external reflectance $K_1(n)$ (bottom) and the mean internal reflectance $K_2(n)$ (top), obtained by numerical integration.

4. CONCLUSION AND FUTURE WORK

We shall examine the influence of small variations of n and k on this mean diffuse reflectance as it gives access to many important optical and visual parameters. We shall examine some categories of concepts involving visual appearance such as metallic lustre, transparency, gloss, or opacity. Angular and spectral variables are very important for modelling (and measuring) optical phenomena in a visualization process where a CIE standard observer is used. Perlescent pigments and color flop, metallic paints, are correctly perceived in a simulation process when including binocular information, as pointed out by Macamy.[6,7] This aspect is very important and is in progress in conjunction

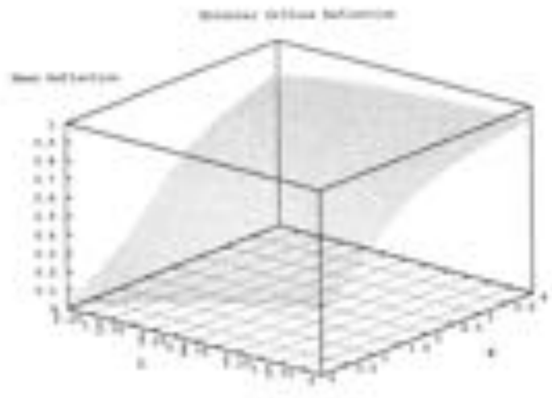


Figure 3. 3D plot of the suface $K_1(n,\kappa)$ giving the mean external rectance for an isotropic diffuse lighting. These results generalize the previous one given in 2 where a unique real index of refraction was used. Here, κ is ranging in [0,4]

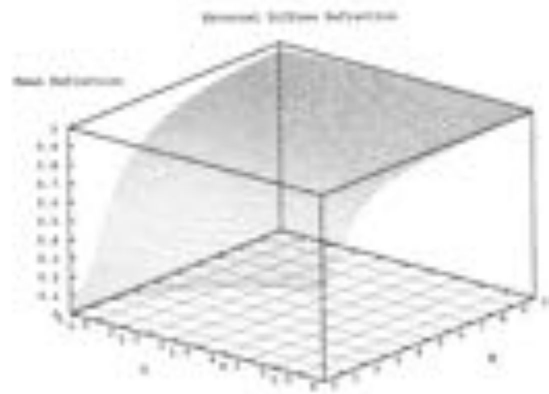


Figure 4. 3D plot of the surface $K_1(n,\kappa)$ where κ is now ranging [0,10.]. This surface is called *Surface of Whole Reflectivities*.

with automotive designers. Several fields of application either scientific, educational or industrial are on demand and concerned by an accurate and predictive tool for visualizing the optical appearance depending on spectral and goniometric variables simultaneously. *Color matching* will probably be replaced by *index matching* to explore the multi-dimensionality of color and visual appearance. Thus, for example, are concerned jewellery, dentistry, archeology, artwork restoration and more generally design. The visual appearance of metallic substances cannot be described in the same way as for composite materials such as opaque paints or plastics where color is mainly due to internal multi-scattering processes and spectral absorption. For metallic samples the only scattereded light is due to surfacic interactions induced by roughness. As examples rendering of many elements of the periodic table using the method called OCRE (Optical Constants for Rendering Evaluation) are given in P. Callet's website.

REFERENCES

1. Piotr BECKMANN and André SPIZZICCHINO. *The Scattering of Electromagnetic Waves from Rough Surfaces.* Pergamon Press, London, 1963.
2. Max BORN and Emile WOLF. *Principles of Optics–Electromagnetic Theory of Propagation, Interference and Diffraction of Light–*. Pergamon Press, Oxford, 1975.
3. Patrick CALLET. Pertinent data for modelling pigmented materials in realistic rendering. *COMPUTER GRAPHICS forum*, 15(2):119–127, 1996.
4. Patrick CALLET. *Couleur-lumière, couleur matière*. Diderot Multimédia, Paris, 1998. 320p., including CD-ROM of computed images.
5. A. MANDELIS, F. BOROUMAND, and H. VANDEN BERGH. Quantitative Diffuse Reflectance Spectroscopy of Large Powders : the Melamed Model Revisited. *Applied Optics*, 29(19), july 1990.
6. C.S. MCCAMY. Observation and measurement of the appearance of metallic materials. part i. macro appearance. *Color Research and Application*, 21:292–304, 1996.
7. C.S. MCCAMY. Observation and measurement of the appearance of metallic materials. part ii. micro appearance. *Color Research and Application*, 23:362–373, 1998.
8. John W.T. WALSH. The reflection factor of a polished glass surface for diffused light. *Illumination Research Technique*, 10, 1926.
9. H. WEAVER, C. KRAFKA, D.W. LYNCH, and E.E. KOCH. *Optical Properties of Metals*, volume 18-1 et 18-2. Fachinformationzentrum, 7514 Eggenstein-Leopoldhafen 2, Karlsruhe, Germany, 1980.

The iridescence color of shells

Yan Liu
Liu Research Laboratories, South El Monte

ABSTRACT

Some shells from both salt water and fresh water show the phenomenon of iridescence color. Pearls and mother-of-pearls also display this phenomenon. In the past, the cause of the iridescence color was attributed to interference. A scanning electron microscope (SEM) was used to study the surface structure of the shell of the mollusk *Pinctada Margaritifera*. There is a groove structure of reflection grating on the surface area in where the iridescence color appears. An optic experiment with a laser obtained a diffraction pattern produced by the reflection grating structure of the shell. The study led to a conclusion that the iridescence color of the shell is caused by diffraction. A SEM image of the shells of an abalone *Haliotis Rufescens* (red abalone) showed a statistically regularly arranged tile structure that serves as a two-dimensional grating. This grating structure causes the iridescence color of the shell of red abalone. The dominant color of the iridescence of shells is caused by the uneven grating efficiency in the visible wavelength range when a shell functions as a reflection grating. The wavelength of the dominant color should be at or near the wavelength of the maximum efficiency of the grating.

Keywords: Iridescence, color, diffraction, wavelength, hue, shell, laser, dominant, pearl, abalone.

1. INTRODUCTION

Iridescence is a well-known natural phenomenon [1 2, 3]. Many kinds of shells, pearls and mother-of-pearls exhibit the iridescence. This phenomenon was attributed to interference caused by the nacre layers of shells. Liu et al [4] studied the iridescence of a shell of the mollusk *Pinctada Margaritifera*, and found that the iridescence is caused by diffraction. The shell of the mollusk has a groove structure which functions as a reflection grating to produce diffraction to cause the iridescence.

The shell of the abalone *Haliotis Rufescens* also shows a very strong iridescence color. The red abalone is often used for studying the biofabrication of the nacre layer of shell and pearl. Fritz et al successfully produced a "flat pearl" inside the red abalone [5]. Schaffer et at [6] and Addadi and Weiner [7] found that aragonite crystals insider a predeposited matrix sheet grow to be aragonite tiles to form the nacre layer. Under a SEM, the inner layer of the red abalone shows a two dimensional aragonite tile structure. This structure is determined by the predeposited matrix sheet of conchiolin. The aragonite tile structure is in a statistically regular pattern, averaging approximately 5 µm in size for the studied shell.

The iridescence of shells and pearls usually shows one or two dominant colors, such as green and pink for the studied shell of the mollusk. The cause of the dominant color was unknown. Sometimes, it was attributed to the dyestuffs inside the nacre layer. Since the dominant color changes with a change of viewing angle, it cannot be caused by the dyestuffs. The diffraction efficiency of a reflection grating is not even in the visible range. This study found that the uneven diffraction efficiency in the visible range causes the dominant color.

2. SURFACE STRUCTURES OF THE SHELLS

2.1. The surface structure of the shell of the Mollusk *Pinctada Margaritifera*

The polished shell of the mollusk shows a parallel grating structure image under a SEM (Figure 1). The grooves are parallel, even, and well arranged. The surface has been polished smoothly with a high reflectance. Therefore, this shell can function very well as a reflection grating. The width of each groove is about 3.38 µm. This shell is equivalent to a 296 grooves-per-millimeter (grooves/millimeter) reflection grating. This reflection grating structure can produce strong diffraction. The pearls and mother-of-pearls with the iridescence always have the similar groove structure.

The thickness of the aragonite nacre is about 0.4 µm for the studied shell. A detailed SEM image of the aragonite nacre layer shows that the nacre consists of irregular polygonal tiles of crystalline aragonite. The tiles are mortared together by polysaccharide and protein fibers called conchiolin. The nacre layer is not optically uniform due to the irregular polygonal tiles and the conchiolin. This non-uniformity of the nacre layer can cause a strong diffusion when a light beam is incident into the surface of a shell. It is the strong diffusion that causes the milky white appearance of shells and pearls. Since diffusion light cannot produce interference, the iridescence of shells and pearls cannot be caused by interference.

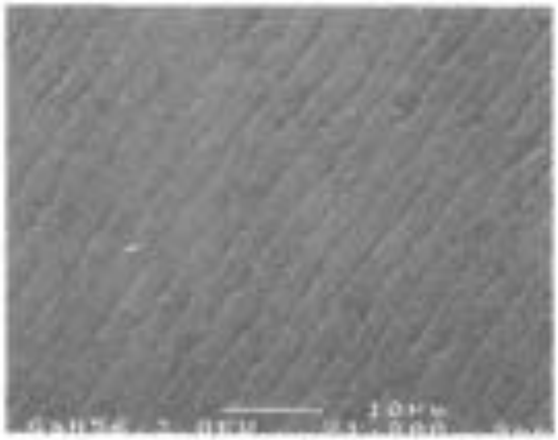


Figure 1. The reflection grating structure of the shell of the mollusk *Pinctada Margaritifera*

2.2. The surface structure of the shell of the abalone *Haliotis Rufescens*

The outside layer of the red abalone shell consists of prismatic calcite. It is called red abalone due to its red appearance outside. The inner layer of the shell displays a strong iridescence color. Figure 2 shows a SEM image of the inner layer. The aragonite titles of the abalone nacre are much rough, slightly convex in shape, and much larger in size than that in the shell of the mollusk. The average size of the tiles is about 5 µm, in the range from 3 to 7 µm.

The aragonite tiles in the abalone nacre layer do not show the groove structure of reflection grating. Each tile can be clearly distinguished under a SEM. The size and the arrangement of the tiles are determined by the predeposited matrix sheet of conchiolin, in which the aragonite crystals grow to be the tiles. The tiles are arranged by the matrix in a statistically regular pattern. Thus, the regular pattern of the tiles can function as a two-dimensional reflection grating, and each aragonite tile serves as an element of the grating array.

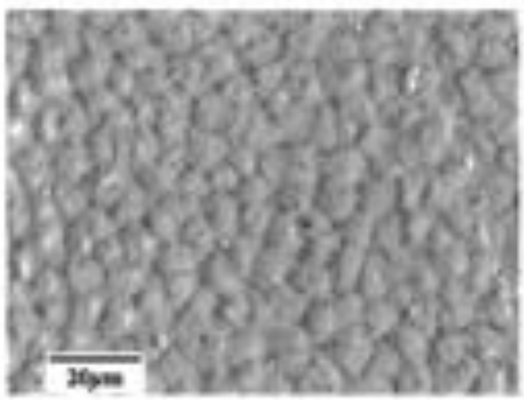


Figure 2. The SEM image of a nacre layer of the shell of the abalone *Haliotis Rufescens*

3. CAUSE OF THE IRIDESCENCE

The diffraction produced by the reflection grating structure of the mollusk shell can be demonstrated by an optical experiment. This experiment uses an argon ion laser to illuminate a piece of the shell of the mollusk. The laser beam is diffracted by the grating structure of the shell, and a diffraction pattern is formed on a screen. Figure 3 shows a detailed diffraction pattern produced by the shell with an argon ion laser at 514.5 nm .

The diffraction maxima from order –2 to –2 can be easily seen in this diffraction pattern. Most of the diffracted light is concentrated in the higher orders to form a large bright area. A more detailed diffraction pattern shows that the bright area consists of the diffraction orders from 3 to 8. The higher order diffractions in the bright area predominately cause the iridescence.

The very strong 0 order diffraction in the diffraction pattern is caused by the mirror surface reflection. Although it is very strong, it does not contribute to the iridescence. The iridescence of the shell is very directional. The shell does not show iridescence observed from the mirror reflection direction, because the 0 order diffraction is the mirror reflection. The shell also does not show the iridescence along the groove direction, because the shell does not refract light along this direction.

Figure 3. A detailed diffraction pattern produced by the shell of the mollusk Pinctada Margaritifera.

The strength of the iridescence is directly related to the groove density and the optical quality of the surface. The polished outside shell of the mollusk with the high groove density and the high optical quality shows the strong iridescence. The inner shell shows a very weak iridescence due to the low groove density and low optical quality of the grating structure.

The aragonite tiles of the red abalone are arranged in a statistically regular pattern. They can function as a two-dimensional reflection grating of a 200 tiles per millimeter density, because the average tile size is about 5 μm. This two-dimensional diffraction grating structure of the shell can produce a very strong diffraction to cause the strong iridescence. This iridescence is caused by a combined diffraction effect from all possible directions and all diffraction orders. This iridescence color is not directional, and can be observed in any direction due to the two-dimensional array grating structure. The rough convex surface of the aragonite tiles also enhances the non-directional effect. We can observe the iridescence of the red abalone from any directions, including the mirror reflection direction.

4. THE DOMINANT COLOR

The iridescence color of shells do not show the whole spectrum, but usually one or two dominant colors. The shell of the mollusk shows a green and a pink dominant color. The shell of the red abalone shows a blue-green and a pink dominant color. Previous to this study, the cause of the dominant color is unknown. It was thought to be caused by the dyestuffs inside the nacre layers. This explanation of the dominant color is flawed, since a color caused by a pure dyestuff does not change with a change of viewing angle. A color changing with a change of viewing angle must be caused by one or more directional optical effects. Since the iridescence color of shell is caused by diffraction, the dominant color should be related to diffraction.

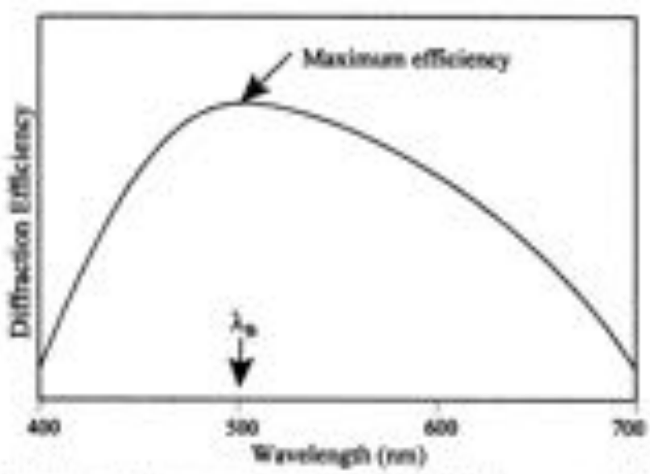


Figure 4. A typical diffraction efficiency curve of a grating. The peak efficiency occurs at the blaze wavelength.

A reflection grating cannot diffract light evenly in the visible wavelength range. Figure 4 illustrates a typical diffraction efficiency curve of a reflection grating [8]. The maximum (peak) efficiency of the grating occurs at the blaze wavelength. The diffraction efficiency curve functions similarly to the spectral reflection curve of a color sample. Therefore, the dominant color of the iridescence of shell is caused by the uneven diffraction efficiency in the visible wavelength range. The hue of a dominant color should correspond to the wavelength of the maximum efficiency. If the dominant color of a shell appears green, for example, the wavelength of the maximum efficiency must be in the green wavelength range about 470 – 540 nm.

A diffraction efficiency curve corresponds to a specified diffraction order, and many other factors, such as the material, the width of the groove or the size of the diffraction element, diffraction angles, and incident angle. The wavelength of maximum efficiency changes with the changes of both incident light and diffracted light. Therefor, the hue of the dominant color of a shell changes with a change of viewing angle. This is the reason why the color of iridescence changes with a slight rotation of a shell due to a change of the viewing angle.

5. CONCLUSION

The shell of the mollusk *Pinctada Margaritifera* has a groove reflection grating structure, and the shell of the abalone *Haliotis Rufescens* has a two-dimensional reflection grating structure. The iridescence color of shells and pearls is caused by the diffractions produced by the reflection grating structures. The intensity of the iridescence depends on the groove density and the optical quality of the diffraction grating structures. A grating structure with a high groove density, a smooth surface, and an even arrangement of the grooves can produce a strong iridescence color.

The cause of iridescence of shell by diffraction can be proved by an optical experiment with a laser. The diffraction pattern of the mollusk shell shows that most diffracted light is concentrated in the bright area consisting of diffraction orders from 3 to 8. Thus, diffraction orders from 3 to 8 predominately contribute to the iridescence of the mollusk shell.

The iridescence of the shell of the mollusk is directional. It cannot be observed in the mirror reflection direction and along the groove direction. The iridescence of the shell of the red abalone is non-directional, and can be observed in any direction, since the grating structure of the shell of the red abalone is two-dimensional, and the surfaces of the tiles are convex in shape.

The dominant color of the iridescence is caused by the uneven diffraction efficiency of the shells as a reflection grating. The hue of a dominant color corresponds to the wavelength of the maximum efficiency of the reflection grating structure. The dominant color changes with a change of viewing angle due to a shift of the wavelength of the maximum efficiency.

ACKNOWLEDGMENTS

I thank Bruno Wan for providing the shell of the mollusk, and Tish and Wes Rankin for providing the shell of the red abalone for this study. I am also grateful to Jim Shigley, Karin Hurwit, Xianhui Pu, Pingyun Feng, and Kurt Nassau for their helps and suggestions.

REFERENCES AND LINKS

1. J. Turner-Valle, Optical interference coatings in nature, Opt. Photon. News **9**. 58-59 (1998).
2. D. W. Lee, Iridescent blue plants, Am. Sci. **85**, 56-63(1997).
3. K. Nassau, The Physics and Chemistry of Color, (Willy, New York, 1983), pp. 265-268.
4. Y. Liu, J. Shirley, and K. Hurwit, Iridescence color of a shell of the mollusk Pinctada Margaritifera caused by diffraction, Optics Express **4**, 177-182 (1999). http://epubs.osa.org/oearchive/source/8639.htm.
5. M. Fritz et al., Flat pears from biofabrication of organized composites on inorganic substrates. Nature, **371**, 49-51 (1994).
6. T. E. Schafer et al., Does abalone nacre form by heteroepitaxial nucleation or by growth through mineral bridges? Chemistry of Materials, **9**, 1731-1740 (1999).
7. L. Addadi and S. Weiner, A pavement of pearl. Nature, **389**, 912-915 (1997).
8. C. Palmer, Diffraction Grating Handbook, 4th edition, (Richardson Grating Laboratory, Rochester, 2000).

* Correspondence: yliu@liulabs.com; phone 1 626 279-9848; fax 1 626 279-9298; http://www.liulabs.com; Liu Research Laboratories LLC, 2202 Seaman Avenue, South El Monte, CA 91733, USA.

New advances in brightness and color characteristics of hybrid electroluminescent display structures

Lilyana S. Yourukova, Kroum M. Kolentsov and Todor I. Kehlibarov

Institute of Solid State Physics
Bulgarian Academy of Science
72 Tzarigradsko Chaussee blvd., 1784 Sofia, Bulgaria

ABSTRACT

An original hybrid technology is used for the preparation of electroluminescent display structures of various color emission. Some new aspects in the brightness and color investigations of these structures will be reported. Brightness B and color parameters in the CIELUV of structures under various excitation conditions are discussed. The possibility to use these display structures in various informational systems in the up-to-date society and their advantages are indicated.

Keywords: Hybrid electroluminescent display, brightness, color emission, color sign information

1. INTRODUCTION

The marked interest in electroluminescent display (ELD) is connected with the every wider use of light color information in various fields of modern society. The color choice of the display is of essential importance and it is determined by the concrete requirements of the purpose. In these cases color is chosen to ensure the most exact and quick receptivity of information at a minimum fatigue of eyesight, while in other cases it is necessary to select a color scale sharply differing from an other to be exactly identified.

The ELD are multilayer sandwich-like structures which emit light of various spectral compositions, i.e. color emission appears upon an application of excitation sinusoidal or impulse voltage of fixed amplitude and frequency. An original hybrid electroluminescent technology (HELT) is used for the various display structure preparation.

2. ESSENCE OF THE HYBRID TECHNOLOGY

The HELT is full and completed cycle of optical, chemical, spray pyrolysis, binder, screen printing and vacuum operations, which make possible the preparation of various hybrid electroluminescent display structures (HELDS). This technology results from scientific investigations, inventions and know-how[1,2]. The HELT is a comparatively cheap one, which ensures the making of various hybrid electroluminescent display (HELD) of high brightness and stability and provides the possibility both for compatibility of color areas, different in size and configuration, and for a change in colority coordinates depending on the exciting conditions.

A schematic diagram of a HELDS is shown in Figure 1. This structure is the basic part of any HELD - letter, digital and other symbol device.

On a plane-parallel glass substrate 1 the lower transparent electrode 2 is formed from a SnO_2:F layer[3]. The active emitting layer 3 is prepared from industrial A_2B_6 compound electroluminophors of various color emissions (blue, green, yellow and red), dispersed in a polyepoxy oligomer used as a binder. The protective layer 4 of the HELDS is a deposited in vacuum wide-bandgap semiconductor. This layer conditions an increase of structure brightness and stability. The reasons for this improvement of HELDS are the electron processes, going on at the interface "active layer - protective layer"[4]. Aluminium electrodes 5 and 6 are deposited in vacuum, too. This prepared HELDS emits a definite color when an exciting impulse voltage U is applied.

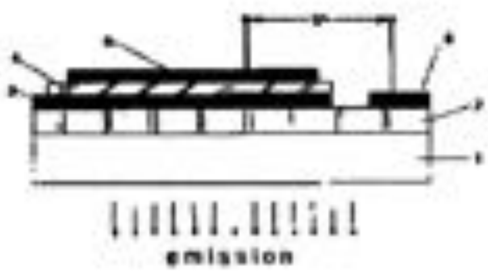


Figure 1. General view of a HELDS

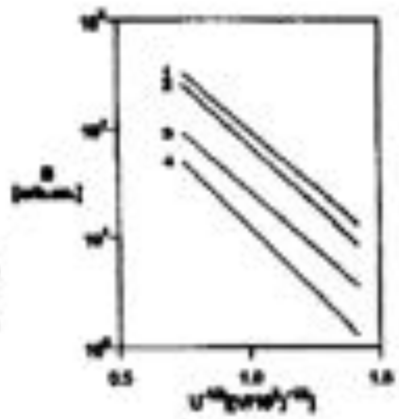


Figure 2. Brightness-voltage characteristics of HELDS

3. EXPERIMENTAL

The HELDS brightness - voltage characteristics are taken down with an especially constructed set-up at frequencies from 400 to 5000 Hz and exciting impulse voltages from 40 to 200 V, respectively. Figure 2 presents these characteristics for HELDS of various color emission (1 - yellow, 2 - green, 3 - blue, 4 -red), taken down at a frequency of 1200 Hz.

The tristimules values of X, Y and Z of the HELDS of various color emission are measured with a Spectra Spotmeter, type UBD-10/4 of Photo Research, made in USA.

The colority coordinates x and y of the HELDS are calculated from the measured tristimules values (see Table 1 a, b). The values of the colotity x and y for a separate HELDS are inflicted on the CIE color diagram in Figure 3 a, b. The color changes of HELD with blue (0), green (□), yellow (△) and red (•) emission depending on the exciting impulse voltage with values 80, 100 and 120 V are given in Figure 3 a, while the color changes in the same HELDS at frequency values 400, 630, 1200, 3000 and 5000 Hz are presented in Figure 3 b. E(x) is the point with coordinates x, y=0.3333 responsible for corresponding to energy equilibrium white color, obtained by a blend of blue, green and red in equal brightness.

NCS values for HELDS of green and yellow emission are determined by a NCS color system at a visual observation and comparation with a fair approach to accurate (see Table 1, a, b, too).

4. DATA ANALYSIS

The graphs of Fig. 2 show that the highest brightness is exhibited by HELDS of yellow and green emissions. This is due to both the properties of used electroluminophors and the peculiarities of electroluminescence in these structures.

From diagrams 3 a, b it can be seen that the color of HELDS of blue, green and yellow emission with the increase of amplitude and frequency of applied voltage moves to the shorts wavelengths while for the HELD of red emission this displacement is to the higher wavelengths. These changes can be connected, on one hand, with the various chemical compositions of used electroluminophors, i.e. with the change of there spectral relation depending on the parameters of the exciting voltage and on the other hand, with the optical properties of the chalcogenide protective layer.

5. SUMMARY

The carried out light and color investigation of HELDS of various color emissions shows that HELD can be successfully used in the color display techniques of the modern society[5,6]. This application is due to the following advantages of theirs:

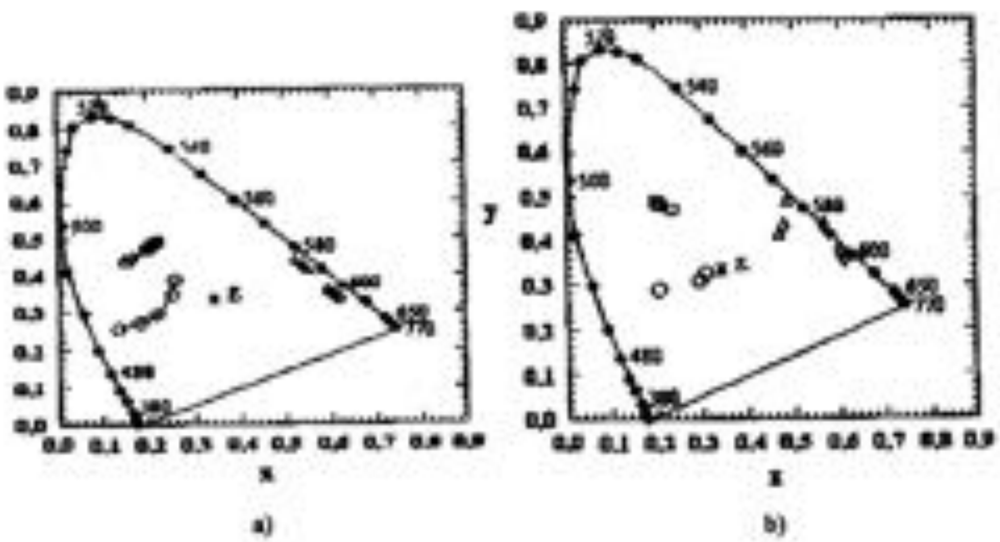
- the HELD have comparatively high brightness and stability, especially these of yellow and green emission;

Table 1 Values of color parameters HELDS of yellow and green emission: a) at a constant frequency

Color emission	Frequency Hz	Voltage V	Color x	coordinates y	NCS values	
yellow	1200	80	0.458	0.446	S 0560	G 80 Y
		100	0.465	0.464	S 0540	G 80 Y
		120	0.473	0.505	S 1030	G 80 Y
green	1200	80	0.180	0.496	S 0550	B 70 G
		100	0.178	0.503	S 0530	B 70 G
		120	0.178	0.502	S 0520	B 70 G

b) at a constant voltage

Color emission	Frequency Hz	Voltage V	Color x	coordinates y	NCS values	
yellow	400	120	0.478	0.503	S 1020	G 80 Y
	630		0.475	0.505	S 1025	G 80 Y
	1200		0.473	0.508	S 1030	G 80 Y
	3000		0.0.468	0.513	S 1040	G 80 Y
	5000		0.456	0.515	S 1050	G 80 Y
green	400	120	0.124	0.498	S 0550	B 70 G
	630		0.205	0.492	S 0525	B 70 G
	1200		0.195	0.485	S 0520	B 70 G
	3000		0.161	0.465	S 0510	B 70 G
	5000		0.155	0.455	S 0505	B 70 G



a) b)

Figure 3. Chromatically diagrams of color changes in HELDS

- the change of the their color characteristics depends on the electroluminophor type and the supply regime.
- the electroluminescent and colorimetric characteristics of HELD remain stable in working regime. This gives the possibility the most appropriate color, perceived by the eye to be determined, without causing damage and fatigue effects on it;

- these displays are ergonomically, energy efficient, radiation-resistant and creating social comfort in their operation.

The developed HELD can be used in electronic clocks and digital boards in the Metropolitan, airfield complexes, auto-and railway stations, dispatch points, commodity and currency exchanges, banks, hospitals, hotels and technological and production lines.

Electroluminescent display products, prepared by the hybrid technology were presented at the International Exhibitions for Innovation and New Products in Bulgaria, Philippines, USA, Japan and Belgium and were awarded on 2 Silver medals (Sofia - 1996, 1998), 2 Golden medals (Sofia - 1997, Manila - 1998), a cup for successful participation (Pittsburgh - 1999) and 2 Diplomas (Tokyo - 2000, Brussels - 2000).

6. FURTHER STUDY

At the present moment works were going on the possibility a three color (GRB) matrix display to be prepared on the basic of the hybrid technology.

ACKNOWLEDGMENTS

The authors which to express their sincere appreciation to the following institutions and companies: Institute of Solid State Physics - Bulgarian Academy of Science, Group "Color" - Bulgaria, TRAFEL Ltd, ISMA Ltd, SIMED Ltd - Bulgaria. This study could not have been completed, without their generous support.

REFERENCES

1. L. Yourukova, A. Szekeres, K. Kolentsov, and A. Paneva, "Some electrophysical characteristics of AC binder electroluminescent structures with As-S protective films", Phys. Stat. Sol. (a), **130**, pp. 455-461, 1992.
2. K. Kolentsov, L. Yourukova, and A. Rachkova, "Polychromatic electroluminescent element", Bulg. Pat. N 157 Y1, pp. 1-7, 1998.
3. K. Kolentsov, A. Rachkova, L. Yourukova, and V. Pamukchieva, "Preparation and properties of SnO_2 films doped with phosphorus and phosphorus plus fluorine", Proc. SPIE. **2262**, pp. 302-307, 1994.
4. L. Yourukova, K. Kolentsov, A. Rachkov, and V. Minchev, "An investigations of properties an characteristics of AC El structures with protective chalcogenide layers", Univ. Ann. Techn. Phys., **27**, pp. 139-146, 1990.
5. L. Yourukova , K. Kolentsov, T. Kehlibarov, and M. Chalmova, "Characteristics and possibilities of two-color electroluminescent display set-up", Proc. of Intern. Color Conference "BULCOLOR 99", Varna, Bulgaria, pp. 240-246, 1999.
6. K. Kolentsov, and L. Yourukova, "Wide-size digital hybrid electroluminescent display", Compt. rend. Acad. bulg. Sci., **52**, pp. 21-24, 1999.

Image Processing Analysis of Traditional Gestalt Vision Experiments

John J. McCann,* McCann Imaging

ABSTRACT

In the late 19th century, the Gestalt Psychology rebelled against the popular new science of Psychophysics. The Gestalt revolution used many fascinating visual examples to illustrate that the whole is greater than the sum of all the parts. Color constancy was an important example. The physical interpretation of sensations and their quantification by JNDs and Weber fractions were met with innumerable examples in which two "identical" physical stimuli did not look the same. The fact that large changes in the color of the illumination failed to change color appearance in real scenes demanded something more than quantifying the psychophysical response of a single pixel.

The debate continues today with proponents of both physical, pixel-based colorimetry and perceptual, image-based cognitive interpretations. Modern instrumentation has made colorimetric pixel measurement universal. As well, new examples of unconscious inference continue to be reported in the literature.[1]

Image processing provides a new way of analyzing familiar Gestalt displays. Since the pioneering experiments by Fergus Campbell[2] and Land[3], we know that human vision has independent spatial channels and independent color channels. Color matching data from color constancy experiments agrees with spatial comparison analysis.[4] In this analysis, simple spatial processes can explain the different appearances of "identical" stimuli by analyzing the multiresolution spatial properties of their surrounds. Benary's Cross[1], White's Effect[1], the Checkerboard Illusion[4] and the Dungeon Illusion can all be understood by the analysis of their low-spatial-frequency components. Just as with color constancy, these Gestalt images are most simply described by the analysis of spatial components. Simple spatial mechanisms account for the appearance of "identical" stimuli in complex scenes. It does not require complex, cognitive processes to calculate appearances in familiar Gestalt experiments.

Keywords: Gestalt complex images, lightness, contrast, assimilation

1. INTRODUCTION

Gestalt theorists protested against "the 'new' German psychology of the late nineteenth century, the psychology of Wundt, G. E. Muller and Titchner"[6]. One of their principle weapons was the direct comparisons of *identical* stimuli that did not appear the same. In Simultaneous Contrast a gray area surrounded by white has the same reflectance as the gray surrounded by black. The gray in black looks lighter than the gray in white. Equal stimuli do not generate equal appearances. The Gestalt psychologists argued that this was evidence that the *whole* (appearance) was not equal to the *sum of the parts* (reflectance of the gray pixels).

The analysis of these phenomena has been divided into contrast and assimilation. Contrast is the name of the mechanism that makes gray in white look darker. Assimilation is the name of the mechanism that make grays in white look lighter. Contrast is often shown to be correlated with center-surround opponent cells. In other words, the result of simple retinal image processing. Assimilation is often used as an example of the need for complex cognitive image processing capable of discounting the illumination. Recent experiments studying White's Effect, and Adelson's and Logvinenko's 'Diamond Walls'[7] have suggested that coarse image sampling can explain these effect.s[8] This paper analyzes four examples of assimilation in terms of their coarse-sampling by large receptive fields with gaussian spatial responses. Further, this paper discusses contrast experiments testing the role of average surround mechanisms.

2. GAUSSIAN SPATIAL AVERAGES

The first set experiments analyses four assimilation experiments using course sampling of the input image with a gaussian spatial filter. The idea is to calculate the low-spatial-frequency component of the input image by receptor pooling. The assumption is that each output pixel is the integrated response of a large receptive pool with a radially symmetric gaussian shape. All four assimilation targets were analyzed with a series of different size pools. For simplicity, only filters with size 128 and sigma 16 are reported here. Figure 1 (top row) illustrates the calculation. It reads a 128 by 128 window of the input image, multiplies by the spatial filter, sums and normalizes to generate the output pixel value for the center of the window. The process is repeated for all pixels more than 63 pixels from the perimeter. Figure 1a (middle & bottom) and Figure 1b (top and bottom) show input images on the left. They show output images on the right along with the output for all gray pixel inputs. The output average values and standard deviations for these gray input pixels is shown below the output images on the right.

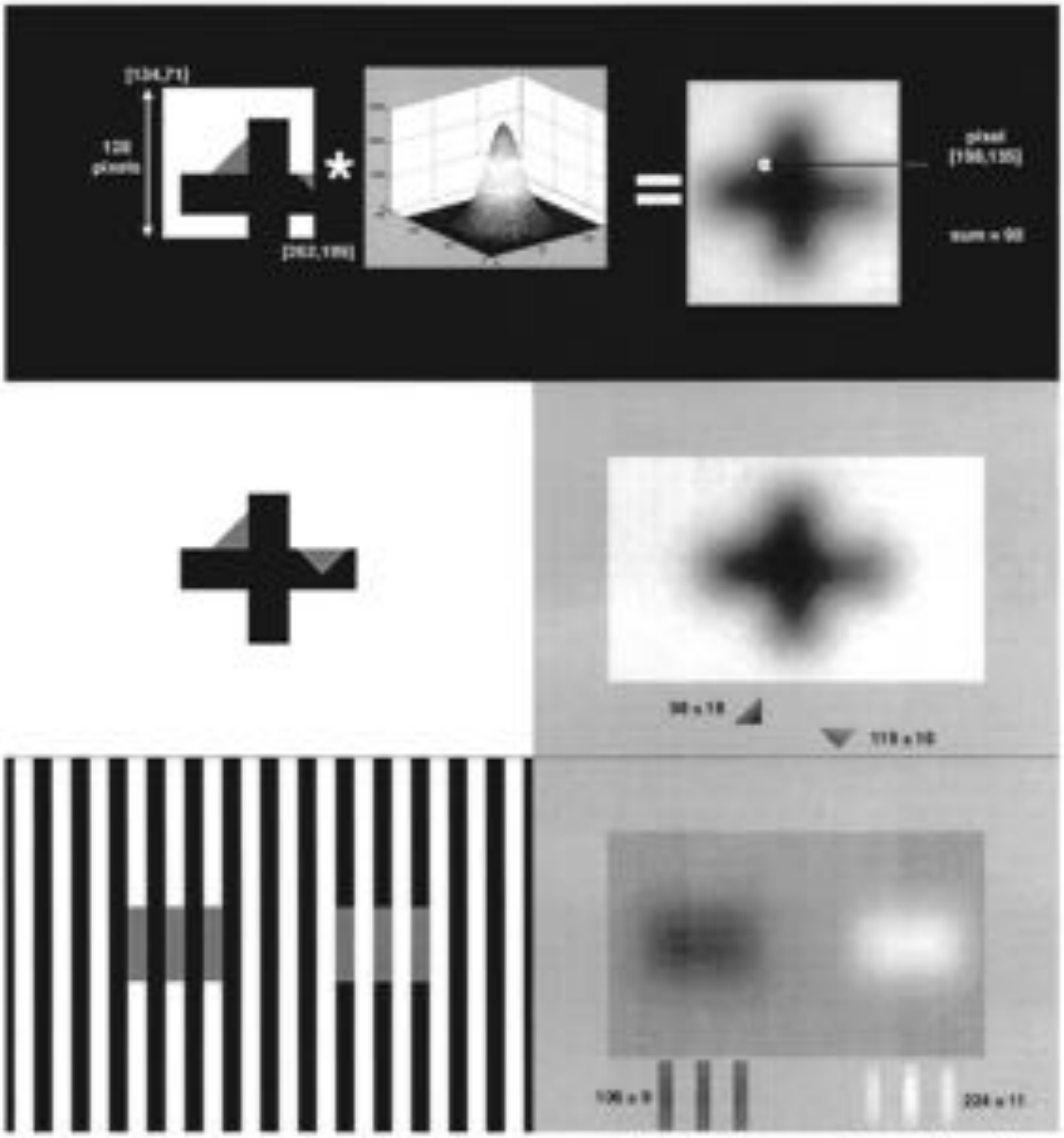


Figure 1a. The coarse sampling analysis of Gestalt experiments. The top row illustrates the process. A gaussian shaped integration filter calculates a pixel-by-pixel coarse spatial average of the original image. The input image has 448 by 320 pixels. It is sampled in a 128 by 128 pixel window. The pixel intensities in the input window are multiplied by the gaussian spatial filter with sigma =16 and size = 128(middle). The normalized sum of all pixels in the window is the output for the pixel in the center of the window. The process is repeated for input pixels that are more than 63 pixels from the outer perimeter, forming a 320 by 192 pixel array. When Figure 1 is viewed at 14 inches the input images subtend 12 by 8.6 degrees and 16 pixels (sigma) equals 26 minutes of arc.

The middle row shows Benary's Cross input image on the left. The right shows the gaussian filtered image. The output values for the equal-input gray areas are shown below. The average intensities for the darker gray triangle is 98, and for the lighter triangle is 119.

The bottom row shows White's Effect input image; the right shows the gaussian filtered image. The average intensities for the darker gray bars is 106, and for the lighter bars is 224.

In all cases the average value on the darker appearing gray patch is lower than the average value of the lighter patch. Similar results have been reported for image scaling techniques instead of gaussian sampling.[19] One does not need invent mechanisms capable of calculating cognitive image maps to explain these assimiliation targets. Receptive pool calculations are all that is necessary. Complex cognitive programs capable of discounting the illuminant can be replaced with receptor pooling.

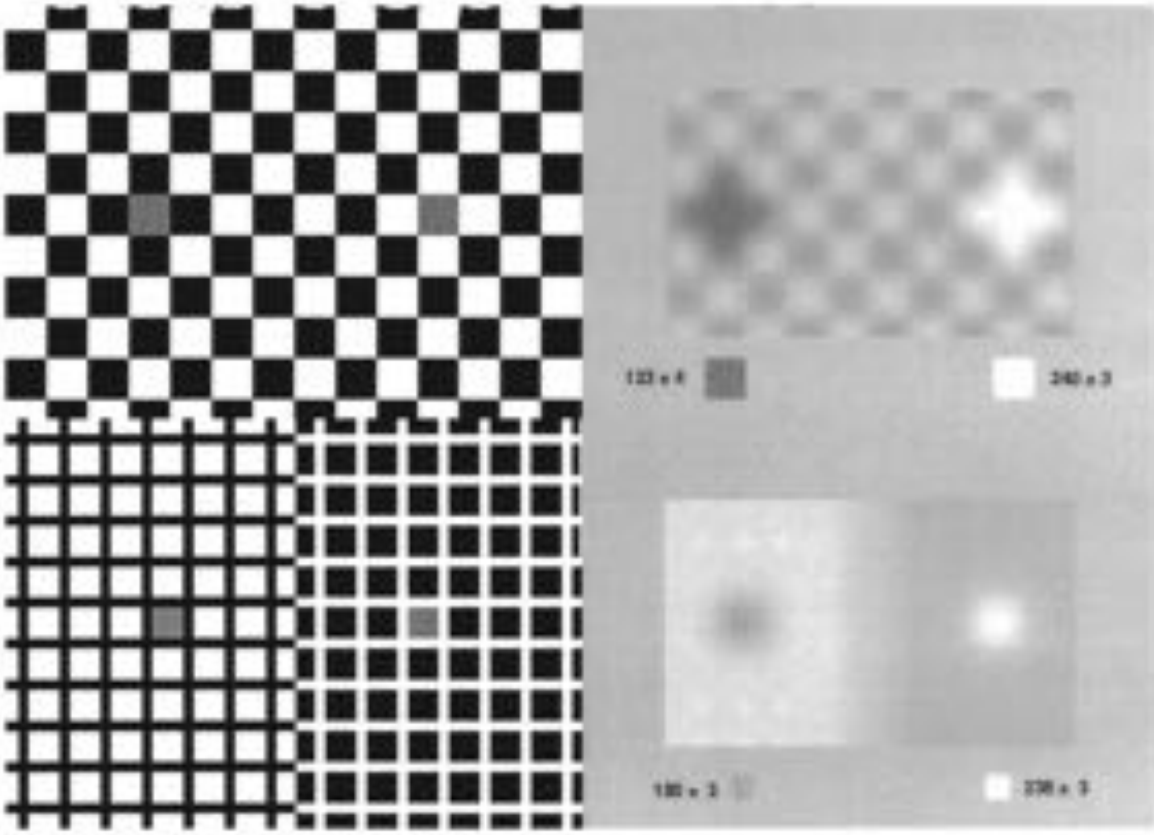


Figure 1b. The top row shows Checkerboard Illusion input on the left. The right shows the gaussian filtered image. The average intensities for the darker gray square is 123, and for the lighter square is 240.

The bottom row shows Dungeon Illusion input; the right half shows the filtered image. The average intensities for the darker gray square is 180, and for the lighter square is 238.

In all cases, The darker appearance on the left side of the input displays corresponded with lower average value. These areas look darker because they have lower average luminances in pooled receptor responses and low-spatial-frequency channels.

3. THE ROLE OF CONTRAST

Although receptor pools can be used as an explanation of these results, they do not provide a comprehensive model of lightness. For this we need to understand how the visual system switches from contrast to assimilation. After that we need to understand how vision combines the reports of different spatial frequency channels.[3] Figure 2 illustrates that contrast is much more complex than the image filtered by center-surround opponent cells. The top row shows that contrast is found in both solid and segmented surrounds. Average surrounds, and hence Barlow and Kuffler [11] cells do not control appearance. The addition of an outer ring of out-of-phase segments reverses the appearance of the grays. This outer surround makes the gray in white look lighter. Contrast has been shut off. Contrast is clearly a much more complex phenomena.

4. CONCLUSIONS

Contrast is the name of the mechanism that makes gray in white appear darker. Assimilation is the name of the mechanism that makes gray in white appear lighter. Gestalt interpretations of assimilation experiments assumed a complex, high-level mechanism capable of discounting the illuminant, or recognizing objects. The calculations shown in Figure 1 show that coarse spatial summation can account for assimilation in four different examples. Experiments by Hecht, Campbell and others have demonstrated the existence of receptor pooling in human vision.

Contrast is often represented as the result of spatially opponent center-surround cells. Barlow and Kuffler first reported such processing in ganglion cells[11]. The examples in Figure 2 demonstrate that contrast is not controlled by the average luminance in the surround, and that the addition of an outer surround stimuli shuts off contrast and allows assimilation.

The complex top-down interpretations of assimilation can be replaced by spatial averages. The simple, opponent interpretations of contrast have to be replaced by complex spatial processing.

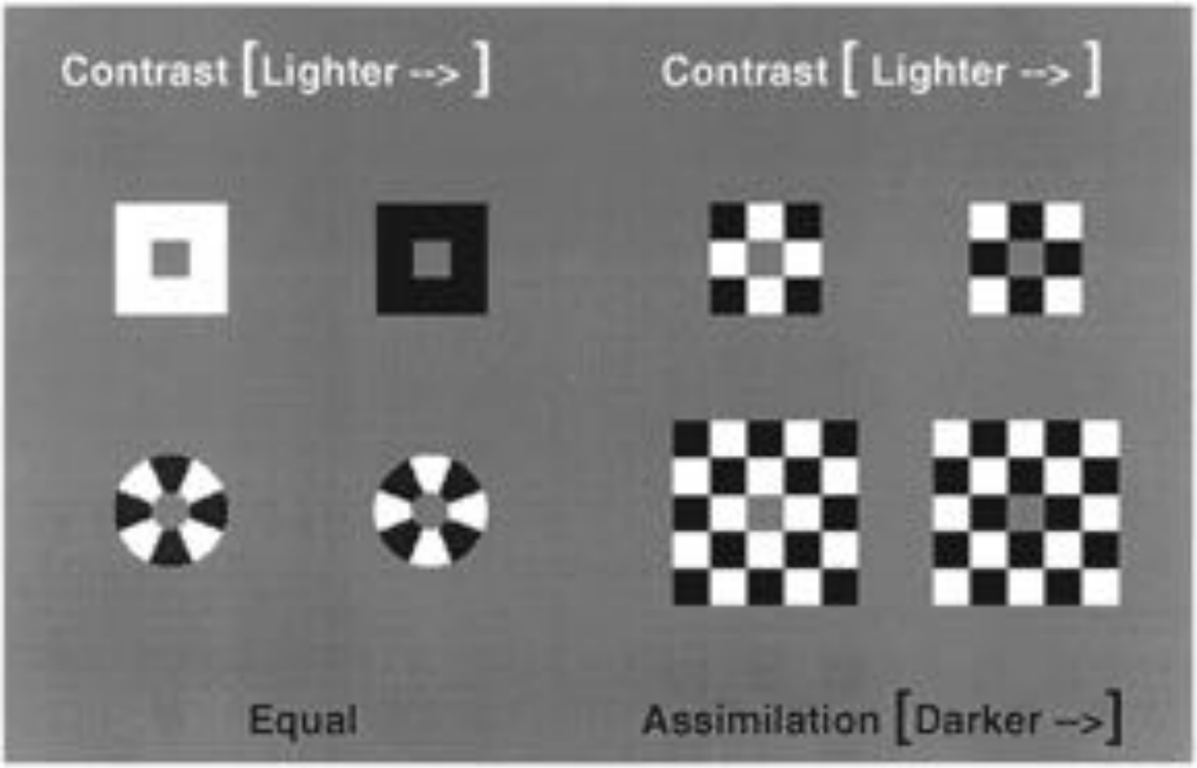


Figure 2. Illustrations of contrast and assimilation using white, black and constant gray luminances. The top left pair of displays illustrates Simultaneous Contrast. The gray in white is darker than gray in black. Segmented surrounds (top right) demonstrate that average surround luminance does not cause contrast. Despite equal averages, contrast persists with half white and half black pixels in the surround segments. Radial segmented surrounds (bottom left) do not exhibit contrast. The addition of an outer surround (bottom right) cancels contrast and introduces assimilation. Now the gray with adjacent white is lighter. In these complex periodic images assimilation is observed because contrast in neutralized.

ACKNOWLEDGMENTS

The author wants to thank Alan Gilchrist, Jack Cowan, Steve Shevell and Mary McCann for very helpful discussions.

REFERENCES

[1] A. D. Logvinenko, "Lightness Induction Revisited", *Perception*, **28**, 803-816, (1999).

[2] O. Braddick, F. W. Campbell and J. Atkinson, "Channels in Vision: Basic Aspects", in *Handbook of Sensory Physiology VII*, R. Held, H. W. Leibowitz and H. Teuber, Springer-Verlag, Berlin, 3-38, (1978).

[3] E. H. Land and J. J. McCann, "Lightness and Retinex Theory", *J. Opt. Soc. Am.*, **61**, 1-11 (1971).

[4] J. J. McCann, S. McKee, and T. Taylor, "Quantitative studies in Retinex theory : A comparison between theoretical predictions and observer responses to 'Color Mondrian' experiments," *Vision Res.* **16**, 445-458 (1976).

[5] W. Benary, "The influence of Form on Brightness", in *A Source Book of Gestalt Psychology*, W, Ellis trans. Kegan, Paul, Trench, Truber & Co. Ltd., London, 104-108, (1950).

[6] M. White, "A new effect of pattern lightness", *Perception*, **8**, 413-416, (1979).

[7] R. L. DeValois and K. K. DeValois, *Spatial Vision*, Oxford University Press, New York, (1988).

[8] E. Boring, "*History of Experimental Psychology*, p. 587, Appleton Century Croft, p. 229,(1957).

[9] J. J. McCann, "Calculating The Lightness Of Areas In A Single Plane", *J. Electron. Imaging*, **10**, pp. 110-122, (2001).

[10] J. J. McCann, "Gestalt Vision Experiments from an Image Processing Perspective", *Proc. IS&T PICS*, Montreal, **4**, pp. 9-14, (2001).

[11] H. Barlow, "Summation and inhibition in the frog's retina", *J. Physiol.* **119**, 69-88, (1953); S. W, Kuffler, "Discharge patterns and functional organization of mammalian retina", *J. Neurophysiol.* **16**, 37-68, (1953).

---

*Correspondence: mccanns@tiac.net, phone 1-617-484-7865; fax 1-617-484-7865; McCann Imaging, 161 Claflin Street, Belmont MA 02478, USA.

TO QUESTION ABOUT THEORY CHROMATIC LIGHT PAINT

Engineer Vozchikov, Lev *

When we give name to color, we usually describe our perception of light, as compared with our own experience and knowledge. Very often perception of color is a complex problem that needs to be described by mathematical, physiological, and physical theories. There is a clear description for the physical task of describing quantities for mixing color pigments. In this article, the author discussed original graphical decision for color equations: the color surface for natural mixtures.

Light mixing theories describe the nature of color, originally in mathematical language of the physical principles for color mixing different substances. Color-mixing system were originally developed based on the three-component chromatic model, which tells us how color works in nature and how color mixing works with pigments. Color theory was developed to show how color pigment structures could be measured. In this article, an algebraic system is shown consisting of mathematical equations, given the surface of color mixing, gives measurement principles of color characteristics by the two quantities. This mathematical system has shown by graphical decision color mixing the nature of the physical 3-component vision. The original model of mixing equally well provides the numerical identification for color mixtures of two or three components pigments.

Clear descriptions of colors on the color surface show the different characteristics of color, and the value that these colors have in light mixing as estimated by the vision perception system. Color surface is very important as a practical conception for understanding the quantitative description of color measurement technology.

The color surface as a graphical model is mathematically necessary to describe the mixing color components of pigments, lights, and substrates. Each single color is positioned as a sum of several primary colors and can be applied in the separate physical task of measuring color, to reproduce color by technology.

Color as the physical characteristic of a substance has the practical meaning in every day practice to guide through many types of color variations. Clear understanding and interpretation of color values is consist with the mathematical equations for color components, reproducing the white light absorption, reflection by the substances with regular color chemical structure, and describing substances such as solid, gases, liquids, organic, inorganic. In this article, an evaluation of the spread of chemical pigment components in growth process plants is demonstrated. We also studied seasonal fluctuations of organic pigment components with the example of ripeness for maturing fruits. We have discussed color structure spreading for toxic smoke, with visualization of the concentration of toxic substances in an open-air environment.

Application of color surface for color digital measurement is practical in cases for color pigments spreading of chemical structures. This article has shown research result in organic fruit specimens, Sorby "rowanberry," a well-known medical plant, and specimens of toxic smoke. Color studies are necessary to get the quantitative description pigment structure in original specimens, technical identification color pigments. Color surface has important meaning for the physical perception of world.

INTRODUCTION, PHISICS TASK

Theory of chromatic light paint use well known seven chromatic tones as easy given visually perception the naturally colors: red, orange, yellow, green, sky, blue, violent. Three addends additive mixture model naturally colors or for another words any nature color shade is possible modeling by mixture of the additive chromatic addends. Let write down conditions of the chromatic light paint by using system algebraic equations. System solution represents chromatic addends mixture: if is known brightness of the falling white light E, light up elementary chromatic ground. Weights mix of chromatic paints addends for example the elementary ground chromatic cluster, is define brightness of the chromatic reflected addends e (x), e (y), e (z) light from the elementary chromatic ground. Breaking the chromatic image on the constant chromatic clusters is giving us a cluster structure of the chromatic image. Each elementary pigment chromatic addend quantitatively define brightness of reflected light proportionally density dyes in additive sum of elementary chromatic cluster. Brightness reflected light by the chromatic cluster is defined by the additive sum brightness of chromatic addends. Additive sum reflected or absorbed light of elementary addends proportionally brightness of falling white light. Three conditions of chromatic paint light mix mathematically should be express in the form of system algebraic equations 1,2,3:

$$E = \frac{e(x)}{X} = \frac{e(y)}{Y} = \frac{e(z)}{Z} \qquad 1$$

$$E(000) = e(x) + e(y) + e(z) \qquad 2$$

$$X + Y + Z = E(000) / E \qquad 3$$

X, Y, Z – is the coefficients of reflection (absorption) chromatic **x, y, z** addends, density dyes [gm / sm²]. **E (000)** - brightness has reflected (absorption) light by the additive mix of pigments, **e(x), e(y), e(z)** - brightness of reflection (absorption) light chromatic additive addends, E- brightness of falling white light on the elementary chromatic cluster.

Let formulate physic paints principles expressed by the mathematically equation 1,2,3 for white light absorbed by the pigment cluster or reflected by the pigment cluster in any color cluster structure image.

Equal chromatic pigments density values define equal weakening of the falling white light.

Brightness of single chromatic cluster is defined by the additive sum brightness chromatic addends.

Weakening of brightness falling white light is defined by the additive sum of the densities chromatic pigments addends.

Quantitative meaning density pigments chromatic addends for each single cluster has expressed by driving equations 1,2,3 to algebraic system equations of addends pigments.

EXPERIMENT, MATHEMATICAL PROCEDURES

By using common solution system 1, 2, 3 we can now write down form of system algebraic equations 4, 5, 6, to express unknown quantities pigments through light brightness.

$$X = \frac{Y \cdot e(x)}{e(y)+e(z)} + \frac{Z \cdot e(x)}{e(y)+e(z)} \qquad 4$$

$$Y = \frac{X \cdot e(y)}{e(x)+e(z)} + \frac{Z \cdot e(y)}{e(x)+e(z)} \qquad 5$$

$$Z = \frac{X \cdot e(z)}{e(x)+e(y)} + \frac{Y \cdot e(z)}{e(x)+e(y)} \qquad 6$$

By expression coefficients a, b, c algebraic system equations replace 4,5,6 to the 7,8,9:

$$a = \frac{e(x)}{e(y) + e(z)} \qquad 7$$

$$b = \frac{e(y)}{e(x) + e(z)} \qquad 8$$

$$c = \frac{e(z)}{e(x) + e(y)} \qquad 9$$

Searching solution will be in the form of system algebraic equations 10,11,12:

$$-X + a \cdot Y + a = 0 \qquad 10$$

$$b \cdot X - Y + b = 0 \qquad 11$$

$$c \cdot X + a \cdot Y - Z = 0 \qquad 12$$

Meaning Y =1 identify system of equations 10, 11, 12, quantity meanings of additive chromatic paints addends is expressed in form of numeral graphic solution system algebraic equations 13, 14, 15:

$$X = a \cdot (1+c) / (1-a+c) \qquad 13$$

$$Y = 1 \qquad 14$$

$$Z = c \cdot (a+1) / (1-a \cdot c) \qquad 15$$

Further to express graphic solution of system equations 1,2,3 through coefficients a, b, c builds the surface of color mixture:

$$E(000) / E = (a+1) \cdot (c+1) / (1 - a \cdot c) \qquad 16$$

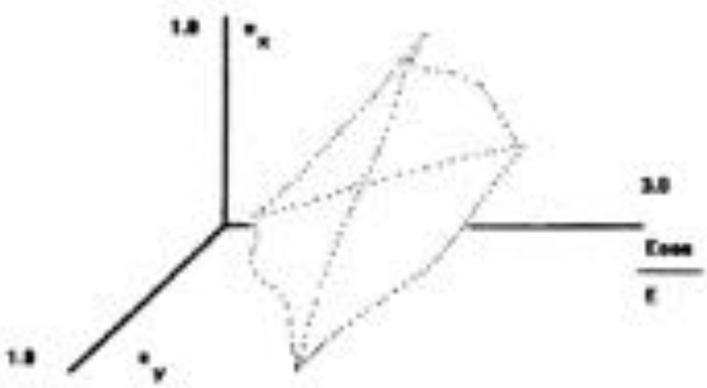


Fig.1 The chromatic surface.

RESULT, DISCUSS WORK RESULT

Graphic solution system algebraic equations chromatic light paint represent on figure 1 by the surface of chromatic mix, with typical lines and points of color mixture.

Equal Ch – line chromatic, Chromos (Greco.)- Color, Equal Ph – line brightness, Photos (Greco)- brightness. In common:

$$e(x) + e(z) = Ph \qquad 17$$

$$e(x) / e(z) = Ch \qquad 18$$

Ph, Ch – constants

Defined above common equations 17, 18 in general coordinate, numerically determined by the lines of equal chromatic numbers and equal brightness, possible quantities measurements result for each single chromatic mixture on the surface of chromatic mix.

Chromatic number Ch is weight level of chromatic mix, proportionally to the pair of nearest left and right chromatic addends. Brightness chromatic mix is equal sum brightness here addends components. Surface of chromatic mix to right for each over pair chromatic natural is chromatic cluster.

Components of chromatic mixture doesn't percept by the observer apart in mix quantitatively determine naught chromatic number natural color mix, nearest to left and to right colors in decomposition of white light specter. Typical lines and points surface chromatic mix, get to section E (000)/E.

On the Fig.1 – surface of chromatic mix, appear as additive sum weight chromatic mix natural decomposition white light in spectrum. Each single chromatic mixture is presented by the chromatic number, sum brightness color additive addends.

CONCLUSIONS

Calculation quality logarithm reception light in common coordinates, to write expressions 17, 18:

$\ln(e(x)+e(z))=\ln Ph$ 19

$\ln(e(x)) - \ln(e(z))=\ln Ch$ 20

Chromatic number to equal quantities chromatic measure weight mix pair chromatic addends. On the show graphically solution equation 19, 20, just to any chromatic natural mixtures. Brightness of weightily chromatic mix, if $C=\ln Ch=0$ (chromo) define on the interval $0<\ln Ph<1$.

Determine bright, to assuming that $Ph = const = p$ chromatic number will be find with help graphical solution:

$e(x)=a,\ e(z)=b$

$\ln(a+b) = \ln Ph = P$ 21

$\ln a - \ln b = \ln Ch = C$ 22

When $a = Ph-b$

$\ln(Ph-b) - \ln b = \ln c$ 23

Further $b = Ph - a$

$\ln a - \ln(ph - a) = \ln c$ 24

Chromatics number weight mix $C=\ln Ch$ [chromo], if $p=const=100$, then domain existence

C: $-\ln Ch < C < \ln Ch$; $0<b<100$, $0<a<100$.

COLOR WORKS

Chromatic clusters structure of color smoke is responsible for the detection toxic concentration gas emission of the smoke free environment. Optical absorption of the gas particulate matter is helping us to estimate the quantities spreading in the chromatic smoke structure. The numerical histogram mono color scale of the smoke sample image measures a gas toxic concentration. Fig. 2: visualization clusters smoke color structure in the image sample. Gray color image of toxic smoke. Fig. 3: numerical estimation of the gas toxic concentration. Histogram show spreading colors pigments by the gas specimen image. Toxic concentration of the smoke particulate matter estimate by the color histogram analyzing in this specimen is below 60%.

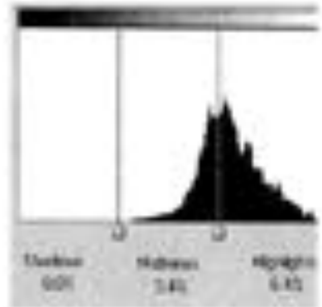


Fig.2 Fig. 3

Numerical descriptions of the color mixture give to us the way of the nature studies. Estimation of chromatic cluster mixture clear descripts the growth process for example fruits Sorby. Purple and yellow pigments in the addends structure, evaluates from orange to the general mature red color of the rowanberry fruits with fluctuations of quantitative by the season, specimens, sorts, medical and food matures grades. Fig. 4: dx / dt is the concentration of cyan, dy / dt is the concentration of carotene. Fluctuations of the pigments components cyan, carotene: fruits rowanberry maturation 6 weeks process.

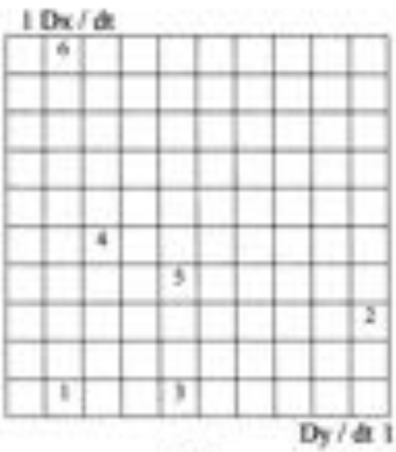


Fig.4

REFERENCES

1.Vozchikov, Lev, The way of transfer image USSR patent 1822997, 12 October 1992.
2.Vozchikov, Lev, The way of color number measure pre patent ROSSPATENT, 1991, 4871080.
3.Vozchikov, Lev, To question about chromatic theory light recorder-transfer color picture, 1993, AIC93, Hungary, Budapest, P20-1.

* e Mail : lvselena@aol.com, laboratory Selena, telephone : 2036029958, 198 Ocean Dr East, Stamford, CT 06902, Greenwich Bus Co., Stamford, CT.

Even color triangle

Avery S. Zoch * Atlas Distributions

ABSTRACT

We construct a class of infinite planer simple graphs[1] that are continua and have the fractal property [2] where the faces of their regions are either triangles or nonconvex pentagons. We choose to embed them in Euclidean two space or plane with the natural product topology which makes them normal topologically[3]. Any one of these continua is sufficient to exhibit all the color or hue names and arities of formation that are created by mixing two primary color units of any chroma or value at proportions that are equal. We call our continuum the Even Proportional Color Triangle (EPCT) and prove that it is a continuum. Functions are made between an infinite discrete proper subset of one EPCT and a set of polynomials to represent the hue names and the set of natural numbers to represent primary, binary, ... color units or color arity given by mixing color units. We formulate MacAdam Hue Limit Theorem (MHLT) which represents the first formal mathematical statement of an observed property of color mixture, which is a panoptic theoretic interpretation of a theorem from real analysis. EPCT can be used to define other continua and it has important properties of dimension theory[4] and yields lemmas and corollaries.

Keywords: color, mixture, continuum, sequences, lattices, functions, algebra, graphs, chromatic, hue

1. INTRODUCTION

Abstract mathematics has played a central role in our modern understandings of the complex technological symbolism that surrounds us from the advent of computers.
The vehicle of logical formulation through atoms and statements to produce axioms allows us to model many complex events[5]. Even such logical models are restricted by statements that have no solution over any time because of the language or alphabet used to formulate them [6] and language itself can effect physical reality [7]. Every language as we know them which is properly inclusive in a universe or model may not describe the universe itself completely. The structure of description limits what may be described. The complete function of a universe may not be comprehended by any single or complex part of itself. Therefore not every aspect of color and observation may be modeled by any single or combined area of mathematics, science or philosophy, as we know them. This does not imply the nonexistence of a fully comprehensive universal schemata or language independent from the axioms and geometric simplifications which have proven themselves incomplete. As we found mathematics in the areas of philosophy and language we find the study of color phenomena in the areas of property, observer, and light.
Some symbolism of colors and their mixtures can be comprehended in the context of abstract mathematics and computers where it can relate to physical, chemical, and biological processes.
There are combinations of abstract and applied mathematics that can encompass many existing theories of color observation[8] and support accurate formulation of a theory of properties and observer used to understand and illustrate mixtures and sets such as those which result from mixing of colors.

It is proven that the spaces representing partitive mixing of two distinct colors at equal proportions can be represented by planer graphs and bounded by embedding them into a planer simple triangular-pentagonal infinite graph [1] and continuum [3] which is bounded by the areas of two triangles.
Not every partitive color mixture is at even proportions and chromatic and we can find geometric anomalies for the cases which are not at even proportions by construction of topological Euclidean color spaces that are not planar[9]. It has been demonstrated that a comprehensive model of color space is non-Euclidean [10] and our model will only consider hue or color names and arities of formation (primary, binary, etc...) from additive or subtractive mixing of two color units at a given constant chroma or saturation and value.

The mixing of color primary units at proportions of ½ or proportions that are equal will encompass all the mixing of color units at proportion of 1/n where n is an even natural number greater than two. It is suggested that there exists an underlying undiscovered meta-symbolic non Euclidean geometry and an unordered predicate calculus to describe new relations given from the freeness of categories, the discrete nature of mixtures and physical quantities, and simplifications of their atypical expressions.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

The algorithms defined in the article EPCT can be input as heuristics for conjecture making artificial intelligence computer programs such as graffiti created by S. Fajtlowicz and there are an infinite number of graphs that result from the finite cases of constructions to use in their database as examples over polynomial time.

2. COLOR AND MIXTURE

The ways we might combine or subtract amounts of units for given resources or elements to create a new unit as a product is of great physical and economic interest.

The consideration of additive, subtractive or imaginary color mixtures has been the generator of many color order systems that help us understand many properties of colors and light [8].

Paul Erdos was concerned with many interesting statements of number theory and the famous "Does NP=P ?" question [10] and first demonstrated a direct proof for a statement of polygons using colorations of graphs with the mathematician Szekeres .

When we want to mix amounts of color object units or primaries to produce new color object units we call it a mixture in parts or a partitive mixture. It is with the generality and symbolic properties of abstract mathematics that we may catalogue all of the uncountably infinite color names and comprehend their geometries [12]. We use the following Schema for Partitive Mixtures (SPM) [13] to define our color units for mixture.

Any singular unit of an object called O that can be considered as a mixture in parts of a natural number n of unit resources can be represented by a real polynomial $a_1X_1 + a_2X_2 + \dots + a_nX_n = O$ where each free X_i for i=1,2,...,n represents one unit of resource i and each fixed real a_i , where they are not all zero, represents the amount or deficit of unit of resource i used to create the unit of object O and $a_1 + a_2 + \dots + a_n = 1$.

We create units that are products as real mixtures. We assume this product space to be discrete and existing so that we are given a continuous function by the lemma of Paul Urysohn [3] from such space that is topologically normal to the closed unit interval with the natural topology. The properties of mixtures reveal themselves like a code when we apply a formulation of topology, functions , and algebra. Such application of pure mathematics also creates many interesting questions in decision theory, probability theory, number theory, graph theory, category theory, universal algebras, genetics ,chemistry , and physics.

Any equal mixture of two primary objects or colors produces a unique binary color or object.

3. ELEMENT PROPERTY AND OBSERVER

In graph theory when we choose to assign a relation between colors and objects it is true that if the relation is not formed correctly it will not be a function by lacking the property mathematicians call well defined [14]. We can overcome this problem by defining the relation from color to object instead of object to color as is done properly in [1]. If the collection of objects are singletons or they are mutually exclusive then we may take a relation from these objects to distinct colors.

To ensure that our applications of mathematics to a theory of color will produce the most accurate applications we must consider that color is an observed property that depends on conditions of observation, time and varied abilities of the observer. The number of standard observers with specific abilities of observation over any time and standard conditions is also a factor to consider .

As we know the events that are not observed must remain in a state of flux for given time for some observers from the principle of Schrodinger's black box [15].

The Heisenberg uncertainty principle tells us that the degree of accuracy derived by observing any single objects property is inversely related to the degree of accuracy which may be derived by observing any other property of this object for a given standard observer during the same time [16]. Concepts such as these are the basis for careful considerations of the relative nature of observer, subject, and property.

4. CONSTRUCTION OF THE TRIANGLE CONTINUUM

The continua that may be defined by the mathematical formulae in EPCT defines a class of continua that are free in the categorical sense[17]. It is a class of continua because there exits an infinite number of triangles with the lengths of their sides are not equal. EPCT is the mutually inclusive union of two Triangle Continua that are made by mathematical construction.
Two consequential arc like continua are defined from EPCT with interesting properties of span as defined by the topologist A. Lelek.
It is proven that the EPCT is a continuum with a case of the Jordan Polygonal Theorem ** for triangles and theorems of point-set Topology one of which states that for normal space any closed and bounded subset of it is normal.

EPCT contains a homeomorphic copy of the triodic Cantor set, which can be exhibited for certain, orientations in a plane with an origin and has the fractal property[18].
The curve de vonKoch [18] is a deformation retract of EPCT and computer programs exist that describe EPCT written in Pascal, FORTRAN, and C++ developed by Atlas Distributions as its trademark.

The smallest number of distinct color units required to assign to every region of an EPCT embedded in a real plane where any two regions which share a boundary arc are assigned distinct color units is two for the infinite case and three for the finite cases of construction. Any EPCT embedded in the plane with the natural product topology is a continuum or compact connected metric space[3].

5. COLOR THEORETIC

We construct collections of polynomials that represent every hue name of color units that are observed as a consequence of additive or subtractive color mixture using SPM and we have that they are infinite in number[13].
We define a binary operation between these hue name polynomials which is algebraically closed.
The set of all vertices of triangles in the EPCT is taken with the axiom of choice[4] and two relations are taken between this set of vertices and the color hue name polynomials or color units called the color identifier and the set of natural numbers called the arity identifier. These relations are functions and relate EPCT to additive color mixture at equal proportions and exhibit revealing geometries based on the arities of formation that follow from such mixtures. The relations that are made can be deduced as functions with the Real Color Closure Theorem[12] properties of real addition, multiplication, and polynomials.

We formulate the MacAdam Hue Limit Theorem of existence for convergent sequences of hue name polynomials which converge to a given color name polynomial[17] as a limit for coefficients of the sequential color name polynomials as follows.

Given any $K \in \Psi_C^*$ and $\eta > 1$ where $K = \sum_{i=1}^{\eta} b_i C_i$ so that $1 = \sum_{i=1}^{\eta} b_i$ then there exists a sequence of color units $\{\omega_j\}_{j=1}^{\infty}$ with for all j>0 we have $\omega_j = \sum_{i=1}^{\eta} a_i^j C_i$ and $1 = \sum_{i=1}^{\eta} a_i^j$ which implies $\omega_j \in \Psi_C^*$ and for all $0 < i \le \eta$ we have $\lim_{j \to \infty} a_i^j = b_i$ and $\{a_i^j\}_{j=1}^{\infty}$ is a real valued sequence for every j>0 .

We write $\overset{h}{\lim_{j \to \infty}} \omega_j = K$ if and only if $\lim_{j \to \infty} a_i^j = b_i$ for all $0 < i \le \eta$ and $\lim_{j \to \infty}$ is the limit of a real valued sequence[2].

And say the color K is the hue limit of the colors ω_j or the hue names of the colors ω_j converge to the hue of the color K .

The set $\overset{\eta}{C}$ is called the Chromatic Primary Color Pallet of η color units.

The set $\Psi_{\overset{\eta}{C}}$ is called the distinct partitive color mixtures for constant chroma and value. The elements of $\Psi_{\overset{\eta}{C}}$ are called hue names and exist from SPM. MHLT can be proven by using Cauchy sequences from real analysis, the properties of the polynomials that we construct to represent hue names of colors, and the completeness of the unit interval with the natural topology, which is normal.

We formulate and prove the corollary Euclidean Convergence of Hue Name to Pure Primary Color, which is a case of MHLT that concerns statements between Euclidean distances of points in the EPCT and convergence of hue name given with the color identifier function. This demonstrates a nontrivial sequence existing by MHLT contained in the image of the color identifier function.

The lemma of Isosceles Geometries of Even Color Space is stated and demonstrates distances of points and containment of line segments for particular geometric requirements in a case of EPCT.

The arities of formation that follow from partitive mixtures are connected by line segments, which may be considered as edges of graphs or lattices [19]. Black holes and other physical events may be understood by using models based on the inverses of the elements of the image of the arity function [16].

ACKNOWLEDGMENTS

Great thanks to my teachers, which include Richard Sinkhorn, Andrew Lelek, and Dennison Brown.

REFERENCES

1. F. Harary, *Graph Theory*, Addison-Wesley Publishing Company, Inc., Philippines, 1969.
2. H. L. Royden, *Real Analysis*, Macmillan Publishing Company, New York, 1988.
3. F.H. Croom, *Principles of Topology*, Saunders College Publishing, a division of Holt, Rinehart, and Winston, Orlando, Florida, 1989.
4. P. Alexandroff, H. Hopf, *Topologie*, Springer, Berlin, 1935.
5. J. W. Lloyd, *Foundations of Logic Programming*, Springer-Verlag, Berlin, 1987.
6. K. Hrbacek, T. Jech, *Introduction to Set Theory*, Marcel Dekker, Inc., New York, 1984.
7. E. Finegan, N. Besnier, *Language its Structure and Use*, Harcourt Brace Jovanovich Publishers, San Diego, 1989.
8. Billmeyer, Saltzman, *Principles of Color Technology*, John Wiley and Sons, Inc., New York, 2000.
9. A. Zoch, "Pascal's Grey Scale", *Atlas Distributions*, v.I, Houston, 1997
10. G.A. Agoston, *Color Theory and Its Application in Art and Design*, Springer-Verlag Berlin Heidelberg, Germany, 1979 and 1987.
11. M. Sudan, "Probabilistic Verification of Proofs", *Documenta Mathematica*, A. Louis, U. Rehmann, P. Schneider, v.III, p.461-470, Geronimo GmbH, Rosenheim, 1998.
12. Zoch, "Total Rational Partitive Color Mixture Continua and Triangles", *Atlas Distributions*, v.I, Houston, 1998.
13. Zoch," Natural Coloration of Graphs", *24th Session of the C.I.E. Proceedings*, M. Konopka, v.I partI, p.195-198, CIE Central Bureau, Vienna, 1999.
14. R. C. Buck, *Advanced Calculus*, McGraw-Hill, Inc., U.S.A., 1978.
15. F. Stevens, *The Six Core Theories of Modern Physics*, The MIT Press, Cambridge, 1995.
16. C. Blanchard, C. Burnett, R. Stoner, R. Weber, *Introduction to Modern Physics*, Prentice-Hall, INC., Englewood Cliffs, 1969.
17. T.W. Hungerford, *Algebra*, Springer-Verlag New York Inc., New York, 1974.
18. H. A.Lauwerier, *Fractals-Endlessly Repeated Geometrical Figures*, Princeton University Press, New Jersey, 1991.
19. B. A. Davey, H. A.Priestley, *Introduction to Lattices and Order*, Cambridge University Press, Great Britain, 1990.

* averyzoch@yahoo.com ; phone 409-741-0866; Atlas Distributions, POBOX 16175, Galveston, Texas, USA 77552
** www. elib.zib.de International Congress of Mathematicians (ICM98), "The Jordan Polygonal Theorem", A. Zoch.

Comparative study in Japan and China concerning aspiration of Asian women towards quality of skin fairness

Miho Saito [*a], Junko Matsumoto [**b], Akira Date [**b], Junfang Li [**b]
[a] Waseda University, School of Human Sciences,
[b] Procter & Gamble Far East, Inc., Kobe Technical Center

ABSTRACT

Beauty is a world common aspiration, but perceptions of what make a woman beautiful vary across cultures and countries. A series of Saito's studies indicated that unlike much of the Western world, in Asia, one common desire is fairer skin tone that epitomizes feminine beauty. Using 105 Japanese women and 105 Chinese women as subjects, a comparative study concerning aspiration of Asian Women toward skin fairness was conducted. In this study, four real skin photo images that have skin tone variations (fair/dark) and skin texture variations (rough/smooth) were used. The fifty-two words describe personality were shown to the subject. The subjects were required to match a suitable skin photo image to the descriptive words. The overall result between China and Japan were very consistent. Both in China and Japan, fairer skin tone with smoother skin texture was accepted very positively. Fairer skin tone with rougher texture tends to provide passive and conservative impression while smoother skin texture with darker skin tone tends to provide friendly and delight impression. The results suggested that in addition to skin tone, the skin texture plays an important role for the personal impressions and it works as a trigger to enhance "ideal skin fairness" for Asian women.

Keywords: preference, color, cross-culture, skin tone, skin texture, personal impression, Asian women, factor analysis, whitening product

1. INTRODUCTION

From the ancient times, women have been seeking beauty as a common aspiration and taking care of facial skin to achieve beauty as well as to provide an ideal first impression. In western countries, suntanned skin has been accepted as in fashion since it projects healthy feeling as well as connoting gorgeous vacation on the beach. On the other hand, Asian women have their unique common desire to facial skin as "fairer skin tone". Actually in Asia, about 75% women aspire to have fairer skin tone than they have now. For the skin care product market, whitening products represent about 25% of total market and continuing to expand. To understand this Asian unique aspiration to "ideal skin fairness", a series of psychological studies regarding as skin tone and impression have been conducted in Asia.

2. BACKGROUND AND RELATED STUDIES

The studies conducted by Saito (1981, 1992a, 1992b,1994,1996b, 1996c) among several cultures showed that several factors; geographical region, sex, and age contributed to color preference. In the studies, Saito suggested that preference for white was a common trend in Asia (Japan, Korea, China, Taiwan, and Indonesia) that was very different from other cultural groups; Americans, Germans, Danes, and Australians. In studies of cultural anthropology, white represents "nobility", "mystery" or "secrecy" in Asia. With such unique and specific value built up over time, white is assumed to appeal to Asian women. Since it was assumed that focusing on skin tone provides more insight into specific cultural aspects, Saito conducted a cross-cultural study on preference of skin tone in Indonesia and Japan [7]. In this study, four color charts were used as stimulus, which were in the range of average skin tone of Asian people. The 52 words that describe personality were shown to match a suitable color chart. The study indicated that both Japanese and Indonesians preferred somewhat fairer skin tone irrespective of gender. As to what skin tone they think most "beautiful", Japanese chose "fair" skin tone while Indonesian chose "somewhat fair" skin tone. Fair skin tone gave the impression of weakness both in Japan and Indonesia followed by several sophisticated impressions; noble, delicate, quiet, clean. However in Japan, "gentle," "passive, "feminine" "polite" words were chosen to represent fair skin tone while in Indonesia, "haughty", "vivid", "characteristic", "stylish", "immature" "frivolity" words were chosen to represent fair skin tone. Differences in liking for skin tone by gender were obvious in choosing a "somewhat dark" skin tone. Both Japanese men and Indonesian men gave a negative evaluation to "somewhat dark" skin tone, checking "poor looking", "insistent" "frivolous" "old" or "superficial". Instead,

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

women rated that color as "neat", "smart", "brisk", "cheerful" or "friendly". The reason of this Asian unique value on fairer skin tone would be because of uniqueness from fair skin tone including aristocratic, noble, weakly and frail impressions in Asia. However, since facial impression is affected not only by the skin tone but also by its texture, further study was conducted to understand the impact of skin tone and texture as well as to understand cross-cultural differences between China and Japan. The preliminary study reported by Saito in 2000 AIC Soul meeting suggested that skin conditions as well as skin tone have an effect on the personal impressions. *

3. OBJECTIVE

To further understand the impact of skin tone and skin texture on personal impressions in Japan and China, a quantitative cross-cultural study was conducted using real photo images as stimulus that have skin tone variations (dark/fair) and skin texture variations (rough/smooth).

4. METHOD AND MATERIALS

Subjects

A total of 105 Chinese women aged 20-49 (35 subjects in their 20's, 35 subjects in their 30's, 35 subjects in their 40's) living in Beijing.

A total of 105 Japanese women aged 20-49 (35 subjects in their 20's, 35 subjects in their 30's, 35 subjects in their 40's) living in Tokyo.

Stimulus

The stimulus were four "photo images of actual skin" with skin tone variations (darker /fairer) and skin texture variations (rough/smooth).

Procedures

52 phrases that describe personality were prepared. The subjects were asked to pick one photo image that best explained the descriptive phrase from the four photo images.

The results were analyzed by 1) Fisher's exact test to test for difference between four visuals and 2) by factor analysis.

5. RESULTS

5. 1 Comparison by rank order

Table 1 shows the ranking of words for each visual in China, Table 2 shows the ranking of words for each visual in Japan. For Visual A (Fair /Smooth), Chinese and Japanese had some positive common impressions that were explained by "beautiful"($p<.01$), "clean"($p<.01$), "likable"($p<.01$), "aristocratic"($p<.01$), "stylish"($p<.01$), "attractive"($p<.01$), and "elegant" ($p<.01$). However in China, "eye-catching"($p<.01$) and "modern"($p<.01$) were also highly chosen for Visual A, while in Japan, "cultivated"($p<.01$) and "polite"($p<.01$) were highly chosen. Fairer and smoother skin seemed to provide beautiful and active impression in China while beautiful but passive impression in Japan.

For Visual B (Fair/Rough), Chinese and Japanese commonly chose "hypocritical", "conservative", "self-possession", "intelligent", "resolute" and "crisply". However, "strong-willed", "looks tired" were highly chosen to explain Visual B in China while "serious", "weakly", "passive" were highly chosen in Japan.

For Visual C, the friendly and delight impressions such as "characteristics", "merry", "delighted", "good person" and "warm" were highly chosen both in China and Japan. Focusing on the difference, "eye-catching", "immature", "healthy", "vivid" were chosen within top 10 ranking to explain Visual C in Japan, while these wordings were chosen within top 20 ranking to explain Visual A in China. The words chosen for Visual D (Dark/ Rough) in China and Japan were very consistent and very negative, such as "old"($p<.01$), "slovenly"($p<.01$), "old-fashioned"($p<.01$), "poor"($p<.01$), "disagreeable"($p<.01$), "unfeminine"($p<.01$), and "looks tired".

5. 2 Factor analysis

Further analysis was conducted by Factor analysis. Six factors were extracted for both Japanese and Chinese studies. Figure 1 is a scatter diagram of the result for Japanese study by Factor 1 x Factor 3. The words that were relatively close were located nearby. For example, "cultivated" and "beautiful" have different connotations but were plotted close together in the diagram because their psychological images were similar for the subjects. Also, "likable", "delicate" and "clean" were placed near. "Healthy" impression was relatively close to "delighted", "merry" and "vivid". "Intimate", "sleek", "crisply" and "frank" were also close to these impressions. On the other hand, negative images, such as "poor", "obstinate", "looks tired", "old" were close together along with high negative values in Factor 1. In this diagram, "unfeminine" impression was close to the negative images.

Table 1: Ranking of words for each visual in China

	Visual A		Visual B		Visual C		Visual D	
Tone	Fair		Fair		Dark		Dark	
Texture	Smooth		Rough		Smooth		Rough	
		(%)		(%)		(%)		(%)
1st	beautiful	92.4**	hypocritical	33.3	resolute	41.0	old	85.7**
2nd	eye-catching	89.5**	conservative	32.4	characteristics	40.0	slovenly	76.2**
3rd	aristocratic	87.6**	strong-willed	32.4	crisply	38.1	old-fashioned	76.2**
4th	clean	86.7**	self-possession	30.5	friendly	38.1	poor	73.3**
5th	likable	85.7**	intelligent	28.6	interesting	37.1	disagreeable	72.4**
6th	stylish	84.8**	looks tired	27.6	merry	35.2	unfeminine	71.4**
7th	modern	83.8**	resolute	27.6	delighted	33.7	looks tired	59.0
8th	attractive	81.9**	crisply	25.7	good person	33.3	passive	54.3
9th	delicate	81.9**	frivolous	24.8	warm	32.4	obstinate	41.9
10th	elegant	81.0**	unhurried	23.8	serious	30.5	conservative	32.4

** $p<.01$ by Fisher's exact test

Table 2: Ranking of words for each visual in Japan

	Visual A		Visual B		Visual C		Visual D	
Tone	Fair		Fair		Dark		Dark	
Texture	Smooth		Rough		Smooth		Rough	
		(%)		(%)		(%)		(%)
1st	beautiful	95.2**	conservative	40.0	delighted	52.4	looks tired	81.0**
2nd	cultivated	89.5**	serious	39.0	eye-catching	51.4	old	77.1**
3rd	elegant	87.6**	weakly	37.1	merry	50.5	unfeminine	73.3**
4th	polite	86.7**	passive	34.3	immature	48.6	slovenly	70.5**
5th	likable	83.8**	resolute	33.3	warm	44.8	old-fashioned	69.5**
6th	attractive	83.8**	crisply	32.4	healthy	41.0	disagreeable	65.7**
7th	clean	81.9**	hypocritical	28.6	characteristics	40.0	poor	65.7**
8th	feminine	79.0**	intelligent	27.6	vivid	40.0	obstinate	51.4
9th	stylish	78.1**	poor	26.7	frank	38.1	arrogant	41.0
10th	aristocratic	76.2**	self-possession	26.7	good person	36.2	strong-willed	28.6

** $p<.01$ by Fisher's exact test

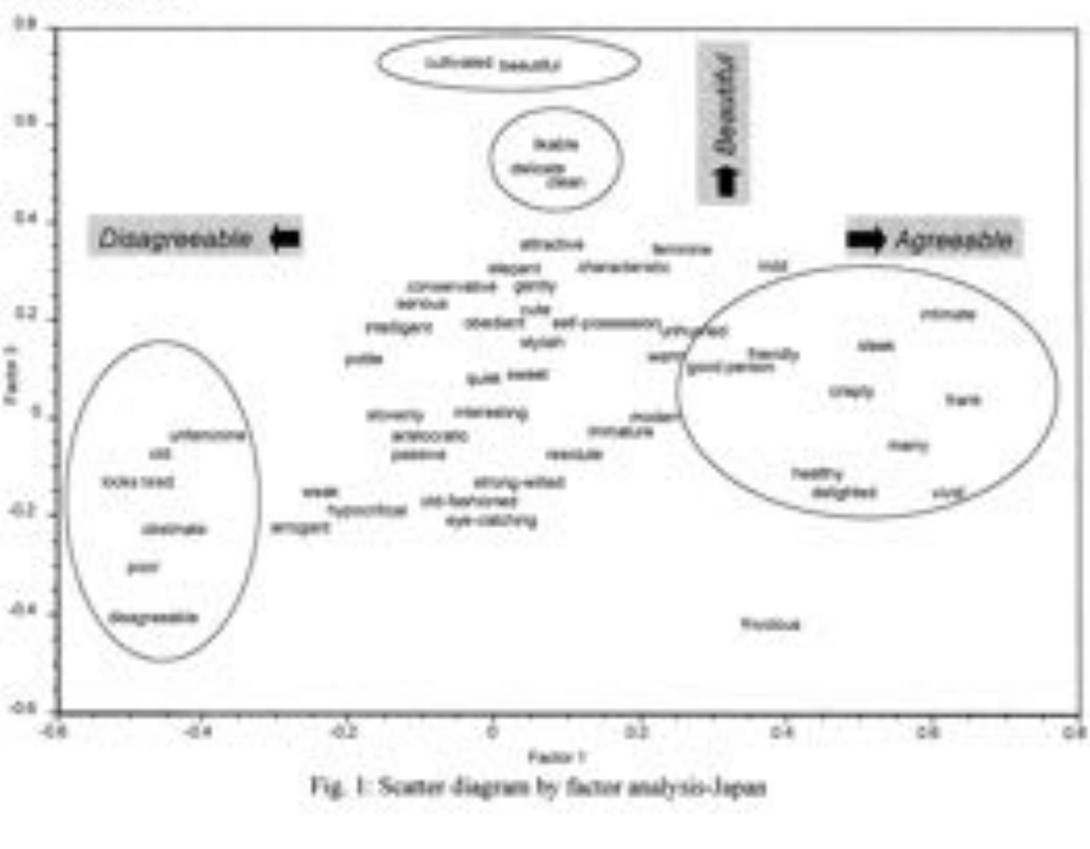


Fig. 1: Scatter diagram by factor analysis-Japan

As for the structure of factors obtained by factor analysis, it was suggested that Japan and China had relatively similar structure. Both Japanese and Chinese results indicated that Factor 1 represented agreeable / disagreeable axis, i.e. "warm", "friendly", "intimate", "gently" and "sleek" had high positive values, whereas disagreeable images had high negative values as stated before. Factor 3 in both countries represented beautiful impressions such as "cultivated", "beautiful", "clean", and "delicate" along with high positive values. Japanese Factor 5 and Chinese Factor 4 indicated obedient and quietness. Intelligence and resoluteness were represented by Factor 4 in Japan, Factor 6 in China. Cross-cultural differences were shown in Chinese Factor 5 and Japanese Factor 6; the former represented stylish images and the latter described feminine / unfeminine axis. In Japan, Factor 2 represented warmness and healthiness, while the factor represented characteristic and vividness in China.

6. DISCUSSION AND CONCLUSIONS

The results indicated that skin texture plays a key role on the impression of personality in addition to skin tone both in China and Japan consistently. Visual A, with fairer tone and smoother texture, provided very positive, ideal and beautiful impressions. On the contrary, Visual D, with darker tone and rougher texture commonly gave negative impressions. However, even though having fairer skin tone, the impression by Visual B was not always positive because of its rough texture. It tended to give passive and conservative impressions. On the other hand, Visual C, with darker skin tone and smoother skin texture, provided friendly and delightful impressions both in China and Japan. Although skin tone has been assumed to drive the personal impression, this study showed that skin texture also affects the personal impressions.

As a cross-cultural comparison, the impressions that affected by skin conditions (skin tone and skin texture) were very consistent between Chinese women and Japanese women. This may be because of the similarity of their cultural background as well as similarity of current fashion trend. However, some interesting differences were also observed. In China, the words that provide an active impression (eye-catching, healthy, vivid) were chosen to explain Visual A (fairer and smoother skin), while these words were chosen to explain Visual C (darker and smoother skin) in Japan. This may be because Japanese women are more influenced by Western trend than Chinese women.

The results by factor analysis showed very similar structure of factors in two countries. This suggested that the principal impressions were common to both Japanese and Chinese women when they rated each stimulus. Although there were some cross-cultural differences, it was presumed that Asian women have common impression and aspiration to fairer skin tone and smoother skin texture. This is one of the reasons why market of whitening products that improve both skin tone and texture continues to expand in Asia.

REFERENCES

1) M.Saito. "A cross-cultural survey on color preference." *Bulletin of the Graduate Division of Literature of Waseda University*, **27**, 211-216,1981.

2) M.Saito. "A cross-cultural survey on color preference in Asian Countries: 1. Comparison between Japanese and Koreans with emphasis on preference for white." *Journal of the color Science Association of Japan,* **16 (1)**, 1-10, 1992a.

3) M.Saito." A cross-cultural survey on color preference in Asian Countries: 2. Comparison between Japanese and Taiwanese with emphasis on preference for white." *Journal of the color Science Association of Japan*, **16 (2)**, 84-96, 1992b.

4) M.Saito. "A cross-cultural survey on color preference in three Asian Cities: Comparison between Tokyo, Taipei and Tianjin." *Japanese Psychological Research,* **36**, 219-232, 1994.

5) M.Saito. "A cross-cultural survey on preference for lightness of complexions: Comparison between Japan and Indonesia." *The Japanese Journal of Psychology*, **Vol.67, No.3**, 204-213, 1996a.

6) M.Saito. "A comparative study of color preferences in Japan, China and Indonesia, with emphasis on the preference for white." *Perceptual and Motor Skills*, **83**, 115-128, 1996b.

7) M.Saito. "Comparative studies on color preferences in Japan and other Asian regions, with emphasis on the preference for white." *Color Research and Application,* **21**, 35-49, 1996c.

8) M.Saito. "Psychological study on the preferences for fair skin in China." *Color 2000, Proceeding Book of 2000 AIC Meeting Seoul*, 51-53, Korean Society of Color Studies, Seoul, 2000.

9) M.Saito, J.Matsumoto, A.Date, and J.Li. "Studies concerning aspirations of Asian women toward Ideal Skin Fairness", *Proceeding Book of 5th Scientific Conference of the Asian Societies of Cosmetic Scientist,* 218-227, Society of Cosmetic Chemists of Thailand, Bangkok, 2001.

Effects of hue, saturation, and brightness on preference: a study on Goethe's color circle with RGB color space

Nilgün Camgöz*[a], Cengiz Yener**[b]
[a]Middle East Technical University; [b]Bilkent University

ABSTRACT

In order to investigate preference responses for foreground-background color relationships, 85 university undergraduates in Ankara, Turkey, viewed 6 background colors (red, yellow, green, cyan, blue, and magenta) on which color squares of differing hues, saturations, and brightnesses were presented. All the background colors had maximum brightness (100%) and maximum saturation (100%). Subjects were asked to show the color square they preferred on the presented background color viewed through a computer monitor. The experimental setup consisted of a computer monitor located in a windowless room, illuminated with cove lighting. The findings of the experiment show that the brightness100%-saturation100% range is significantly preferred the most (p-value<0.03). Thus, color squares that are most saturated and brightest are preferred on backgrounds of most saturated and brightest colors. Regardless of the background colors viewed, the subjects preferred blue the most (p-value<0.01). Findings of the study are also discussed with pertinent research on the field. Through this analysis, an understanding of foreground-background color relationships in terms of preference is sought.

Keywords: Color, Color Combinations, Color Preference.

1. INTRODUCTION

Colors are rarely viewed in isolation. The everyday experience of viewing involves background-foreground color combinations, which is necessary to distinguish one visual stimulus from another. Following a prior study by Camgöz[1], this study intends to further explore effects of hue, saturation, and brightness on preference of colors presented on colored backgrounds through a modified experimental setup.

2. METHODOLOGY

2.1 Experimental setup

It consisted of a computer monitor located in a windowless room, illuminated with cove lighting (Fig. 1). Cove lighting was preferred as it excluded the possibility of glare on the monitor and created a perfect diffuse environment without any highlights that might have distracted the subjects. Standard Philips TL 54 fluorescent, having 6200 color temperature (CT) and 72 color rendering index (CRI) was used in the coves for lighting the room.

Figure 1: The experimental setup.

2.2 Experimental procedure

The subject group consisted of 85 undergraduate students studying in art/design related departments. They were presented image sets through a computer monitor from which they were asked to make a preference of a foreground color square on a colored background. The image set consisted of six background colors selected from Goethe's color circle presented from RGB (Red, Green, Blue) color space. Each image had 35 color squares of differing hues, saturations, and brightnesses on them. Each subject made preference choices for the six different background colors. After they have made choices, the subjects were asked to view and assess the same six images again. The first time they viewed and answered the experiment question is referred to as

* ncamgoz@hotmail.com; phone +90 312 230 09 80; fax +90 312 229 45 93; http://www.metu.edu.tr; Department of Architecture, Faculty of Architecture, Middle East Technical University, 06531 Ankara, TURKEY; **cengiz@bilkent.edu.tr; phone +90 312 16 62; fax +90 312 266 41 36; http://www.bilkent.edu.tr; Department of Interior Architecture and Environmental Design, Faculty of Art, Design, and Architecture, Bilkent University, 06533 Bilkent, Ankara, TURKEY.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

"1st observation," while the second viewing is referred to as "2nd observation" in this paper. The experiment verbally asked the subjects: "Which color square would you prefer on the background color on the screen?" The subject group was 85 students who had also taken the experiment of Camgöz[1].

2.3 The image sets

Adobe Photoshop[2] software was used to create the images. The image set consisted of 6 images each with a different background color. The colors were picked as the 6 main hues of Goethe's color circle, having maximum saturation and brightness. The list of background colors is: Red, R255-G0-B0; Yellow, R255-G255-B0; Green, R0-G255-B0; Cyan, R0-G255-B255; Blue, R0-G0-B255; Magenta, R255-G0-B255. On every background color, all the remaining hues (excluding the background hue itself) are represented in 5 separate rows. Each hue row is then divided into 7 columns, where the hue was represented with varying brightness and saturation levels (Fig.2).

	A	B	C	D	E	F	G	
1	Yell. B=25 S=100	Yell. B=50 S=100	Yell. B=75 S=100	Yell. B=100 S=100	Yell. B=100 S=75	Yell. B=100 S=50	Yell. B=100 S=25	1
2	Gr. B=25 S=100	Gr. B=50 S=100	Gr. B=75 S=100	Gr. B=100 S=100	Gr. B=100 S=75	Gr. B=100 S=50	Gr. B=100 S=25	2
3	Cyan B=25 S=100	Cyan B=50 S=100	Cyan B=75 S=100	Cyan B=100 S=100	Cyan B=100 S=75	Cyan B=100 S=50	Cyan B=100 S=25	3
4	Blue B=25 S=100	Blue B=50 S=100	Blue B=75 S=100	Blue B=100 S=100	Blue B=100 S=75	Blue B=100 S=50	Blue B=100 S=25	4
5	Mag. B=25 S=100	Mag. B=50 S=100	Mag. B=75 S=100	Mag. B=100 S=100	Mag. B=100 S=75	Mag. B=100 S=50	Mag. B=100 S=25	5

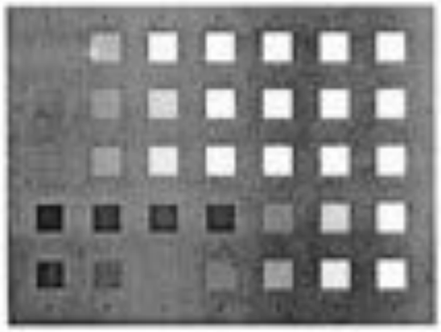


Figure 2: Construction of the image with red background.

3. FINDINGS

The SAS[3] (Statistical Analysis System) software was used in the analysis of the collected data. The statistical method Analysis of Variance (ANOVA) was applied to the collected data. Duncan's Multiple Range Test was also applied. Results from the ANOVA Procedure and Duncan's Multiple Range Test are included in appendix. The statistical results show that hue has an effect on preferences on background colors of red and magenta (p-value 0.0066, 0.0248 for 1st obs., 0.0242, 0.0304 for 2nd obs.) (see app., table 1&2). The background color of cyan also indicates a hue effect through the second observation (p-value 0.0159) (see app., table 2). On background colors of red, cyan, and magenta, blue is the hue that is most preferred. On the background color of magenta, the hue cyan is also preferred as much as blue. There does not seem to be a consensus in terms of hue for the other background colors. Brightness-saturation has an effect on preferences on specific background colors (p-value between 0.0021-0.0307, excluding green for 1st obs., between 0.0003-0.0293 for 2nd obs.) (see app, tables 1&2). For all the background colors, brightness100%-saturation100% range (BS100) is rated as the most preferred (see app., tables 1&2). Thus, hues with maximum brightness and maximum saturation are preferred on colored backgrounds. For the background color of magenta, brightness100%-saturation25% and brightness100%-saturation50% are also preferred along with brightness100%-saturation100% range (see app., tables 1&2). Background effect was also investigated. The statistics show a brightness-saturation effect (p-value 0.0001 for both obs.) (see app., tables 3&4) and a hue effect (p-value 0.0056 for 1st obs., 0.0002 for 2nd obs.) (see app., tables 5&6) on any background color viewed. Thus, despite of the changing hues of the background, certain brightness-saturation levels and certain hues are preferred over others (brightness-saturation 100% and blue, see app., tables 3, 4, 5&6).

4. DISCUSSION

The studies on color preference may be analyzed in two groups: studies of color in isolation and studies of color in combination. Guilford[4], Smets[5] and Eysenck[6] did experiments within controlled environment on color preference, where color was treated in isolation. Studies involving preferences for color combinations include Helson and Lansford[7], and Camgöz[1]. The brightness100%-saturation100% range is significantly preferred the most in this experiment (p-value between 0.0003-0.0307, app., tables 1&2). Thus, color squares that are most saturated and brightest are preferred on backgrounds of most saturated and brightest colors. This finding supports experiments with isolated colors. Guilford[4], Smets[5], Guilford and

Smith[8] and Sivik[9] all stated that brighter and more saturated colors in isolation are more preferred. Only Eysenck[6] stated a contradicting result of brighter colors being less preferred. Washburn and Grose[10], Reddy and Bennett[11] studied color combinations where they demonstrated that brightness contrast was sought for favorable colors. In their studies, as the brightness contrast was increased, a more preferred color combination was obtained. There is no brightness contrast between the background and foreground colors in preferences of subjects. The study confirms findings of Camgöz[1]. One exception to the preferred brightness100%-saturation100% range is observed on the magenta background, where brightness100%-saturation25% and brightness100%-saturation50% are also preferred along with brightness100%-saturation100% (p-value 0.0252, 1st obs.; 0.0005, 2nd obs.) (see app., tables 1&2). Regardless of the background colors viewed, the subjects preferred blue the most (p-value 0.0056, 1st obs.; 0.0002, 2nd obs.) (see app., tables 5&6). Wijk et al.[12], Guilford[4], Eysenck[6], Granger[13], Guilford and Smith[8], all found that blue was preferred the most when isolated colors were presented. Sivik[9] stated blue as the color preferred in more instances despite its change in brightness and saturation. Washburn and Grose[10], Camgöz[1] found that blue was the most preferred color regardless of its background. Blue is preferred on the background colors of red, magenta, and cyan (app., tables 1&2). This confirms the initial experiment of Camgöz[1] where RGB values and quantity of hues selected were different. Cyan is also preferred on magenta background along with blue. This finding was not present in the initial Camgöz[1] experiment.

5. CONCLUSION

Analyses of data demonstrated that brightness-saturation levels are more significant than the hue component in color preferences. The findings of the initial Camgöz[1] experiment showed significant hue component in color preferences. This may be due two reasons: the increased amount of images viewed by the subjects or the increased number of subjects in the initial Camgöz[1] experiment. Both reasons suggest that hue preferences require either an increased exposure to images (the more they look the more likely they arrive on a consensus) or an increased number of subjects. Colors having maximum brightness and maximum saturation levels rank higher than any other brightness-saturation combination. Previous experimental studies on isolated colors also suggested an increase in rated pleasantness with an increase in brightness and saturation (see sec. 4). Blue is the most preferred hue regardless of the background shown, which also confirms the findings of previous studies (see sec. 4). The general preference for blue supports findings from different studies having subject groups from various cultures. There seems to be a global inclination towards preferring blue regardless of its presented medium. The findings of the first observation and the second one confirm each other. Thus, the subjects make similar decisions at two different times. This may suggest a consistency for color preferences in a short time gap. These findings also confirm the findings of the initial Camgöz[1] experiment where the color circle selected differed from this one. This may also suggest that different hues from the same hue group (blues, reds, yellows, etc.) may incite similar sensations, resulting in similar responses. Note that brightness-saturation levels for both experiments are the same. The conclusions of the study presented above should be assessed by taking into account the experimental setup and the characteristics of the subject group involved. The results of this study purport to contribute to the available data on the subject in hope to broaden the understanding on color preference.

REFERENCES

1. N. Camgöz, "Effects of Hue, Saturation, and Brightness on Attention and Preference," Diss., Bilkent U, Ankara, 2000.
2. *Adobe Photoshop 4.0*, CD-ROM, Adobe Systems, 1996.
3. *SAS*, vers. 6.12: *SAS/STAT User's Guide*, Release 6.03 ed., SAS Institute Inc., Cary.
4. J. P. Guilford, "The affective value of color as a function of hue, tint and chroma," *J. of Experimental Psychology* **17**, pp. 342-370, 1934.
5. G. Smets, "A tool for measuring relative effects of hue, brightness and saturation in color pleasantness," *Perceptual and Motor Skills*, pp. 1159-1164, 1982.
6. H. J. Eysenck, "A critical and experimental study of color preferences," *Amer. J. of Psychology* **54**, pp. 385-391, 1941.
7. H. Helson and T. Lansford, "The Role of Spectral Energy of Source and Background Color in the Pleasantness of Object Colors," *Applied Optics* **9.7**, pp. 1513-1562, 1970.
8. J.P. Guilford and P.C. Smith, "A System of Color-Preferences," *Amer. J. of Psychology* **72.4**, pp. 487-502, 1959.
9. L. Sivik, "Color Meaning and Perceptual Color Dimensions: A Study of Color Samples," *Goteborg Psychological Reports* **4.2**, 1974, and L. Sivik, "Studies of color meaning," *Man-Environment Systems* **5**, pp. 155-160, 1975.
10. M. F. Washburn and S. L. Grose, "Voluntary control of likes and dislikes: the effects of an attempt voluntarily to change the affective value of colors," *Amer. J. of Psychology* **32**, pp. 284-289, 1921.
11. T.V. Reddy and C. A. Bennett, "Cultural Differences in Color Preferences," *Proc. of the Human Factors Society, 29th Annual Meeting*, pp. 590-593, 1985.
12. H. Wijk et al., "Color discrimination, color naming and color preferences in 80-year olds," *Aging-Clinical and Experimental Research* **11.3**, pp. 176-185, 1999.
13. G. W. Granger, "An experimental study of color preferences," *J. of General Psychology* **52**, pp. 3-20, 1955.

APPENDIX
P-values and Duncan Groupings

Table 1: Brightness-saturation and hue effect (1st observation)

Background colors	p-values for brightness-saturation	Duncan grouping for brightness-saturation	p-values for hue	Duncan grouping for hue
Red	**0.0064**	BS100	**0.0066**	Blue
Yellow	**0.0307**	BS100	0.1526	Overlapping
Green	0.0645	Overlapping	0.6762	None different
Cyan	**0.0118**	BS100	0.0893	Overlapping
Blue	**0.0021**	BS100	0.0832	Overlapping
Magenta	**0.0252**	BS100, S25, S50	**0.0248**	Blue, Cyan

Table 2: Brightness-saturation and hue effect (2nd observation)

Background colors	p-values for brightness-saturation	Duncan grouping for brightness-saturation	p-values for hue	Duncan grouping for hue
Red	**0.0024**	BS100	**0.0242**	Blue
Yellow	**0.0293**	BS100	0.4595	None different
Green	**0.0077**	BS100	0.1269	Overlapping
Cyan	**0.0131**	Overlapping	**0.0159**	Blue
Blue	**0.0003**	BS100	0.3601	None different
Magenta	**0.0005**	BS100, S25	**0.0304**	Blue, Cyan

Table 3: Brightness-saturation and background effect (1st observation)

	p-values for brightness-saturation	Duncan grouping for brightness-saturation
On any background color	**0.0001**	BS100

Table 4: Brightness-saturation and background effect (2nd observation)

	p-values for brightness-saturation	Duncan grouping for brightness-saturation
On any background color	**0.0001**	BS100

Table 5: Hue and background effect (1st observation)

	p-values for hue	Duncan grouping for hue
On any background color	**0.0056**	Blue

Table 6: Hue and background effect (2nd observation)

	p-values for hue	Duncan grouping for hue
On any background color	**0.0002**	Blue

Cross-cultural Differences in Color Preferences: Implication for International Film Distribution

Kyung Jae Lee, Purdue University

ABSTRACT

This paper proposes the necessity of manipulating colors of movie contents to fit diverse audiences around the world. Since films are highly color-dependent messages, it is critical to understand how people in different cultures respond differently to color. In recent years, the international market for filmed entertainment has grown more than the U.S. market. However, a lack of research on audience preferences shows no constant guide for the motion picture industry. The film production stage is often disregarded to deliver the appropriate visual color contents for local audience when U.S. films are distributed to foreign markets. Therefore, it is assumed that it would cause distractions for local audiences and it could result in poor ticket sales. When the U.S. produced films are distributed in Asia, colors of original films are always shown without manipulation. It is common that when a U.S manufactured car is imported to Japan, a driver seat is installed on the right side and also other parts are modified for local customers. Film development is also significantly dependent on audience behavior, so film content also needs to be localized for the different culture. This paper will only address a hypothesis of the implementation of color marketing methodology present in motion pictures.

Keywords: color preference, cross-cultural study, East Asia, film, media, color marketing, image quality, communication model, consumer behavior

1. INTRODUCTION

Entertainment media is a powerful place to deliver visual information. Due to market trends that are largely affected by consumer preferences, the complexity and dynamic characteristics of entertainment graphics are very volatile and tend to increase product development cycles. Even inside the mass-market environment developed by the film industry, technological innovation enables opportunities for customer specific content.

A movie is a cultural product. Hollywood producers and researchers have tried to find the 'golden rules' for financial success. However, unpredictability of audience behavior has been a challenge, not only in the production stage but also the distribution stage in the U.S. domestic market. Attempting to predict international audience preferences in culturally diverse and economically distinct countries may lead to another approach. This approach is based on culture diversity and variables that could be considered as significant as the currently used *Psychological and/or Economical Approaches*[1]. By combining existing and emerging technology in concert with various cultural color standards, the possibility of developing a workable media solution is possible.

In recent years, cultural contents of the East have been applied to entertainment media releases in the U.S. domestic market. The nationwide distribution of Japanese films includes *Pokémon, Princess Mononoke and Godzilla 2000*. When considering the Japanese produced and U.S. Disney distributed *Princess Mononoke*, Disney tried to edit the film contents to adapt it to the domestic market.[2] However, the Japanese producers did not permit the editing of the film. This resulted in Disney releasing the original version with limited success. The cross-cultural approach may become another variable to analyze the color preferences of both domestic and international audiences.

2. NEW PERSPECTIVE: COLOR APPROACH IN MEDIA AND CROSS-CULTURE

Color code can be a direct sales stimulus to consumers[3]. Marketing psychologists indicate that consumers decide the acceptance or rejection of images within ninety seconds and 60 % of their decisions depend on color[4]. Most movies last over one hour and movie trailers usually last around 30 seconds. Color perception affects the experience of music[5]. In filmmaking, the technique of aural illusion has been used with matching the visual illusion. Therefore, applying color elements in the movie content should be carefully designed.

Color rendering is a major issue to address when increasing overall image quality[5]. When applying a color marketing distribution methodology to rendering interactive media products, an investigation into different color characteristics that exist between static haptic and electronic multimedia products is needed. One of the differences is found relative to a 'the change in time' in multimedia products. Especially in filming, continuity of lighting sequence is a desirable necessity during filming[6]. If consumers could regard a multimedia product as single entity such as a cloth, an industry could offer different color versions of the same media contents for diverse consumer groups.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

"Color," said Isaac Newton, "belongs to the mind and not the object."[6] Even different wavelengths of light may be independent of an observer, the psychological characteristics of color depends on an observer[7]. Color naming is "guided by social values" such as culture as well as "constrained by physiology"[8]. Cultural variations classify a different range of colors on human emotions. Furthermore, naming and meaning of colors are interpreted differently between cultures. Even mass media generalize American culture where many colors have been stereotypically reinforced by advertising[4]. Also, some television programs have an inherent visual consistency based on the thematic visual elements[9]. If an audience abroad hardly recognizes images as realistic and believable, they could decide to reject accepting information regardless of image quality.

3. COLOR COMPARISON BETWEEN EAST ASIA AND US

In consumer science, a cultural system has been studied with three functional areas: ideology, ecology, and social structure[10]. Color has been used to express different cultural systems through human history. While the color study of Newton was based on the measurements of light rays, Goethe applied himself to the phenomenon of color[11]. In the East, philosophers defined color as 'symbolism of cultural value' itself and it has been the principal of color theory. Primary colors of East Asia have been developed and used based on Feng-Shui symbols and theory[12]. These days many restoration projects in traditional buildings and 3D simulation are underway in East Asia. However, traditional buildings were built by the Feng-Shui principle and the architects have been strictly trained for many years under this rule. Therefore, 3D professionals who are only familiar with RGB and CMYK color models could find it difficult to accurately translate the colors of traditional architecture when they create a simulation. The recent research also shows how different pedagogical backgrounds in culture influence the visualizing processes between American and Russian students[13].

The earlier research investigated the differences in color interpretation between US and Korea using Munsell hue notation[14]. This research showed that color interpretation of yellow, blue, and green in Korea indicated a wider range than in the US. Also, some people did not clearly classify between green and blue. Another research clearly demonstrated that the common color preference of white in three neighboring Asian areas[15].

4. THE ANALYSIS OF COLOR MISINTERPRETATION DURING FILM PRODUCTION

Consumers often suffer sensory overload from exposure to far more visual information than they are capable or willing to process. As a result, they use perceptual filters to pay attention to images[16]. The process of color selection during filming might not entirely depend on using numeric color values. Frequently, the color selection for props and location design is prepared through verbal description or color rendering from an art director. Due to the length of movie running time, the preferred color reproduction approach might not be applied to generate optimal color reproduction on each frame. In addition, when spoken description of color matching applies to cross-cultural environments, each culture interprets color message under habituated experience. This personalized information prevents effective communication on transferring desired color data into digitized form. When foreign producers work with a local location director, color mismatching could happen when it is referred to verbally. Even this problem could continue to exist through production and postproduction stage. *Figure 1* shows a scenario of a potential color misinterpretation using the Shannon & Weaver communication model when US films are delivered to Japanese audience[14].

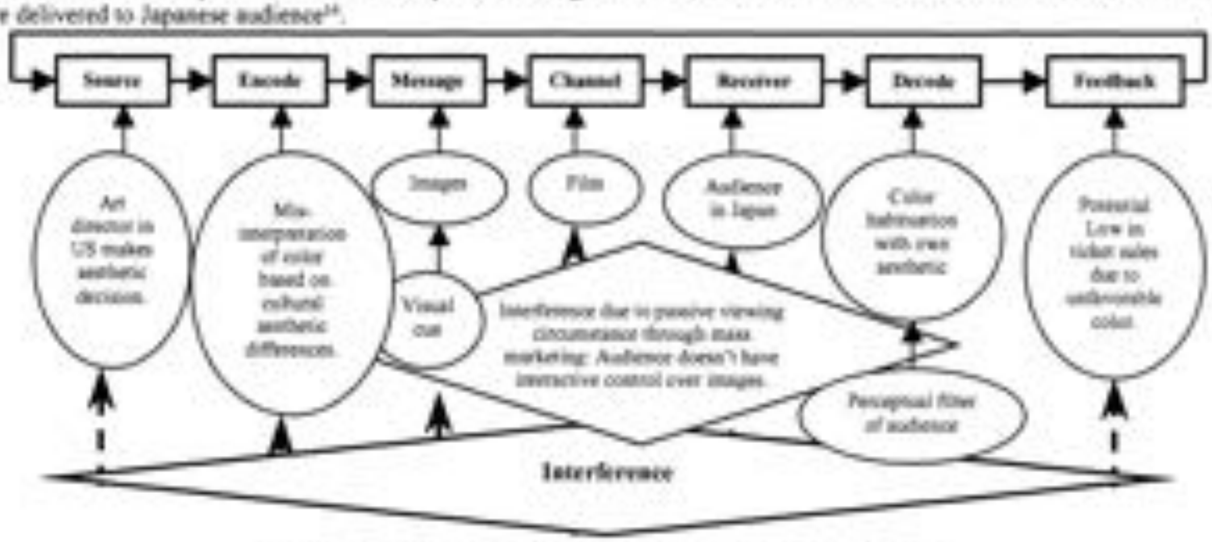


Figure 1. Color misinterpretation during film production and distribution

5. SURVEY

A preliminary survey was conducted to attempt to verify *interference* in color preference of potential movie audiences. The surveyed population consisted of 40 college students and 10 faculty at Purdue University in the USA. They filled out a color preference test instrument that asked them to discriminate between original film images and color-corrected images displayed on a CRT monitor. Basically, the survey consisted of two questions that focused on image preference (*Figure 2*). The first question asked participants to select one of two images; an original screen shot image with a color-corrected image from a movie, *Godzilla 2000* (*Figure 3*). The reason for selecting this movie was that the *Godzilla* character has been widely recognized for years by most audiences. *Godzilla 2000* was released both in Japan and the USA. A color treatment was applied to the original Japanese produced image. The color corrected image (*Figure 3b*), was modified with increasing the amount of blue using *Adobe Photoshop 5.0*. Blue[17] has been a popular color to advertisers[18]. About 96% of the American survey subjects preferred the blue-added color corrected image to the original Japanese image. The other question focused on identifying the color preference of survey participants relative to a movie poster produced by a Japanese production company (*Figure 4*). The movie poster[19] was advertised on the special edition of the American Film Market 2000 in *Variety* magazine. Three images were used at that time. Only two people of 50 favored the original film poster captured from a scanner (*Figure 4a*). Twenty-six preferred the image manipulated only by sharpness and contrast without changing colors (*Figure 4b*). The other twenty-two favored the blue-added image without changing other quality attributes (*Figure 4c*). Several subjects believed the movie poster was released more than 10 years ago due to its overall yellow appearance. Survey participants thought the data lacked a needed level of scientific rigor; therefore, the results only indicate a potential for further investigation and cannot be presented as significant. The intent of the author is to restructure the survey into a formal pilot study.

	Godzilla 2000 (Figure 3.)		*Another Heaven* (Figure 4.)		
	a. Original image	b. Color corrected by adding blue	a. Original image	b. Add sharpness and contrast	c. Color corrected by adding blue
Preference rate	4 %	96 %	4 %	52 %	44 %
Number of Subjects (50)	2	48	2	26	22

Figure 2. Percentile of Preference of Original images and Color corrected images

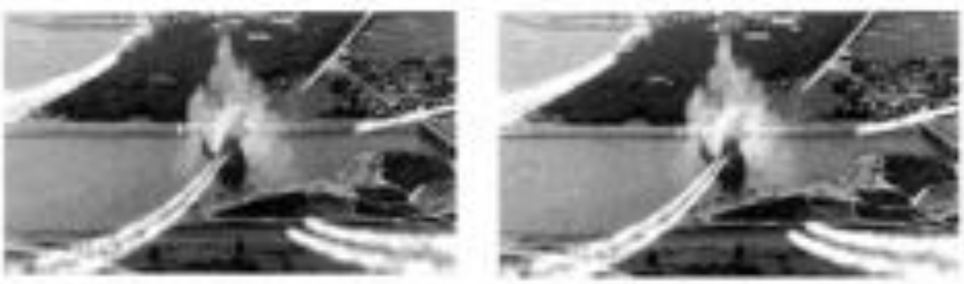


Figure 3. a. Original image b. Color corrected by adding blue

Figure 4. a. Original image b. Add sharpness and contrast c. Color corrected by adding blue

6. HYPOTHESIS OF IMAGE MANIPULATION ISSUES DURING FILM PRODUCTION

In an attempt to build a hypothesis of production techniques, a few scenarios were investigated. For example, if color researchers were able to develop accurate cultural profiles of color preferences, a cultural specific color palette could be developed to build better color channels. In addition, applicable color forecasting methods[20] could be another tool to enable prediction of audience behavior. Therefore, an art director could re-arrange color groups for different cultural areas before distribution to an international market. Also, during the postproduction stage, CG technicians may develop different color correction methods to filter offensive colors. Visual manipulation could be another method for film editing for international distribution besides dubbing in different languages utilizing an acoustic approach.

7. FURTHER STUDY

Because a consistency of environment colors already exists, cultural color message has a certain basis. By decoding unique cultural color messages, local audiences could easily catch the original message of a foreign film. Experimenting with color interaction across cultural lines could be one way to attract culturally different moviegoers. If the digital cinema industry grows faster, color manipulation of film could be easily tested for international film distribution. Cross-cultural color approach could help reduce uncertainty associated with production, distribution, and exhibition decision-making processes in the motion picture industry. Eliminating communication interferences from different color preferences could produce reliable color renditions for target consumers. This approach could increase overall image preferences of consumers and it could be carefully combined with image quality attributes for the emerging digital technology.

REFERENCES

1. B. R. Litman, H. Ahn, "Predicting Financial Success of Motion Pictures, The Early '90s Experience," *The Motion picture Mega Industry*, 172-197, Allyn and Bacon, Needham Heights (1998).
2. R. Lyman, "A Darkly Mystic World From Japan Arrives in Hollywood," *New York Times* (October 21, 1999).
3. A. M. Barry, *Visual Intelligence: perception, image, and manipulation in visual communication*, 126-134, 264-266, State University of New York Press, Albany (1997).
4. J. L. Morton, "Color Communication," *Colorcom, [online]* WWW: http://www.colorcom.com/color.html (1999).
5. E. N. Dalal, D. R. Rasmussen, F. Nakaya, P. A. Crean and M. Sato, "Evaluating the Overall Image Quality of Hardcopy Output," *Proc. PICS-98 Conference*, 169-173, Portland (1998).
6. S. Calahan, "Storytelling through Lighting, a Computer Graphics Perspective," *Advanced RenderMan: Creating CGI for Motion Pictures*. A. A. Apodaca, L. Gritz, 337-382, Morgan Kaufmann, San Francisco (2000).
7. S. E. Palmer, *Vision Science-photons to phenomenology*, 95-100, Massachusetts Institute of Technology, Boston (1999).
8. R. E. MacLaury, "Social and Cognitive Motivations of Change: Measuring Variability in Color Semantics," *Language*, 67:1 34-62 (1991).
9. J. Martino, N.Dimitrova, L. Agnihotri, H. Elenbass," Color Super-Histograms for Video Representation: Preliminary Research and Findings," *Proc. Sketches & Applications, ACM Siggraph Conference*, New York, 236 (1999).
10. M. R. Solomon, *Consumer Behavior: buying, having, and being*, 495-498, Prentice-hall, Upper Saddle River (1999).
11. J. F. Goethe, *Goethe's color theory*. R. Matthaei, 5-8, Van Nostrand Reinhold, New York (1971).
12. S. Brown, *Practical Feng Shui at Work*. Barnes & Nobles, New York (1998).
13. A. Faiola, "Cross-cultural landscapes of visual intelligence: An investigation of visualization problem-solving across cultural boundaries," *Proc. International Visual Literacy Association Conference 2000*, 113-122, Eskilstuna, Sweden (2000).
14. Y. Kim, M. Lee, "Comparison of Korean basic color-names and the ISCC-NBS color-names in terms of their representations in color space," *Proc. Korean Society of Color Studies* (In Korean), 29-34, Seoul, Korea (1998).
15. M. Saito, "Comparative studies on color preference in Japan and other Asian regions, with special emphasis on the preference for white," *Color Research & Application*. 21.1: 35-49 (1996).
16. C. E. Shannon, W. Weaver, *The Mathematical Theory of Communication*, University of Illinois Press, Urbana (1949).
17. M. Cooper, A. Mathews, *Color Smart: How to use color to enhance your business and personal life*, Pocket Books, New York (2000).
18. M. McCarthy, "Advertisers choose steely blue hues to lure consumers," *New York Times*, New York, 1B (May 30, 2000).
19. Shochiku International, "Another Heaven", *Variety*, 105 (Feb. 21-27, 2000).
20. H. Linton, *Color Forecasting: A Survey of International Color Marketing*, 147-158, Van Nostrand Reinhold, New York (1994).

*Correspondence: klee9@purdue.edu; phone 765-496-4791; fax 765-494-9267; Purdue University, 220-15 Nimitz dr, West Lafayette, IN 47906, USA.

How life is associated with colors in Chinese culture - Utilizing colors based on Chinese Five-essence Theory

Tien-Rein Lee*
Chinese Culture University

ABSTRACT

Chinese believe that Feng-shui, Ch'i, Tao, Yin and Yang are major components rooted in Chinese culture. Many people know life has to balance and harmonize with nature and the universe through the Five-essence. Ancient wisdom is successfully interwoven with mankind and the natural world. Elements such as orientation, season, color, sound, facial organs, viscera, stars, and numbers can be associated with life through the Five-essence Theory. Since color is one of the major components of the Five-essence Theory, everything in our life can be associated with colors through a conjoined converting process. Color selection process is part of the interaction between human beings and the universe. Depending on the achievement one is pursuing, the Five-essence Theory model can be treated as an interface between destiny and human beings. This study reports how life is associated with Chinese Five-essence based paradigms. Models were used to explain how Chinese utilize Five-essence Theory to select colors in their daily lives.

Keywords: Color, Chinese culture, Five-essence Theory

1. INTRODUCTION

Colors are omnipresent and are closely related to our lives. Colors have a great impact on our living and have an added value in that they can change an object's sense of value. If they are used properly, colors can produce synergy. Yet, when we change colors, we may not know the reasons for the change (Lee, 2000). Color changes and selection can be systematized through a reliable selection system. The apex of color selection can manifest the principles and aesthetics of color applications.

Traditional culture in China has combined the Book of Change, Tao, Chi, Ying and Yang, Five-Essence, and eight diagrams for ages. Color selection and combination processes are part of the interactions between human beings and the natural world, the universe. If it is possible to interpret and inspect these processes in terms of modern applications in the hope to apply traditional philosophical principles of China to color selection, it is possible to form a Chinese "Principles of Colors." For example, by checking personal-birth data, one's personalized color scheme can be proposed through Five-essence Theory.

2. COMMUNICATION MODEL OF COLOR UTILIZATION

In pre-historic times, colors were endowed with healing properties because at that time, the sun and rainbows were divine symbols. In the seventeenth century, scientific color theories were mostly influenced by experiences in painting. This was even more noticeable in the search for "primary colors." In the eighteenth century, scientific theories of colors gradually became universal and artists also started to incorporate color-related knowledge from science researchers into their works. As early as 1810, painters such as Overback and Pforr believed that the colors of the clothes of characters in paintings represented their personalities (Gage, 1999). This represented a practical method of utilizing colors to transmit messages. The communications process model (Figure 1) of Shannon & Weaver (1949) can be changed to illustrate how color can be communicated. An investigation into how to properly utilize color information and effectively transmit it to achieve the expected results can be understood.

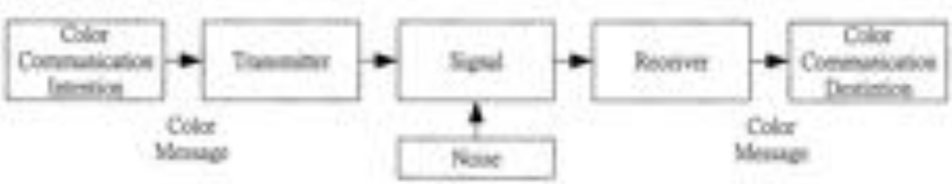


Figure 1: Linear Communications Process of Colors

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

3. COLOR SELECTION PROCESS

(1) Colors and Living—Colors are closely related to our daily living experiences and can achieve their effects on all concerns: food, clothing, housing, transportation, education, and entertainment and health care.

(2) Color Selection Methods—The decision process of color selection can be classified into two types: direct observation and data-driven (Lee, 2000) Color selection by direct observation is determined by users who decide on colors and color combinations without relying on any currently existing logic or theories. Data-driven color selection is determined by users who select colors and color combinations based on some currently existing color selection rules.

Both the attribution theory and self-efficacy theory focus on conscious cognitive processes to anticipate goals and rewards and to use judgment, evaluation, and decision-making capabilities. Therefore, why colors should be selected using any particular method has a need for further comparison (Figure 2). Based on the color decision-making process, the processes and results of their satisfaction differ when you do not know how to select or do not know which alternatives are available, or do not know which systems can be utilized.

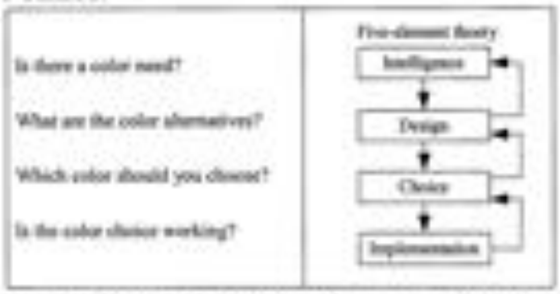


Figure 2: The color decision-making process (T. R. Lee, 2000)

(3) Non-artistic Color Selection—For decision processes that do not follow artistic value only, other commonly found color selection methods include the following:

- i. Screening color combination method, based on nature—imitating color combinations existing in nature.
- ii. Spectrum and color system: the primary color selection method—based on the color systems of the light spectrum.
- iii. Color image selection method--- a color image scale, based on semantic needs.
- iv. CHAKRAS Color Selection— Chakra theory, matching corresponding body parts to related colors.
- v. Five-Essence Generation and Restriction Color Selection Method--Chinese color principles are applied to the Five Essence of Yin and Yang, then changed to color selection systems after they have been combined with one's living conditions.

(4) Factors Affecting Selection—The principles or logic of color combining can be directed by religion, culture, philosophy, folklore, fortune telling, modern trends, poems, verses, paintings, metaphysics, living experiences, together with individual's modeling of the natural world and observation of the external environment. Sometimes the principles can be investigated whereas sometimes they are unconsciously generated and therefore difficult to investigate.

4. COLOR SELECTION BASED ON FIVE-ESSENCE THEORY

The Theory of Five Essence was first seen in the "Book of Books (Shu)." In the beginning of the West Han, the Theory of Five Essence was applied to fortune telling and developed into a system (Lin, 1994) The "Essence" in the so-called "Five Essence" means to "do things in accordance with heaven." "Doing things in accordance with heaven" includes five orientations and the four seasons, generational taboos and restrictions, different types of rhythms, and different types of relationships. Ancient people applied such knowledge and principles to fortune telling and directed people how to observe the lot of heaven in line with the customs of the people, to change misfortune to luck, and avoid omens and attain luck.

(1) Five essence—gold (metal), wood, water, fire, and earth. The Chinese say that they are the most important five types of elements in the earth and heaven. They have their own properties and strengths. They are omnipresent. According to these properties, they can display different symbols and show different interactive movements, simplicity, and can be used

infinitely. Those things attributed to each element are essentially equivalent and have all the characteristics of that element. That is, the Essence Wood contains the elements of direction: South; season: summer; Organ: tongue, Color: Red. Each element is equal to each other and all can be manipulated in such a way as to attract "Creative" or dispel or avoid "destructive" properties.

Table 1: Conjoint Table of Five Essence

Five Essence	Wood	Fire	Earth	Gold (metal)	Water
Five Colors	Cyan	Red	Yellow	White	Black
Five Orientations	East	South	Center	West	North
Four Seasons	Spring	Summer	Last 18 days of four seasons	Autumn	Winter
Five Sounds	Chiao	Chan	Kun	Shang	Yu
Five Faicial-Organs	Eyes	Tongue	Body	Nose	Ears
Five Viscera	Liver	Heart	Spleen	Lungs	Kidneys
Five Regularities	Benevolence	Virtue	Trust	Justice	Wisdom
Eight Gua	Chien, Zun	Li	Gen, Kun	Chien, Dui	Kan
Ten Numbers	1, 2	3, 4	5, 6	7, 8	9, 10
Ten Heavenly Stems	Jia, Yi	Bing, Ding	Wuu, Ji	Geng, Xin	Ren, Gui
Twelve Earth Branches	Yin, Mao	Si, Wu	Chen, Shu, Chou, Wei	Shen, You	Hai, Zi

The Five-essences are woven into daily life and thought. They are symbolically represented in the universe by things and concepts that we consider to be real. For example, the elements that represent the essence water are black color, north direction, winter season, ears of facial organs, kidneys of 5 viscera, wisdom of 5 regularities, and number 9 and 10. These are categories we consciously experience in daily life. There is an interdependence of these elements and a compatibility that makes them equivalent. So, any of these elements, colors for example, can be used as a solution to a any given issue that arises in one's daily life.

The Five-essence Theory is a goal-achieving model. Any issues raised can be interpreted through this theory once the method of solution (creative or destructive) has been decided upon. Then one can utilize any of the elemental categories to perform the destructive or creative process.

(2) Operations Mechanisms of Five-Essence Theory - Reciprocal Generation and Restriction (Creative-Destructive) of Five Essence—

i. The Creative Essence: These five most basic elements can be said to be the "chi" of "following heaven and promoting vital energy circulation" with their different personalities and particularities. In essence, they have a chained relationship of interdependent generation and reciprocal restriction with one another.. So, for example, if one were having trouble with one's eyes, one would find the "eyes" as an organ are contained in the essence Wood. One would then look to Wood's creative Essence, that essence that feeds Wood creative, healing and protective energy. That essence is Water. Now, the color associated with water is black. So, by literally bringing the color black into the one's immediate environment, an improvement is made. This is how the Creative essence functions. (Figure 3)

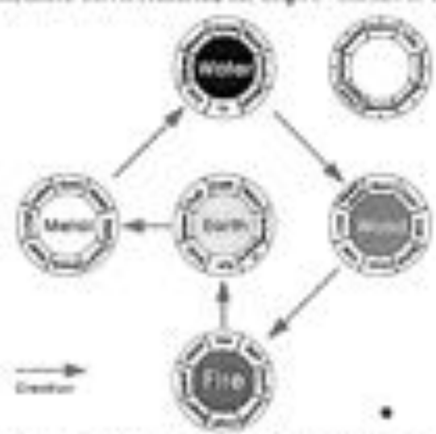


figure 3: Conjoint diagrams of five colors, five orientations, four seasons, five sounds, five solid viscera, and five regularities of Five-Essence reciprocal generation (Creative) Model

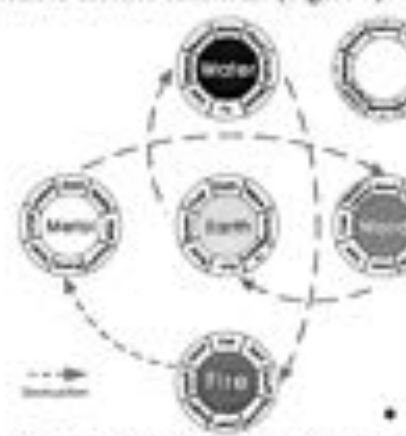


figure 4: Conjoint diagrams of Same components of Five-Essence Reciprocal Restriction (Destructive) Model

ii. The Destructive Essence: The destructive essence is preventative for the most part. It is the avoidance of the elements that work against one. Again, using a person whose personal data indicates he is Wood, wishes to prevent destructive forces from entering his life. He would notice that the Essence Metal is the source of his destructive energy, and as such would wish to avoid the color White. (Figure 4)

(3) Color Selection and Combination Methods by Means of Five-Essence Theory---The five essences cycle in the four seasons. Therefore, in four seasons, gold, wood, water, fire, and earth multiply endlessly. Based on Heaven Bodies and the bad sign circulation theory of prosperity and decline of five essence, there are three selection models that apply Chinese philosophy for color combination as follows:

i. Pursue after mean equilibrium---of same class.
ii. Reciprocally supplementing (growth and nature's nourishing) ---give birth to me; I live .
iii. Reciprocal restriction (restraint)---destroy me; I destroy.

First, The chart below (Figure 5) shows the procedure for properly utilizing the Five-essence Theory. Once one's essence attribution is determined, one chooses the manner in which he will attempt to change his life, in this case, color. Then, keeping one's purpose in mind, one will decide if a creative or destructive theory is the best possible course of action. Alternatives are discovered and finally, a color is selected.

Figure 5: Color selection and combination process by means of personal data through Five-essence Theory

5. CONCLUSION

Since color is a visual category it is easier for practitioners to use, it is easy to change the color appearance of one's immediate environment. Five-essence Theory is a quasi-rational conceptual model with practical applications. It has yet to be validated by empirical studies, although it is indeed deeply rooted in Chinese culture and consciousness.

REFERENCES

Chiazzari, S., *The Complete Book of Color: Using Color for Lifestyle, Health, and Well-being*, Dorset: Element, Shaftesbury, 1999.

Gage, J., *Color and Meaning: Art, Science, and Symbolism*, University of California, California , 1999.

Gerritsen, F., *Theory and Practice of Color: A Color Theory Based on Laws of Perception*, Van Nostrand Reinhold, New York, 1983.

Hang L. & Hang Y., *Fenghua and City. Tientsin*, Ban Hua Literary, China, 1999.

Klotsche, C., *Color Medicine: The Secrets of Color/Viberational Healing*. Light Technology Publishing, Sedona , 1999.

Kobayashi, *Color System*, Kodansha, Tokyo, 1999.

Lee T. R., "A Study of Color Choosing and Matching Methods with Rationales", 2001 Color Conference Proceeding, 73-86, Taipei, 2000.

Lin Y. H., *Newest Eight Characters Fortune Telling*, Ta Fu Bookstore, Taiwan, 1994.

Mahnke, F., *Color, Environment, and Human Response*, Van Nostrand Reinhold, 1996.

Rossbach, S., & Yun, L., *Living Color: Masteer Lin Yun's Guide to Feng Shui and the Art of Color*, Kodansha International, New York, 1994.

Walker, M., *The Power of Color*, Avery, New York, 1991.

* Correspondence: trlee@mail.pccu.edu.tw; phone 8862-2861-5945; fax 8862-2861-5594; Center for Information & Communications, Chinese Culture University, 55 Hwa-Kang Rd. Taipei, Taiwan, 111 R.O.C.

Mood-perception of interior colors in a gym

Haruyo Ohno*, Naoko Koizumi*
Otemae university

ABSTRACT

When people enter a gym, they feel more like exercising in some cases than other cases. The interior color of the space may be a contributing factor. This paper discusses how the interior color of a gym affects female subjects in their twenties and forties to fifties both physiologically and psychologically.

Keywords: interior color, mood-perception, aerobic exercise, POMS,

1. INTRODUCTION

In the rapidly aging society of Japan[1], the number of people aged 65 or over exceeds 17.1% of the population, with lifestyle-related diseases due to lack of exercise soaring. The author considers that building spaces with consideration to health improvement should provide a comfortable environment that encourages people to continue regular exercise, in order to maintain lifelong mental and physical health [3-5]. In this study, several colors were examined as interior colors for spaces in which people who intend to improve their health can exercise comfortably. Cases involving competition were excluded.

2. TEST PROCEDURE

Tests were conducted in two series for items given in Table 1. The subjects were females in their twenties and forties to fifties who constantly took exercise. The examined interior colors were red, blue-purple, yellow-red, green, wood paneling, black, white, and gray. The psychological and physiological states of the subjects were measured three times: before they entered the experiment space, before they began to exercise in the space, and after they finished exercising for 60 minutes. Their psychological state was assessed by the Profile of Mood State (POMS)[7], and the physiological measurements included stature, body weight, blood pressure, body temperature, heart rate, and the number of steps. They exercised for 1 hour once a week.

Table 1: Research/measurement items

Research/measurement items	Before entering the room	In the room	
		Before exercise	After exercise
Interior color preference		O	O
POMS evaluation	O	O	O
Stature	O		
Body weight	O		
Blood pressure	O	O	O
Body temperature	O	O	O
Heart rate	O	O	O
No. of steps			O
Test time	Winter (March)		
Exercise (once/week)	Type	Aerobic exercise (low impact), Resistance exercise	
	Time	60 min (10:00-11:00)	
Test I	White (N 7.5), gray (N 5), black (N 1.5 ~ 2), wood paneling (7.5 YR 6/8) Floor: wood (5 YR 7/5)	20s: 16 people 40s-50s: 14 people Room temp. : 15-17°C, Relative humidity: 50-60%	
Test II	Red (5 R 4/14), blue-purple (5 PB 3/10), yellow-red (7.5 YR 7/14), wood paneling (7.5 YR 6/8), green (5 G 4/8) Floor: wood (5 YR 7/5),	20s: 8 people 40s-50s: 14 people Room temp. : 15-17°C, RH: 50-60%, Illuminance: 400-500 lx (artificial + daylight)	

POMS evaluation was made three times: before entering the space, before beginning exercise in the space, and after finishing exercise. During the exercise, the subjects faced the instructor. The subjects in their forties to fifties had done such exercise for 8 to 10 years. The research investigated psychological influence of the interior color from the relationship

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

between the color preference of the subjects and POMS[3,4]. POMS simultaneously analyzes the scales of six moods to evaluate the state of each subject's feeling that changes depending on her condition: T-A (tension-anxiety), D (depression), A-H (anger-hostility), V (vividness), F (fatigue), and C (confusion). Fifty or more on the V scale was rated "normal," while less than 50 "needs special attention." For other scales, less than 60 was rated "normal," between 60 and 70 "needs special attention," and 70 or more "needs diagnosis." When the profile of these points resembled an iceberg with a high point on the V scale, the color of the space was assessed as being favorable. Figure 2 shows the heart rate of subject TS for 10 minutes before entering the exercising room, before beginning exercise in the room, during exercise and after finishing exercise.

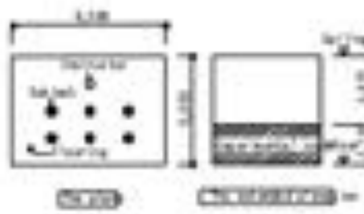


Figure 1: Plan and elevation of gym

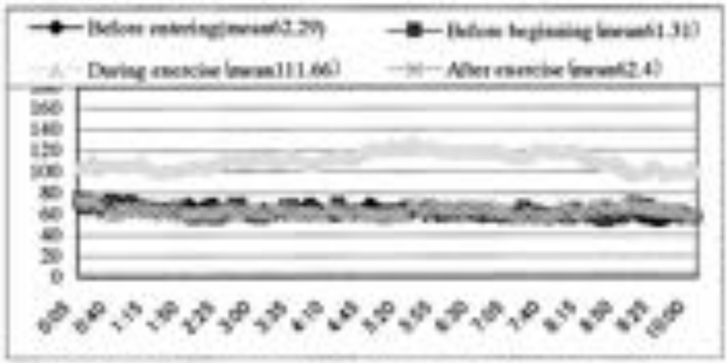


Figure 2: The heart rate of subject TS in their 20s using yellow-red.

3.A RESULTS AND DISCUSSION

3.1 Achromatic colors

1) Ratings of interior colors

Table 2 gives the subjects' ratings of interior colors for the exercising space. Those in their twenties rate d the gray space low, while preferring colors that do not stand out and natural wood colors for an exercising space. Subjects in their forties to fifties preferred light colors, such as cream and pale pink, and few cited achromatic colors.

Table 2: Assessment of interior colors of exercising space

	Examined color	20s	40s-50s
Test I	White	Glaring and sickening; cool; eye-irritating; nauseating, easier to exercise than black and gray; eye-irritating and causes eye ache	Glaring and aching to look at, slightly nauseating; cold
	Gray	Better than black but not encouraging, better than black; cannot concentrate; discouraging	Feel pressure; calm
	Black	Not feel like exercising; no satisfaction after exercise; suffocating and small; soothing; discouraging	Dark; feel depressed; feel down-hearted; worried
Test II	Red (5 R 4/14)	Feel eye ache (87.5%); feel headache (25%); eye-irritating (12.5%); cannot concentrate (12,5%); feel sick (12.5%)	Feel eye ache (50%); cannot concentrate (17.6%); feel headache (14%); feel sick (7%); eye-irritating (7%)
	Blue-purple (5 PB 3/10)	Feel sick (12.5%);	Feel headache (8%)
	Yellow-red (7.5 YR 7/14)	Eye-irritating (25%); cannot concentrate (12.5%)	Feel eye ache (23%); feel headache (23%); cannot concentrate (8%)
	Green (5 G 4/8)		Another type of green would be better, feel unsettled; dark
	Wood (7.5 YR 6/8)	Easier to exercise than achromatic colors; sleepy	Feel eye ache

2) POMS evaluation of subjects in their 20s

POMSs before and after entering the room were compared using the medians of the answers by all subjects for Test I. When the interior of the exercising room was white, the POMS profile showed the shape of a W before entering the space, with points for T-A, F, and C being slightly high. After entering the space, the po ints decreased on all scales and settled to show similar profiles. When the interior color was black, the points for T -A, F, and C were high before entrance, and the points were the same after entrance. The results were similar for gray. After exercise, a n iceberg-shaped profile was achieved in a white room with an increase on the V scale and decreasing levels on other scales. When the room was black, V increased, but T-A, F, and C also increased to form a V-shaped profile. In a gray room, V increased and T-A, D, A-H, and C decreased to show settlement, but the profile formed a V with a high point on the F scale. In the case of wood paneling, V increased while others decreased, showing an iceberg shape, which indicates a very favorable state of feeling. Accordingly, white and wood paneling exhibited the effect of exercise, whereas black and gray led to V-shaped profiles, in which A-H was the lowest, instead of iceberg profiles.

3) POMS evaluation of subjects in their 40s-50s

Figure 4 shows the medians of POMS evaluations in Test 1. When comparing the POMSs before and after exercise, V slightly increased in a white room but D, F, and C also increased. This led to a V -shaped profile instead of an iceberg, indicating no effect of exercise. In a black room, V increased while T-A, D, and A-H decreased to show psychological settlement, but the profile formed the shape of a V, with an increased F. In the case of a gray interior, T -A, V, and F increased to form a V-shaped profile. In a room with wood paneling, V rema ined the same but others decreased with an increase in F, leading to an iceberg profile. Accordingly, wood paneling was found to bring about a proper effect of exercise, whereas white, black, and gray interior did not lead to favorable iceberg profiles but V-shaped profiles, with A-H being the lowes.

3.2 Chromatic colors

1) Ratings of interior colors

Table 2 gives the subjects' ratings of interior colors for the exercising space. Most subjects in their twenties complained of sore eyes, headaches, and a negative feeling after exercising in a red room. They also found physical problems after exercising in yellow-red and blue-purple rooms. Younger subjects preferred colors that did not stand out or colors of natural trees. Middle-aged subjects similarly felt physiological discomfort in red, yellow-red, and blue-purple rooms. They preferred light colors, such as cream and pale pink for an exercising space.

T-A(tension-anxiety), D(depression), A-H(anger-hostility), V(vividness), F(fatigue), C(confusion)
①Before entering ②Before beginning exercise ③After finishing exercise

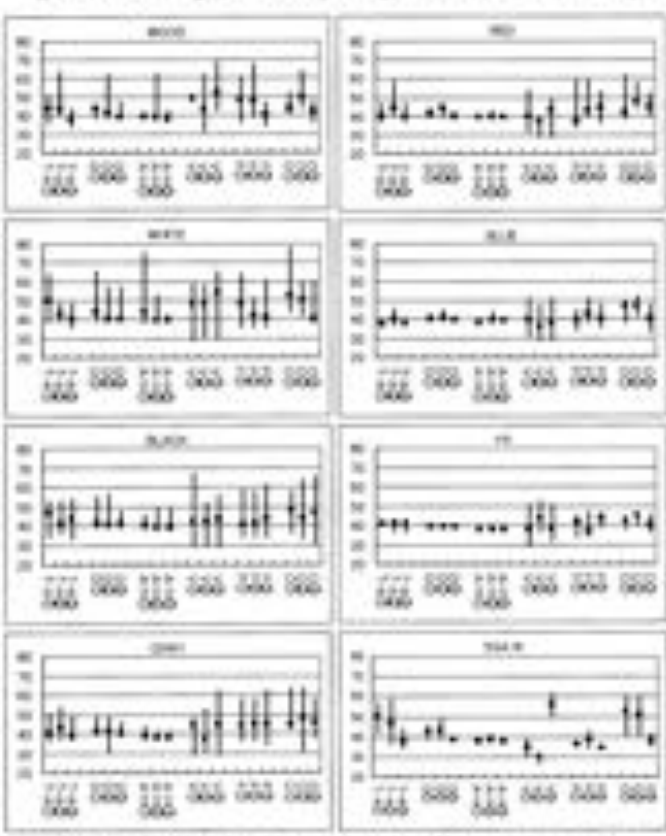


Figure 3: Medians of answers from subjects in their 20s.

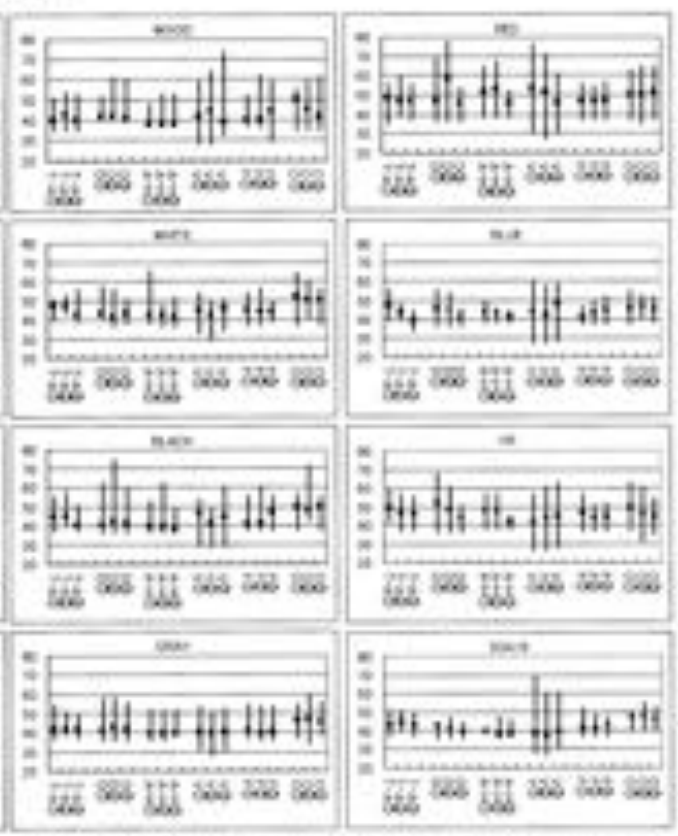


Figure 4: Medians of answers from subjects in their 40s-50s.

2) POMS evaluation of subjects in their 20s

Figure 3 shows the medians of answers from subjects in their twenties. In the case of wood paneling, F and C were slightly high before exercise, but V increased after exercise, forming an iceberg profile indicating a state of favorable psychological condition of the subjects. The exercise was therefore considered properly effective. When the subjects entered a red room, V decreased while T-A, D, and C slightly increased. After exercise in the red room, V turned up higher than before entrance, but T-A and C were as low as before entrance, not showing an iceberg profile. Accordingly, a red space is found to induce a psychologically unfavorable feeling the moment the subjects enter the space. Though V slightly increases after exercise, red is not a color that produces a favorable effect of exercise. Blue-purple caused V to decrease and T-A, D, A-H, and F to increase after the subjects entered the room. Though V slightly increased after exercise, it was lower than the level before entering the exercising space. T-A, D, A-H, and F after exercise increased to the levels before entering the space. Similarly to red, blue-purple is an interior color that produces a psychologically unfavorable effect the moment the subjects enter the space. Though V slightly increases after exercise, the value remains lower than that before entering the blue -purple space. Blue-purple does not form an iceberg profile or produce a favorable effect of exercise. In the case of yellow-red, V and C increased after the subjects entered the space, while F decreased. Exercise reduced V to the same level as that before entrance, increased F to a level higher than that before entrance, and reduced C. Yell ow-red is a color that spurs people to do exercise, but causes them to feel only tired after exercise. It does not show an iceberg POMS or produce any favorable psychological effect of exercise.

3) POMS evaluation of subjects in their 40s to 50s

Figure 3 shows the medians of the POMS evaluation of subjects in their 40s to 50s. In a room with wood paneling, the points on D and C scales were high before exercise, but these decreased after exercise, resulting in an iceberg profile with a high V value, indicating a psychologically favorable change of the subjects. This suggests that wood paneling produced a proper effect of exercise.

When the interior color was red, V slightly decreased and D increased after the subjects entered the space. After exercise, F and C slightly increased while the points on the other scales all decreased, showing no iceberg profile. Accordingly, red is an interior color that disturbs people's psychological condition, and exercising in such a room further dismays them. Entering a blue-purple room caused ratings on T-A, D, A-H, and V scales to decrease, while F and C slightly increased. After exercise, V slightly turned up, but the scale value was low, indicating no favorable effect of exercising. In the case of yellow-red, V increased and others decreased when the subjects entered the space. After exercise, V slightly increased but not higher than other scales, forming no iceberg profile that indicates psychological effectiveness of exercise. Yellow-red is therefore not desirable as an interior color for an exercising space.

4.Conclusions

Interior colors of gyms were examined to obtain data about interior environments conducive to lifelong comfortable exercise. As a result, the following were found:

1) The preference for achromatic colors of subjects in their 20s differed from the preference of those in their 40s to 50s, but both age groups liked white. Differences were also found in the taste for chromatic colors.
2) Many preferred light and pale colors that were soothing to the eye for the interior color of an exercising space. Few preferred achromatic colors.
3) The tendencies of POMS evaluations of individuals tended to be similar to one another.
4) Wood paneling evidently produces a favorable psychological effect on those in their 20s but not so much on those in their 40s to 50s.
5) Black and gray were found to be discouraging interior colors by POMS evaluation, and exercise did not offset the unfavorable feeling in the color environment, providing little satisfaction to both age groups.
6) Both age groups felt depressed by just entering a red space and a blue-purple space. Exercise did not produce any psychological effect to offset the unfavorable feeling in the color environment.
7) Yellow-red encouraged people who entered the space, appearing to be good for exercise, but the ratings were not improved by exercise, with little feeling of satisfaction.

Exercise-related facilities to be constructed should provide an environment that is not only safe to use but also induces a comfortable feeling after exercise. In that sense, architects' desire to emphasize uniqueness of color design may pose a problem particularly for public buildings for use by many people.

REFARENCES

1)McNair DM, Lorr M, Droppleman LF: Profile of Mood States, San Diego; Educational and Industrial Testing Service.1992

2)White paper; Annual report on health and welfare1999/2000:Organization of the Minister of Health and Welfare (20015)

3)Edited by William P. Morgan; Physical Activity and Mental Health, 1999.

4)Haruyo Ohno : Evaluation of colors used for housing environment, Journal of the color science association of Japan, vol.19,supplement.no.1,pp.114-115(1995)

5)Haruyo Ohno, Naoko Koizumi :A Study on the Mood/Perception of Interior Colorraning Achromatic-colors In an Exercise Room color forum Japan 1999 proceeding,167-170(1999)

*ohnoh@otemae.ac.jp; phone +81-727-70-6334;fax +81-727-70-6916; Faculty of socio-cultural studies, Otemae university,2-2-2,Inano,Itami,Hyogo,Japan 664-0861

Numerical expression of colour emotion and its application

Tetsuya Sato*, Kanji Kajiwara*, John Xin**, Aran Hansuebsai***, Jim Nobbs****
* Kyoto Institute of Technology, ** Hong Kong Polytechnic University, *** Chulalongkorn University,
**** University of Leeds

ABSTRACT

Human emotions induced by colours are various but the emotions are expressed through words and languages. In order to analyse the emotions expressed through words and languages, visual assessment tests against colour emotions expressed by twelve kinds of word pairs were carried out in Japan, Thailand, Hong Kong and UK. The numerical expression of each colour emotion is being tried as a formula with an ellipsoid-shape resembling that of a colour difference formula. In this paper, the numerical expression of 'Soft-Hard' colour emotion was mainly discussed. The application of colour emotions via the empirical colour emotion formulae derived from *kansei* database (database of sensory assessments) was also briefly reported.

Keywords; Numerical expression, colour emotion, cross-culture comparison, colorimetric method, IT

1. INTRODUCTION

Colour physicists have been trying to derive a numerical visual scale with physical viewpoint while colour psychologists have been investigating colour perception and human behaviour with psychological viewpoint. The interface connecting physical and sensational parameters is very important. However, there is a big gap between the two areas. The main target of colour physicists is focused on colour itself, and that of colour psychologists is focused on human brain.

In order to analyse the mechanism of colour perception and cognition in brain, it is necessary to have quantitative scales. Word is the output of the colour perception, cognition and feeling and it is the most useful key for communication. Therefore, our research group is paying attention to words and languages. We investigated the use of the colour emotional words such as *deep*, *warm* and *soft*, which describe psychological sensations [1], and also we have been trying to derive visual scales of the psychological sensations [2-5]. These scales were numerically expressed as empirical formulae based on CIELAB and Munsell colour systems. With the scales, the magnitude of human colour emotions can be predicted through an instrumental method.

Unfortunately, real visual scales are not only corresponding to only the scales expressed by the colour systems and their parameters. The human emotions induced by colours might be different. One way of deriving visual scales to express colour emotions is to utilise the quantitative relationship between the colorimetric values and visual assessments.

On the other hand, there is a need for colour communication systems through multimedia are needed. Developments of colour communication systems have been achieved in the domains of communicating colour and image not the emotions or our feelings induced by colours. Generally, feelings are communicated through words and languages. In this paper, the application of the colour emotions via the empirical colour emotion formulae derived from *kansei* database is reported.

2. NUMERICAL EXPRESSION OF COLOUR EMOTION

The empirical colour emotion formulae have been derived in our current and previous researches [2-5]. These formulae predict the magnitude of human emotion induced from a colour. The initial work on the numerical expression of the colour emotions included 12 *kansei* word pairs is in shown Table 1.

Each colour emotion was numerically expressed as a formula with an ellipsoid-shape resembling that of a colour difference formula. A larger colour emotion value indicates a stronger colour emotions induced. The generic formula of the visual scale for colour emotion in the CIELAB colour space is given as the following;

$$CE = [\{k_L(L^*-L^*_O)\}^2+\{k_a(a^*-a^*_O)\}^2+\{k_b(b^*-b^*_O)\}^2]^{1/2}+k_M \quad (1)$$

where, CE is the predicted value of a colour emotion, L^* is CIELAB metric lightness, C^* is CIELAB metric chroma, L^*_O, a^*_O, b^*_O are CIELAB L^*, a^* and b^*, when the colour emotion is at its minimum, k_L, k_a, k_b are the constants of the contribution of CIELAB L^*, a^* and b^*, and k_M is the constant for scaling

Table 1 *Kansei* word pairs used for visual assessments

Symbol	Japanese	English	Thai	Chinese (Cantonese)
DP	Koi - Awai	Deep - Pale	Khem - Jang	Sem - Tsin
DYP	Dootekina - Seitekina	Dynamic - Passive	Kloenwai - Sangobning	Dung - Zing
DV	Hakkirishita - Bonyarishita	Distinct - Vague	Dodden - Seod	Tsing sik - Moo wu
GP	Hadena - Jimina	Gaudy - Plain	Choodchad - Reab	Zak Jim - Pok sou
HL	Omoi - Karui	Heavy - Light	Nuck - Bow	Zung - Hing
LD	Akarui - Kurai	Light - Dark	Sawang - Mued	Gwong - Em
SH	Yawarakai - Katai	Soft - Hard	Numnual - Kangkradang	Jau jyn - Gin ngang
SS	Medatsu - Medatanai	Striking - Subdued	Chadjan - Kamukkamoe	Dyt muk - Jau wo
SW	Tsuyoi - Yowai	Strong - Weak	Khemkang - Oanaer	Koeng - Joek
TT	Sunda - Nigotta	Transparent - Turbid	Prongsai - Tueb	Tung tau - Wan zuk
VD	Azayakana - Kusunda	Vivid - Dull	Sodsai - Mon	Sin ming - Em tam
WC	Atatakai - Tsumetai	Warm - Cool	Roo - Yen	Nyn - Lang
Assessed in	Japan	UK	Thailand	Hong Kong

3. APPLICATION OF THE NUMERICAL EXPRESSION OF COLOUR EMOTION

Currently, the keyword of the application of colour technology is *colour communication*. The colour communication is to reproduce colours and to manage colours. Especially, it is the most important to communicate colour images accurately. While the current application of colour communications are in the domain of colour reproduction accuracy and colour management, it is suggested in this study the communication of colour emotions induced by colours, in addition to the communication of colours. With *kansei* database and colour emotion formulae, we envisage the development of some useful tools for *Information Technology*. Colour emotion scales obtained can be transformed to CIELCh, CIELAB, XYZ, and RGB values through a reverse operation, which can be output as colours by display devices [5,6]. This colour output can be used by applications such as product design and development, which can then be further extended to applications on Internet. The process of the application is shown in Figure 1.

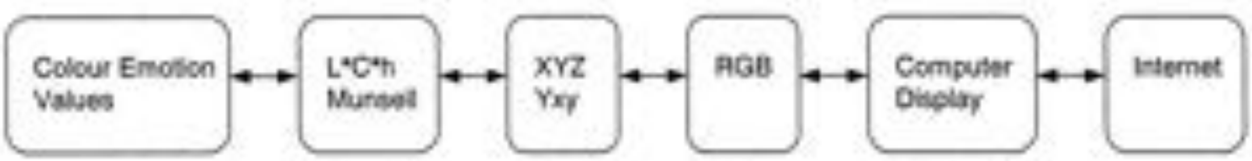


Figure 1 Process for the expression of colour emotions on a computer display and Internet

4. APPLICATION OF THE CROSS-CULTURE COMPARISON

It is not so easy to communicate feelings between two languages, especially the magnitudes of the feelings, and in general, a word of one language has no unique counterpart in other languages. How can we communicate the magnitude of colour emotion on a cross-culture platform?

As an example, the formulae of 'Soft-Hard' colour emotions in Japan, Thailand, Hong Kong and United Kingdom, which were derived from the relationship between visual assessments and CIELAB values of colour samples, are shown as followings;

$$SH_{JP} = [(3.2L^*)^2+\{2.4(1-\Delta h_{290}/360)C^*\}^2]^{1/2}-180 \quad (2)$$
$$SH_{TH} = -[\{3.5(L^*-100)\}^2+\{2.0(1-\Delta h_{290}/360)C^*\}^2]^{1/2}+155 \quad (3)$$
$$SH_{HK} = [(3.2L^*)^2+\{1.0(1-\Delta h_{290}/360)C^*\}^2]^{1/2}-180 \quad (4)$$
$$SH_{UK} = -[\{2.9(L^*-100)\}^2+\{2.5(1-\Delta h_{290}/360)C^*\}^2]^{1/2}+155 \quad (5)$$

where, JP, TH, HK and UK are Japan, Thailand, Hong Kong and United Kingdom, respectively.
L^* : CIELAB metric lightness
C^* : CIELAB metric chroma
Δh_{290} : CIELAB metric hue-angle difference from h=290, $0 \leqq \Delta h_{290} \leqq 180$

Table 2 shows the correlation coefficients between the visual assessments of the four countries and the instrumental predictions by the formulae. The correlation coefficients between visual and instrumental assessments were around 0.9. Therefore, the formulae will be able to be applied to the objective assessment of 'Soft-Hard' colour emotion through colorimetric method.

Table 2 The correlation coefficient between visual and instrumental 'Soft-Hard' colour emotion assessments

	JP	TH	HK	UK
Correlation coefficients	0.913	0.855	0.927	0.882

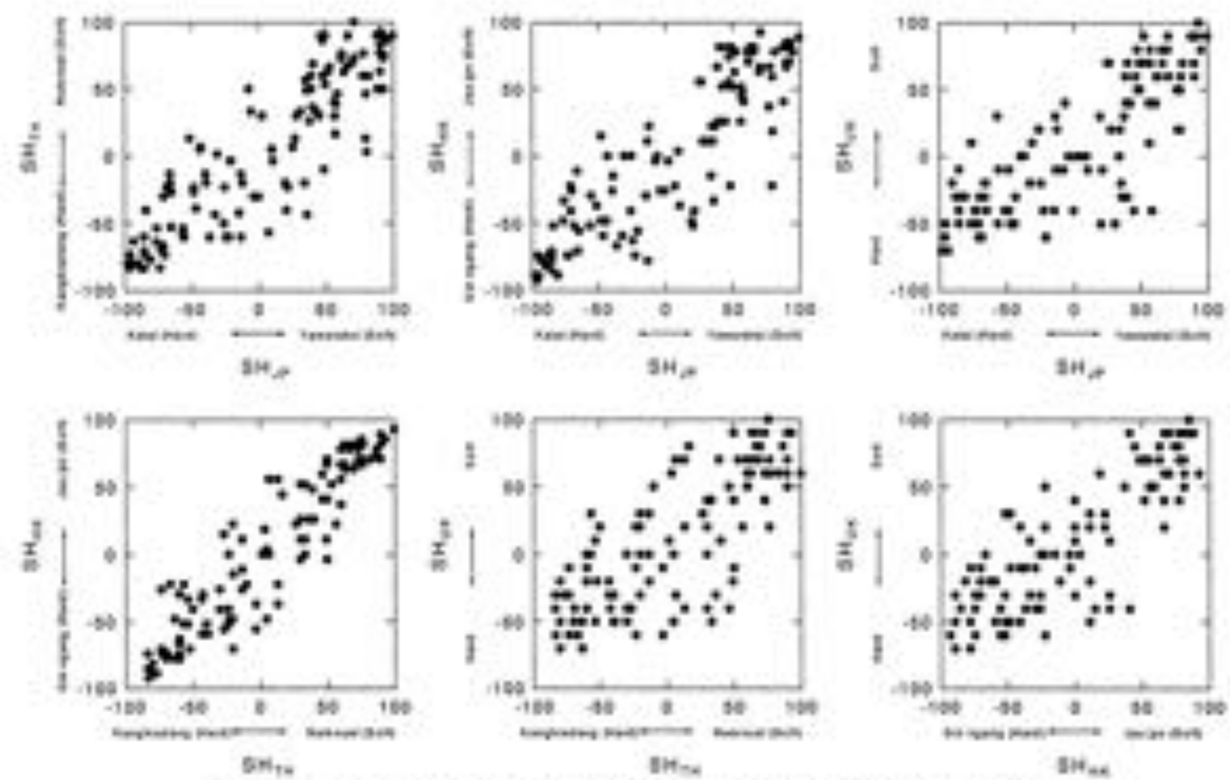


Figure 2 The comparison between 'Soft-Hard' assessments obtained in four countries

Figure 2 shows the relationships between visual assessments carried out with the same colour samples in the four countries. The size of colour samples was 114, and the numbers of observers were 60, 60, 60 and 30 in Japan, Thailand, Hong Kong and UK, respectively. The most 'Soft' colour areas in the four data sets were the same as high lightness colours near white, and the most 'Hard' areas were low lightness colours near black in all of the four countries. But, on the whole, the magnitudes of the emotions were a little different. The highest similarity was found in the relationship between Thai and Hong Kong 'Soft-Hard' emotions. The lowest one was found in the relationship between Thai and UK.

The correlation coefficients between visual assessments obtained in two countries were given in Table 3. Additionally, the correlation coefficients between instrumental assessments predicted through the colour emotion formulae were also given in Table 3. The high correlation between instrumental assessments means that the colour emotion formulae can be applied to the quantitative translation of colour emotions based on colorimetric values.

Table 3 The correlation coefficient between 'Soft-Hard' colour emotion assessments obtained in four countries

	JP-TH	JP-HK	JP-UK	TH-HK	TH-UK	HK-UK
Visual assessment	0.879	0.876	0.817	0.933	0.784	0.850
Instrumental assessment	0.949	0.986	0.907	0.987	0.990	0.960

5. SUMMARY AND FURTHER STUDY

Comparing the *kansei* databases collected in the four countries, we should find the similarity and discrepancy among the results. This study on 'Soft-Hard' colour emotion and our recent studies showed that some colour emotions were not identical. However, the comparison and conversion can be obtained through the use of colour emotion formulae. The understanding of differences in colour emotions and the use of this knowledge in the development of new products are very important.

As further studies, the discrepancy and similarity among the databases should be analysed in details. The analysis will be useful to make way for estimates of the cultural influence of each country. But the *kansei* database used in this study is not enough to discuss about the details of the influence from culture. Because just only one database in a country was used in this study, and the observers' age was around twenty years old. Many *kansei* databases should carefully be collected, and the databases should be analysed more quantitatively with objective viewpoints.

REFERENCES

1. T.Nakamura, T.Sato, K.Teraji, and T.Fukuda, Arrangement of Color Image Words into the Non-Luminous Object Color Space (*in Japanese*), *Journal of the Color Science Association of Japan*, **18**, p.10-18, 1994
2. T.Nakamura, H.Hoshino, T.Sato, and K.Kajiwara, Numerical Evaluation of Colour Image Words on Colorimetry, *Proceedings of the 8th Congress of the International Colour Association*, Kyoto Japan, p.699-702, 1997
3. T.Sato, K.Kajiwara, T.Nakamura, and H.Hoshino, Quantitative Evaluation and Categorising of Human Emotion Induced by Colour, *Advances in Colour Science and Technology*, **3**, p.53-59, 2000
4. T.Sato, K.Kajiwara, J.H.Xin, A.Hansuebsai, J.Nobbs, Methodology for Deriving Visual Scale Based on Colour Emotion, *Proceeding of Colour and Visual Scales 2000*, Egham U.K., 4 pages, not paginated, 2000
5. T.Sato, K.Morimoto, K.Kajiwara, and T.Kurokawa, Development of Sportswear Design Assisted System Based on Numerical Expression of Colour Emotion (*in Japanese*), *Descente Sports Science*, **21**, p.27-42, 2000
6. T.Sato, K.Kajiwara, H.Hoshino, T.Nakamura, J.H.Xin, A.Hansuebsai, and J.Nobbs, Application of Numerical Expression of Colour Emotion, *Proceedings of the AIC Midterm Meeting*, Seoul Korea, p.130-132, 2000

Correspondence: * tsato@ipc.kit.ac.jp; phone/fax +81 75 724 7578; http://res.ipc.kit.ac.jp/~tsato/sato/menu.htm; Dept of Design Engineering and Management, Kyoto Institute of Technology, Matsugasaki, Sakyo-ku, Kyoto 606-8585, Japan

Study on Sports and Colors
-The Color Effect of Team Shirts on Basketball Games-

Masanori IWASE , Science University of Tokyo

ABSTRACT

The research for basketball has been focused upon the color effect on the team shirts by means of sports and colors. University basketball club members and university students (who did not belong to the university basketball club members) participated in this study. Colors of team shirts were analyzed by A.H. Munsell's method (Hue ,Value, Chroma) . To each of four games were given four different color conditions : The first is on condition that players of both teams wore different five-colored team shirts (white, red, blue, green, orange). The second is on condition that all players of both teams wore white team shirts. The third is on condition that all players of the one team wore red team shirts and the others wore orange. The fourth is on condition that all players of the one team wore blue team shirts and the others wore green. The questionnaire, the number of shots, and passes were analyzed of statistics (x^2 :l × m contingency table) on the above mentioned conditions.

The results were as follows :

1) The number of successful shots that university basketball club members made were higher than university students.

2) The number of unsuccessful passes that university students made were higher than university basketball club members.

3) Analyzed by statistics (x^2:l × m contingency table), the apparent distinction of the color effect was not found.

These results could be due to players requirements of momentary judgment such as their recognition of the other players face or voice. This seems to depend upon different factors of the subject himself on a physical strength level as well as on a technical level.

Key words: Sports , color of team shirts

INTRODUCTION

The research for basketball has been focused upon the color effect on the team shirts by means of sports and colors. University basketball club members and university students participated in this study.

PURPOSE

Comparisons between university basketball club members and university students team shirt colors and the effect on the number of successful and unsuccessful shots, as well as the number of successful and unsuccessful passes.

METHOD

Colors of team shirts were analyzed by A.H. Munsell's method (Hue ,Value, Chroma) (See Table 1). Each of the four games were given four different color conditions. The first condition is that players of both teams wore different colored team shirts. Each team member wore a shirt of the following colors:white, red, blue, green, and orange. The second condition is that all players of both teams wore white team shirts. The third condition is that all players of one team wore red shirts and the other team wore orange. The fourth condition is that all players of one team wore blue shirts and the other team wore green (See Table 2). A Total of eight games were played (four games twice). The duration of each was 10 minutes. Hypothesis is as follows: In the first condition, where there are many shirt colors on the court, few passes will be made, few passes will be successful, and few shots will be attempted. In the second and third conditions, the number of shots will increase and the number of unsuccessful passes will decrease. In the fourth condition, many shots and passes will be attempted and many passes will be successful (See Figure 1). The questionnaire, the number of shots, and passes were analyzed by statistics (x^2 : 1 × m contingency table) on the above mentioned conditions.

Table 1. The Color (Hue Value/ Chroma) of Team Shirts

Color	Hue Value / Chroma (A.H. Munsell)
white	9.74 PB 8.83 / 1.94
red	6.15R 4.35 / 12.62
blue	6.06PB 2.99 / 7.47
green	9.91GY 5.98 / 11.42
orange	9.68R 6.27/ 14.32

Table 2. The Color Condition of Game

Condition	Team Shirts Color	
condition 1	white · red · blue · green · orange	white · red · blue · green · orange
condition 2	All white	All white
condition 3	All red	All orange
condition 4	All blue	All green

Figure 1. Hypothesis

RESULT AND DISCUSSION

By analyzing the results of statistics (χ^2) , no apparent distinction can be made on the effect the color (See Figure 2 and Figure 3). The results of the four conditions have been divided into four categories: successful shots, unsuccessful shots, successful passes, and unsuccessful passes.

Successful Shots:

The basketball club members dominated the number of successful shots. They made more successful shots than the university students. Hypothesis that the number of successful shots would increase in the order of the conditions (1, 2, 3, 4). That is, condition four should have the highest number of successful shots and condition one should have the least. The results were quite different and the most successful shots occurred in condition one for the basketball club members. The results for the most successful shots for the basketball club members were in the order of conditions one, four, two, and three. The results for the most successful shots for the university students were in the order of conditions two, four, one, and three.

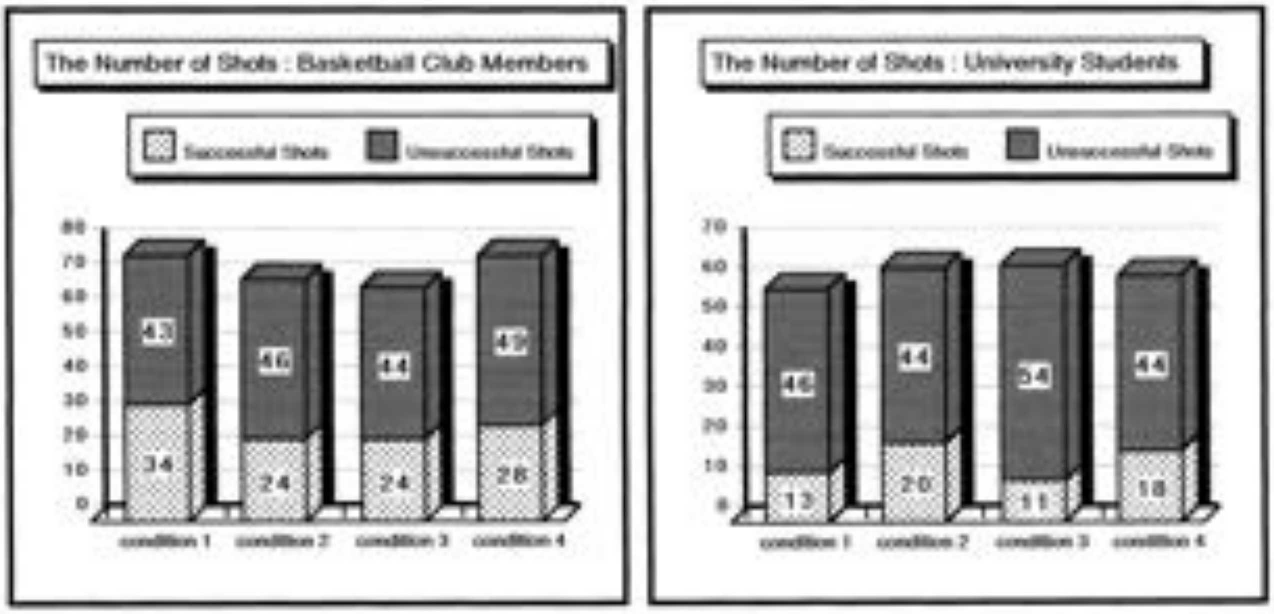


Figure 2. The Number of Shots

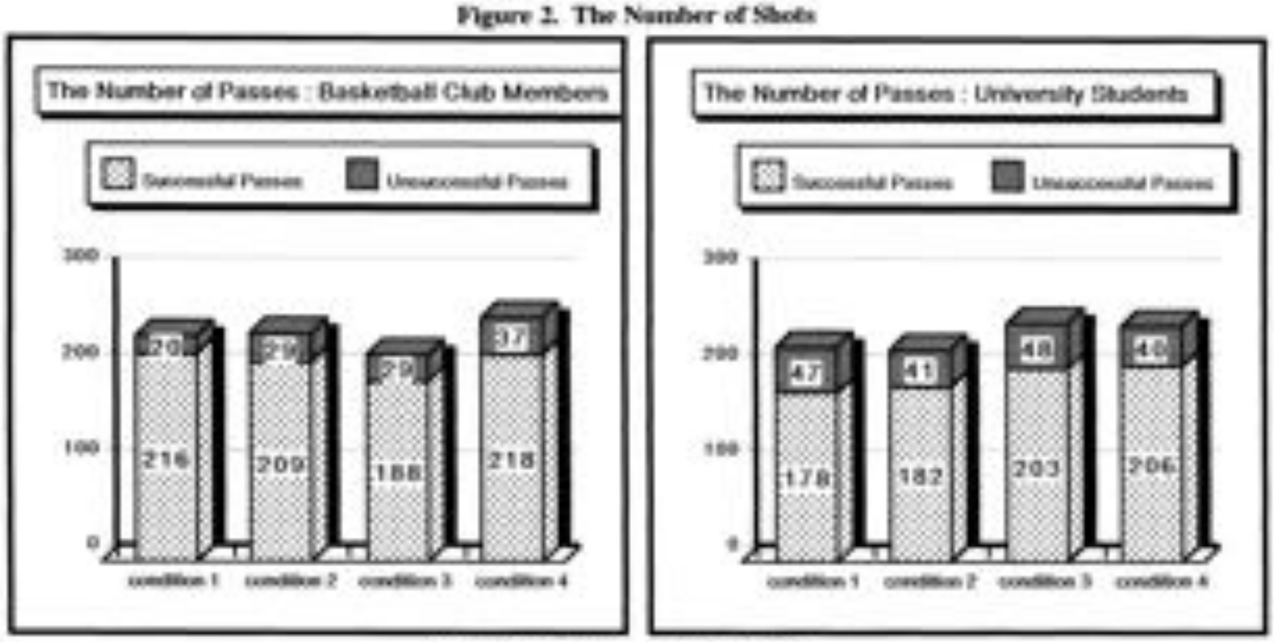


Figure 3. The Number of Passes

Unsuccessful Shots:

University students missed the most shots in condition three and the basketball club members missed the least in condition one. The predicted outcomes of the four conditions were one, two, three, and four with condition one having the most misses and condition four having the least. The basketball club members missed the most in condition four when it was expected that they would have missed the least. The basketball club members also missed the least in condition one when many shot errors were predicted.

Successful Passes:

The basketball club members held the highest number of successful passes in condition four. This was in direct agreement with hypothesis. However, they also had the second highest number of successful passes in condition one, which was predicted to be the lowest. University students completed the least number of passes in condition one, which was expected.

Unsuccessful Passes:

Two categories emerged in the results of the unsuccessful passes: the university students and the basketball club members. The university students missed the most passes but did so in condition three. It was predicted that this would have happened in condition one. Oddly, the basketball club members missed the least number of passes in condition one where it was predicted that they would miss the most passes.

Several factors that come into play and must be considered are player's physical strength, his endurance, and technical skill. Background colors that are present in the player's field of vision must also be taken into account.

According to the results of statistics (x^2), the apparent distinction of the effect upon the colors has not been found. This would seem to depend upon different factors of the subject himself on a physical strength level as well as on a technical level. Several effects upon background colors should also be taken into consideration.

CONCLUSION

The results were as follows :

1) The number of successful shots that university basketball club members made were higher than university students.

2) The number of unsuccessful passes that university students made were higher than university basketball club members.

3) Analyzed by statistics (x^2:l×m contingency table) the apparent distinction of the color effect was not found.

Colors have an important role in sports. Teams are readily identified by their team shirts color combinations and make it possible for players to easily distinguish teammates from opposing team members. Background colors, such as the stand, fans, floor, team shirts, etc. must effect the player's shots and passes. Furthermore, the player's technique, strength, and experience all weigh heavily in influencing his abilities. Although the team shirts performance enhancing effects did not hold up in this study, the color of equipment used in sports is still of great importance. These results could be due to players requirements of momentary judgment such as their recognition of the other players face or voice. This seems to depend upon different factors of the subject himself on a physical strength level as well as on a technical level.

Future studies must be done to discover the relationships between athlete's performance and colors that surround them. Different color combinations such as black, brown, yellow, etc. and their effects on performance must be investigated. Players' age and ability such as junior high and high school students as well as professionals (NBA) must be evaluated. And finally, the effects of color and the particular sport being played such as soccer, rugby, american football (NFL), ice hockey (NHL), etc. demands further study and understanding.

REFERENCE

Dunwoody, L. : A Methodological Consideration in Color Research, Perceptual and Motor Skills, 72, 1125-1126, 1991.

Iwase, M., Takai, S. : A Color Effect of Uniform on Ball Game, Center for Health and Physical Education Science University of Tokyo Annual Report, 3, 12-18, 1996.
Iwase, M. : The Color Effect of Uniforms on Ball Games (1) - From a Basketball Game by Means of General Students -, Color forum Japan 1998 Proceedings, 45-48, 1998.
Iwase, M. : Study on Validity of Target Marker Line Mitt, Color forum Japan 1998 Proceedings, 163-166, 1999.
Iwase, M., Takai, S., Sugiyama, K. : The Fundamental Research of Memory Ability at a Vision - The Effect of The Presentation Time of a Stimulus on Short-Term Memory -, Study in Liberal Arts and Sciences, 32, 1999
Iwase, M., Takai, S., Sugiyama, K. : The Color Effect of Uniforms on Ball Games (2) - From a Basketball Game by Means of College Basketball Members -, Journal of The Color Science Association of Japan, 24, 1, 11-18, 2000.
Iwase, M. Koga, K. : Study on The Presents Team Shirts Condition of JPB (Japan Professional Baseball), Color forum Japan 2000 Proceedings, 129-132 2000.
Iwase, M. Koga, K. : Study on The Presents Team Shirts Condition of MLB (Major League Baseball), Color forum Japan 2000 Proceedings, 145-148, 2000.
Nakshian, J. S. : The Effect of Red and Green Surrounding on Behavior, Journal of General Psychology, 70, 146-161, 1964.

A New Comparison of Psychological Meaning of Colors in Samples and Objects with Semantic Ratings

Tien-Rein Lee*
Chinese Culture University

ABSTRACT

In color preference and color-meaning research, color chips are widely used as stimuli. Are meanings of isolated color chips generalizeable to contextualized colors? According to Taft (1996), few significant differences exist between chip and object ratings for the same color. A similar survey was performed on 192 college students. This article reports the results of the study comparing semantic rating of color applied to a variety of familiar objects. The objects were a cup, T-shirt, sofa, car, notebook, and MP3 player, all images that represent daily life familiar objects. Subjects rated a set of 16 color chips, against 6 bipolar, 7-step semantic differential scales. The scales consisted of beautiful-ugly, soft-hard, warm-cool, elegant-vulgar, loud-discreet, and masculine-feminine. Analyses performed on the data indicated that unlike Taft's findings on 1996, significant differences existed between chip and object rating for the same color in every scale. The results of the study have implications for the use of color chips in color planning which suggest they are not compatible with the generality of results of the earlier color meaning research. Generally, a color judged to be beautiful, elegant, and warm when presented as a chip does not equal beautiful, elegant, and warm when applied to the surface of an object such as a cup, T-shirt, sofa, car.

Keywords: color, color sample chip, object color, color feeling, color preference.

1. INTRODUCTION

As early as Osgood et al. asked subjects to rate 6 colors on 5 objects (shirt, ice cream, rug, car, and cake mix) and one color spot against 20 semantic differential scales in 1952. Color samples (chips) are used extensively in color communication. Generally, the subject is asked to rank a set of color chips by preference or to rate them against one or more semantic scales. One critical question is arose whether preferences for and meanings of isolated color chips are generalizable to contextualized colors. Trying to improve the longstanding criticisms in color research, only few studies have been conducted to examine the relationship between evaluations of colors applied to chips and to objects. For the color professional wishing to implement empirical findings derived from color preference and meaning studies in his/her daily work, the question of the generality of such research results is of great importance.

Some researches found that color preferences are dependent on the type of object studied (Holmes and Buchanan, 1984). Saito (1983) figured out the comparison of the preference data for chip and automobile colors showed "a fair extent" of context effect. Minato (1977) found that color preference ratings were influenced by the type of product. He concluded that the colors (isolated chips) people prefer most may not be appropriate choices for products if they do not reflect the "character" of the product. According to Taft (1996), generally only few significant differences existed between chip and object rating for the same color.

In summary, it appears that color associations and preferences are at least in part influenced by the object or context to which the color is applied. Appropriateness of colors to objects may be an important factor in determining the correspondence between semantic ratings of isolated color chips and colored objects, as is the semantic scale against which the chip and object are judged.

2. METHOD

Subject–211 college students between the ages of 18 and 25 took part in the study. They were screened for color deficiencies by using the Ishihara Color Vision Test. Six students failed to pass the test, while 13 subjects failed to complete all ratings. Therefore, a total of 192 subjects completed the survey.

Semantics Scale–Six pairs of the 7-step, bipolar semantic differential scales were employed. They are beautiful-ugly, warm-cool, elegant-vulgar, loud -discreet, and masculine-feminine come from Taft's study and the researcher added soft-hard as the sixth pair.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

Color Stimuli–Same format as Taft's study, a set of 16 digital color chips, each measuring 70 X 105 mm, was prepared. Of the colors selected, 8 were chosen to represent an even coverage of the outer edge of the NCS hue circle; 3 colors were of low chromaticness (pink, brown, beige); and 3 were achromatic (black, gray, and white). The colors corresponded to the Berlin & Kay's (1991) 11 basic color terms. The researcher added the magenta as the 16th color. The chips were located against a gray (approximately equal to 18 degree reflectance) background. The names and its distribution in CIE chromacity diagram space for the colors used are shown in Figure 1.

Objects–Color photographs of six objects (designated: cup, shirt, sofa, car, notebook, and MP3 player) were taken by a one-million pixel digital camera. Each of the object photos was then digitally colorized to match the 16 colors of the digital chips. All pictures were then scaled so that the colored surface of the object approximated the size of the chip. Finally, the objects were mounted against a light gray background approximately equal to 18 reflectance). (See Figure 1.)

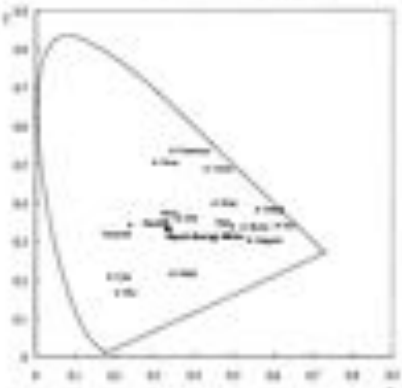


Figure1: Color terms and its plots in CIE chromaticity diagram space.

Figure 2. Stimulus materials: scaled grayscale renderings of objects and chip. 1. Cup 2. T-shirt 3. Sofa 4. Car 5. Notebook 6. Mp3 player.

The chip and the 6 objects were presented on the screen in a random sequence against a light gray background. Objects were familiar, everyday artifacts that the subjects would have had an opportunity to see on a regular basis and in the full range of colors the objects normally appear in.

Procedure–Subjects first received both written and oral instructions about the task. A total of 119 pictures (6 object series and a color chip series consisting of 16 different colors each, plus a series of 7 repeated pictures) were then displayed individually on a 21" Barco PCD 321 Calibrator Talk Monitor. Subjects were requested to "rate the object in the color it appears against each of the 6 scales." No time limit was stipulated. On average, they took about 32 minutes to complete the task. A short break was given midway through the test period, if requested by the subject.

The same object (sample) in 16 different colors was presented as a series of random series. Within the chip and object series, the order of presentation of pictures was randomized. The series were also randomized; however, the repeated pictures were presented after all other series had been displayed. Between presentations of pictures, the screen was black for approximately 2 seconds to reduce after-image effects. The pictures were displayed using the same computer on which they had been produced and edited. Subjects all viewed the pictures in the same room under approximately the same lighting conditions. The monitor were calibrated every 10 subjects.

3. RESULTS

Data consisted of subject ratings on 6 bipolar, 7-step semantic differential scales of 6 objects and one chip, each presented in the same 16 different colors. Each subject rated all 112 pictures (plus 42 repetitions) against all scales. Analyses performed on the data were principally sets of analyses of variance (ANOVA) with repeated measures by semantic scale. Post hoc mean comparisons between chips/objects were made primarily within colors between chip and object ratings. Object-to-object comparisons also reported where relevant to the aims of the study.

The mean ratings of the objects and chips in each of the 16 colors were first computed for each of the 6 scales. The results are shown, ranked by mean chip ratings for each color, by scale in Figure 3.

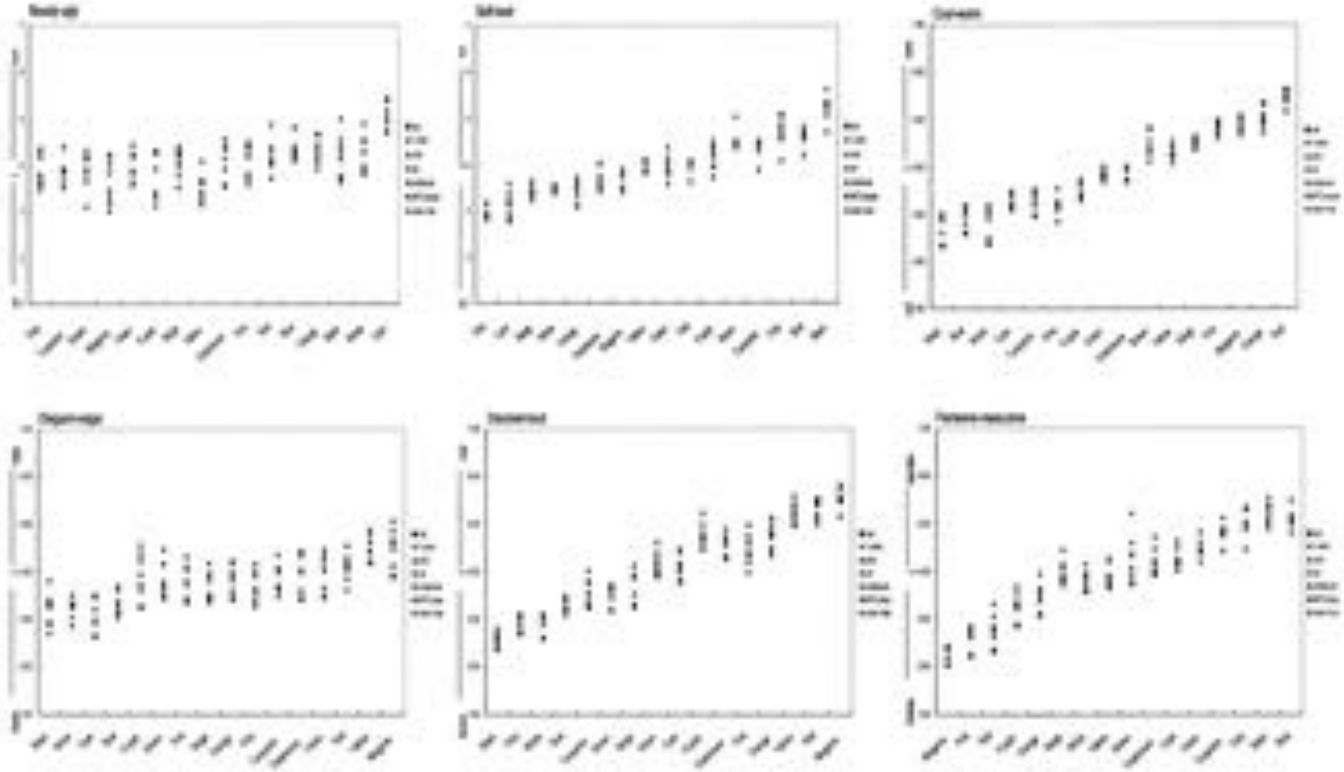


Figure 3. Mean rating of colors on chip and objects against the 6 semantic scales. Colors are ranked by mean chip ratings.

As shown in Figure 3, there is no significant tendency for the color on the chip to have either lower or higher mean ratings than majority or the of all the objects in the same color.

Separate analyses of variance (ANOVA) (color * object) with repeated measures on both factors were conducted for each semantic scale. These analyses yielded significant interaction effects for all scales (ugly-beautiful, $F(15, 90)=18.43$, $p<0.0001$; soft-hard, $F(15,90)=5.34$, $p<0.0001$; cool-warm, $F(15, 90)=7.09$, $p<0.0001$; elegant-vulgar, $F(15, 90)=12.2$, $p<0.0074$; discreet-loud, $F(15, 90)=7.14$, $p<0.0001$, feminine-masculine, $F(15,90)=9.13$, $p<0.0001$, found that on all scales differences did exist in the ratings of colors, indicating colors in general rated differently depending on the context in which they are presented.

In order to determine which scales, colors, objects contributed most to these differences and if such differences corresponded to differences between chip and object ratings. Consequently, one-way ANOVA with repeated measures were conducted for each color for each of the 6 semantic scales. Mean differences between chip and object ratings within colors were subsequently tested using the Tukey HSD method. The results of these analyses are shown in Table 1.

Table 1 : Summary table of significant differences between rating of colors on chips and on objects in each scale.

[illegible]	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]		[illegible]	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

Object name abbreviations are C=cup, T=T-shirt, S=sofa, R=car, N=notebook, M = mp3 player. Object names in italics indicate significant qualitative toward the left side of the scale differences between chip and object rating e.g..

Semantic Scales–For each scale, a total of 96 possible differences exist between chip and object ratings (6 objects * 16 colors). The number of statistically significant differences was considerably much, as shown in the Table 2-a.

Colors–As shown in Table 2-b, many significant mean differences were found between chip and object ratings occur in relation to most of colors. A great number of differences were found on each color respectively.

Objects–Inspection of Table 2-c reveals that the total differences 61.28% (353/576) between chip and object ratings of the all objects.

Table 2: Statistics for mean differences between rating of chips and objects.

a	Soft Hard	Feminine Masculine	Discreet Loud	Cool Warm	Ugly Beautiful	Elegant Vulgar	Total
Count	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Percent	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

b	Brown	Green	Beige	Black	White	Red	Turquoise	Blue	Cyan	Grey	Pink	Purple	Magenta	Orange	Chartreuse	Yellow	Total
Count	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Percent	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

c	Sofa	[illegible]	Cup	Notebook	T-shirt	Car	Total
Count	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Percent	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Consistency of Subject Ratings–A total of 7 images (6 objects and 1 chip) were shown twice to the subjects in order to check the test-retest reliability of the subject ratings in each semantic scale. These images were randomly selected from the total set of 112 images. These 7 images were randomly displayed as a set subsequent to the ratings of all other pictures in the scale. Mean differences were computed between subject ratings of the images on the first and second viewing. All mean differences are less than one scale unit, indicating good consistency of ratings between the two viewings (Osgood, 1957). The mean difference for the 6 scales are shown in Table 3.

Table 3: Mean difference of test-retest scores across semantic scales.

Scale	discreet-loud	soft-hard	elegant-vulgar	ugly-beautiful	cool-warm	feminine-masculine
Scores	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

4. DISCUSSION

Generally speaking, the results of this study have shown significant differences in semantic ratings between chips and objects. The implication is that color chips may not serve as an economic medium to survey the subjects' feelings for objects. Using color chips in color design and planning may lead to inaccurate representations.

The differences between Taft's and this study's findings might be caused by cultural differences and the subject pool size. There are also limitations of this study: 1. Digital images are still not the same as real objects. Color applied to the object surfaces electronically lack nuances. Would this affect the visual effect? The validity of the image representation needs more evidence. 2. This study concentrates on isolated single colors; no interactions with combined colors were checked. 3. The subjects of this study were college students majoring in Communication Studies. A wider variety of participants, including a cross-cultural subject survey are needed along with wider variety of colors and objects for further studies to generalize the results.

5. REFERENCES

1. B. Berlin and P. Kay, Basic Color Terms: Their Universality and Evolution. University of California Press. Berkeley, 1969.
2. C. B. Holmes and J. A. Buchanan, Color preference as a function of the object described. Bull. Psych. Soc. 22, pp.423-425, 1984.
3. C. Osgood and G. Suci, The Measurement of Meaning. University of Illinois Press Urbana, 1957.
4. C. Taft, Color Meaning and Context: Comparisons of Semantic Ratings of Color on Sample and Objects, COLOR research and application, pp.40-50, 1997.
5. S. Minato, Color in industrial design, in AIC Color '77. Proceedings of the Third Congress of the International Colour Association, F. W. Billmeyer and G. Wyszecki. Eds. , Adam Hilger Ltd., Bristol, 1977.
6. T. Saito, Latent spaces of color preference with and without a context: using an automobile as a context. Color Res. Appl. 8, pp.101-113, 1983.

* Correspondence: trlee@mail.pccu.edu.tw; phone 8862-2861-5945; fax 8862-2861-5594; Center for Information & Communications, Chinese Culture University, 55 Hwa-Kang Rd. Taipei, Taiwan, 111 R.O.C.

Orthogonal spectral reflectance model

Nobuhito Matsushiro* and Noboru Ohta

Munsell Color Science Laboratory, Center for Imaging Science, Rochester Institute of Technology, 54 Lomb Memorial Drive, Rochester, New York 14623-5604.
* Visiting Scientist from OKI Data Corporation, Japan.

ABSTRACT

In this paper, we will discuss about what is the most different spectral reflectance in comparison with a reference spectral reflectance under various illuminants. A measure is defined based on an information criterion whose probability is derived using metameric mismatch volume. The solution of the orthogonal spectral reflectance is derived as an optimization problem maximizing the information criterion. Maximizing the information criterion implies that the two information of spectral reflectances are the most different from the view point of information theory. Experimental results of the optimization derive physical shape of the orthogonal spectral reflectance for a given spectral reflectance.

1.INTRODUCTION

In this paper, we will discuss about what is the most different spectral reflectance (hereafter called orthogonal spectral reflectance) in comparison with a reference spectral reflectance under various illuminants. For the discussion, a distance between two spectral reflectances is defined based on an information criterion whose probability parameter is derived using a mismatch volume of metamers. Metamers are pairs of color stimuli with the same tristimulus values but with different spectral distributions, and by changing spectral reflectance, the metameric match is broken down and spread out. Though there has been research about boundaries of mismatches of metamers by N. Ohta and G. Wyszecki[1], the meaning of the magnitude of the mismatch volume has not been explained based on objective scales generally accepted. In this paper, the meaning of the magnitude will be explained from the view point of information theory. Maximizing the information criterion implies that the two information of spectral reflectances are the most different from the view point of information theory. The solution of the orthogonal spectral reflectance is derived as an optimization problem maximizing the information criterion.

In Section 2, the orthogonal spectral reflectance model and the advantage of the information theory approach are described, in Section 3, a solution method of the orthogonal spectral reflectance is described, in Section 4, experimental results are shown, and finally conclusions are provided.

2.ORTHOGONAL SPECTRAL REFLECTANCE MODEL

2.1.Mismatch Volume

Two illuminants with different spectral distributions $S(\lambda)$ and $S'(\lambda)$ give rise to metamer stimuli for a spectral reflectance $\rho(\lambda)$ if their corresponding tristimulus values are equal.

Under the first spectral reflectance (reference spectral reflectance) $\rho^{st}(\lambda)$, the metameric match is described as follows, where (X^{st}, Y^{st}, Z^{st}) is the tristimulus values of the metamers,

$$
\begin{aligned}
X^{st} &= \sum_\lambda S(\lambda)\rho^{st}(\lambda)\bar{x}(\lambda) / \sum_\lambda S(\lambda)\bar{y}(\lambda) = \sum_\lambda S'(\lambda)\rho^{st}(\lambda)\bar{x}(\lambda) / \sum_\lambda S'(\lambda)\bar{y}(\lambda) \\
Y^{st} &= \sum_\lambda S(\lambda)\rho^{st}(\lambda)\bar{y}(\lambda) / \sum_\lambda S(\lambda)\bar{y}(\lambda) = \sum_\lambda S'(\lambda)\rho^{st}(\lambda)\bar{y}(\lambda) / \sum_\lambda S'(\lambda)\bar{y}(\lambda) \\
Z^{st} &= \sum_\lambda S(\lambda)\rho^{st}(\lambda)\bar{z}(\lambda) / \sum_\lambda S(\lambda)\bar{y}(\lambda) = \sum_\lambda S'(\lambda)\rho^{st}(\lambda)\bar{z}(\lambda) / \sum_\lambda S'(\lambda)\bar{y}(\lambda)
\end{aligned}
\qquad (1)
$$

where,

λ : wavelength,

$\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$: color matching functions.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

When the spectral reflectance is changed from the first one $\rho^{(1)}(\lambda)$ to the second one $\rho^{(2)}(\lambda)$, the corresponding tristimulus values are given by,

$$
\begin{aligned}
X^{(2)} &= \sum_{\lambda} S(\lambda)\rho^{(2)}(\lambda)\bar{x}(\lambda) / \sum_{\lambda} S(\lambda)\bar{y}(\lambda) \\
Y^{(2)} &= \sum_{\lambda} S(\lambda)\rho^{(2)}(\lambda)\bar{y}(\lambda) / \sum_{\lambda} S(\lambda)\bar{y}(\lambda) \\
Z^{(2)} &= \sum_{\lambda} S(\lambda)\rho^{(2)}(\lambda)\bar{z}(\lambda) / \sum_{\lambda} S(\lambda)\bar{y}(\lambda)
\end{aligned}
\tag{2}
$$

$$
\begin{aligned}
X'^{(2)} &= \sum_{\lambda} S'(\lambda)\rho^{(2)}(\lambda)\bar{x}(\lambda) / \sum_{\lambda} S'(\lambda)\bar{y}(\lambda) \\
Y'^{(2)} &= \sum_{\lambda} S'(\lambda)\rho^{(2)}(\lambda)\bar{y}(\lambda) / \sum_{\lambda} S'(\lambda)\bar{y}(\lambda) \\
Z'^{(2)} &= \sum_{\lambda} S'(\lambda)\rho^{(2)}(\lambda)\bar{z}(\lambda) / \sum_{\lambda} S'(\lambda)\bar{y}(\lambda)
\end{aligned}
\tag{2'}
$$

Here the metamerism is broken down and, $(X^{(2)},Y^{(2)},Z^{(2)}) \neq (X'^{(2)},Y'^{(2)},Z'^{(2)})$.

If we take into consideration a number of metameric illuminants giving the tristimulus value $(X^{(1)},Y^{(1)},Z^{(1)})$ for a spectral reflectance $\rho^{(1)}(\lambda)$, they will give a spread of the tristimulus values for a spectral reflectance $\rho^{(2)}(\lambda)$. This spread forms a concave closed solid in a color space called mismatch volume[1].

2.2.Information Criterion

For finite precision of calculation of Eq.(1) using finite precision of $\rho^{(1)}(\lambda)$, $\rho^{(2)}(\lambda)$, $S(\lambda)$ and $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$, there exist finite number N of metamers. The N number of metamer points spread in the mismatch volume. Intuitively, a finite number N of information described at a certain point becomes to be described in a wide space. An information without ambiguity becomes to have ambiguity. The correctness of the prediction for the position of each point in a spread mismatch volume is in inverse proportion to the magnitude of a mismatch volume. Therefore, 1/(mismatch volume) corresponds to the probability of the prediction, and by using the parameter in the following general information criterion,

$$I = -\log(1/(\text{mismatch volume})), \tag{3}$$

the mismatch volume is explained in a generally accepted scale. Maximizing the information criterion implies that the two information of spectral reflectances are the most different from the view point of information theory.

In the information theory approach, theoretically almost infinite number of $S(\lambda)$ can be considered in a continuous mismatch volume of finite boundary. The approach pays attention to a volume in other words a magnitude of information and not pay attention to each sampling point in the volume. Therefore for almost infinite number of $S(\lambda)$, this approach is reasonable.

3.SOLUTION METHOD

Linear programming is employed to calculate the volume of the solid[1]. It is difficult to derive the solution maximizing the volume of the solid by analytical methods, because the calculation complexity of a volume is at least tri-linear. Hence, a searching method for optimization called simulated annealing[2] is employed.

The closed solid can be derived by using linear programming method in which eq.(1) and $0 \leq S(\lambda)$ are the constraints, and eq.(2) is the objective function. $(X^{(1)},Y^{(1)},Z^{(1)})$ is a metameric color which is fixed, and for various values of $S(\lambda)$, $(X^{(2)},Y^{(2)},Z^{(2)})$ takes mismatch values by changing the spectral reflectance from $\rho^{(1)}(\lambda)$ to $\rho^{(2)}(\lambda)$.

The volume of the closed solid corresponds to a degree of difference between the first spectral reflectance and the second spectral reflectance, and we will optimize the second spectral reflectance maximizing the information criterion by using simulated annealing. In simulated annealing, n number of spectral values $\rho^{(2)}(\lambda_i)$ $(i=1,2,\cdots,n)$ quantized in the spectral range are n dimensional parameters to be optimized. In the process, reconfiguration of parameters $\rho^{(2)}(\lambda_i)$ $(i=1,2,\cdots,n)$ is performed and for each reconfiguration, acceptance or non-acceptance is determined. The reconfiguration and determination of its acceptance are repeated, and the final state of the reconfiguration is the optimized solution. The following function ΔI is defined for the judgement of acceptance or non-acceptance of a reconfiguration.

$$\Delta I = (I \text{ value after reconfiguration}) - (I \text{ value before reconfiguration}), \tag{4}$$

where, I indicates the information criterion of Eq.(3).

4.EXPERIMENTS

Experiments deriving the orthogonal spectral reflectance have been performed. The wavelength range 400nm-700nm was divided into eight sections. The cost function was the information criterion. The initial temperature was $T=1$ and $\Delta T = 1/10$[illegible]. The reconfiguration on $\rho^{o}(\lambda_i)$ $(i=1,2,\cdots,n)$ was performed by using random numbers. The random numbers determined that which section i should be reconfigured, and modified value $\Delta\rho(\lambda_i)$ should be positive or negative. The step size of the modification was $|\Delta\rho(\lambda_i)| = 1/10$[illegible]. The metameric color (X^{o}, Y^{o}, Z^{o}) was determined using the flat illuminant spectrum.

Figure 1 (a)(b) show reference spectral reflectances, and Figure 2 (a)(b) show corresponding orthogonal spectral reflectances, respectively. These are physical shapes of the orthogonal spectral reflectances.

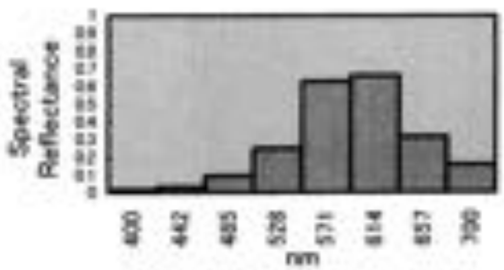


Figure 1 (a)

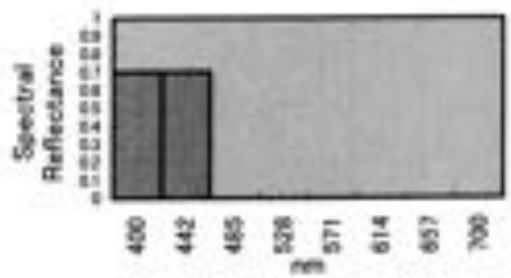


Figure 1 (b)

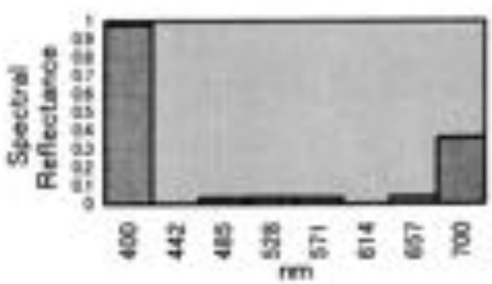


Figure 2 (a)

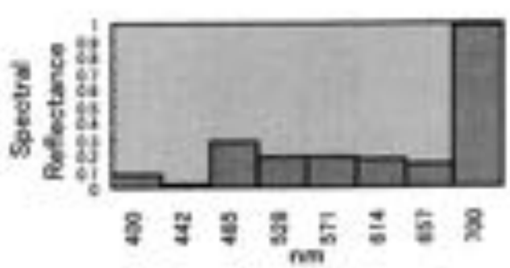


Figure 2 (b)

5.CONCLUSIONS

Orthogonal spectral reflectance model describing the most different spectral reflectances pair has been proposed based on metameric mismatch. First, the meaning of the magnitude of a metameric mismatch volume was explained from the view point of information criterion. Second, using the information criterion, a solution method of the orthogonal spectral reflectance was described. Experimental results of the optimization derived physical shape of the orthogonal spectral reflectance for a given spectral reflectance.

This paper is one of contributions which systematize color science from the view point of information theory.

REFERENCES

1)N. Ohta and G. Wyszecki, Theoretical Chromaticity-Mismatch Limits of Metamers Viewed Under Different Illuminants, J. Opt. Soc. Am., 65, p.327 (1975).
2)S. Kirkpatrick, Optimization by Simulated Annealing, J. Statist. Phys., 34, p.975 (1984).

Influence of Light Source and Illuminance on Benham Type Subjective Colors

Yutaka Kurioka*, Shunshiro Ohnishi, Makoto Iwata and Atsushi Tanaka

ABSTRACT

To investigate influence of light source and illuminance on Benham type subjective colors, a tehnique using twenty eight figures that have different arc positions is proposed. An incandescent lamp and three wavelengths fluorescent lamp were used as light sources, and subjective colors were measured. Patterns of the diagrams on hue and chroma for the two kinds of lamp are different. The difference between the light sources is clearly recognized.

Keywords: Benham figure, Subjective color, Light source, Illuminance, Munsell renotation

1. INTRODUCTION

Usually a Benham type figure is composed of a black semi-disk and a white semi-disk with three or four sets of black fine arcs. Using the above figure, influence of light sources and illuminances has not be investigated so clearly. To investigate influence clearly, we used twenty eight figures which have only one arc and the angle θ from the black semi-disk was changed 0 to 135 degrees by 5 degrees step[1)2)]. An example of the figures is shown in Fig. 1.

The figures were rotated at speed of 480rpm, illuinated by the two kind of lamps, and their subjective colors were measured comparing with the standard chips of Munsell renotation. Results are demonstrated on diagrams of hue and chroma.

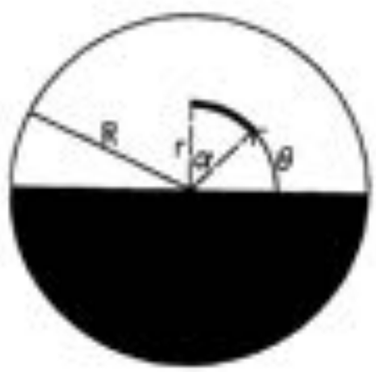


Fig. 1 A figure used for observing subjective colors

2. METHOD

The figure used for observation is shown in Fig. 1. The radius r of an arc was 50 mm and its width 1 mm. The angle α subtended by the arc was 45 degrees in the experiments. The figure was made on a white paper (value N9.5) by black toner (value N1.5) of a laser printer, and was rotated in clockwise at speed of 480 rpm.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

As light sources, an incandescent lamp(TOSHIBA, 100W, abbreviated as I lamp) and a three wavelength type fluorescent lamp(FL20SS-EX-D, abbreviated as TWF lamp) were used. Illuminance of the figures was changed from 300 and 600 lux. Illuminating and viewing condition was 0 / 45 degrees. A distance between the center of the figure and subject eyes was about 60 cm.

Subjective colors were measured comparing with the standard color chips of Munsell renotation. The standard color chips were illuminated by the standard fluorescent lamp with high Ra value (FL20S-N-EDL), and illuminance of the standard chips was 450 lux. Subject MI was an male of 24 years old with normal trichromat. The darkroom was used to avoid stray light.

3. RESULTS

An example of subjective colors observed for different angle θ s is shown in Table 1. Light source is I lamp and illuminance 300 lx. Comparison of subjective colors between two light sources is made in Fig. 2. Filled circles indicate the results for I lamp and hollow circles those for TWF lamp. Illuminance was 300lux.

Hue of colors varied from R through YR, Y, GY, G, BG, B to PB for I lamp, and similarly from RP through R, YR, Y, GY, G, BG, B, PB, P to RP for TWF lamp. Observed range is rather wide for TWF lamp and results for two

Table 1. An example of subjective colors observed for 28 angles

(Incandescent lamp, 300 lx)

Angle θ	HV/C	Angle θ	HV/C
0	2.5R6/10	70	2.5BG6/3
5	2.5R6/8	75	5BG6/3
10	5R6/8	80	7.5BG7/4
15	5R7/6	85	7.5BG7/3
20	10R5/8	90	10BG7/3
25	2.5YR5/1	95	7.5BG5/2
30	5YR5/6	100	10BG7/1
35	2.5Y7/6	105	2.5B6/2
40	5Y8/6	110	2.5B7/2
45	7.5GY7/4	115	5B7/1
50	5G6/4	120	5B7/2
55	7.5G7/6	125	2.5PB6/3
60	7.5G6/3	130	7.5PB4/3
65	10G6/4	135	10PB5/3

lamps at each angle are not always the same. Value of colors varies 4 to 8 for I lamp and 2 to 7 for TWF lamp. Chroma of colors gradually decreases for I lamp as the angle θ increases. Chroma is 10 for R, 1~2 for BG or B, and again rises to 3 for PB. For TWF lamp, aspect of chroma is different from that for I lamp. There are three peaks of chroma; 8 for 7.5R, 6 for 10Y and 2.5 GY and 8 for10PB and 2.5P.

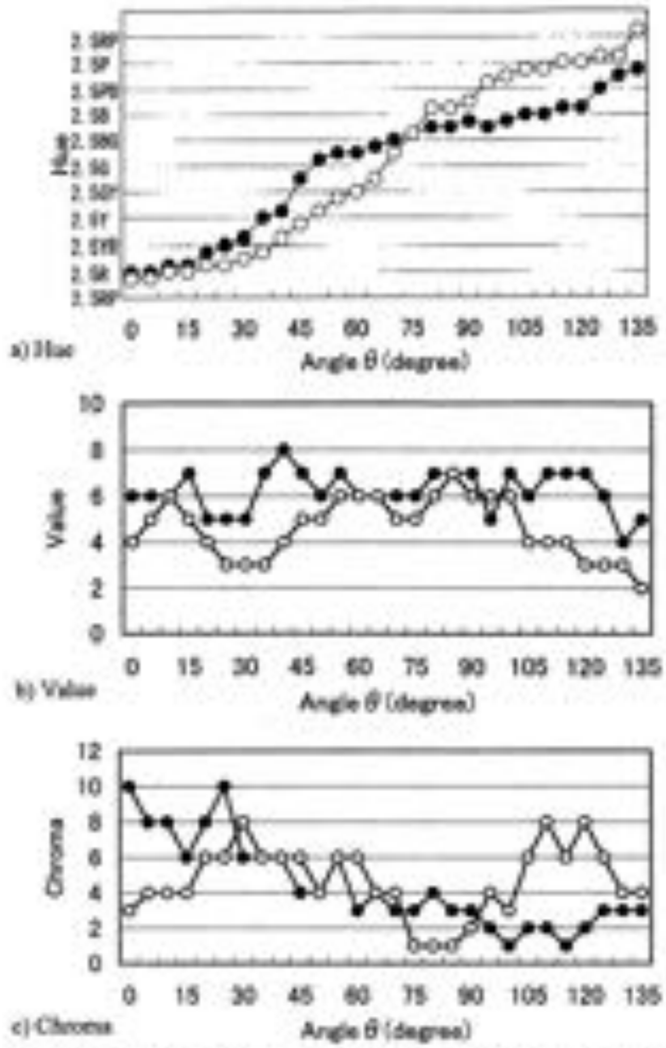


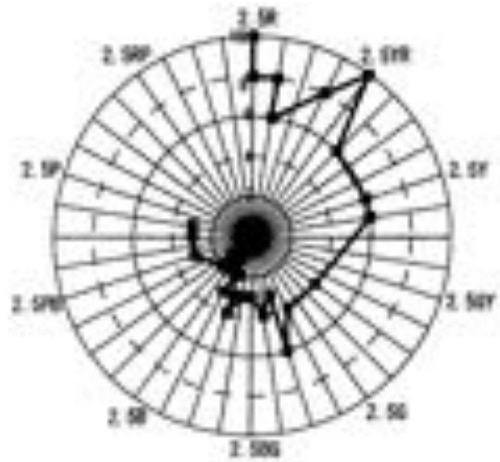
Fig. 2: Comparison of subjective colors between two light sources (300 lx)
(● : Incandescent lamp, ○: Three wavelength fluorescent lamp)

4. DISCUSSION

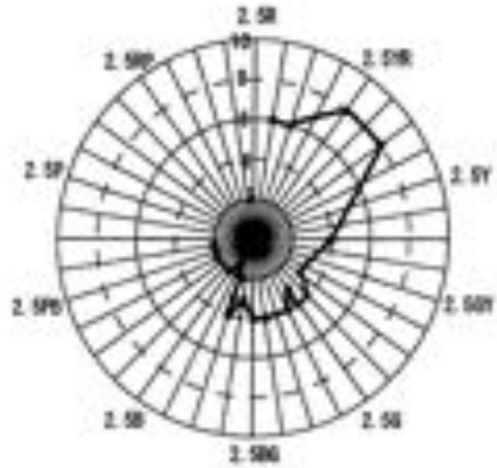
Polar diagrams of hue and chroma for I and TWF lamps are shown in Fig. 3. Diagrams show the case of illuminance 300 and 600 lx. The shape of diagrams for TWF lamp is clearly different from those of I lamp. Difference between the diagrams for the two lamps comes from differnce of the spectral distributions. Incandescent lamp has a peak in red or infrared region, and three wavelengths fluorescent lamp three peaks in 450, 540 and 610 nm. Some difference exists between diagrams for illuminance 300 and 600 lx, but are not so large.

5. CONCLUSION

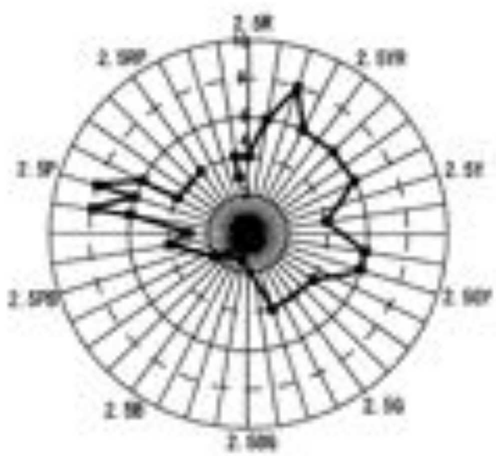
1. Both the light source and illuminance influence on Benham type subjetive colors. Patterns of the diagrams are different. The technique using twenty eight figures that have different arc positions is useful.
2. Pattern differences of subjective colors due to light sources comes from spectral distribution.
3. Pattern differences of subjective colors due to illuminance is not so large. Further work is necessary to investigate influence of illuminance on subjective colors in detail.



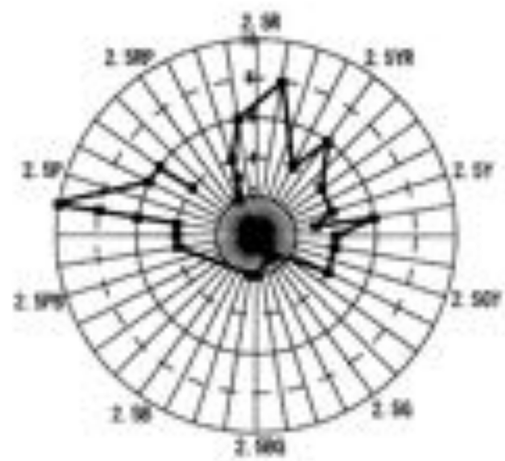
a) Incandescent lamp, 3oo lx



b) Incandescent lamp, 600 lx



c) Three wavelengths fluorescent lamp, 300 lx



d) Three wavelengths fluorescent lamp, 600 lx

Fig. 3 : Polar diagrams of hue and chroma

REFERENCE

1) K. Ohtsuka, S. Ohnishi and Y. Kurioka: Effect of illuminance on Benham type subjective color, Proceeding of Kansai district conference, Color Science Association of Japan (1999) 12-13
2) M. Iwata, A. Tnaka, S. Ohnishi and Y. Kurioka: Effect of Illuminant on Benham type subjective color, Proceeding of Kansai district conference, Color Science Association of Japan (2000) 22-23

* correspondence: kurioka@ee.kindai.ac.jp; phone +81-6-6721-2332; fax: +81-6-6727-4301; Kinki University, Interdisciplinary Graduate School of Science and Technology, 3-4-1, Kowakae, Higashi-Osaka, Osaka 577-8502, JAPAN

Semantics of color and determination of information

Nikolai V. Serov, Dept. of Psychophysiology, State Institute of Psychology, Saint-Petersburg, Russia*

ABSTRACT

The aim of this investigation is to describe the semantics of color and to give the determination of information on the basis of using light-color properties of radiant flux. The determination obtained permits to introduce reliable criteria of information separated into linked or unlinked, and also to give the formula for estimation of the spectral luminous efficiency V(λ) and complementary colors in Hering theory.

Keywords: Hering theory, linked information, spectral luminous efficiency, complementary colors

1. INTRODUCTION

The necessity of interdiscipline investigation of color and information is widely apprehended both in chromatism and, particularly, in Theory of Information, which is the science linking natural and humanitarian disciplines and, simultaneously, being a single whole[1]. On the one hand, colors are formed due to disintegration of light into absorbed, transmitted, dissipated and reflected components, when this flux interacts with a substance. On the other hand, the information flow is sometimes, divided into linked, unlinked, linked-unlinked and unlinked-linked components of information correspondingly. In such a case, linked information is considered to be the one that is correlated with the combination of the components and intercomponent interactions similar to *relatively stable functional conditions in systems having internal structural information* (N. Wiener).

It follows from the above that the formalization of semantics of light-color flux is the most up-date task for adequate semantic determination of linked information especially. Therefore, in the first approximation, the model of information codes in color space may be represented as the relative sum of wavelengths λ_i, being a function of λ_o. Consequently, any metameric color with dominant wavelength λ_o can be represented as the relative sum of complementary colors having dominant wavelengths λ_1 and λ_2. Hence, the obvious condition of coordination between radiation alphabets and a substance permits to define linked α and unlinked τ values of information:

$$\sigma\lambda_o = \alpha\lambda_1 + \tau\lambda_2 , \qquad (1)$$

where λ_o is the wavelength that defines a dominant color by means of probability distribution λ_i;
λ_1 and λ_2 are the wavelengths (correlated with a pair of complementary colors), that when being additively summed with probabilities α and τ will give metameric or achromatic (white) radiant color $\sigma\lambda_o$;
σ, α and τ are relative quantities of initial, linked and unlinked information, that may be represented by spectral coefficients of brightness, absorption and transmission, correspondingly.

Generally speaking, energy, entropy and, consequently, information of color may be referred to the extensive values. This is easily proved in LIT – dimension system, where L - space, I - information and T - time. From the above appears that we may use any extensive relative values, e.g. brightness, luminous flux or luminance, as the information attributes. According to equation (1), we may interpret σ, α and τ coefficients as probabilities of realization of relevant codes λ_i. Actually, since they determine the relative quantity of information in a flux, it is possible to represent them as the ratios:

$$\sigma = I_0 / I_0; \quad \tau = I / I_0 , \quad \alpha = (I_0 - I) / I_0 , \qquad (2)$$

where I_0 is initial quantity of information (at the entry);
I is the quantity of information transformed in the system, that may be interpreted unlinked (at the exit);
$I_0 - I$ is the quantity of information linked in the system.

2. DEFINITION OF INFORMATION

So, it is the relative values that define probabilities of linked and/or unlinked states of information in a system. Attention must be paid to value α, whose meaning is evidently correlated with Weber-Fechner Law in equation (2), where I_0 is the value of an «adapted» irritant, $I_0 - I$ is the difference threshold. In other words, probability α can characterize the unknown link between the objective (according to equation 2) and the subjective (according to Weber-Fechner Law) values for one-dimensional sensory irritants.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

According to this correlation, value τ may define the character of unlinked (i.e. not interacting with system components in accordance with code λ_i) information. But under the Probability Theory, value $1/\tau$ will define non-entropic active (actualized) character of linked information, that interacts with system components according to code λ_i. Hence, from here the «working» definition of color information appears, which takes into the account both entropic and non-entropic characteristics of a signal: *information is the correlated distribution of probabilities of a source according to the relevant codes of linked and unlinked states of a receiver.*

Under the Conservation of Energy Law, such definition permits to interpret the well-known condition of probability normalization as the principle of conserving probabilities of states in a closed system:

$$\sigma = \alpha + \tau = 1\,. \tag{3}$$

Principle (3), being approximated to equation (1) enables us to estimate relative values of linked α and unlinked τ values of information, using known (2) codes λ_i :

$$\alpha = (\lambda_2 - \lambda_a) / (\lambda_2 - \lambda_1), \quad \tau = (\lambda_a - \lambda_1) / (\lambda_2 - \lambda_1), \tag{4}$$

where α and τ define the relation between the values of the same name as the differences that take into consideration their distribution relative to intercorrelated codes λ_i .

According to equation (2) and (4), it is not difficult to represent the quantity of initial I_0 , linked I_a and unlinked I_τ information in absolute units as the differences of probability distribution λ_i :

$$I_0 = i_\lambda (\lambda_2 - \lambda_1), \quad I_a = i_\lambda (\lambda_2 - \lambda_a), \quad I_\tau = i_\lambda (\lambda_a - \lambda_1), \tag{5}$$

where i_λ is the spectral density of information, bit·nm^{-1}.

The equations given above enable us to apply the information conservation law to the closed system ($I_0 = I_a + I_\tau$). For pragmatic purposes, let's compare these definitions with theoretic and experimental data[1]. In accordance with Bouguer-Lambert's Law,

$$\tau = \exp\,[-k(\lambda)\,c], \tag{6}$$

where τ is the unlinked information coefficient, that is correlated in (5) according to code λ_i;
$k(\lambda)$ is the index of information linkage, correlated in accordance with code λ_i;
c is the amount of components in the system, that receive linked information $k(\lambda)$.

It is easy to prove the semantic relation between definition (6) and Hartley equation for estimating information quantity. This permits to measure $k(\lambda)$ in bit (in binary system $k(\lambda)_2 = 3.32\, k(\lambda)$), if c is measured in bit $^{-1}$. According to equations (1), (4) and (6), the value of information transmission T is correlated with the probability ratio of unlinked I_τ and initial I_o information. On those ground, it is possible to apply addition property to value $k(\lambda)$:

$$\sum_i \mathrm{k}(\lambda)_i \;= -\sum_i \; c_i^{-1} \log_2 \tau\,, \tag{7}$$

where $\sum k(\lambda)_i$ is the total index (related with components c_i) of information, that is the quantity of information, in bits.

The investigation of special situation of dependence $k(\lambda, \tau)$ for a white color source and for achromatic colors of a receiver shows that for white color (when $\tau = 1$), the quantity of linked information $k(\lambda) = 0$; for black color (when $\tau \to 0$) value $k(\lambda) \to 0$; and for middle-grey color (when $\tau = \alpha$) value $k(\lambda) = 1$. These results permit to suggest some relationship of function (7) with well-known representation of information quantity made by Shannon:

$$H = -\sum_i \; p_i \; \log_2 p_i\,, \tag{8}$$

where H is the information quantity in a message, including i states and p_i probabilities.

3. SPECTRAL LUMINOUS EFFICIENCY

The relationship between information-energy and light parameters can be represented using spectral luminous efficiency V_λ for an eye. However, in normal condition, an eye perceives not the color of a source but the color reflected by the surface of a given object. In such a case, as a rule, the maximum value of curve V_λ coincides with minimum value of color fatigue curve, that is mainly dependent upon the area S of the sample observed. For simplicity, light reflection, diffusion and absorption by eye media may be neglected if to assume that about 80 % of light achieves retina. Then, flux value Φ_ρ, reflected by the sample and perceived by retina may be represented as follows:

$$\Phi_\rho = \rho_\lambda \Phi_e \tag{9}$$

where Φ_o - initial luminous flux and ρ_λ - spectral reflectance (coefficient of color light reflected by the sample). Consequently, absolute spectral luminous efficiency V_λ^{abs} turns to be proportional to the value of effective flux:

$$V_\lambda^{abs} = \alpha_\lambda E_\varphi , \qquad (10)$$

where α_λ - spectral absorptance by retina,
$E_\varphi = d\Phi_\varphi/dS$ illuminance, in lux.
From this equation we can obtain the value of V_λ^{abs}:

$$V_\lambda^{abs} = \alpha_\lambda \rho_\lambda E_o \qquad (11)$$

From definition (1) it follows that luminous flux having dominant wavelength λ_o and formed by any pair of complementary colors with wavelength λ_1 и λ_2, is perceived with an identical eye. It is called a metamer (a metameric stimulus). According to all stated above, we may substitute illuminance E instead of information I in equation (2), while in equation (1), (3) and (4) we may substitute reflectance factor ρ_λ for transmission factor τ:

$$\sigma\lambda_o = \alpha_\lambda\lambda_1 + \rho_\lambda\lambda_2 , \qquad (12)$$

$$\sigma = E_\varphi / E_\varphi , \quad \rho_\lambda = E/E_\varphi , \quad \alpha_\lambda = (E_\varphi - E) / E_\varphi , \qquad (13)$$

$$\sigma = \alpha_\lambda + \rho_\lambda = 1, \qquad (14)$$

$$\alpha_\lambda = (\lambda_2 - \lambda_o) / (\lambda_2 - \lambda_1), \quad \rho_\lambda = (\lambda_o - \lambda_1) / (\lambda_2 - \lambda_1). \qquad (15)$$

From equations (12) - (15) we may derive the equation:

$$E_o = \varepsilon_\lambda(\lambda_2 - \lambda_1). \qquad (16)$$

where ε_λ - spectral illuminance density (lux/nm).

4. OPPONENT NATURE OF COLOR VISION

Substituting equation (13) and (16) in equation (11), it is possible to estimate value V_λ^{abs} for the photopic vision V_λ and scotopic vision V_λ'. According to CIE data, $\lambda_o(V_\lambda)$=555 nm and $\lambda_o'(V_\lambda')$=510 nm. Let's substitute these values in the equation that is universal for absolute values V_λ^{abs}:

$$V_\lambda^{abs} = \varepsilon_\lambda(\lambda_2 - \lambda_o)(\lambda_o - \lambda_1)/(\lambda_2 - \lambda_1). \qquad (17)$$

From this we obtained the curves represented in Figure 1 for the unit of retina area and ε_λ. Take notice that after substituting $\lambda_o(V_\lambda)$=555 nm in equation (17), we obtained curve V_λ' that reached its maximum at wavelength λ_o=510 nm. If substituting wavelength equal to $\lambda_o(V_\lambda')$=510 nm, we obtained curve V_λ that reached its negative maximum at wavelength 555 nm.. Probably, this fact may be explained by opponent nature of color vision predicted by E. Hering, which is practically, the basis of NCS - system [3]. It was proved experimentally by G. Svaetichin, E. MacNichol (1958), D.H. Hubel, T.N. Wiesel [4] etc.

As a matter of fact, opponent nature of photopic V_λ and scotopic V_λ' mechanisms is confirmed even at retina level. For example, for yellow spot (taking into account chromatic aberration) the derivative maximum of wavelength from transmission value ($d\tau/d\lambda$) corresponds strictly to maximum absorption of rhodopsin at 510 nm. It is a well-known fact that rhodopsin is absent in yellow spot, i.e. in cones structure. At the same time, optical density derivative for rhodopsin achieves maximum at 555 nm, that is not seen on absorption curve for rods structures. In this connection it is worth mentioning, that when substituting in equation (17) the increasing values $\lambda_o(V_\lambda)$=555→650 nm, *an arm* appears on curve V_λ', besides λ_{max}=510 nm. After that, the second maximum starts to grow at λ = 560 nm (Figure 2).

Thus, equation (17) enables us to give analytical representation of opponent theory for color vision. Assume that value $E_\rho=\rho_\lambda E_o$ is being constant for an eye. Then, according to equation (11), we may represent the above mentioned nature of such structures as the difference:

$$V_\lambda' - V_\lambda = E_\rho(\alpha_\lambda' - \alpha_\lambda), \qquad (18)$$

where V_λ - spectral luminous efficiency, that is usually defined as the ratio of absolute spectral luminous efficiency V_λ^{abs} to its maximum.

Let's substitute equation (15) in equation (18). We obtain:

$$V_\lambda' - V_\lambda = E_\rho(\lambda_o - \lambda_o') / (\lambda_2 - \lambda_1). \qquad (19)$$

According to equation (16) we get:

$$V_\lambda' - V_\lambda = \varepsilon_\lambda(\lambda_o - \lambda_o') E_\rho / E_o . \qquad (20)$$

This equation may be transformed into:

$$V_\lambda' - V_\lambda = \varepsilon_\lambda \rho_\lambda (\lambda_0 - \lambda_0'). \qquad (21)$$

Thus, we finally obtained the equation that shows the relationship between luminous efficiency V_λ, V_λ' and subjective parameters (λ_0, λ_0'). It also shows the relationship with objective spectral characteristics of initial luminous flux ε_λ and the one, reflected from color object observed ρ_λ. In both parts of equation (21), the members of both differences are opponent to each other, i.e. opposite in sign (±). Probably, this confirms the efficiency of equation (21) in developing the opponent theory for color perception at retina level as well.

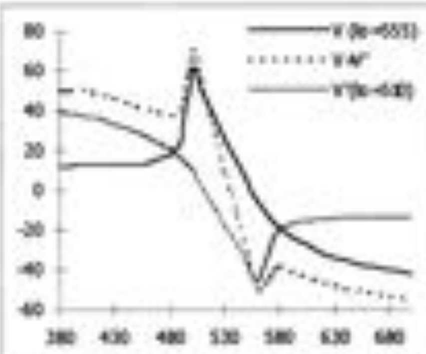


Figure 1. Evaluation of absolute values V(λ).

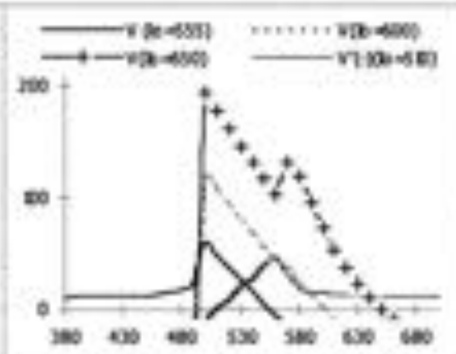


Figure 2. The raising of second max. at V(λ).

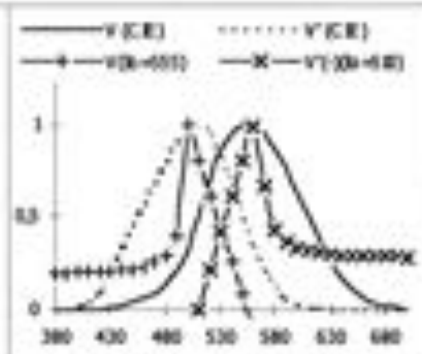


Figure 3. Evaluated data and CIE data.

5. CONCLUSIONS

Figure 3 shows both the differences $V_\lambda' - V_\lambda$ (CIE) and the ones, obtained in accordance with equation (19) for unit value E_ρ at $\lambda_0 = 555$ and $-\lambda_0' = 510$ nm. The raising of basis line is, probably, explained by 20 % reflection of light by ocular media, mentioned above. Under such approximation, the obtained results are considered to be satisfactory for developing principles of opponent theory in color vision.

In conclusion, let us find the equation for complementary colors. (It was recommended by Commission Internationale de l'Éclairage – CIE: $(\lambda_1 - A)(B - \lambda_2) = C$, where A, B, C – empirical constants). When correlating equations (13) and (21), we obtain:

$$(\lambda_1 - \lambda_0)(\lambda_0' - \lambda_2) = I(I_0 - I)/\varepsilon_\lambda^2. \qquad (22)$$

where λ_0 and λ_0' are maximum value for V_λ and V_λ', correspondingly; λ_1 and λ_2 are dominant λ of complementary colors.

As is evident from (22), equation for complementary colors CIE may be represented as some kind of a product of light transmission and absorption related to the square value of brightness of spectral density or, in other words, as relative product of linked and unlinked information.

Thus, the opponent nature of curves V_λ and V_λ' results from mutual complementarily, if absorption takes place by pigments in different retina areas. This enables us to explain the causes of saccadic nature for vision (as periodical calculation of absorption difference V_λ and V_λ') and Land's experiments (as opponent relationship between unlinked information about outer environment and linked information in retina).

REFERENCES

1. N.V. Serov, *Light-color therapy. Sense and meaning of color: information - color - intellect.* (in Russian), pp.153-227, Rech, St. Petersburg, 2001.
2. C.H. Graham, "Discriminations that depend on wavelength", *Vision and visual perception,* Ed C.H. Graham., P. 350-369, John Wiley & Sons, New York - London - Sydney, 1966.
3. A. Hard, L. Sivik, "A theory of colors in combination. A descriptive model related to the NCS color-order system", *Col. Res. & Appl.*, **26**, pp. 4-28, 2001.
4. D.H. Hubel, T.N. Wiesel, "Brain mechanisms of vision", *Sci. Am.* **241**, pp. 130-144, 1979.

* Correspondence: nv_serov@mail.ru; ul. Shevchenko 3 «B» -11, St Petersburg, 199106, Russia.

How Do We Control Color?

The production and reproduction of colored objects, spaces, etc. gets more and more sophisticated.
Controlling it keeps most of us employed!

Color Management
Tutorial: The Whys and Hows of Color Management
King , Why color management*
Symposium: The State of the Art and Future of Color Management
Pawle, Borg, The evolution of the ICC-profile connection space*
Jung, Büring, Quality evaluation of current ICC-profile generation tools for CMYK-output devices*
Chung, Sa-areddee, CMS for digital photography: a case study
Kotera, Suzuki, Mita, Saito, Image-dependent color mapping for pleasant image renditions
Woolfe, Spaulding, Image-dependent color mapping for image state architecture
Beretta, Buckley, Trends in color imaging on the Internet

Symposium: Imaging Techniques of Spectral Estimation (Spectral Imaging)
Bernsm, Visible-spectrum imaging techniques: an overview*
Hill, Optimization of total multispectral imaging systems: best spectral match versus least-observer metamerism*
Miyake, Tsumra, Haneishi, Hayashi, Gonio photometric imaging for recording of reflectance spectra of 3D object
Baribeau, Spectral estimation from laser scanner data for accurate color rendering of objects
Sun, Fairchild, A new procedure for capturing spectral images of human portraiture
Hauta-Kasari, Lehtonen, Parkkinen, Jaaskelainen, Representation of spectral images in data communications
Imai, Berns, Spectral estimation of artist oil paints using multifilter trichromatic imaging

Symposium: The Artist and Digital Media
Glicksman, White Is green: new schematic diagrams
Luke, The paperless or vanishing society*
Luke, Development of the uniform color scales by the Optical Society of America and the introduction of Color Cleaver to make the colors accessible

Symposium: Color Issues for Digital Archives
Saunders: Accurate colour images: from expensive luxury to essential resource*
Susstrunk, Color strategies for image databases*
Gschwind, Digital slide reproduction using densitometry*
Tran, Lenz, Spaces of probability distributions and their applications to color based image database search

**** denotes invited papers***

<u>Symposium</u>: How is CIE Helping Us Make Color Work

Pointer, CIE: vision, colour and imaging*
Fairchild, Status of CIE color appearance models*
Luo, The CIE 2000 colour difference formula: CIEDE2000*
Newman, Making color work in CIE Division 8*
Vienot, Report on a fundamental chromaticity diagram with physiologically significant axes*

<u>Color Appearance</u>

<u>Oral Sessions</u>:

Moroney, Background and the perception of lightness
Juan, Luo, Magnitude estimation for scaling saturation
Li, Luo , A uniform colour space based upon CIECAM97s
Mizokami, Shinoda, Ikeda , Degree of color constancy yielded in a photograph perceived as 3D space
Yamauchi, Ikeda Shinoda, Demonstration of the light source color on a photograph

<u>Poster Papers</u>:

Ayama, Suda, Kumagai, Quantitative evaluation of color appearance between different media and appearance modes
Kusumi, Ikeda, Shinoda, Color constancy and color appearance mode in relation to the visual field size
Kwak, MacDonald, Luo, Colour appearance comparison between projected and self-luminous colours in dark surround
Mukai, Takeuchi, Ayama, Kanaya, An objective method for quantifying whiteness perception by applying CIECAM97s
Sanchez, Fairchild, Quantification of the Helmholtz-Kohlrausch effect for CRT color monitors
Sueeprasan, Luo, Modeling incomplete adaptation under mixed illuminants
White, Pointer, The measurement of appearance

<u>Color Difference</u>

<u>Oral Sessions</u>:

Hong, Luo, Perceptually based colour difference for complex images
Klassen, Colour difference metrics and surround effects: preliminary results
Zhu, Cui, Luo, New experimental data for investigating uniform colour spaces
Xin, Lam, Comparative study of visual colour differences using reflective and self-luminous colour stimuli
Cui, Luo, Rigg, Investigation of the "crispening effect" on lightness differences
Berns, Derivation of a hue-angle dependent, hue-difference weighting function for CIEDE2000
Kuehni, Uniform color space is not homogeneous
Gay, Hirschler, Determination of industrial colour tolerance limits: case studies in the textile industry

<u>Poster Papers</u>:

Kim, Song, Kim, Lightness-difference data set for evaluation of CIELAB-based colour-difference formulae
Lübbe, Visually assessed colour description including the luminance of the background
Rodrigues, Locke, Weighting function for the measurement of lightness differences in gonioapparent and dark colors
Xu, Yaguchi, Shiori, Relationship between color discrimination threshold and suprathreshold olor-difference perception

**** denotes invited papers***

Color Tolerance

Poster Papers:

Azuma, Kituo, Naruse, Sugiura, Acceptability color tolerances for CRT reproductions of real objects
Han, Chou, Cui, Rigg, Luo, Instrumental color control for metallic coatings

Industrial Color

Oral Sessions:

Hutchings Singleton, Plater, Dias, Food colour and appearance measurement, specification and communication: Can we do better?
Simon, The process industries: graphic arts, paint, plastics, and textiles: all cousins under the skin
Kettler, Complex refractive index and colour of quinacridone pigments
MacDougall, Discontinuity, bubbles and translucence: major factors in food colour measurement
Chong, The role of digital printing and color technology in the digital revolution for the textile world
Simeonova, Narendran, Colored light application in retail display
Xu, Luo, Rigg, Evaluating the quality of daylight simulators using metameric samples
Viggiano , A perception-referenced method for comparison of radiance ratio spectra and its application as an index of metamerism

Poster Papers:

Ahn, Moon, Song, A study of skin colors of Korean women
Akbar, Color matching techniques
Takata, Akimoto, Kawada, Takahashi, Kumagai, Measurement of skin colors of world population and application for preparing make-up products
Csány, Color reproducibility and dyestuff concentration
Golob, Golob, Rogan, Color quality control of sewing thread production for the automotive industry
Kalivas, Dyeing fabrics with metals
Lam, Xin, Sin Quantifying the color of D65 simulator
Mima, Sato, Relation between blocking property against UV-rays by dyed fabric and its color fastness to light
Osaki, Reproduction of various colors on Jacquard textiles by only eight kinds of color wefts
Westland, Iovine, Bishop, Kubelka-Munk or neural networks for computer colorant formulation

Color Measurement

Oral Sessions:

Eppeldauer, A feference rristimulus colorimeter
Miyazawa, Kurashiki, Hauta-Kasari, Toyooka, Broad-band color filters with rbitrary spectral transmittance using a liquid crystal tunable filter (LCTF)
Nadal, Colorimetric characterization of pearlescent coatings
White, Taylor, The effect of instrument design on diffuse reflectance measurements
Sakatani, Ito, The effect of gloss on perceived lightness
Baba, Suzuki, Study on geometric conditions for reflection measurement II: Effects of light trap size of integrating sphere
Hirschler, Gay, Industrial colour measurement: the state of the art
Witt, Colorimetric control of photographic prints: the problem of fluorescence
Schanda, Muray, Kránic, LED colorimetry

Poster Papers:

Battle, Oana, Shannon, Advances in color measurement
Chung, Xin, Sin, A comprehensive comparison between different mathematical models for inter-instrument agreement of reflectance spectrophotometers
Clarke, Hanson, Harmonisation of scales of colour measurement
Gabel, Goniochromatic color measurement systems: the past 20 years
Hanson, Clarke, The determination and correction of errors in surface colour measurement

Hanson, Clarke, The determination of uncertainty in spectrophotometric surface colour measurement
Hiltunen, Mutanen, Jaaskelainen, Parkkinen, Thermochromism in color measurement
Kim, Geometry free white standard reference plate
Liu, Chen, Bu, Feng, The CIE colorimetric system fails to calculate the chroma of a Nd:YAG crystal under the fluorescence illuminant F7
Marcus, Ruevski, Battle, Galloway, Personal digital assistants and color measurement
Montes, Campos, Pons, Heredia, Tristimulus weights functions to calculate must colors coordinates from 10 nm bandwidth spectral data
Nieves, Valero, Hernández-Andres, García, Romero, Influence of the mean luminance on the detection thresholds for red-green chromatic gratings
Noriega, Morovic, MacDonal, :Lempp, Colour characterisation of cine film

Color Order Systems

Oral Sessions:

Brill, Fairman, Hemmendinger, Ladson, Leonardo 2000: the softcopy screen book
Indow), Uniformities in OSA-UCS and in NCS tested by color difference prediction based on principal hue components
Kobayas, Yosiki, An effective conversion algorithm from OSA-UCS to CIEXYZ
Oleari, Color opponency and scale uniformity in the OSA-UCS system: the geometrical structure

Poster Papers:

Choi, A verification study of NCS (natural color system) notation
Green-Armytage, Colour zones: explanatory diagrams, colour names, and descriptive adjectives
Nemcsics, Recent experiments investigating the harmony interval based colour space of the Coloroid Colour System
Nilsson, The quality of the NCS colour samples today and tomorrow
Rozsovits, Products of Coloroid Color System
Paltridge, Thomson, Yates, Westland, Color spaces for discrimination and categorization in natural scenes
Varela, Colour and symbology: symbolic colour order systems

Color Imaging Applications

Oral Session:

Ingram, Printing processes—oportunities and limitations
MacDonald Morovic, Xiao, Evaluation of a colour gamut mapping algorithm
Song, Luo, Colour difference thresholds for cross-media colour image reproductions
Köig, Ohsawa, Yamaguchi, Ohyama, Hill, A multiprimary display: discounting observer metamerism

Image Analysis & Synthesis

Oral Session:

Bouzit, MacDonald, Does sharpness affect the reproduction of colour images?
Takemura, Miyazaki, Kanafus, Urabe, Toyoda, Ishikawa, Hatada, Developing a new psychophysical experimental method to assess image quality
Wesolkowski, Fieguth, Color image segmentation using a region growing method
Kobayasi, Suzuki, Mathematical analysis of color combination and color composition of images
Tominaga, Ishida, Wandell, Illuminant estimation of natural scene using the sensor correlation bethod
Meyer, Westland, Walker, Wingard, A computer graphic system for rendering gonio-apparent colors
Tanaka, Tominaga, Estimation of a 3D spectral reflection model for color image rendering

Poster Papers:

Cunthasaksiri,Hansuebsai, Pungrassamee, Ando, Color image processing using sRGB sub-divided space technique

Haneisha, Sakuda, Honda, Polyhedral gamut representation of natural objects based on spectral reflectance database and its application

Ohsawa, Koenig, Yamaguchi, Ohyama, Multi-primary display optimized for CIE1931 and CIE1964 color matching functions

Connah, Westland, Thomson, Parametric investigation of multispectral imaging

Color Reproduction

Poster Papers:

Alessi, Cottone, Color reproduction scheme for Kodak OLED technology

Chalmers, Colour aliasing and colour reproduction in digital photography

Gonçalves, Pereira, Pereira, Color applied to printing graphic design: The importance of lighting in the color perception and specification process

Other Poster Papers on "How do we Control Color?":

Rinaldi, The concept of *white light* in stage lighting

Why Color Management?

James C. King

Adobe Systems Incorporated

Abstract

It seems that everywhere you look there is some article or discussion about color management. Why all the fuss? Do I need to management my colors? We have been creating colored artifacts for a very long time and I don't think we have needed color management. So why now? Most of these discussions also refer to the ICC. What is that? These and other questions will be answered in a straightforward manner in plain English. Adobe Systems has pioneered the use of desktop computers for color work, and the author has helped Adobe pick its way down conflicting color paths with confusing road signs over the last 10 years.

Device Independent Desktop Color Management

Desktop Color Management has had a shady past. It is believed to be very difficult, hard to understand, and possibly not a good thing to attempt. I don't believe any of that and after this presentation, I hope that you will have a better, clearer understanding and like me will become a true believer.

Users are looking for color predictability and consistency. They would like a colored page to be reproducible on a variety of technologies with consistent results, even though different devices reproduce color differently. For example, when the same values are sent to two different devices (the same RGB values are sent to different displays, or the same CMYK values are sent to different CMYK printers), the resulting colors are usually quite different—unless the devices are identical and process the values identically. In order to get similar results, different values need to be sent to different devices. What's needed is a way to take the values that represent the desired color on one device, and from them produce corresponding values that reproduce the "same" color on another device. These transformations are done by using tables, equations, or other tricks. The quality of today's products is judged, in part, by how they perform these transformations.

In Figure 1 some given "source" values are shown being transformed to a modified set of values appropriate to a different "destination" device. If we were to create a transformation to map from each of N sources to each of M destinations, we would have to create M times N unique transformations as shown in Figure 2.

Figure 1

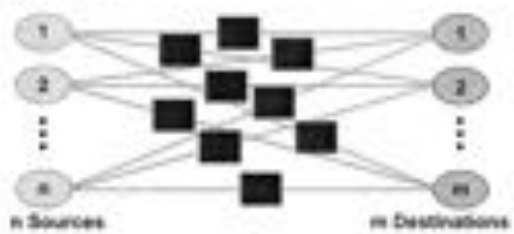


Figure 2

If we were to add a new destination device to the list we would have to add N new transforms, one for each source. Conversely, a new source would dictate that we make M new transforms, one for each destination. A common way to simplify the situation is to introduce a fixed standard color space as shown in Figure 3. One transform per source is all that is needed to relate the source to the standard and one transform per destination is all that is needed to conform to each destination. This is now an additive problem and the introduction of a new device only requires the introduction of one new transform either to or from the standard. The use of this principle is a major part of what the color management system (CMS) vendors are referring to as "device independent color[3,4]."

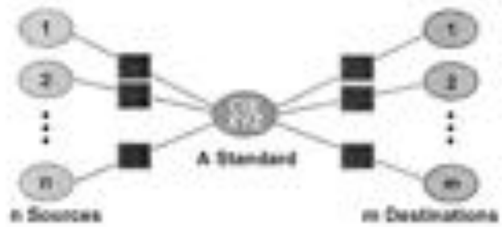


Figure 3

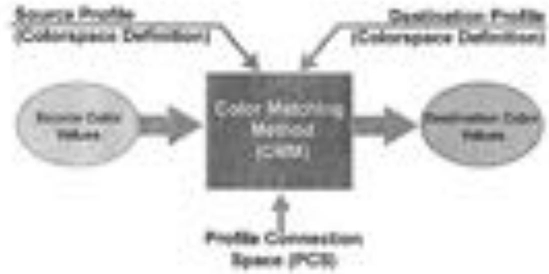


Figure 4

The current transformation technology used by most of us is to have a generic transform mechanism that is customized by what we here call "colorspace definitions" as shown in Figure 4. Note that the colorspace definitions are a small amount of information compared to the large amount of data that might need to be transformed (the sources color values) such as for a large color image. The International Color Consortium (ICC) at www.color.org has standardized the "colorspace definitions" and has called them "profiles". The format chosen matches that of Apple's ColorSync®[2] Profiles and nearly all major operating system and color system vendors have agree to use that format. The transforms are implemented in what is commonly called a color matching module or color matching method (CMM). In an ICC-based color management system, the standard reference space into or out of which the color data is transformed is called a Profile Connection Space (PCS). The two PCS's in the ICC system are CIE-XYZ and CIELAB. Details of the current ICC Profile Format Specification are available on the ICC web site at www.color.org.

One other powerful idea that most of the current systems share, is an optimization that is introduced by "smashing" the two transforms into one. The definition for what has to be done is provided in terms of the PCS, gaining the device independent benefits as noted earlier. However, no sacrifice in processing efficiencies need be made. Separating the *definition* from the *execution* is key.

Example of Desktop Color Management

Figure 5 shows an example of a color managed workflow that you might find, for example, while using Adobe® Photoshop®. Note that there are "workspace color values" or working colorspace in which the current job is kept. In order to update the display, color values in the workspace need to be converted to values in the display color space. This is constantly being done as the image is updated. Conversions from the working space to the display space requires a profile for each. The monitor profile is supplied by the operating system since the display is used across all applications and is a component of the basic machine. The working colorspace is established by the user by choosing among several available within Photoshop.

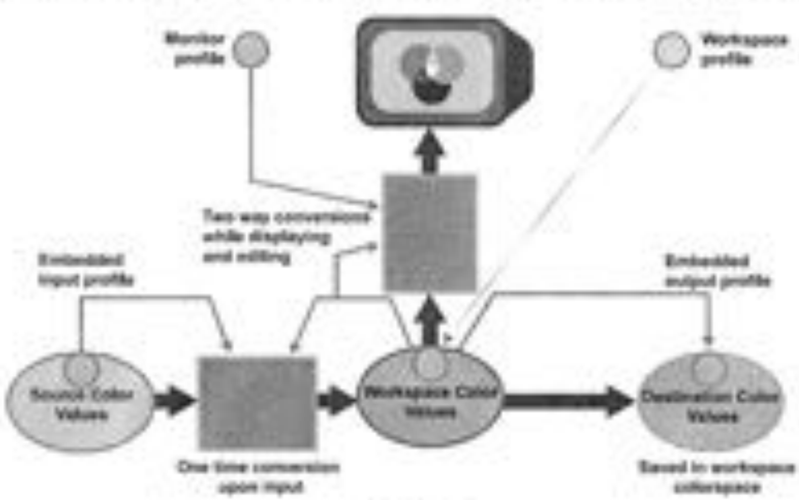


Figure 5.

If the input or source colors are in a colorspace that is other than the working colorspace then upon opening usually they will be converted into the working colorspace. This requires that the input has a colorspace profile associated with it to define the color values in the input. If the work is saved it is saved in the workspace colorspace and the profile for that space is saved with the data.

Gamut Mapping and Rendering Intents

The gamut of a colorspace is the total set of colors that can be represented within that colorspace. Typically a device CMYK colorspace will represent less saturated and fewer colors than an RGB colorspace. When the gamut of the source and destination colorspaces differ a "gamut mapping" needs to be performed. Those colors that cannot be represented in the destination need to be altered to colors that can be represented.

The ICC has defined four different general mapping categories: perceptual, saturated, and colorimetric (relative and absolute). If one is working with a company logo or any other object where it is important to preserve the colors colorimetrically, then one will want source colors to match colors in the destination (colorimetrically). For those colors that have no match some "closest possible" match should be found. This type of gamut mapping is called "colorimetric". There are two versions depending upon whether the colors are adjusted for white points or not. Usually relative colorimetric matching is done.

Experience has shown that colorimetric gamut mapping of pictures can be improved upon and so a "perceptual" method of gamut mapping is preferred for pictures. Usually these mappings make changes even to the colors that can be matched. The human visual system is more sensitive to relative color differences than it is to absolute values so changing the mapping to preserve those differences yields better looking results. When producing a business graphic or other schematic material, it may be more important to have the best solid saturated colors that a device can produce rather than to have an accurate color that the device might produce in a poorly rendered way. So for these kinds of objects one uses a "saturated" gamut mapping. There is a correspondence between gamut mapping methods and what has come to be called "rendering intents". More about rendering intents a little later. For the perceptual and saturated intents considerable latitude is allowed in the interpretation and implementation since no one has demonstrated a single best method to do the gamut mapping.

Often complex pages may have several objects each associated with a different one of the classic mapping methods. The logo requiring the best possible colorimetric mapping, the picture a perceptual mapping and the graph a saturated mapping. Within the ICC method for color management, the gamut mapping is accomplished by the color conversions being controlled by data found in the source and destination profiles. Typically gamut mapping is performed on the output side when translating from the Profile Connection Space (PCS) to the destination colorspace. Different profile data is needed for different gamut mappings. A minor dilemma arises because the choice of gamut mapping or "rendering" is determined by the source objects yet effects the output profiles. We do not want to carry output profiles with our source data since that would tie that source to only one destination.

Carrying a large variety of destinations is also not a good design. So a clever trick is used. We associate one of four "rendering intent" values with each source object. They tag the source objects as to which of the basic four gamut mappings is most appropriate for that object but do not specify anything further that might involve an output or destination device.

When this source material is finally converted to a particular destination device one of four different gamut mappings can be performed on any given object provided the output profile contains the data required to do any of four different gamut mappings. So, ICC output files do require four different sets of mapping data, one for each rendering intent. (Actually, since it is possible to obtaining one colorimetric mapping from the other, only three independent sets of data are required.)

Figure 6 is a diagram of how the rendering intent chosen by the user effects the processing done by Photoshop while outputting an image to a printer. In this case, the whole Photoshop workspace is considered to be one object and it is all rendered with a single intent chosen by the user.

Figure 7 shows how color management and the various profiles and conversions are used to do what is typically called "soft proofing". Soft proofing refers to producing an image on the monitor that closely resembles the gamut-reduced image that might be produced on a gamut limited output device (think CMYK). The color values are first converted as if they were going to be sent to the printer, and then they are converted back to the monitor colorspace.

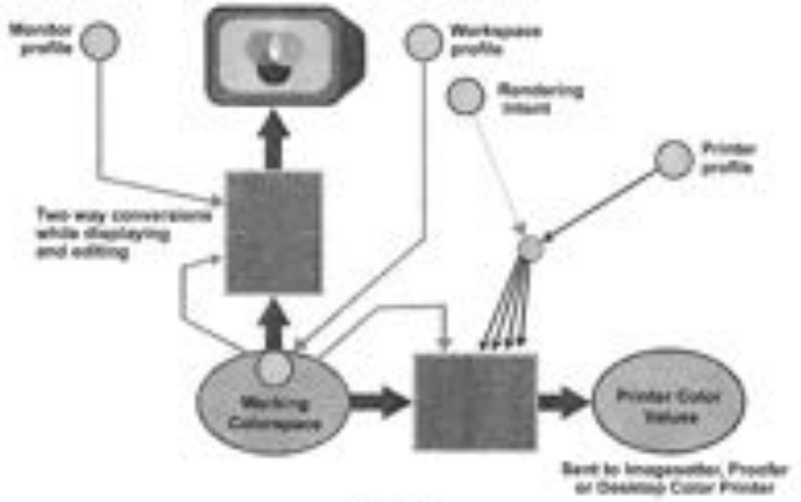


Figure 6.

During the conversion to the printer values, any important gamut mapping is performed. Then care is taken when converting those printer values to ones for the display not to do any further gamut mapping and thus preserving the reduction in gamut in the overall display.

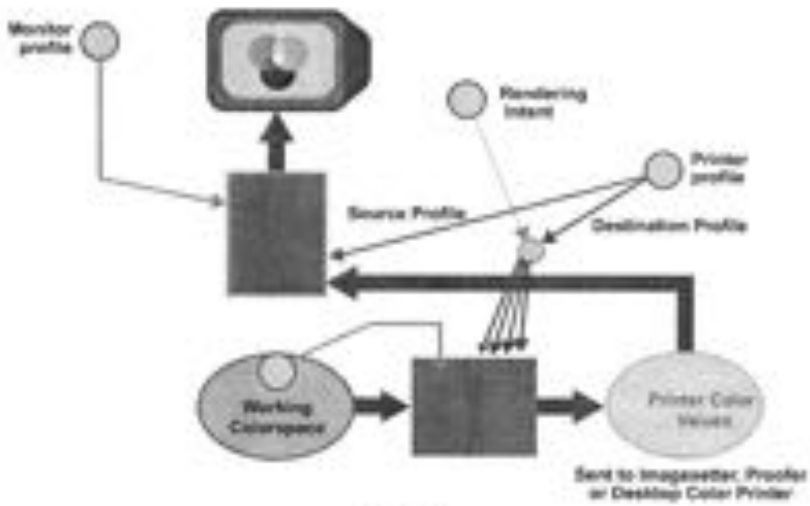


Figure 7.

Conversion Glitches

There are too many situations where the ICC workflows don't produce as good as results as one would hope for and rightfully expect. What accounts for these less-than-expected results? Here are 5 areas where things can be improved.

1. Quantization

If someone mentions that your color data may have been quantized, then run the other direction. This term has been inherited from the world of analog to digital conversion where analog data has to be broken in to digital representations with fixed precision and range and hence "quantized". However, in color management the term refers to what computer scientists would more likely call "truncation" or "loss of data". It usually means dropping lower order (right most) digits in a result in order to allow the result to be represented in a certain number of binary digits.

It is somewhat unfortunate for color management that the computer industry standardized on the 8-bit byte as a basic computer storage and computational unit. With 8-bits one can represent or encode 256 distinct values. For many situations 256 levels or colors or variations per color channel matches the human visual system reasonably closely. However, if the coding of data into the 8-bit bytes is done without regard for the way that the values to be represented spread themselves out in a coding scheme, the 8-bit representation can become very lossy when representing color values. We would have seen far fewer bad color conversions had the computer industry standardized on 12-bit bytes or early color products had just use 16-bit values.

2. Gamut Mapping

Since the most notorious color gamut compressions involve reducing the total number of colors that can be represented then going back to the original values is usually impossible. What has been lost is lost. So it is best to delay any steps where gamut compression can occur to avoid reducing the gamut of the data we have. It must be done for output to gamut reduced devices but it is best to reduce your data in this way only in the last step.

3. White Point/Black Point

The International Color Consortium (ICC) is now a group of more than 60 companies working on and agreeing to a standard profile specification, and implicitly through that, agreeing to a standard way in which to perform color management and color conversion. The clarity of the agreements hasn't always been perfect and the specification has several places where the explanation and wording can be greatly improved. The ICC is working on this and will soon come out with a revised specification that is much improved. There is also other more long term work being done within the ICC to change some of the fundamental assumptions of the current architecture with hopes of making bigger advancements. This is also work in progress.

4. Bad Arithmetic

It is both surprising and expected that some programmers don't do a very good job of having the programs that they produce to good arithmetic. Any time when one does computation on a computer she has to worry about loss of significance and magnified error creeping into our computations. In the early days of computer development "numerical analysis" was a strong discipline where one learned in excruciating detail how to do computations that maintain the maximum amount of useful information. People writing color management software should at least pay a passing glance at this older establish discipline.

5. Interpolation Errors

Interpolation is a simple process of guessing a result value intermediate between two known values. For smooth functions this is a very effective way to reduce table sizes when functions are to be computed by simply looking up the proper answer in a table. For many functions the table would be required to have an impractical number of entries so tables with fewer entries are provided and the smoothness of the function is relied upon to make computation of intermediate results meaningful.

However, given that rounding and/or truncation are used to make the table values, and then averaging calculations are made to determine intermediate values it becomes clear that the table entries have to be represented to a higher precision than that required of the output. This is an observation that has generally been overlooked by the ICC and others and if corrected could result in slightly more precise results.

Compound Documents

Many of the pages or screen views that are created are made from many individual elements. They are compound documents. What if each of the contributing elements have been created with their own different colorspace? Figure 8 shows how this is typically handled in Photoshop. Photoshop maintains the idea of a working colorspace and as each contributing element is opened and included into the final document, it is converted to the working colorspace. Each input is expected to come with its own appropriate input profile and the profile associated with the working colorspace is used as the output or destination for the color transformation.

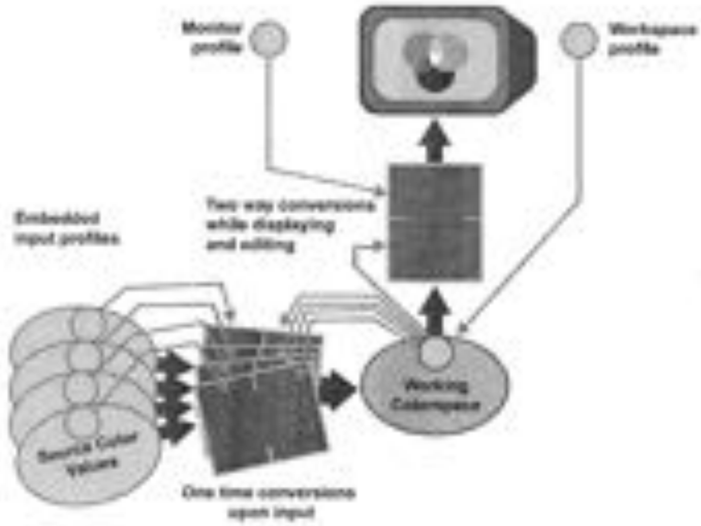


Figure 8.

In a layout application like PageMaker, a different strategy is possible. All conversions are deferred and the colorspace and associated profile are kept with each element. As the document is being displayed on the monitor many different color transformations are setup, one for each different element of the compound document. During the output of the final document all element may then be converted to a common output colorspace as shown in Figure 9. Or if the output device is a PostScript®[3] device the compound document, including all of its various input profiles can be sent on to allow the colorspace conversions to be done within the PostScript device. Notice that each element of the compound document has a rendering intent associated with it. This allows each of the elements to choose the appropriate type of gamut mapping from the output profile.

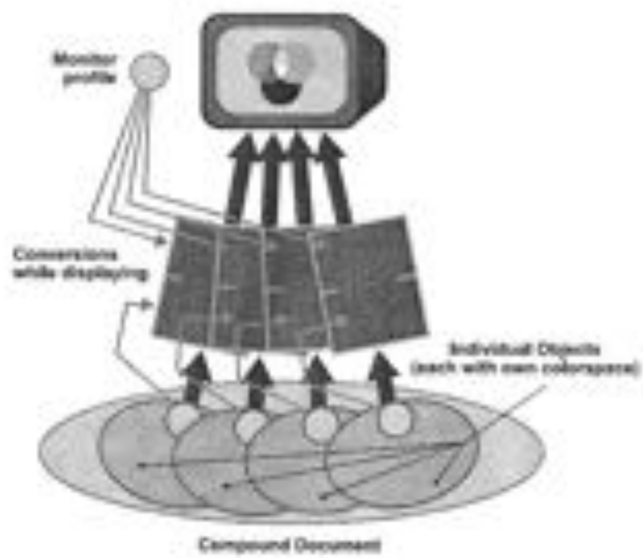


Figure 9.

Conclusion

At the start of this paper we tried to emphasize that color management is a requirement because devices produce color differently and require different color values to produce similar results. This part seems inevitable. However, we seem to be pushing too much of the work needed to accomplish color management onto the computer user. Let me give you an analogy. Early automobiles had a lever that the driver had to adjust that is no longer seen on automobiles today. It was called a spark advance. The exact timing of when the spark plug is to fire to cause the gasoline to explode in each engine cylinder has to be adjusted depending upon how fast the engine is running and upon how much load is being drawn from the engine. Drivers of early cars had to learn exactly how to set this spark advance as the car is accelerating, decelerating and especially when starting the engine. The fact that drivers no longer use these controls isn't that the spark does not need advancing on modern engines. It just means that engineers have figured out how to do the spark advance automatically and more accurately than the human driver can do it. We need to find which of the various things we are asking our computer users to do with respect to color management are to become spark advances. Which things can we do in our systems automatically and better than the user can?

Acknowledgements

Rob Buckley conceived of this paper and talk and urged me to do it. He also was a great help in reducing what started as an oral presentation into a written presentation. Thank you Rob.

References

1. Ron Gentile, Device independent color in PostScript, February 1993, IS&T/SPIE Int'l Symposium on Electronic Imaging, http://imaging.org.

2. Apple Computers, ColorSync. http://www.apple.com/colorsync.

3. Adobe Systems Incorporated, February 1999, PostScript Language Reference Manual, 3rd Edition, Addison-Wesley Publishing Company, 912 pages, ISBN 0-201-37922-8 (This book can be downloaded from Adobe's web site in soft copy form: http://www.adobe.com or http://partners.adobe.com/asn/developer/technotes/postscript.html.)

4. James King, On the Desktop Color System Implied by the ICC Standard, November 1998, IS&T/SID Color Imaging Conference, http://www.imaging.org.

Invited Paper

Evolution of the ICC Profile Connection Space

George Pawle* and Lars Borg
Eastman Kodak Company; Adobe Systems Inc.

ABSTRACT

The architecture used by the ICC to manage color is based on a device-independent color space called the Profile Connection Space (PCS). Each device relates its color space to that of the PCS, which allows source device profiles to be constructed without knowing the actual destination device and destination device profiles to be constructed without knowing the actual source device. The concept works well and has been widely adopted over the past several years. However, this widespread adoption has increasingly meant that profiles from various vendors will be connected in a color management system. In order for these profiles to work together, they must both implement the PCS in the same manner. Generally, this has been done well, but increasing quality expectations have shown that there are some areas in which the interoperability of profiles could be improved. The ICC has recently approved modifications to the PCS that address these issues.

This paper will first describe the current ICC PCS, how it is used, and the interoperability problems that have been encountered. Next, it describes the PCS modifications and shows how they improve the interoperability of ICC profiles.

1. ICC SPECIFICATION HISTORY

The International Color Consortium was originally formed as the ColorSync Consortium, which was organized to develop a second revision to Apple Computer's ColorSync color management system. The name was later changed to the ICC, but the revision number was retained, so the first revision of the ICC specification was identified as revision 2.

A few years later, the ICC issued a revised specification, which was labeled revision 3. The internal version of the profile format, however, remained at 2. In an attempt to avoid confusion, the upcoming major revision of the ICC specification identifies the internal profile format as revision 4.

2. REVISION 2 PCS

Annex A of the ICC specification (ICC.1:1998-09) defines the PCS "as the CIE colorimetry which will produce the desired color appearance if rendered on a reference imaging media and viewed in a reference viewing environment." It defines the measurement conditions to be those of ANSI CGATS.5-1993 and the reference viewing condition to be ANSI PH2.30-1989, which is a D50 graphic arts viewing environment. It uses CIE colorimetry normalized to the PCS white point of D50. These definitions have often caused the PCS to be described as "print-like."

The basic definition is further refined by the definition of rendering intents. The term "rendering" has been used in many ways, but here it is used very generally, to mean some type of color adjustment to accommodate the differences between color spaces. The two most important rendering intents are perceptual and colorimetric. The specification also defines saturation intent, but it is rarely used and will not be discussed in this paper. The colorimetric intent has two flavors, relative and absolute, but absolute is derived from relative, so the two are generally considered as a single intent.

The perceptual intent is used when you want to obtain the most pleasing or best looking result. It would typically be used when making a final CMYK print of a scanned photographic print. In this case, the profile builder wants to make full use of the characteristics of the source and destination devices. The input (the direction is relative to the PCS) transform in the scanner profile converts from scanner device codes to PCS values. In order to "produce the desired color appearance", the profile builder must clearly understand the "virtual device" of the PCS.

The colorimetric intent is used when you want to see, as closely as possible, the exact colors of the original. It is typically used either when proofing on a hard copy printer or when soft-proofing on a monitor. It is also used when printing named colors.

9th Congress of the International Colour Association, Proceedings
of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

In addition to the definition in Annex A, an additional annex, Annex E, goes into some detail explaining the various implications of the definitions. It points out the need for a consistent understanding or interpretation of the PCS. It discusses the various types of devices and how profiles would be constructed for each of them.

At first, this would seem to be a comprehensive description and would allow consistent use between various profile producers. However, when you begin building a transform for a profile, questions about the PCS quickly arise. For example, Annex A refers to an "ideal reflection print." However, what are the actual characteristics of such a medium? Annex E provides some guidance by defining it as "an idealized print, to be viewed in reflection, on a "paper" that is a perfect, non-selective diffuser (i.e., D-min = 0), with colorants having a large dynamic range and color gamut." This is much better, but still leaves a lot to the imagination.

The rendering intents have been described as they were originally conceived, as a means to adjust colors as they are moved from the PCS to the output device. The original specification followed this concept by defining output profiles that had transforms for all of the rendering intents. The profiles for monitors and color spaces, however, were defined to have only a single transform to and from the PCS, and the profiles for scanners have only a single transform into the PCS. But, does that transform correspond to the colorimetric or perceptual intent? The profile provided no means to specify the intent, so the two intents needed to use the same encoding method to ensure compatibility. As will be shown next, there are conflicts between the two intents which makes using the same encoding method difficult, if not impossible.

2.1 Perceptual Transforms

Consider building a perceptual transform that converts colors from a scanner to the PCS. The PCS uses relative colorimetry, so the white point of the scanned medium will be mapped to D50 in the PCS. But, where should you map the black point of the scanned medium? The PCS medium is an ideal reflection print, which implies that its colorants can print such that there is zero reflectance at the darkest point. This corresponds to a maximum density (D-max) of infinity, which means that the PCS print has an infinite dynamic range. Clearly, the black point of the scanned media should not be mapped to a D-max of infinity, but to what level should it be mapped? There is no guidance in the specification about the black point of the reference medium, but one is needed. As a result, most profile builders use zero as the PCS black point, simply because it was the only available reference, even though it really cannot be correct.

Now the range of the tone scale has been set. The next question is "What does it look like?" It is a seemingly obvious question, but critical to the profile builder, who must know this in order to be able to generate the "desired appearance." The ideal medium is not like any real medium, especially in the shadows, so it is difficult to estimate what the PCS appearance will be at any given point on the tone scale. To provide a more easily understood medium, profile builders would conceptually map the white and black points of the PCS to values that could be from a real medium. They would use a minimum density (D-min) around 0.05 and a D-max of 2.4 to 3.5. They would then apply a shift and scale to these values to obtain the actual PCS values.

This helped understand the PCS, but unfortunately, the ICC did not define the D-min and D-max of the PCS. Fortunately, the PCS uses relative colorimetry, which largely masks these interpretation differences between profile builders. Most profiles work well together despite the difference. However, as quality demands are increased, the difference becomes apparent.

A related problem occurs with the gamut of the reference medium. It is not specifically defined in Annex A and Annex E states only that it is "large." The lack of a known gamut would seem to be a serious problem, but in practice it is not a large source of differences. As with the tone scale mapping, most profiles will work well together, with the differences becoming apparent only when the quality demands are increased.

2.2 Colorimetric Transforms

Colorimetric transforms would seem to be straightforward, but there are problems associated with their construction. First, Annex A and Annex E do not distinguish between the perceptual and colorimetric intents as they relate to the PCS. They imply that the reference medium and the reference viewing environment should be used for both intents. They also state that just one form of colorimetry is used for the PCS. This means that it should be possible to combine, for example, a perceptual input transform with a colorimetric output transform, such as with a scanner transform (which is typically perceptual) and a monitor transform (which is typically colorimetric). At first, it would seem that the single PCS definition for all intents would facilitate this operation. However, the name "colorimetric" suggests that the PCS values are directly related to measurement colorimetry. The black point of a typical medium would have an L^* value of about three, but recall that most perceptual transforms encode the black point as 0. This is clearly a mismatch that will prevent proper communication of shadow information.

Another problem is that the PCS definition did not distinguish between the various rendering intents, which implied that the colorimetric values should be referenced to the ideal reference medium. Because the reference medium was poorly defined and because some profile builders felt the reference medium should not be considered at all, there was inconsistency in how this was done.

It was clear that when the actual measurement conditions are not the same as those of the PCS, some form of adaptation would be needed. Yet, it was not clear what type of adaptation should be used. Would it simply be chromatic adaptation? The specification states that the PCS represents "desired appearance", so should the adaptation state of the viewer be included, even with the colorimetric intent?

The use of the media white point, which defines the relationship between the media-relative colorimetric intent and the ICC-absolute colorimetric intent, was also uncertain. This issue surfaced almost as soon as the original profile specification was published! With Revision 2, it was not clear if and when adaptation should be applied to the media white point. This was particularly a problem with monitor profiles. Should the actual white point of the monitor be encoded in the media white point, or should the adapted value be used? If a single monitor is being used, the viewer will usually adapt to the white point of the monitor, however, if two monitors are being viewed simultaneously, it is not clear what the adaptation state of the viewer will be. This led different interpretations of the content of the media white point.

Finally, there is the issue of terminology. The ICC uses the terms "relative colorimetry" to mean colorimetry relative to the media of the device and "absolute colorimetry" to mean colorimetry relative to the illuminant of the PCS, which is D50. The CIE uses "relative" to mean relative to a single illuminant, which corresponds to the ICC use of "absolute." The CIE does not have a definition of "absolute" with respect to colorimetry. This mismatch of terminology has caused further confusion.

3. REVISION 4 PCS

The ICC worked for several years to resolve these problems. The solution agreed upon for Revision 4 of the specification (which has a recommended introduction date of November 2001) was based upon three concepts:

1) Separate definitions for the perceptual and colorimetric intents

2) A clear relationship between PCS values and measured colorimetry

3) Acknowledgment that while this PCS will meet the needs of most workflows, there are some for which it is not completely defined

The first part of implementing these concepts was to use better terminology. The terms "relative colorimetry" and "absolute colorimetry" have been replaced with "media-relative colorimetry" and "ICC-absolute colorimetry." The media-relative colorimetric intent is defined as "Rescal[ing] the in-gamut, chromatically adapted tristimulus values such that the white point of the actual medium is mapped to the white point of the reference medium (for either input or output). The ICC-absolute colorimetric intent is defined as "The chromatically adapted tristimulus values of the in-gamut colors are unchanged." The specification also notes that ICC-Absolute corresponds to "relative colorimetry" in CIE terminology.

3.1 Perceptual Transforms

The basic definition of the perceptual intent is "the PCS values shall represent hypothetical measurements of a color reproduction on a reference medium. By extension, for the perceptual intent, the PCS represents the appearance of that reproduction as viewed in the reference viewing environment by a human observer adapted to that environment." This definition does two things: it relates the PCS values to measurements and makes it clear that the state of adaptation of the observer must be included when calculating PCS values.

The reference medium and the reference viewing environment are clearly stated to apply only to the perceptual intent. They do not apply to the colorimetric intent. The reference medium is "a hypothetical print on a substrate having a neutral reflectance of 89%. The darkest printable color on this medium shall have a neutral reflectance of 0.30911%, which is 0.34731% of the substrate reflectance. These are the white point and black point of the reference medium. The reference medium therefore has a linear dynamic range of 287.9:1 and a density range of 2.4593." This makes both the white point and black point well defined at realistic levels. Just this simple expedient of clearly setting the top and bottom of the tonal range will make it much easier to conceptualize the appearance of the reference medium. This, in turn, will greatly improve the interoperability between the perceptual intents of profiles.

The reference viewing environment is the same as in Revision 2, with two important additions. The illumination level has been set at 500 lux, which is the level the ISO specifies for display and judging of reflection print viewing. The PCS illuminant is still D50, but in addition, the chromatic adaptation state has been defined to correspond to the chromaticity of D50. This was often assumed when using the Revision 2 specification, but now is clearly stated.

3.2 Colorimetric Transforms

The colorimetric intents are now defined such that the PCS values for a colorimetric transform relate directly to measurement data. The only correction to the measured data would be in the case that the measurement illuminant is not D50. In this case, a chromatic adaptation will be needed to convert the colorimetry to be relative to D50. The media-relative colorimetric intent is defined as "the PCS values [that] represent media-relative measurements of the captured original (for input profiles), or media-relative color reproductions produced by the output device (for output profiles)." The ICC-absolute colorimetric intent is defined as "the PCS values [that] represent measurements of the captured original relative to a hypothetical perfectly reflecting diffuser (for input profiles), or color reproductions produced by the output device relative to a hypothetical perfectly reflecting diffuser (for output profiles)."

The colorimetric intent is, in general, not expected to involve rendering. This is explicitly made clear by stating that the reference viewing environment and reference medium do not apply to the colorimetric intent. It is in this section of the PCS definition that the limitations of a print-centric PCS are acknowledged. A print-like PCS cannot encompass the characteristics and viewing environments of media such as transparencies, which presents challenges in some situations. For example, attempting to proof a transparency on a monitor is likely to require some type of rendering to produce an image on the monitor that most closely shows what the transparency would look like. The specification states "In transforms for the media-relative and ICC-absolute colorimetric intents, the PCS values may represent a color rendering of the actual original captured for input profiles. Likewise, for output profiles, the PCS values may be color rendered by the output device to the actual medium. However, wherever ICC profiles are used, the PCS values resulting from such transforms shall be interpreted as the colorimetry of the original and reproduction, regardless of whether such colorimetry is the actual colorimetry." This statement says only that some rendering may be needed, but does not say in which circumstances it might be needed or what should be done in those circumstances. Several suggestions of possible PCS definitions and associated operations have been proposed, but all of these approaches are complex and it would be difficult to achieve consensus on one of them. Therefore, the ICC decided to retain the print-centric Revision 2 PCS and allow modification for unusual situations.

3.3 Other Issues

The separate definitions of the perceptual and colorimetric intents raise the question "What happens when they are combined?" The answer to the question was provided not directly in the new PCS definition, but rather indirectly in the profiles. Scanner, monitor, and color space profiles now may have transforms for all of the rendering intents. This removes the ambiguity of combining transforms that have different intents. Now the expectation is that when transforms are connected through the PCS, the intents on either side of the PCS will match.

There are workflows that contain different intents. An example is printing a scan perceptually and soft-proofing the print on a monitor. The workflow would be (scanner -> pPCS) (pPCS -> printer) (printer -> cPCS) (cPCS -> monitor), where the "p" or "c" prefixed to "PCS" identifies the rendering intent of the transform to be perceptual or colorimetric, respectively. This example shows that when the rendering intent changes in a workflow, it changes at the device, not at the PCS.

At the same time, it is worth noting that the two definitions use the same encoding method, so that the numbers will match up if transforms with different intents are combined. One case in which this would happen is when a profile has a single transform for all intents, as is the case in Revision 2.

The use of the media white point, which defines the relationship between the media-relative colorimetric intent and the ICC-absolute colorimetric intent, has been clearly stated. In Annex A, the specification states "If chromatic adaptation is being applied to the PCS values, the adaptation should be applied to the mediaWhitePointTag values as well."

The use of the chromatic adaptation transform has been clarified in general. Adaptation transforms are still a subject of active research and lively debate, so it was not possible to specify a particular method. However, the places where it is used and a means to identify the particular method (the chromaticAdaptationTag) have been provided. In addition to stating where it should be used, Annex D (formerly Annex E) also provides a step-by-step example of calculating PCS values for a colorimetric transform.

4. CONCLUSION

The definition of the ICC PCS has been dramatically improved, but it does not fix all of the problems of the PCS. It is still print-centric, which limits its ability to manage high-dynamic range devices. The encoding range is capped at the white point of the PCS, so there is no headroom available to encode speculars. It does not define the gamut of the reference medium. Nevertheless, its various components are much more tightly defined and the functions of the various parts have been clearly identified. This will lead to better understanding of the PCS and result in better interoperability between profiles from differing sources.

REFERENCES

1. Specification ICC.1:1998-09, "File Format for Color Profiles." International Color Consortium, 1998.

2. ANSI CGATS.5-1993, "Graphic technology - Spectral measurement and colorimetric computation for graphic arts images."

3. ANSI PH2.30-1989 - "Color Prints, Transparencies, and Photomechanical Reproductions - Viewing Conditions."

* Correspondence: pawle@ekbos.com; phone 978-323-7655; Kodak Systems and Solution, 900 Chelmsford Street, Lowell, MA 01851, USA

Quality Evaluation of Current ICC-Profile Generation Tools for CMYK-output Devices

Eggert Jung[b], Hendrik Büring[a], Patrick G. Herzog[a]

[a]Aachen University of Technology, Technical Electronics Institute, 52056 Aachen, Germany

[b]NexPress GmbH, 24107 Kiel, Germany

ABSTRACT

ICC-Color Management tools claim to give both accurate and consistent results. However, using these tools of distinct manufacturers, different results are likely to occur even if the same parameters are given. Obviously the manufacturers do not focus on the same criteria doing their optimizations, which leads to the fact that each tool has its own strengths and weaknesses.
In this study, new methods for comparing ColorManagement tools were evaluated, and with these methods, ICC profiles[1] generated by five CM tools of current leaders on the market were investigated in order to point out their weaknesses and strengths. In addition, the influence of using various ColorMatchingModules (CMM) was tested. For the generation of each ICC profile, the same measurements (ISO 12642=ANSI IT8.7/3 target of Iris InkjetPrinter) were used. Since the standardized ISO 12642 file format, in which the measurement data are stored, was not accepted by each of the tools, the data-file had to be converted to proprietary formats. The investigated quality aspects were accuracy, consistency and smoothness, with ΔE_{ab}[2] and ΔE_{94}[3] taken as the criteria. For each aspect, performance was visualized by mapping the ΔE values to pseudo colors, giving a very intuitive view on the investigated subject.
Results showed that ColorManagement tools indeed achieved good color fidelity, especially if generated as large profiles.
Keywords: color management, ICC profiles, color fidelity, error visualization

1. INTRODUCTION

Color Management plays an important role in today's color reproduction. In order to achieve color fidelity, each part of the color reproduction chain, i.e. input, output and monitoring device, is characterized by a profile. Those profiles are gained using measurements, taken by some color measurement instrument at standardized conditions (e.g. D50 illuminant, 2°-observer), and a profile generating software. The software uses some kind of interpolation or approximation technique to fit the measurement data into a model of the device to be characterized, therefore being a substantial part of a CM tool. The International Color Consortium (ICC) profile file format[1] has become a standard to communicate and interchange profiles. An ICC output profile mainly consists of color lookup table (LUT) pairs, so-called A2B and B2A tables, where A and B denote the device dependent and the device independent color space, respectively. There are three (possibly identical) LUT pairs, enumerated from 0 to 2, enabling the user to choose a rendering intent: perceptual, colorimetric or saturation.
The information stored in the profiles enables a CMM-Software (=ColorManagement- resp. ColorMatching-Module) to carry out necessary color space conversions between the respective native device color space and some device independent color space, e.g. CIELAB ($L^*a^*b^*$). It is not imperative to use a profile generating software in conjunction with the respective CMM of the same manufacturer, however not surprisingly the manufacturers claim their own products to be optimized for best working together. On the other hand a CMM is not always part of a CM tool, since CMMs are included in ICM 2.0 (MS) or ColorSync (Apple). In the extended study, 6 tools (labeled by capital letters A,B,…) were chosen to be investigated with respect to accuracy, consistency and smoothness (during the investigation updates of B,C,D were added with index numbers, e.g. B_1).
Used evaluated tools : Colortune 3.01 (Agfa); ColorBlind 4.0 (Color Solutions), ProfileEditor 2.0E and 2.2 (Kodak); Profiler 3.2 (Monaco); ProfileMaker Pro 3.0 and 3.1 (Logo/Gretag); PrintOpen 3.1 and 4.0 (Heidelberg)

Further author information:
H.B.: E-mail: buering@ite.rwth-aachen.de, URL: http://www.ite.rwth-aachen.de/buering/
P.G.H.: E-mail: herzog@ite.rwth-aachen.de, URL: http://www.ite.rwth-aachen.de/herzog/
E.J.: E-mail: Eggert_Jung@nexpress.com

With each tool, a CMYK output profile was generated and stored in ICC profile format.

2. IMPORT OF MEASUREMENT DATA

For the generation of each ICC profile, the same measurements (ISO 12642=ANSI IT8.7/3 target of Iris InkjetPrinter) were used. The ASCII data file, generated using tool B and an X-Rite DTP41 stripreader measurement device, was expected to be in standardized ISO 12642 file format. However a missing column prevented tool A from importing the ASCII data: instead of the enumeration of the color patches (1..928), a grouped numbering (e.g. 0A1) was given, labeled „SAMPLE_ID", which is in fact the right label for the missing enumeration (the grouped numbering is optional according to ISO 12642). This mistake has been corrected in tool B_2. After this minor modification, the ASCII data file was ready to be imported by tool A, tool B and tool D.
Tool D allowed to export measurement data, however the file format was not ISO compliant again, because of missing information and wrong enumeration (this has been recently corrected in a new version). Tool A had no capabilities to take measurements, only being able to import ASCII data.
Moreover, tool C could not deal with the standardized ISO 12642 format, neither import nor export was possible. Thus its proprietary file format had to be analyzed: The data must be converted to $L^*a^*b^*$ space using the whitepoint of the paper (first patch: illuminant E). Furthermore, the manufacturer seemed to use proprietary CMYK test targets only, not the ANSI IT8.7/3 target. It turned out that the large CMYK target had the same CMYK values as an ANSI IT8.7/3 target, however the patches were scrambled. In order to use the measurement data, a MS Excel sheet was created to reorder and convert the ISO file to the proprietary file format. Finally, tool C imported the converted file.

3. PROFILE GENERATION

Using the appropriate (i.e. more or less converted) data file format, the measurement data file was imported into each profile generation tool. Next, an output profile for a CMYK output device was generated. Whenever applicable, default values were used, with exceptions as follows:

In each case, a maximum black ink coverage of 95% and Under Color Removal (UCR), no Gray Component Replacement (GCR) black generation were selected; where possible, large profile size was chosen for maximum accuracy and consistency, automatic correction of measurements was disabled for improved accuracy and maximum accuracy was chosen instead of smoother transitions.

The resulting profiles had properties as shown in Table 1:

tool	A	C	D	B	B_2
max. ink	350 %	370 %	360 %	370 %	
$LUT_{CMYK \to Lab}$	9^4, 16 bit	8^4, 16 bit	9^4, 16 bit	16^4, 16 bit	
$LUT_{Lab \to CMYK}$	17^3, 16 bit	16^3, 16 bit	33^3, 16 bit	32^3, 8 bit	33^3, 16 bit
file size	459 KB	469 KB	1.07 MB	1.1 MB	1.4 MB
smaller sizes:					
$LUT_{CMYK \to Lab}$	-		9^4, 16bit	13^4 or 11^4, 8 bit	
$LUT_{Lab \to CMYK}$	-		25^3, 16 bit	32^3, 8 bit	32^3 or 21^3, 8 bit
file size	-		580 KB	530 KB or 449 KB	680 KB or 260 KB

Table 1: Profile properties

Obviously the manufacturers of the CM tools disagreed upon the necessary profile LUT grid size and precision. This resulted in a wide file size range of about 0.5 to 1.5 MB.

4. PROFILE QUALITY ASPECTS

In order to compare the generated profiles, three quality aspects were defined: accuracy, consistency and smoothness.

The first aspect, accuracy, means that the measurements incorporated into the profiles are reproduced by the A2B-transform of the ICC profile, given the CMYK values of the ISO 12642 testchart. This can be quantified as a ΔE color difference between the measurements, numerically converted to $L^*a^*b^*$, and the $L^*a^*b^*$ output of the profile.

Secondly, the consistency was checked using generated $L^*a^*b^*$ slices and six natural color images, containing flesh tones, neutral colors, memory colors, saturated colors as well as different structures and smooth transitions. To perform this task, each image was converted from $L^*a^*b^*$ to CMYK and back to $L^*a^*b^*$ using the B2A-transform and the respective inverse A2B-transform of the ICC profile sequentially. The ΔE color difference between the original and the reproduced $L^*a^*b^*$ image, calculated for each pixel, shows either the consistency - or the introduction of errors - of the profile in different regions of the $L^*a^*b^*$ color space.

Finally for smoothness tests, generated smooth gray and color wedges in $L^*a^*b^*$ space were mapped to CMYK and back to $L^*a^*b^*$ using the ICC profile and again the ΔE color difference was calculated. However, not the original $L^*a^*b^*$ wedges served as the reference, but the reproduced versions, shifted along the direction of the wedges. Thus the color difference was calculated between each step and its neighbour, with smooth wedges generating constant differences.

5. PROFILE TESTING

Adobe Photoshop in conjunction with the CMM Export Filters of the tools A to C was used to map $L^*a^*b^*$ to CMYK colors and vice versa. Especially, for tool A and tool C profiles, their 'native' CMM export filter was tested because of their comparatively poor quality (that was not surprising due to the small profile size used).

With respect to the defined quality aspects consistency and smoothness, the colorimetric and the perceptual part of each ICC profile were tested (accuracy: colorimetric part only) and the error was quantified in terms of ΔE_{ab} and ΔE_{94}. For this purpose, a new Photoshop Filter module was created using the Adobe Photoshop SDK and MS Visual C++. This Filter module, called `DeltaE`, was designed to process images in $L^*a^*b^*$ color space with 3 additional "alpha" channels, containing the L^*, a^* and b^* channel of the reference image, respectively. Thus, each time a test image was to be compared with a reference, the reference channels had to be copied using Photoshop channel calculations. After the filtering, the six channels contained ΔL (with an offset of 50), Δa, Δb, $10\cdot[\Delta E_{ab}$, ΔE_{94} and $\Delta(C)$ (to be replaced by ΔE_{2000} in near future)]. Due to the 8bit channels and the multiplication by 10, color differences in the range 00.0 to 25.5 can be shown in a fixed point representation.

Last, the grayscale error channels were converted to indexed mode images and a pseudocolor table was applied for better and more intuitive visualization. In this paper, only some grayscale image samples are shown; more pseudocolor images in full color are available on the website http://www.ite.rwth-aachen.de/buering/cmt.html .
In order to automate this process, some Photoshop Actions were recorded (Photoshop 5.0+ required): The first duplicated the active image and set the name of the copy to *RefLab*, the second used Photoshop channel calculations to append the image called *RefLab* (as three additional alpha channels) to the active image, the third selected the six channels and called the Filter module `DeltaE`, and the last converted the selected gray channel to an indexed pseudocolor image.

6. RESULTS

In the following subsections, subset-results of the investigation are shown as grayscale images. On top of each figure, the investigated image is shown along the color table used for error visualization. The strenghts and weeknesses of each CM tool can be clearly observed.

6.1 Accuracy

Accuracy was expected to be an easy task, however there were huge differences between the profiles. With each profile, an ISO 12642 / ANSI IT8.7/3 CMYK output target was mapped to $L^*a^*b^*$ color space. ΔE values were calculated given the numerically transformed measurements as a reference. Tool B seemed to be CMY optimized; tool A and tool C profiles are too small, probably. The influence of the CMMs was very small, compared with the errors introduced by the profiles.

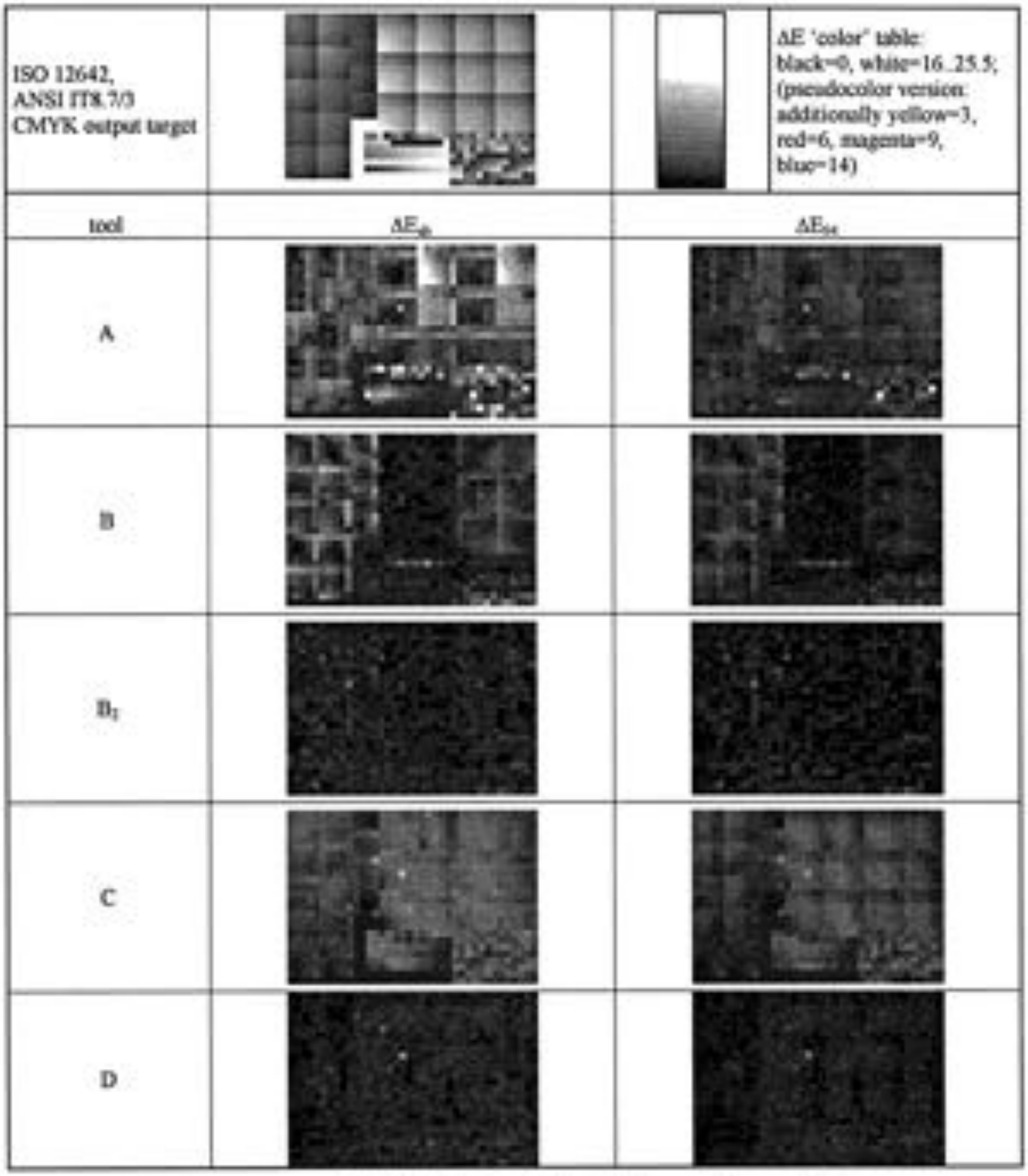


Fig. 1: Accuracy measured in ΔE_{ab} (middle) resp. ΔE_{94} (right), shown using grayscale images (pseudo color version available, see http://www.ite.rwth-aachen.de/baering/cmt.html)

6.2 Consistency
Consistency was checked using six natural color images, containing flesh tones, neutral colors, memory colors, saturated colors as well as different structures and smooth transitions. To perform this task, each image was converted from $L^*a^*b^*$ to CMYK and

back to L*a*b* using the B2A-transform and the respective inverse A2B-transform of the ICC profile sequentially. The ΔE color difference between the original and the reproduced L*a*b* image, calculated for each pixel, shows either the consistency or the introduction of errors of the profile in different regions of the L*a*b* color space.
Additionally, the Kodak Color Evaluation Target and a Kodak IT8.7-2 Target, both converted to Lab, were mapped and analyzed the same way. The Kodak Color Evaluation Target serves as the demonstration object in this paper.

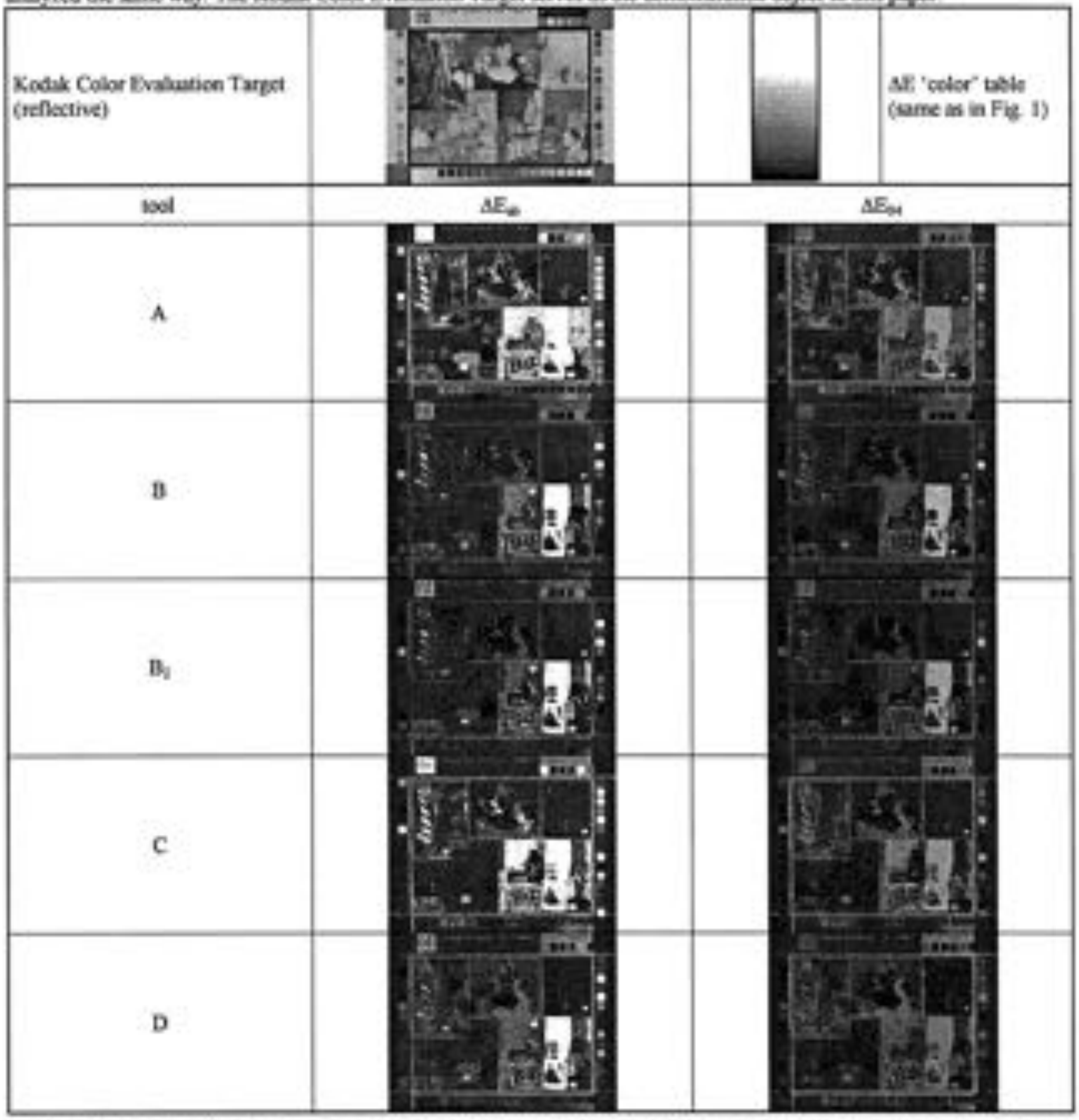


Fig. 2: Consistency of the colorimetric part of the profile measured in ΔE_{ab} (middle) resp. ΔE_{94} (right), shown using grayscale images (pseudo color version available, see http://www.ite.rwth-aachen.de/buering/cmt.html)

The same 'color' table as in the last subsection was used to give an intuitive view on the ΔE values resulting from inconsistencies of the investigated ICC profile. There were only minor differences between the colorimetric and the perceptual part of the profiles in terms of consistency, therefore perceptual images are not shown.

It turned out that the saturated colors were most critical with respect to consistency. Obviously, the gamut of the reproduction device (CMYK printer, IRIS inkjet) is not entirely used by some of the profiles. As given in this subset the
Tools D and B_2 performed best, whereas tool A and C showed rather poor performance.
The performance of tool A and C could gradually be increased using a so-called "profile chain", a builtin feature of the respective CMMs. This was not surprising since that way the CMM could convert the colors internally without the need for storing temporary device dependent images, thus preventing the occurrence of additional quantization errors. However it was not possible to gain similar performance compared to profiles generated by tool B_2 or D.

6.3 Smoothness

Finally, generated smooth gray and color wedges in $L^*a^*b^*$ space were mapped to CMYK and (colorimetric) back to $L^*a^*b^*$ using the ICC profile and again the ΔE color difference was calculated. However, not the original $L^*a^*b^*$ wedges served as the reference, but the reproduced versions, shifted along the direction of the wedges by one (top) to 32 (bottom) units. Thus the color difference was calculated between each step and its neighbours, with smooth wedges generating constant or smooth changing differences. The investigated wedges and some example results are shown in Fig. 3.

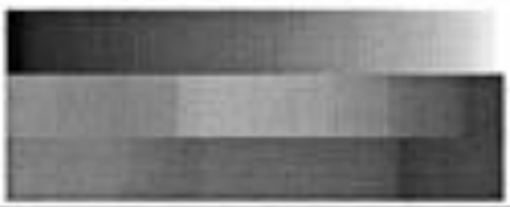
	gray wedge: L^*=0..100, $a^*=b^*=0$ $a^*=b^*$=-128..127, L^*=80 $a^*=b^*$=-128..127, L^*=50
	example result: optimal gray wedge reproduction
	example result: chroma clipping below $a^*=b^*$= -28 and above $a^*=b^*$= 70

Fig. 3: Gray and cyan-to-orange wedges, equally spaced in $L^*a^*b^*$ and some example results
(pseudo color version available, see http://www.ite.rwth-aachen.de/buering/cmt.html)

For the sake of clarity, a color table different from that of Fig. 1 to 2 is used in Fig. 3 & 4, shown in the upper part of Fig. 4.

The smoothness of the resulting wedges can be observed in Fig. 4 as follows:

1.) Wedges consisting of steps of equal difference generate horizontal lines.
This was the case near the gray axis for all profiles tested. Especially the gray axis itself seemed to be reproduced with reasonable smoothness except the region near L*=0, where some clipping occured (colorimetric part) due to limitations of the output device.
2.) The white space in the middle of the colored wedges was caused by the high color difference of up to $32*2^{5}$ chroma units.
3.) Each contour, e.g. the border of the white space, gives an idea of the derivative of the color wedge.

Following weeknesses and strengths were discovered:
- Tool A introduced some artefacts in the orange (L^*=80, $a^*=b^*$>0) and brown (L^*=50, $a^*=b^*$>0) parts of the color wedges. As a result, the wedge got distorted: A chroma maximum was observed.
- Tool $B_{(2)}$ showed the best colorimetric reproduction of the color wedges, as can be seen watching the border of the white space. However, considering perceptual mapping, the orange and brown parts of the color wedges were not as smooth as in the case of tool D, which in turn offered only a smaller output gamut at L^*=80.

- Tool C didn't apply chroma clipping (see Fig. 3), which should be used for colorimetric mapping.
- The opposite was true for tool D, strong chroma compression or even chroma clipping is used at the gamut boundary for both mapping tables.

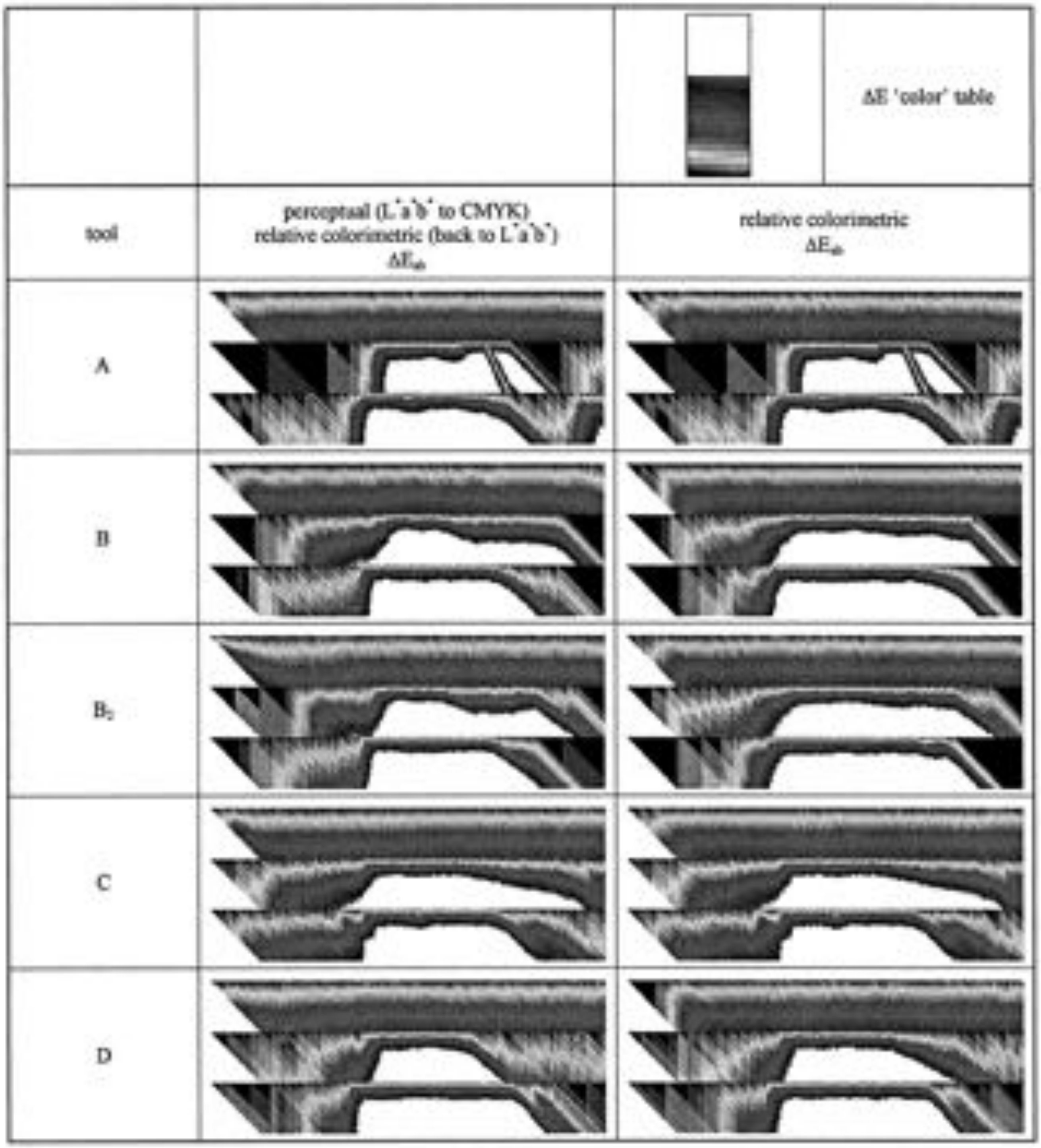


Fig. 4: Smoothness of mapped gray and color wedges in $L^*a^*b^*$ space, shown as pseudocolor ΔE_{ab}
(pseudo color version available, see http://www.ite.rwth-aachen.de/buering/cmt.html)

CONCLUSION

Color fidelity can only be achieved if each device is characterized properly, which is best done using a suitable Color Management tool. Unfortunately, ICC-ColorMangement tools of distinct manufacturers gain different results even if the same parameters are given. Obviously the manufacturers use different techniques to fit the measurement data into a model of the device to be characterized, which leads to the fact that each CM tool has its own strengths and weaknesses.

In this study, a new visualization technique was evaluated to show the performance of ICC profiles generated by six CM tools with respect to three investigated quality aspects called accuracy, consistency and smoothness, with ΔE_{ab} and ΔE_{94} taken as the criteria. In addition, the influence of using various CMMs was tested. In order to gain comparable profiles, the same measurement data were used for the generation of each ICC profile. Surprisingly the exchange of the measurement data was difficult due to some mistake of the CM tool manufacturers, thus not using the standardized ISO 12642 file format. Additionally, the file had to be converted to the proprietary format used by tool C.

The results show that there were huge differences between the profiles tested, especially in terms of accuracy and consistency. As an example, it was recognizable that one profile generation tool (tool B) was optimized on the CMY part (without black ink), whereas another one (tool D) had a better overall performance. With the new version of tool B (tool B_1), however, equal or even better color fidelity was achieved. In general, profiles with more grid points performed better, as is was expected. There is only minor influence of the selected CMMs on the investigated profile quality aspects.

REFERENCES

1. Specification ICC.1:1998-09, "File Format for Color Profiles", International Color Consortium, 1998.
2. CIE Publication No. 15.2, "Colorimetry", Vienna, 1986
3. CIE Publication No. 116, "Industrial Colour-Difference Evaluation", Vienna, 1995

CMS for digital photography, a case study

Robert Y. Chung* and Darunee Sa-areddee*, R • I • T

ABSTRACT

The objectives of the study was to compare image quality from digital photography to RGB-printer under two digital imaging workflows: legacy-based and CMS-based. Due to the difference in judging criteria, the study shows that legacy-based digital imaging workflow can produce pleasing images as good as CMS-based workflow. But ICC-based CMS out performs legacy-based workflow in matching the color appearance of the source images. This is a welcome feature in direct mail catalogs whereby printed images need to match the appearance of the merchandise closely.

Keywords: Color management, digital photography, workflow, image quality

1. INTRODUCTION

A number of technology advancements prompted this study: (1) the abundance and affordability of multi-mega pixel digital cameras; (2) RGB-based digital printers require less user skills to yield good print quality; and (3) improved ICC-based color management technology since its inception in 1993[1]. This study attempts to find out if ICC-based color management offers distinct advantages in terms of image quality and productivity over a legacy-based digital imaging workflow.

2. LEGACY-BASE WORKFLOW VS. CMS-BASED WORKFLOW

To carry out this study, the difference between a legacy-based workflow and a CMS-based workflow were differentiated. In a legacy-based workflow, the user pays little attention to device calibration and profiling. A typical scenario in a legacy-based workflow: (1) an image is captured by a digital camera and downloaded to a computer, (2) the image is adjusted by the user and output to a printer, (3) the digital file is tweaked in the image editing software based on visual feedback of an existing output, (4) the tweaked file is sent to the printer. The desired image quality eventually is achieved after several such iterations and is a function of the user's skill.

In a CMS-based workflow, the user has to calibrate imaging devices used and ensure that devices stay in calibration. A typical scenario in a CMS-based workflow: (1) an image is captured by a digital camera and downloaded to a computer, (2) the image is converted from the camera RGB space to the internal RGB space of the image editing software, (3) Image-dependent adjustments, such as cropping, image size, spatial resolution, sharpness, etc., are performed; (4) the image is converted from the internal RGB space of the image editing software to a printer space and output to the printer. The print-ready digital file requires no tweaking if the source image is desirable. The desired image quality depends on the proper use of the CMS technology and less on the user's skill.

3. EXPERIMENTAL

The objective of the study was to compare image quality from digital photography to RGB-printer under two digital imaging workflows: legacy-based and CMS-based. Image quality is defined in two ways: reproduction quality and picture quality. Reproduction quality is the visual assessment of the image quality in relation to a reference, e.g., a printed image of an oil painting in comparison with the original painting. Picture quality is the visual assessment of the image quality with the observer's own criteria as to what's pleasing.

Key technologies used in the study were a Kodak DC290 digital camera capable of producing more than 2 mega-pixel RGB images, a Mac G3 with a 21" Studio Display color monitor, Photoshop 5.02 capable of image adjustments and ICC implementation[2], and an Epson SP5000 ink jet printer. A number of ICC-based color management technologies were used for device calibration and profiling. Among them, Kodak Colorflow Profile Editor was used to build profiles for the digital camera under controlled lighting conditions; Colorflow Profile Editor was also used for printer profiling along with

GretagMacbeth's SpectroScan (an automatic color measurement and data entry device); OptiCal 3.0 was used for monitor profiling along with X-Rite's DTP 92 colorimeter.

To test for reproduction quality, a 2-dimensional oil painting and a three-dimensional still life scene were photographed. The initial reproduction plus two iterations (labeled as A, B, and C) were designed to represent the legacy-based workflow. For the CMS-based workflow, only the initial output using perceptual rendering intent (labeled as D) was allowed. A paired comparison method was used to collect psychometric data from 20 observers[3]. All 20 observers are college students majoring in either photography or printing technology. These students were asked to select one of the two images (A vs. D, B vs. D or C vs. D) as to which image, while viewing under standard graphic arts standard viewing conditions[4], was closest to the original painting or the still life scene.

To test for picture quality, four digital images containing memory colors (broccoli, a school bus, fruits and a brick building) were prepared. In this case, only the images from the third iteration of the legacy-based workflow and the initial output from the CMS-base workflow were compared. The same 20 observers, made up of college students studying photography and printing, took part in the paired comparison test.

Figure 1 summarizes the design of experiment. Raw digital images were captured by a Kodak DC290 digital camera under controlled interior lighting conditions. This was the common starting point for both workflows. The authors were experienced ICC CMS users and Photoshop users. The entire experiment was carried out in a laboratory environment at RIT's School of Printing Management and Sciences. For ICC-based CMS workflow (right-hand-side of Figure 1), the DC290 camera profile and the Epson SP5000 printer profile were applied to raw images in Photoshop's Profile-to-Profile conversion prior to color hard copy output. For legacy-based workflow (left-hand side of Figure 1), color hard copy of the raw image was used as a visual aid for image adjustments using many Photoshop's image adjustment tools. A total of three color output was allowed for each of the images tested.

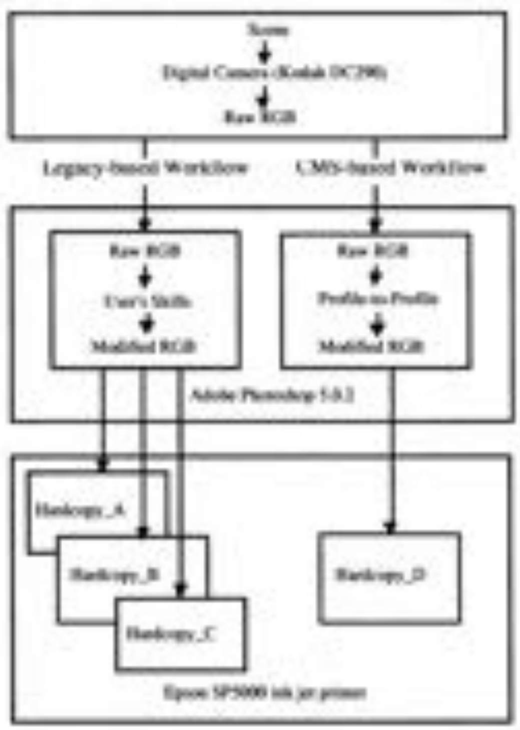


Figure 1. The experimental design conducted in the study

4. DATA ANALYSIS

For reproduction quality testing, Figure 2 illustrates the outcome of the paired comparison of the oil painting. To recap, reproduction quality means the visual assessment of image quality in relation to a reference. As can be seen, the initial output of the oil painting from CMS-based workflow out performs all three images from legacy-based workflow. The same can be said for the still life scene (Figure 3).

Without any further statistical analysis, Figure 2 and 3 suggest that CMS-based workflow offers higher reproduction quality than legacy-based workflow. In addition, CMS-based workflow offers higher productivity than legacy-based workflow because it is capable of matching the source images without iterations.

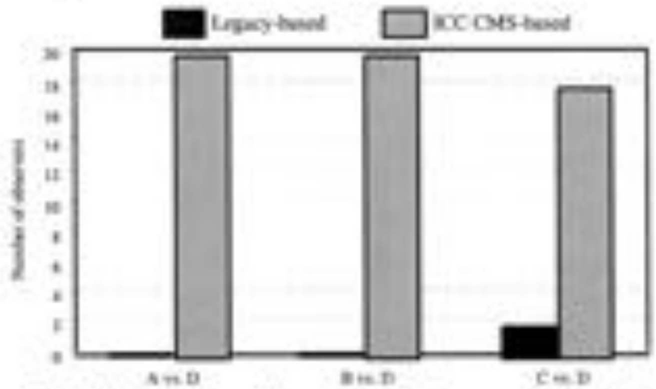


Figure 2. Paired comparison of the oil painting for reproduction quality

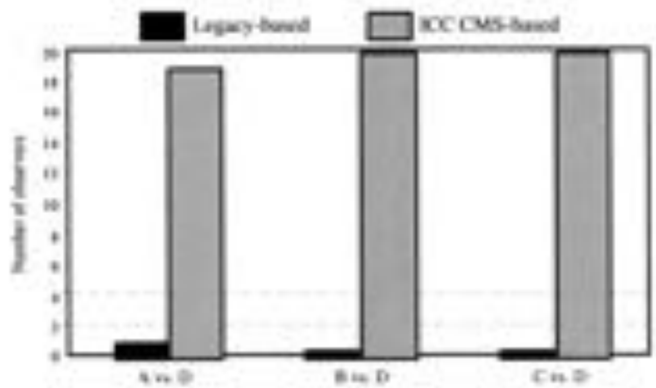


Figure 3. Paired comparison of the yarn scene for reproduction quality

For picture quality testing, Figure 4 illustrates the outcome of the paired comparison of four different images. Here, picture quality means the visual assessment of the image quality with the observer's own criteria in mind. About one-half of the observers preferred memory colors from the third iteration of the legacy-based workflow to the initial output of the CMS-based workflow. No further statistical analyses was applied. We can not conclude that there is a significant difference between the two workflows in producing pleasing color images. But we're confident that (1) CMS-based workflow offers higher productivity than legacy-based workflow despite the fact that it also requires more efforts in device calibration.

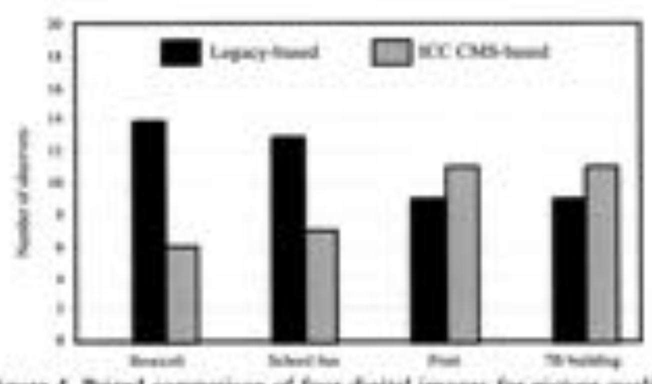


Figure 4. Paired comparison of four digital images for picture quality

5. SUMMARY

In digital imaging practices, it's strategic to account for device-dependent variables prior to addressing image-dependent variables. Legacy-based systems fail to recognize this point since they address both sets of variables through image adjustments. Even if legacy-based workflow can achieve the desired outcome, e.g., pleasing color reproduction, the cost of iteration is high and the adjusted image is bound to the device at the image editing stage. On the contrary, CMS technology separates device-dependent parameters from image-dependent variables. By adopting CMS-based workflow, a user can produce consistent image quality from digital photography to color hard copy without iteration.

Due to the difference in judging criteria, the study shows that legacy-based digital imaging workflow, with iterations included, can produce pleasing images comparable to a CMS-based workflow. But ICC-based CMS, requiring no iteration, out performs legacy-based workflow in matching the color appearance of source images. This is a welcome feature in direct mail catalogs where printed images need to closely match the appearance of the merchandise.

6. FURTHER STUDY

It would be valuable to show how to convert legacy-based workflow to CMS-based workflow for increased image quality and productivity. In this regard, the role of the monitor and the selection of the internal RGB working space at the image editing stage are critical.

The case study focused on the advantages of the CMS method when using an RGB-printer as the output device. A PostScript RGB-printer accepts RGB data in various file formats and uses its internal color management mechanism to convert the RGB data to CMYK (or more than CMYK) data prior to raster image processing and hard copy output. The simplicity of the process makes it ideal for designers and photographers. But an RGB data file is considered not press ready. Therefore, a similar study could be performed using a CMYK-printer, i.e., either a CMYK digital proofer or a printing press. The objective would be to compare legacy-based workflow to CMS-based workflow to provide further evidence that the imaging and publishing industries can benefit from CMS-based workflow.

ACKNOWLEDGMENTS

We wish to express our sincere appreciation to the following companies for donating color management hardware and software to RIT's School of Printing Management and Science: ColorVision, DuPont, GretagMacbeth, gti, Kodak and X-Rite. Without their generous support, this study could not have been completed.

REFERENCES

1. International Color Consortium, Color Management: Current Practice and the Adoption of a New Standard, http://www.color.org/wpaper1.html.
2. Color Management Systems — Technical Guides, http://www.adobe.com/support/techguides/color/colormanagement/cmssol.html.
3. "Tests Based on Methods of Randomization," Distribution-free Statistical Tests, Prentice-Hall, 1968.
4. ISO/DIS 3664 Viewing conditions — Prints, transparencies and substrates for graphic technology and photography.

---

* Correspondence: rycppr@rit.edu; phone 716-475-2722; fax 716-475-7029; http://www.rit.edu/~rycppr; RIT School of Printing Management and Sciences, 69 Lomb Memorial Drive, Rochester, NY 14623, USA.

Image-dependent Color Mapping for Pleasant Image Renditions

Hiroaki Kotera, Mitsunori Suzuki, Takeshi Mita, and Ryoichi Saito
Dept. of Infromation and Image Sciences, Chiba University, Japan

ABSTRACT

This paper presents an image-dependent color mapping strategy to get the pleasant color renditions from two different approaches: (1) Mapping by Image Segmentation (**MAPSEG**) (2) Mapping by Histogram Specification (**MAPHIST**). **MAPSEG** is basically applied to match the device color to known original. The mappings are performed for the principal component (PC) to be matched in between the segmented areas of original and printed images. **MAPHIST** works to recover the faded or degraded colors for unknown original. It expands the de-saturated image gamut by Gaussian histogram specification (GHS) and makes full use of device gamut to render the pleasant images.

Keywords: Color mapping, Segmentation, PCA, Gamut expansion, Histogram specification, Preferred color

1. INTRODUCTION

So far, a variety of color mapping technologies has been developed based on image-independent. We reported an object-to-object color mapping method[1] based on image segmentation. The key to success lied in the better image segmentation. In the previous paper, the setting of initial seed points influenced to the segmentation. Here the image-dependent setting of seed points and the automatic color correction experiments by MAPSEG are reported. On the other hand, Gamut mapping algorithm (GMA) between display and print is a topics in cross-media color reproduction. However the current GMAs are mostly addressed to gamut compression not expansion. While, the printer gamut has been growing wider and wider and the source images don't always fulfill the entire device gamut. The second topic is focused on the gamut expansion to recover the vivid colors from the faded or de-saturated colors based on image-dependent.

2. COLOR MAPPING BY IMAGE SEGMRNTATION

MAPSEG is oriented to make match the unpleasant colors to ***the known original*** or the objective pleasant ***references***.
Fig. 1 shows the conceptual model of **MAPSEG**. In this system, for example, an imperfect printed image by inkjet is re-scanned by a flat bed scanner and automatically corrected to match to its original already scanned. First, the original image is segmented into several key color areas. Second, each segmented pixels are projected onto principal component (PC) space, and the each PC is matched in between the segmented areas of original and print. Here the printed colors automatically corrected to those of original, where the different correction matrices are applied to each segment. Basically PC matching applies 3 by 3 matrices just as linear color masking. In the preferred color reproduction, the segmented memory colors for the uncorrected image are matched to the trained reference colors such as flesh tint, blue sky, or green grass.

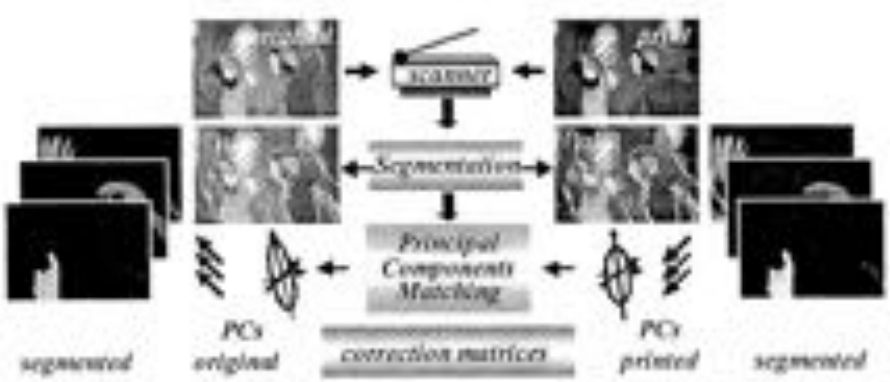
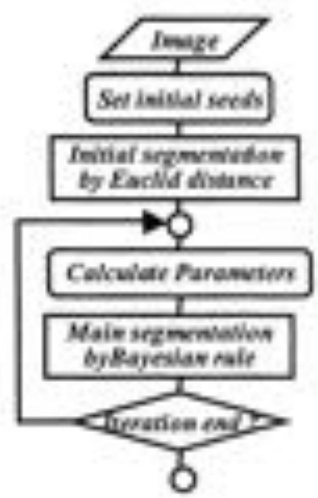


Fig.1 Object-to-object PC color matching system by image segmentation



2.1 MAPSEG ALGORITHM

First, the color classifier segments the image. In our experiments, the Bayesian classifier worked better than Euclid or Mahalanobis distance classifiers. Letting a CIELAB color vector be X and the mean vector be μ, the maximum likelihood is obtained when the following discrimination function[2] is minimized for k.

$$d(Bayes) = -\log\{p(k)\} + \frac{1}{2}\log\left(\left|{}_k\Sigma_X\right|\right) + \frac{1}{2}(X - {}_k\mu)^t\, {}_k\Sigma_X^{-1}(X - {}_k\mu) \qquad (1)$$

where $p(k)$ means the occurrence probability of class k.

Euclidian distance is used for initial segmentation to start the Baysian classifier, by setting the initial seed points as mean vector μ. Once the image is segmented, the parameters ${}_k\Sigma_X$ and $p(k)$are calculated and the main Bayesian classifier is turned on. The segmentation error was improved by iterating the classification renewing these parameters. Next, PCA is done and the color matching matrices are extracted. In the final stage, color corrections are executed to make match the colors in between the each segmented areas of original and printed images (Fig. 1).

In PC space, the correction matrix ${}_kM_C$ works to match the printed color vector of class k, ${}_kX_{PRT}$ to that of original ${}_kX_{ORG}$ by

$${}_k\hat{X}_{ORG} - \mu_{ORG} = {}_kM_C({}_kX_{PRT} - \mu_{PRT}) \qquad {}_kM_C = ({}_kA_{ORG}^{-1})({}_kS)({}_kA_{PRT}) \qquad (2)$$

${}_kA$ is formed by the eigen vectors $\{{}_k\varphi_1, {}_k\varphi_2, {}_k\varphi_3\}$ of covariance matrix ${}_k\Sigma_X$ and ${}_kS$ is a scaling matrix for class k given by

$${}_kS = \begin{bmatrix} \sqrt{{}_k\lambda_{1ORG}/{}_k\lambda_{1PRT}} & 0 & 0 \\ 0 & \sqrt{{}_k\lambda_{2ORG}/{}_k\lambda_{2PRT}} & 0 \\ 0 & 0 & \sqrt{{}_k\lambda_{3ORG}/{}_k\lambda_{3PRT}} \end{bmatrix}, \quad {}_k\lambda_{iORG}: \textit{i-th eigen value of class k for original} \qquad (3)$$

2.2 Seed Points and Segmentation Results

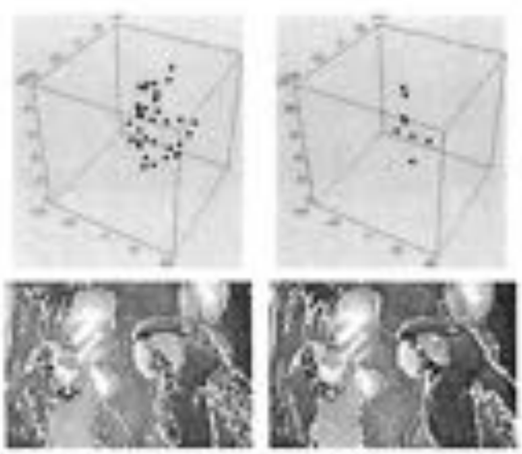
The following four types of initial seed points for classifier were tested.

Seeds on (1) *regular lattice points*, (2) *body centers in non-empty cubes*, (3) *image gravities in divided sub-spaces including constant pixels*, (4) *body centers in non-empty cubes with higher pixel densities*

The image-dependent seed points (3) or (4) resulted in the better segmentations to separate the clustered colors than independent methods (1) or (2). Fig.2 compares the initial seeds points and the segmented boundaries between (2) and (4).

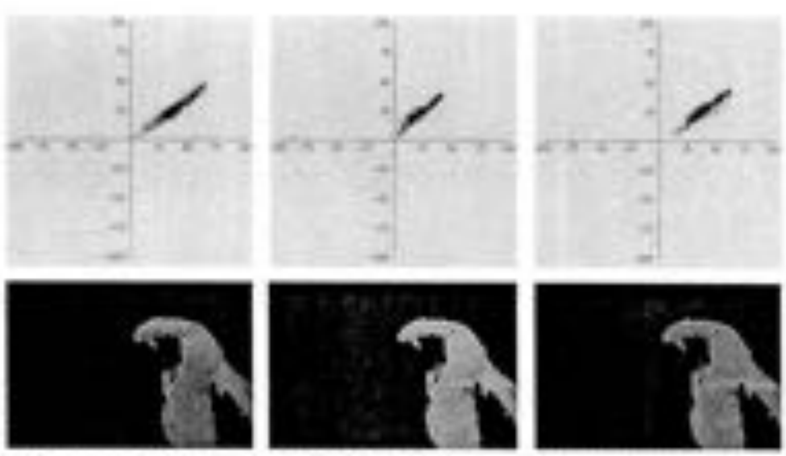
2.3 MAPSEG Results

An example of automatic color correction by MAPSEG for inkjet print is shown in Fig.3. The color differences in default printer driver was improved to about a half by PC matching after three times iteration of Baysian classification. In this sample, the image is segmented to 8 areas and 8 different matrices are operated to each segment and combined to final image.



(a) Type (2) seed points and segmented result (b) Type (4) seed points and segmented result

Fig.2 Comparison of initial seed points



(a) original color map for a segmented image (b) before correction (c) after correction

Fig.3 Automatic color correction for segmented object by MAPSEG

3. Gamut Expansion by Histogram Specification

3.1 Extraction of 3D Image Gamut and Comparison with Device Gamut

In our image-dependent GMA[2], first, the gamut size of given image is compared with that of device. If the image gamut is larger than device, the compression GMA is selected and if extremely smaller than device, the expansion GMA is selected. To run the GMA, we should decide which gamut is larger image or device. A simple way to extract the image gamut shell is to divide the entire space into small segment. Here the color space was divided by ($\Delta\theta$, $\Delta\varphi$) in polar angle. The maximum radial vector is extracted to image centroid in each segment and the gamut sizes are compared by these representative vectors (Fig.4).

$$\theta = \tan^{-1}\left(\frac{b^* - b^*_{avg}}{a^* - a^*_{avg}}\right) \qquad \varphi = \tan^{-1}\left(\frac{L^* - L^*_{avg}}{\left[(a^* - a^*_{avg})^2 + (b^* - b^*_{avg})^2\right]^{1/2}}\right) \qquad (4)$$

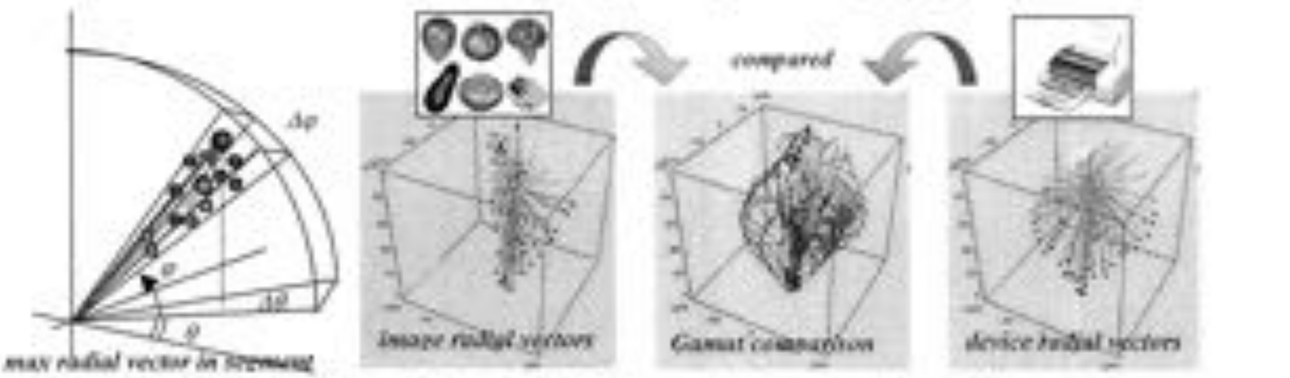


Fig. 4 3D Gamut surface extraction and size comparison by representative radial vectors.

3.2 Gamut Expansion by MAPHIST

The major objective of gamut expansion is to recover the degraded colors taken under insufficient illumination or faded colors after long preservation. It is difficult to restore the lost colors exactly, but possible to render the pleasant colors by expansion. MAPHIST is based on histogram specification to Gaussian (GHS)[7]. To simplify the process, the histograms of luminance and chrominance are expanded separately in YCC space as the following steps (Fig.5).

(1) RGB to YCC conversion (2) GHS for Y component (3) Segmentation of chroma component (4) GHS for chroma

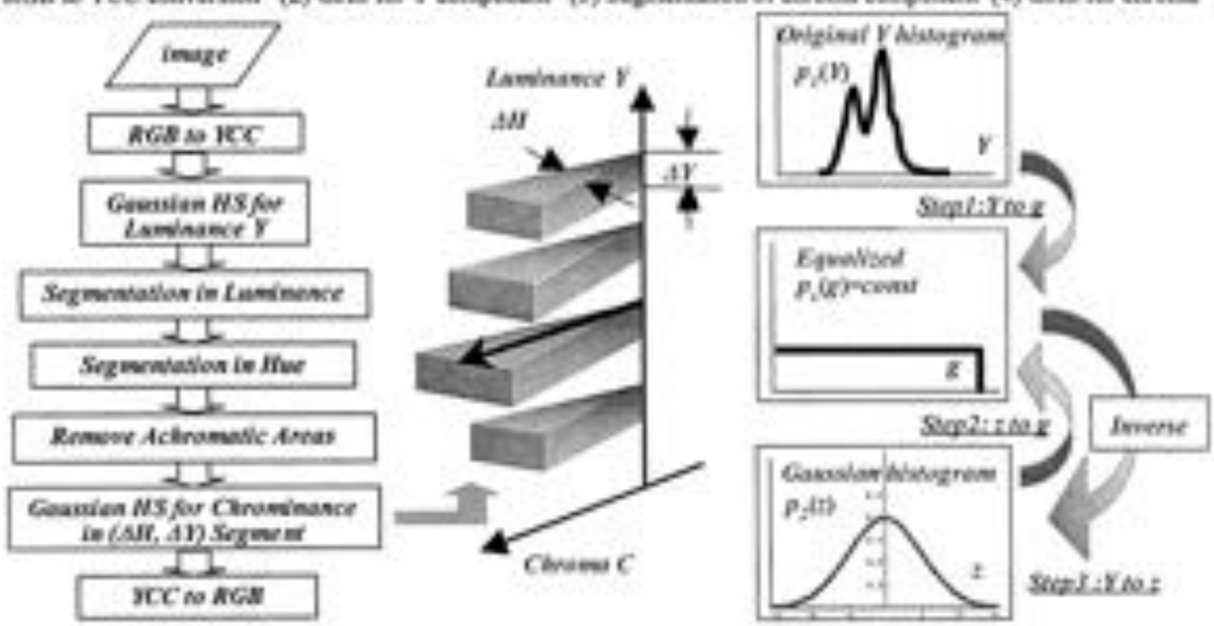


Fig.5 Gamut Extension Process by Color Histogram Specification

3.3 Gaussian Histogram Specification for Luminance Y

There is no definitive solution to what shapes of the color histogram are comfortable. In our pre-experiments, Gaussian histogram was an effective candidate to create the natural and pleasant images. In the step 1, the original histogram of luminance Y is equalized to flat histogram g. In the step 2, the target histogram is also equalized into constant g. And, in the step 3, by connecting these two from Y to g and z to g, the objective transform z is given by its inverse from Y to z. As a result, the histogram Y is converted to Gaussian as the following equations.

Step1: [Y to g] $g = F(Y) = \int_0^Y p_Y(x)dx,\ \ p_G(g) = \text{constant}\ ,\ p_Y(Y)$ =the probability density of Y occurrence (5)

Step2: [z to g] $g = G(z) = \int_0^z p_Z(x)dx,\ \ p_G(g) = \text{constant}\ \ p_Z(z) = \frac{1}{\sqrt{2\pi}\sigma} exp\left[-\frac{1}{2\sigma^2}(z-\bar{z})^2\right]$ (6)

Step3: [Y to z] $z = G^{-1}(g) = G^{-1}(F(Y))$, inverse transform (7)

3.4 Gaussian Histogram Specification for Chroma image

After the histogram specification of Y, the chromin-ance components are segmented into n*m small sectors (n slices by ΔY in Y and m divisions by ΔH in hue angle H). Then chroma C of each sector is extended by Gaussian HS as same as Y without changing color hue. For example, whole pixels are segmented into totally n*m $=10$*$16=160$ sectors and each was extended by individual Gaussian HS.

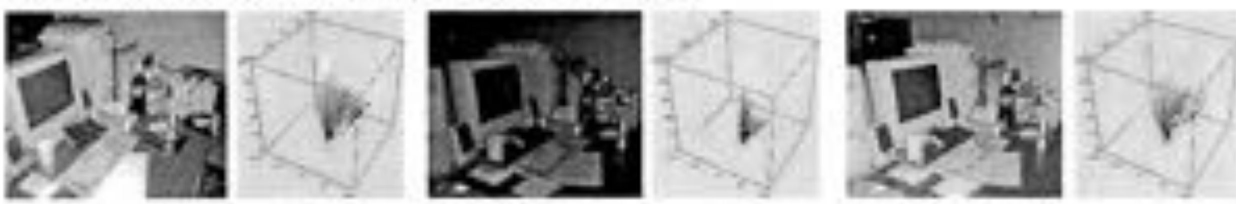
3.5 Considerations on Neutral Gray and Multiple Peaks

Sometimes, the Y histogram has not always a single peak but multiple peaks. For such cases, the histogram was specified to multiple Gaussian functions centered at relatively expanded peak positions in Y histogram.

Furthermore, the achromatic areas were excluded beforehand from the process to avoid the unwanted coloring of grayish pixels.

3.6 Results by MAPHIST

Fig.6 shows an improved image by MAPHIST. (a) is our laboratory scene taken by digital camera with flash and (b) is a test image without flash. It is highly de-saturated both in luminance and chrominance and the colors are distributed in very narrow gamut areas. (c) shows the image after gamut expansion by MAPHIST. The chroma was segmented to 16*10 ΔH-ΔY sectors and each sector was expanded by Gaussian HS algorithm. The picture (b) taken in dim light was dramatically improved to comfortable image (c) with the bright and vivid colors. As clearly shown in their color maps, the shrunk gamut shape of test image (b) was very well stretched similar to that of normal image (a).



(a) Normal image with flash (b) Test image without flash (c) After gamut expansion by MAPHIST

Fig.6 Gamut expansion result by MAPHIST (The right shows color map in CIELAB space)

CONCLUSIONS

The paper introduced an image-dependent color mapping strategy from two different approaches. **MAPSEG** is oriented to match the unpleasant colors to ***the known original*** or the objective pleasant ***references***. The mapping to the preferred colors by MAPSEG is now under testing. **MAPHIST** is intended to recover the highly degraded colors for unknown original. It expands the de-saturated image gamut by Gaussian histogram specification (GHS) and makes full use of device gamut to render the pleasant images. Both algorithms are based on the common concept of "***image-dependent***". Future works should be continued to find the stable and robust parameters to be applied for variety of images through the psychophysical evaluation experiments.

References

1. H. Kotera, et al, "Object-Oriented Color Matching By Image Clustering", Proc.6th CIC, p.154-158, 1998.
2. Chen H. S and H. Kotera, "Three-dimensional Gamut Mapping Method Based on the Concept of Image-dependent", Proc. NIP16, p.783-786, 2000
3. H. Kotera, et al, "Image-dependent Gamut Compression and Extension", Proc. PICS2001, p.288-292, 2001

Color Image Processing Using an Image State Architecture

Geoffrey J. Woolfe and Kevin E. Spaulding
Eastman Kodak Company, Rochester, New York

ABSTRACT

Most digital images can be broadly classified into scene-referred and output-referred image states. This image state concept is the basis for an image processing architecture in which captured images are converted to a standard scene-referred color encoding where appropriate scene-state algorithms are applied. A rendering transform can then be used to convert images to a standard output-referred image state for further processing before the final printing/display of the image. This architecture is facilitated by the definition of standard image color encodings known as *RIMM/ROMM RGB*.

1. INTRODUCTION

The plethora of color encodings used to encode digital images in various applications has significantly complicated the interchange of images between different digital imaging systems, as well as the development of image-processing algorithms. Algorithms developed for use with images in one color encoding do not necessarily have the expected behavior when used with images in another color encoding. Accordingly, many people have advocated for the use of a standard color encoding (or perhaps a small number of standard color encodings) for the storage, interchange, and manipulation of digital images. Often, these proposals have involved specifying a particular output-device-dependent color space, such as SWOP CMYK or sRGB, to be a "standard". Although these spaces are device-dependent, they can often be related to device-independent colorimetric values through the defined characteristics of a reference device. However, one significant problem with specifying an output-device-dependent color space as a standard is that typically it will limit the encodable color gamut and luminance dynamic range of images according to the capabilities of that specific output device. For example, hardcopy media and CRT displays typically have very different color gamuts. Therefore, using sRGB (which is based on a particular CRT model) as a standard color encoding necessarily involves clipping many colors that could have been produced on a given hardcopy medium.

The problem of limited color gamut and dynamic range can be overcome by using device-independent color spaces such as CIE XYZ and CIELAB. However, these color spaces are not particularly well suited for the manipulation of images. Additionally, quantization errors that would be introduced by encoding images in such color spaces would be significantly larger than necessary because a large percentage of the code values correspond to unrealizable colors.

It is important to bear in mind that the specification of image colorimetry alone is not sufficient to fully and unambiguously specify color appearance. Communication of color appearance requires knowledge of the state of visual adaptation of the observer, which is controlled by the viewing environment. Thus, to unambiguously communicate the desired color appearance, whether in a device-dependent or device-independent encoding, it is necessary to specify both the colorimetry and intended viewing environment of the image.

2. IMAGE STATE ARCHITECTURE

In addition to colorimetry and viewing environment, one also needs information about the *image state* in order to correctly process an image. Images in an *output-referred* (*rendered*) image state generally should be treated differently than images that are intended to be an encoding of the colors of an *original scene*. It is well known that a pleasing rendered image does not usually result from matching the colorimetry of the corresponding scene. Among other things, the tone/color reproduction process that "renders" the colors of a scene to the desired colors of the rendered image must compensate for differences between the scene and rendered image viewing environments. For example, rendered images generally are viewed at much lower luminance levels than those of typical outdoor scenes. Consequently, an increase in the overall contrast and colorfulness of the rendered image usually is required in order to compensate for perceptual losses in these qualities at lower viewing luminance levels. Additional increases in the shadow contrast of the image also are needed to compensate for viewing flare associated with rendered-image viewing conditions. The tone/color reproduction process also must account for the fact that the dynamic range of an output-referred image usually is substantially less than that of an original scene. It is therefore necessary to discard and/or compress some of the highlight and shadow information of the scene to fit within the dynamic range of the output-referred image. In addition, psychological factors such as color memory and color preference must be considered in image rendering. For example, observers generally remember colors as being of higher purity than they really were, and they typically prefer skies and grass to be more colorful than they were in the original scene. The tone/color reproduction aims of well-designed imaging systems will account for such factors.

Because the colorimetry of scenes and their corresponding rendered images are intentionally and necessarily different, it would be ambiguous to try to represent images in both image states using the same color encoding. For example, if someone

9th Congress of the International Colour Association, Proceedings
of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

were to give you the CIELAB values for a particular image and did not provide any information about whether the color values were scene color values or output-referred color values, you would not know how to make the best print of the image. If the color values were output-referred color values, it simply would be necessary to determine the device code values needed to produce the corresponding color appearance in the output-viewing environment. However, if the color values represented original scene colors, it would be necessary to modify the image colorimetry by applying the appropriate tone/color reproduction aims before printing the image. Therefore, scene-referred images must be distinguished from and treated differently than output-referred images.

2.1 Color Encodings

In order to fill the need for standard large-gamut color encodings, Eastman Kodak Company has developed two color encodings known as *Reference Input Medium Metric* (*RIMM RGB*) and *Reference Output Medium Metric RGB* (*ROMM RGB*).[1,2] *RIMM RGB* is ideal for the manipulation, storage, and interchange of images from sources such as digital cameras that naturally capture *scene-referred* image data. Likewise, *ROMM RGB* serves a similar purpose for images from sources such as print scanners and other devices that produce images in a rendered *output-referred* image state. An additional scene-state encoding, *Extended Reference Input Medium Metric* (*ERIMM RGB*) has been developed for encoding images with very high dynamic ranges, typical of those captured by photographic negative film. These color encodings are all based upon a common additive RGB color space having imaginary primaries in order to enable the encoding of a wide color gamut. The characteristics of the *RIMM RGB* and *ERIMM RGB* encodings are consistent with the properties of typical images in scene-referred image states while the characteristics of the ROMM RGB encoding are consistent with the properties of rendered images. The characteristics are summarized in Table 1.

Table 1: Characteristics of *RIMM RGB*, *ERIMM RGB*, and *ROMM RGB* Encodings

Characteristic	***RIMM RGB***	***ERIMM RGB***	***ROMM RGB***
Image State	Scene-Referred		Output-Referred
Adapting Luminance Level	15,000 cd/m^2		160 cd/m^2
Viewing Surround	Average		
Viewing Flare	0		0.75 %
Adaptive white point chromaticity	Equal to that of CIE standard D50: x = 0.3457, y = 0.3585		
Colorimetric data encoding	Flareless or flare corrected colorimetric measurements based on the CIE 1931 Standard Colorimetric Observer		
Minimum Encodable Y	0.0		0.30911[1].
Maximum Encodable Y	200	31623[3]	89.0[2]
Available Bit Depth	8, 12, 16	12, 16	8, 12, 16
Primaries	Red: x = 0.7347, y = 0.2653 Green: x = 0.1596, y = 0.8404 Blue: x = 0.0366, y = 0.0001		

[1] This corresponds to the black point of the *ICC PCS* reference medium or $Y_{PCS} = 0$

[2] This corresponds to the white point of the *ICC PCS* reference medium or $Y_{PCS} = 100$

[3] This corresponds to $\log_{10}(Y_{max}/100) = 2.50$

2.2 Image Processing Workflow

A diagram illustrating how these standard color encodings can be used as the basis for general imaging system architecture is shown in Fig. 1. Camera systems are generally designed to capture and encode scene information. A photographic film camera often encodes scene information on a color negative film. Using knowledge of the film's characteristics one can decode the optical densities on the film to obtain information describing the original scene. Alternately, one might choose to make an optical print of the negative onto a color photographic paper. This process results in the scene information encoded in the negative being rendered. The rendering so obtained is a result of the imaging characteristics of the photographic system, which is controlled by its physical and chemical properties. Likewise, digital cameras convert scene information to digital counts using their photodetectors. If one were to obtain access to the raw signals from the photodetectors, then knowledge of their imaging characteristics would enable one to obtain a representation of the original scene. Cameras can also provide rendered images. If a photographic camera is loaded with color transparency film then the image captured on the film has been rendered to be suitable for projection in a darkened viewing environment. This rendering is accomplished by the imaging characteristics designed into the transparency film and its associated processing chemistry. Digital cameras often convert scene information to produce output-referred images suitable for direct viewing on a computer display. These images are typically encoded in a standard output-referred video encoding such as *sRGB*. The rendering in this case results from the application of an image-processing algorithm within the camera.

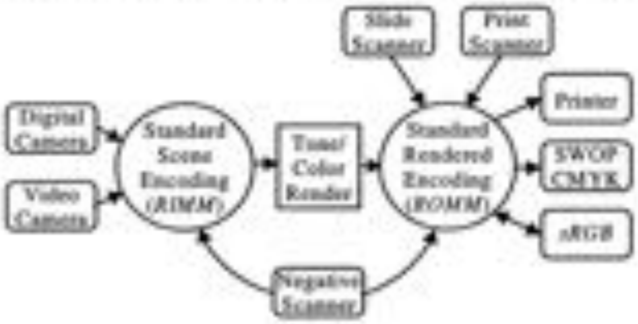


Fig. 1. Image state diagram showing standard color encodings.

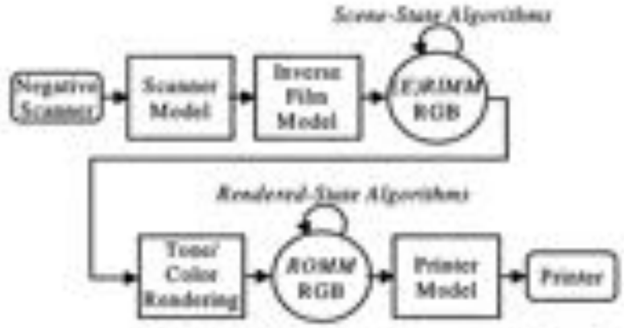


Fig. 2. Typical image processing path using image states.

As an image is processed from capture to output, its information content progressively decreases due to the application of image-processing algorithms and, more importantly, the need to compress the dynamic range and color gamut of the scene to fit within the capabilities of an output device. Some classes of image processing algorithms are designed to make use of extended dynamic range image data that is only available for scene-referred image. It is important that these algorithms be applied before the image is rendered to an output-referred state. Similarly, other types of algorithms are designed to operate on output-referred images and should be applied post-rendering. These concepts are illustrated in Fig. 2 that shows a processing path for scanning a photographic negative and converting it to a standard scene-referred color encoding where image-processing algorithms are applied. A rendering operation is then used to transform the image to a standard output-referred color encoding where further image processing takes place prior to printing. The types of image processing operations that are appropriate for each stage in this workflow will be discussed in more detail in the following sections.

2.3 Scene State Image Processing

Many algorithms have been designed to correct color and neutral balance problems in images. Such problems typically arise from variations in the color temperature of the capture illuminant and the exposure used in the camera. Since these problems are created at the scene capture stage, the easiest and most logical place to correct them is in a scene-referred image state. For example, consider the case of a backlit scene with a brightly lit background, and a dimly lit foreground. In this case, a scene-referred image would generally contain information in both of these regions that could be used to make a print that is properly rendered for one region or the other. In order to make an output-referred image from this scene, it is necessary to make a choice about which part of the image is important. However, scene-state images can retain all of the information available at capture and can delay any decision on how the scene should be rendered. This retains the maximum amount of flexibility in the system. Another option that is available with a scene state image is to apply a scene-dependent rendering algorithm that renders spatially separate regions of the image differently to create a rendering that retains discernable detail in both brightly lit and dimly lit regions of the image. An image processed using such an algorithm often produces a more realistic reproduction of our memory of the original scene than a rendering algorithm that maintains accurate luminance relationships.

There are a number of image-processing algorithms that can benefit from a reasonably accurate knowledge of the color characteristics of objects in the scene. Such algorithms include image-understanding algorithms, such as face, sky, or foliage detectors, and preferred-color transforms. Preferred-color transforms are designed to modify the original colors of an image to colors that more closely match the memory or preference of a viewer. They are often applied to strong memory colors such as human flesh and hair, blue sky or foliage. These algorithms can often perform better when applied to scene-referred image data rather than output-referred images. This is because the color appearance attributes of objects is typically more consistent in scenes than in rendered images because of the wide range of rendering transforms that can be used. This results in more reliable and finely tuned algorithm performance than would be possible with output-referred images.

2.4 Rendering Transforms

Any transform that processes a scene-referred image to produce an output-referred image is known as a rendering transform. Rendering transforms modify the image in a way that compensates for the difference in reference viewing environments between the scene-referred and output-referred image states and takes into account the limited dynamic range of the output medium as well as any viewer color reproduction preferences. Because the adapting luminance of a scene referred image is much higher than that of an output-referred image the rendering transform needs to account for phenomena that cause a change in color appearance attributes with luminance level. Arguably, the two most important such phenomena are the Hunt effect and the Stevens effect. Hunt[7] used haploscopic-matching experiments to show that as the luminance of a color stimulus is increased, its perceived colorfulness also increases. Thus, the chroma of the rendered image viewed at low luminance levels must be increased in order to convey the apparent colorfulness of the original scene when it was viewed under a much higher adapting luminance. Stevens and Stevens[4] showed that as the luminance level increases, the perceived lightness of light colors increases while that of dark colors decreases. This phenomenon indicates that the rendering transform must boost the luminance contrast of the output-referred image relative to that of the scene-referred image in order to produce a perceptual contrast match when the different adapting luminances are considered.

Another key difference in viewing environment between the scene-referred and output-referred images is the presence of viewing flare in the rendered image-viewing environment. In order to compensate for flare it is necessary to boost the contrast, particularly for shadow regions, of the rendered image. Finally, it is necessary to map a high dynamic range scene image onto a limited dynamic range output medium. This is achieved with pleasing results by a compression of both the highlight and shadow contrasts.

An appropriate rendering transform can be constructed in many ways. One approach may be to use a color appearance model such as CIECAM. Color appearance models are capable of accounting for effects such as the Hunt and Stevens effects, but additional transforms will be required to account for flare and for dynamic range mapping. A simpler but very effective rendering transform is to use simple one-dimensional tone scale functions applied to the nonlinear RGB channels of the *(E)RIMM RGB* image. The primaries of the *(E)RIMM RGB* and *ROMM RGB* were deliberately selected to be identical so that such a simple rendering transform could be used without the additional complication of matrices required for a primary transformation. Furthermore, the locations of these primaries were optimized to minimize the impact of hue shifts that can result from the use of such rendering transforms.

2.5 Rendered State Image Processing

The final stage of image processing prior to output involves algorithms that are appropriate for application to output-referred images. These algorithms often involve making creative or artistic modifications to the final reproduction. Consider an algorithm that is designed to montage several images together with added text and borders specified using PANTONE®[*] colors. This algorithm is clearly most appropriate for application in an output-referred image state since all elements of the montage will be components of a rendered image and the PANTONE® specifications refer to printed colors. Another image-processing algorithm that is appropriate for the output-referred image state is the use of "blue-screen" techniques in which a subject is photographed against a plain blue (or sometimes green) screen and their image is digitally placed into one of a number of fantasy background scenes created by a graphic artist. The background scene is digitally represented as a rendered image and the image of the subject must be rendered to provide an appropriate match to the background. The compositing of the two images can then take place in an output-referred image state. Color adjustment of advertising images is also often appropriately executed in an output-referred image state. Many companies have strict standards concerning color reproduction of their product packaging or trademarks. Adjusting the image colors to meet these standards is most accurately and conveniently achieved using a rendered image.

3. CONCLUSIONS

We have demonstrated that images can only be fully be characterized if the image colorimetry, intended viewing environment and image state are known. This information allows unambiguous communication of the intended color appearance and image interpretation, and is necessary to determine the meaning of pixel values, the usefulness of the image and the types of algorithms that can be applied to the image. The *(E)RIMM RGB* and *ROMM RGB* color encodings have been developed to facilitate the communication and manipulation of image color appearance for both scene-referred and output-referred images respectively. We have discussed the types of image processing algorithms that are appropriate for scenes and rendered images and described the requirements of rendering transforms needed to process scene-referred images into output-referred images. The image-state architecture is a convenient way to organize an image processing system that ensures that algorithms are placed at an appropriate place in the workflow where they will work with maximum reliability and effectiveness.

REFERENCES

1. K. E. Spaulding, G. J. Woolfe and E. J. Giorgianni, "Reference Input/Output Medium Metric RGB Color Encodings (RIMM/ROMM RGB)", in *Proceedings of IS&T's PICS Conference*, 155-163 (2000).
2. "Photography – Electronic still picture imaging –Reference Output Medium Metric RGB Color encoding: ROMM-RGB" PIMA 7666: 2001.
3. R. W. G. Hunt, "Light and dark adaptation and the perception of color," *J. Opt. Soc. Am.* **42**, pp. 190-199, 1952.
4. J. C. Stevens and S. S. Stevens, "Brightness functions: Effects of adaptation," *J. Opt. Soc. Am.* **53**, pp. 375-385, 1963.

[*] PANTONE is a trademark of Pantone, Inc.

Trends in color imaging on the Internet

Giordano B. Beretta,* Hewlett-Packard and Robert R. Buckley,** Xerox

ABSTRACT

We review three technological changes that will have an impact on color imaging on the Internet: bright LCD display replacing dim CRTs, compression based on foveation, and contents based image retrieval.

Keywords: color consistency, rendering, visual compression, image retrieval, LCD displays

1. INTRODUCTION

At the Color '97 AIC meeting in Kyoto one of us had given a paper[1] on this topic, in which we discussed color issues with the various Internet image formats and compared compression in the color domain to compression in the spatial domain. Our trend predictions at the time relied on the availability of cheap processing and on the observation that Internet access was becoming faster and cheaper. In fact, today's Internet is characterized by rich graphic content, created with one of the numerous software packages available for this purpose and browsed over fast connections.

After four years and with the speed at which the Internet and Web have progressed, we are at a juncture in Internet imaging where an update is necessary. The current trend is for people to not be any longer tethered to a desktop; instead they use the Internet wherever.

The industry is responding with small mobile Internet devices—palm-tops, personal digital assistants (PDA) and multi-function cellular phones—where the communications channels have lower bandwidth and the devices themselves have only a small screen real-estate. Combined with their low power requirements and low purchase price, these mobile devices allow a larger portion of the world's population to use the Internet in an even more personalized way than has been possible with the desktop PC. Multimedia in general and images in particular, are expected to play a significant role in defining such personalization.[5]

In a mobile wireless world of casual users it is necessary to develop new methods for serving color images on the Internet. In this paper we discuss three technological changes for consideration when developing research strategies for color imaging on the Internet: display technologies, compression for very low bit rates, and image retrieval. The technologies developed for the nomadic users will be applied also to the desktop, where LCDs will replace CRT displays.

2. LCD DISPLAYS AND COLOR INTEGRITY

2.1 LCD Display Technology

Today, LCD devices are mainstream. In 1997, a professional quality 19" CRT display for 1280×1024 pixels cost approximately $1500; today a 17" LCD display with 1280×1024 pixels costs $1000. It is true that CRTs are also becoming less expensive, but at a slower rate. According to an article in the March 2001 SID Information Display, the price-ratio difference will fall from 4.1× in 2000 to 2.0× in 2005. This is for desktop and laptop computers; in PDAs we will see the adoption of OLED displays, which from a color imaging perspective have the same implications.

An LCD monitor cannot be calibrated the same way as a CRT. A slightly more complex model has to be derived because LCDs often have sigmoidal TRCs. However, as has been shown by Gibson and Fairchild[4] and more recently by Okano and Shiotani[10], a fairly accurate characterization of LCD displays is possible. Today's commercial software for ICC profile creation copes very well with LCD devices.

The traditional aim of computational color reproduction has been to achieve color fidelity. The first step was achieving a colorimetric match between a hardcopy original and a printed copy. The second step was to achieve an appearance match between a softcopy and a printed copy. These methods are based on colorimetry and efforts have been made to port the underlying methodology to the Internet. Hunt[7] reviewed the requirements for color reproduction on the Internet for applications such as Web shopping. Several commercial products are available to support color management on the web, using either client- or server-based techniques that require the end user to perform a simple monitor calibration.

Device characterization—e.g., in the form of ICC profiles—is only one component of color reproduction, the other important component being the viewing conditions. In homes and wireless applications, the viewing conditions can be expected to deviate significantly from those normally encountered in a controlled graphic arts studio or even an office. Moreover, it the user cannot be expected to understand colorimetry and follow calibration procedures. The patent literature describes low-cost devices that can detect the ambient conditions and feed them into a color appearance model. However, although such devices can work in a fixed workstation, it is hard to imagine that a mobile user would carry one around at all times.

Fortunately there is a technological discontinuity. Although CRT manufacturers today claim 100 Cd/m^2 luminance for whites, this is not at the D_{65} white point required by standards such as sRGB. For a typical high end graphic arts CRT display we measured a luminance of 84 Cd/m^2 after calibrating it as close as was possible to D_{65} without removing the cover. After a further system calibration including the display controller and color management system to achieve 6500°K correlated color temperature, we measured a luminance of 79 Cd/m^2, 30% less than the nominal spec.

In the case of LCD displays for workstations, the luminance is typically 200 Cd/m^2, three times that of a CRT, and the typical contrast ratio for a medium range LCD is 350:1. The LCD displays for portable computers are not yet up to such specifications due to battery limitations.

2.2 Visual Processes and LCD Displays

At a typical indoor workstation illuminance of 500 lux, a CRT with a white luminance of 80 Cd/m^2 is darker than its surround, therefore viewers will not adapt to the display and see it more like an object in their field of view. In the case of an LCD device, the reproduced image is brighter than the surroundings, a viewing condition similar to that of a film slide on an illuminator.

As Evans observed[3] (p.599), under the illuminator condition color constancy mechanisms in the human visual system (HVS) correct for improper color balance. This means that, under typical viewing conditions, color fidelity is less of an issue for desktop LCD displays than for CRT displays. As Evans further notes[3] (p. 596), we tend to remember colors rather than to look at them closely; for the most part, he notes, careful observation of stimuli is made only by trained observers. Evans concludes that it is seldom necessary to obtain exact color reproduction of a scene to obtain a satisfying picture, although it is necessary that the reproduction shall not violate the principle that the scene could have thus appeared.

We can interpret Evans' consistency principle[3] (p. 600) as what is important is the relation among the colors in a reproduced image, not their absolute colorimetry. A color reproduction system must preserve the integrity of the relation among the colors in the palette. In practice this suggests that two conditions should be met. The first is that a color should not cross a name boundary, the second is that the field of reproductions error vectors of all colors should be divergence-free. The intuition for the divergence condition is that no virtual light source is introduced.

3. Intelligent Data Compression

3.1 Region of Interest

In our Color 97 paper[1] we discussed the JPEG encoding method. JPEG is not especially suitable for transmitting large digital images or image sequences over a slow wireless "last mile" link. A new standard known as JPEG 2000[8] has been approved that addresses the issue of achieving acceptable image quality at very low bit rates. JPEG2000 also adds many features that allow users, and in particular Internet users, to interact with the compressed data in ways not supported by JPEG.

When Hunt[6] showed how to count and save bits when encoding color images, each bit was equally important. Extending Hunt's accounting, as is long known[3] (p. 589) when observers look at a scene their eyes are in almost constant motion (EM, eye movements). However, detailed vision occurs only when the eyes hesitate or dwell on (foveate) particular positions in the image—called human regions of interest (hROIs)—and the mind's eye (i.e., the brain) fills in the blanks. The hROIs are also known as areas of fixation and the EMs between ROIs are also known as saccades.

To achieve good image quality at very low bit rates, JPEG2000 uses wavelets. More important, JPEG2000 enables encoding ROIs at a higher bit rate than the remainder of the image. In practice, the ROIs will be compressed to a rate similar to JPEG, while the image areas in the periphery or outside the ROI are encoded at a very low bit rate. The number of foveation points is image dependent, so it is difficult to compile simple statistical data, but experience shows that for typical images the compression rate can be increased by an order of magnitude.[13]

Although in the HVS the hROIs are foveated relying on top-down processing, L. Stark and his collaborators[13] have succeeded in developing a set of bottom-up computer vision algorithms that can identify algorithmic regions of interest (aROI). In visual experiments, they have found very good correlation between aROIs and hROIs, thus providing guidelines for the deployment of JPEG 2000 ROI encoding.

These algorithms can also be used for intelligent clipping, dynamically reducing an image to fit a palm-top's small display without the need to scale it to a hard-to-recognize size or to scroll it. All an image server has to do is to compute the aROIs, compute their convex hull, and apply a clipping algorithm.

3.2 Compound Documents

Over the years a number of algorithms has been developed that perform well on particular types of images. Examples are JPEG for pictorial images, and JBIG2, JBIG and MMR for binary images. Unfortunately each algorithm behaves poorly if at all on image types for which they were not designed, which is a problem for compound documents that combine multiple types within a single image. As the digital world is becoming visually richer, such images are becoming much more common.

The Mixed Raster Content (MRC) imaging model has been approved in ITU-T Recommendation T.44[9]. With this model, an image is segmented according to the image types it contains and each type encoded with the most appropriate algorithm. This significantly improves the compression rate on typical compound documents, compared to single algorithms such as JPEG.

4. Content Based Image Retrieval

After the browser, the second most popular World Wide Web tool is the search engine. The prevalence of images has quickly spurred the need for locating them. The first image search engines searched the text in alternate image fields and around images, assuming them to be captions. In reality this text is often misleading and such search engines are not very useful.

Even if images would be manually tagged, this semantic information would not be universal, and the Internet is a global medium. For example, the Francophone surrealism movement has created a great number of visual artworks that convey a message based on the context in which an image is viewed. Also, the textual description of an image changes over time. For example, in 1912 the Eiffel Tower was a futuristic object, while today it is a historical monument.

These problems are avoided by content based image retrieval (CBIR) algorithms. The first generation of such algorithms is based on metrics like the color histogram of images and other similar bottom-up approaches. However, the HVS matches images in a top-down process, even at the most rudimentary levels.[11] As a result, current CBIR algorithms are useful only in very restricted domains.[5]

The fallacy of metrics like color histograms is clear when one compares the images from a stock photo agency to those generally found on the Internet. While the former have been carefully rendered to a normalized intent, the latter are most often the raw output from digital cameras or scanners. A first step is to clearly specify for each image whether it is rendered for a particular output medium or unrendered. A family of large-gamut rendered/unrendered color encoding specifications has recently been proposed under the designation RIMM/ROMM RGB.[14] A second step is to develop bottom-up algorithms that can perform a canonical rendering operation, a process variously referred to as automatic enhancement[2] or intelligent enhancement.[12]

However, ultimately a useful CBIR algorithm must be based on top-down processes, because in humans image comparison is based on cognition. In addition, Internet imaging is different from conventional imaging in that the main issue is scalability; a methodology to support bulk indexing of large image collections still eludes the research community. Another peculiarity of Internet imaging is that client and server communicate according to standardized protocols. Today's CBIR implementations are closed systems, which means that they are specific to particular applications and cannot be universally deployed. Although a protocol has been proposed (see http://mrml.net/ for a description), it has not yet been widely recognized by the research community.

Finally, scientific progress is facilitated by the availability of performance metrics, which allow the critical comparison of different approaches. Establishing benchmarks for retrieval algorithms is a monumental task. The specific issues for image retrieval have been discussed in a recent paper on CBIR performance analysis.[5] Currently an international effort is underway for creating a benchmark (see http://www.benchathlon.net/ for more information).

References

1. G. Beretta, V. Bhaskaran, K. Konstantinides, and B.K. Natarajan, Encoding Color Images for the World Wide Web, AIC Color 97, Proc. 8th International Congress of the AIC, Vol. II, 666669, 2530 May 1997, Kyoto, Japan
2. R. Eschbach, Printing Images from the WEB, Proc. Internet Imaging II, SPIE Vol. 4311, 16, 2426 January 2001, San Jose, California
3. R.M. Evans, Visual Processes and Color Photography, JOSA 33, 11, 579-614, November 1943
4. J.E. Gibson and M.D.Fairchild, Colorimetric Characterization of Three Computer Displays (LCD and CRT), Munsell Color Science Laboratory Technical Report, January 2000
5. N.J. Gunther and G.B. Beretta, A Benchmark for Image Retrieval using Distributed Systems Over the Internet: BIRDS-I, Proc. Internet Imaging II, SPIE Vol. 4311, 252267, 2426 January 2001, San Jose, California
6. R.W.G. Hunt, Bits, Bytes, and Square Meals in Digital Imaging, CIC 1997, 15, 1720 November 1997, Scottsdale, Arizona
7. R.W.G. Hunt, How to Shop on the Web Without Seeing Red, CIC 2000, 27, 710 November 2000, Scottsdale, Arizona
8. JPEG2000: see http://www.jpeg.org/JPEG2000.htm for the latest information
9. ITU-T Recommendation T.44 - Mixed Raster Content (MRC), November 1, 1955
10. Y. Okano and N. Shiotani, ICC Profiles Compensating the Color Reproductions of Liquid Crystal Display Panel, Proc. IS&T PICS Conference, 403406, April 2225, 2001 Montréal, Quebec
11. A. Pascual-Leone and V. Walsh, Fast Backprojections from the Motion to the Primary Visual Area Necessary for Visual Awareness, Science Vol. 292, 510-512, 20 April 2001
12. D. Pfeiffer, Intellihance Client Side and Server Side Architectures for Photo Site Image Enhancement, Proc. Internet Imaging II, SPIE Vol. 4311, 4452, 2426 January 2001, San Jose, California
13. C.M. Privitera, L.W. Stark, Y.F. Ho, A. Weinberger, M. Azzariti, and K. Siminou, Vision Theory Guiding Web Communications, Proc. Internet Imaging II, SPIE Vol. 4311, 5361, 2426 January 2001, San Jose, California
14. K.E. Spaulding, G.J. Woolfe, and E.J. Giorgianni, Reference Input/Output Medium Metric RGB Color Encodings (RIMM/ROMM RGB), Proc. IS&T PICS Conference, 155163, March 2629, 2000 Portland, Oregon

* Correspondence: beretta@hpl.hp.com; phone 650-857-6713; http://www.inventoland.net/; Hewlett-Packard, 1501 Page Mill Road, 4U-6, Palo Alto, CA 94304, USA

** Correspondence: RBuckley@crt.xerox.com; phone 716-422-1282; fax 716-265-8871; Xerox Corporate Research & Technology, 800 Phillips Road, 0128-30E, Webster, NY 14580, USA

Visible-Spectrum Imaging Techniques: An Overview

Roy S. Berns,* RIT Munsell Color Science Laboratory

ABSTRACT

A multi-spectral imaging symposium was held during AIC01 consisting of invited and contributed papers. An overview of visible-spectrum imaging techniques was presented by the moderator (R. Berns), described in this paper.

1. INTRODUCTION

During the past decade, several academic and government institutions have initiated research that is aimed at producing visible-spectrum images. That is, for a given scene or object projected onto a two-dimensional plane, there is a desire to measure spectral properties as a function of spatial position. Similar research has been ongoing for several decades in the field of remote sensing; see reference 1. Details and relevant references about visible-spectrum imaging are given by the participants in this symposium, references 2 - 7. Other useful references are the proceedings from the annual International Symposium on Multispectral Imaging.

A reasonable question is why extend typical color imaging to visible-spectrum imaging? For well-managed color-imaging systems, it is common to produce high-quality color matches between objects and their color reproductions, whether in softcopy or hardcopy form. Implicit in this significant achievement is a carefully controlled and standardized set of conditions including illumination and viewing geometry, absolute spectral properties of the illumination (for object colors), ambient flare, background and surround conditions, state of chromatic adaptation, and observer spectral sensitivity (i.e., color-matching functions). This situation is a practical realization of colorimetry: two stimuli with identical tristimulus match when viewed under identical conditions. (In the case of cross-media color reproduction, identity is a result of chromatic-adaptation compensation.) However, carefully controlled and standardized conditions are rarely achieved in practice. Furthermore, conditions often change despite well-known standards. With a change in conditions, the match is no longer guaranteed. The mismatch is a result of metamerism between the various stimuli. Minimizing metamerism is readily accomplished by matching spectral properties in addition to colorimetry. In order to attempt a spectral match, the original stimulus' spectral properties must be known. Visible-spectrum imaging provides this knowledge.

There are two basic approaches used for visible-spectrum imaging. The first is to build an imaging spectrometer. Using either an interference filter wheel or a liquid-crystal tunable filter, an image is captured at a number of wavelengths across the visible spectrum for a defined wavelength increment and bandpass. Many spectrophotometers for color measurement have a range from 380 nm to around 750 nm with a 10 nm increment and bandpass. A given scene would require 37 images. Depending on the camera's total number of pixels, data-storage requirements are formidable. An alternate approach is to sub-sample the visible spectrum. Various interpolation techniques can be used to estimate the missing wavelengths, particularly because spectral data in the visible region are quite smooth and have few transitions. The sub-sampled data can also be combined with *apriori* spectral data of a specific coloration system or a set of test targets. This last approach is the focus of this overview.

2. SPECTRAL ESTIMATION FOR ADDITIVE IMAGING SYSTEMS

Consider a well-setup color CRT display composed of three types of phosphors. Figure 1 shows a plot of the blue channel at various levels of excitation. When each curve is normalized by dividing the measurement by its peak output, also plotted in Figure 1, it is seen that the curves plot on top of one another. This implies that each curve can be estimated by scaling the maximum output, Eq. 1,

$$L_{\lambda,b} = B\, L_{\lambda,bpeak} \quad (1)$$

where $L_{\lambda,bpeak}$ is the peak spectral radiance, B is a scalar, and $L_{\lambda,b}$ is an arbitrary measurement. Scalar B is most easily determined by the ratio of the arbitrary measurement divided by the peak output at the wavelength of peak output:

$$B = L_{\lambda,b} / L_{\lambda,bpeak} \text{ at } \lambda_{max} \quad (2)$$

Determining B only requires a measurement at a single wavelength. A device can be built that consists of a single detector, with it's peak sensitivity centered at λ_{max}. If the spectral radiance of the blue channel's peak output is known *apriori*, the spectral radiance at any level of excitation can be determined using a very simple instrument. This instrument has been defined as an abridged spectrometer.[8] In spite of the severe amount of abridgment, it is able to accurately estimate spectral radiance, limited by the accuracy of the *apriori* spectral measurement and the validity of Eq. 1.

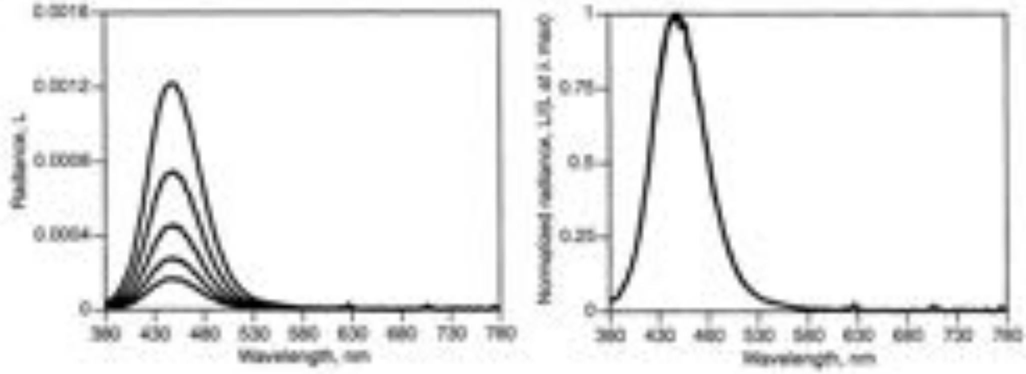


Figure 1. Spectral radiance and normalized spectral radiance of a color CRT's blue channel at several levels.[8]

This concept can be extended to all three channels, by building an instrument with three detectors, each with spectral sensitivity centered at the wavelength of each phosphor's peak output across wavelength. The peak wavelengths and peak spectral radiance for a color CRT are plotted in Figure 2. Notice that at these three wavelengths, the other two channels have some output. If the amount of green channel emission is varied while the red output is held constant, the red channel detector will not have a constant signal but will vary as a function of the green output. This "crosstalk" occurs for all three channels. The conversion from the three detector-output-signals to spectral radiance for any color produced by the display is achieved by Eqs. 3 and 4:

$$L_{\lambda} = R\, L_{\lambda,rpeak} + G\, L_{\lambda,gpeak} + B\, L_{\lambda,bpeak} \quad (3)$$

$$R = f(S_r, S_g, S_b), G = f(S_r, S_g, S_b), B = f(S_r, S_g, S_b), \quad (4)$$

where S_r, S_g, and S_b are the three detector signals centered at the peak wavelengths of the red, green, and blue channels, respectively. Quite often, the conversion function is a linear operation such as a (3x3) matrix. If the display exhibits poor channel independence, the matrix can be expanded via polynomial regression or using a multi-dimensional look-up table and linear interpolation. Now the abridged spectrometer consists of three channels.

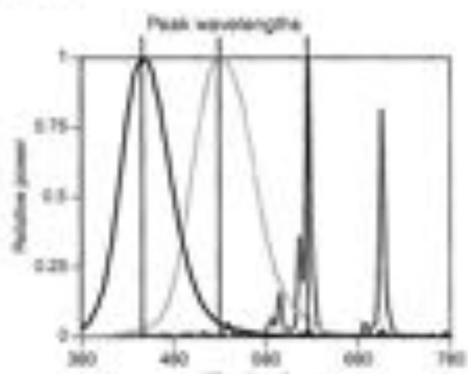


Figure 2. Normalized spectral radiance of a color CRT at peak output.[8]

Because of signal-to-noise considerations and potential differences in the wavelength location of different batches and types of red, green, and blue phosphors, the single wavelength is expanded to a narrow-band RGB-type instrument. Ignoring issues of synchronization, any RGB digital camera can become an imaging spectrometer when measuring color

CRT displays. Since colorimetry can be calculated from the spectral data in the usual fashion, the camera can measure the colorimetric coordinates of each pixel. As the bandwidth of the sensor's spectral sensitivities increases, the conversion function becomes a required operation. This concept can also be used to improve the accuracy of colorimeters designed for display measurements.[9,10]

3. SPECTRAL ESTIMATION FOR SUBTRACTIVE IMAGING SYSTEMS

Subtractive systems include photographic materials and various thermal-printing technologies. Historically, spectrophotometers had excessively large measurement apertures for most photographic applications. Recognizing that a specific photographic material achieves its full color gamut by three colored dyes, the idea of using small-aperture densitometry to determine dye concentration coupled with the *apriori* spectral measurements of each photographic dye facilitated the ability to estimate spectral density as a function of spatial position. Spectral density can be converted to spectral transmittance, T_λ, (for positive films) or reflectance, R_λ, (for print paper). This is known as the conversion from integral to analytical density.[11] Equations 3 and 4 become Equations 6 and 7:

$$D_\lambda = -\ln(T_\lambda/T_{\lambda,g}) \quad \text{or} \ -2\ln(R_\lambda/R_{\lambda,g}) \tag{5}$$

$$D_\lambda = C\,D_{\lambda,cyan} + M\,D_{\lambda,magenta} + Y\,D_{\lambda,yellow} \tag{6}$$

$$C = f(D_r, D_g, D_b),\ M = f(D_r, D_g, D_b),\ Y = f(D_r, D_g, D_b), \tag{7}$$

where D_λ is spectral density, subscript g notates the substrate, C, M, and Y are concentrations of the cyan, magenta, and yellow dyes, and D_r, D_g, D_b are the narrow-band densitometer readings. Because of cross-talk, a matrix is required to relate the densitometer readings with the dye concentrations. This is analogous to spectral estimation of additive systems except it is performed in a logarithmic rather than linear spectral space.

When performing spectral estimation using imaging devices such as cameras and scanners, their detectors have linear photometric responses whereas subtractive systems are governed by logarithmic models. This is remedied by an additional nonlinear transformation. This enables non-colorimetric devices to achieve high colorimetric accuracy by the intermediate stage of spectral estimation; see for example, reference 12.

4. SPECTRAL ESTIMATION FOR REFLECTING OBJECTS

Spectral estimation for the above additive and subtractive systems is a determined system: Three phosphors or dyes require three sensors. For many objects requiring spectral estimation, the number and spectral properties of the objects' colorants are unknown. The solution is to derive a set of "statistical colorants." The statistical techniques of principal component analysis or singular value decomposition are usually used. The goal is to reduce the dimensionality such that a reasonable number of statistical colorants can be used to match the entire ensemble of spectra. The "statistical colorants" are a set of spectra. The minimum number of spectra, referred to as eigenvectors, is derived that describe the variance in the set of data. Each successive eigenvector accounts for a smaller and smaller percentage of the total variance. Depending on the spectral properties of the set of objects, five to twelve eigenvectors are usually sufficient for reasonable spectral estimation.

A test target or set of standard reference materials is analyzed using principal component analysis and measured using a multi-channel spectrometer or digital input device. The number of channels is often the same as the number of selected eigenvectors. A transformation is derived relating the device signals with the "concentrations" of the "statistical colorants." Using the eigenvectors and transformation, an object or scene's spectral properties can be estimated. The accuracy of the estimation depends on how well the set of "statistical colorants" represents the true colorants, properties of the input device, particularly noise and each channel's spectral sensitivity, and the transformation.

The Munsell Student Set[11] provides a convenient example. It is a set of matte painted papers produced using a number of pigments. The Student Set is a useful teaching tool and approximates the Munsell color-order system. 154 samples from the set were measured using a bidirectional reflectance spectrophotometer. The reflectances are plotted in Figure 3. The amount of spectral variability suggests that a set of spectra can be derived that can be combined such that a spectral match is achieved for each sample.

The reflectance data were analyzed by principal component analysis. The mean and first seven eigenvectors are plotted in Figure 4. (The spectra spanning between positive and negative reflectance factor is common in principal component analysis.) Each successive vector has a smaller range of reflectances, consistent with each vector accounting for less and less of the total variance. Another trend is that the eigenvectors are increasingly spectrally selective. The lower-variance eigenvectors are accounting for subtle differences in colorants' reflectance spectra. The cumulative percentage of variance explained by each eigenvector is listed in Table 1. With eight eigenvectors, 99.94% of the spectral variance is accounted for. Equation 8 describes spectral estimation using the eigenvectors.

$$R_{\lambda,estimate} = R_{\lambda,mean} + \sum_i S_i V_{\lambda,i} + \varepsilon_\lambda \qquad (8)$$

where $V_{\lambda,i}$ is the ith eigenvector, S_i is the eigenvector scalar (not to be confused with the signals defined in Eq. 4), and ε_λ is spectral error caused by the data reduction..

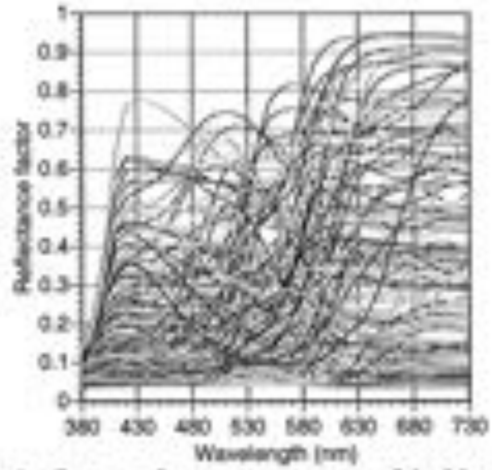


Figure 3. Spectral reflectance factor measurements of the Munsell Student Set.

Determining the number of eigenvectors required for spectral estimation depends on spectral and colorimetric accuracy requirements. In addition, the number of channels in the measurement system is also a factor. With more channels, it makes sense to use more eigenvectors. A spectral curve was selected arbitrarily and reconstructed using the mean and the first eigenvector, the mean and the first two eigenvectors, and so on up to seven eigenvectors, plotted in Figure 5. With an increase in the number of eigenvectors, spectral accuracy increases, but at a decreasing rate. The color difference between each spectral estimation and the actual spectrum ranges between 2.5 and 0.1 ΔE^*_{94}.

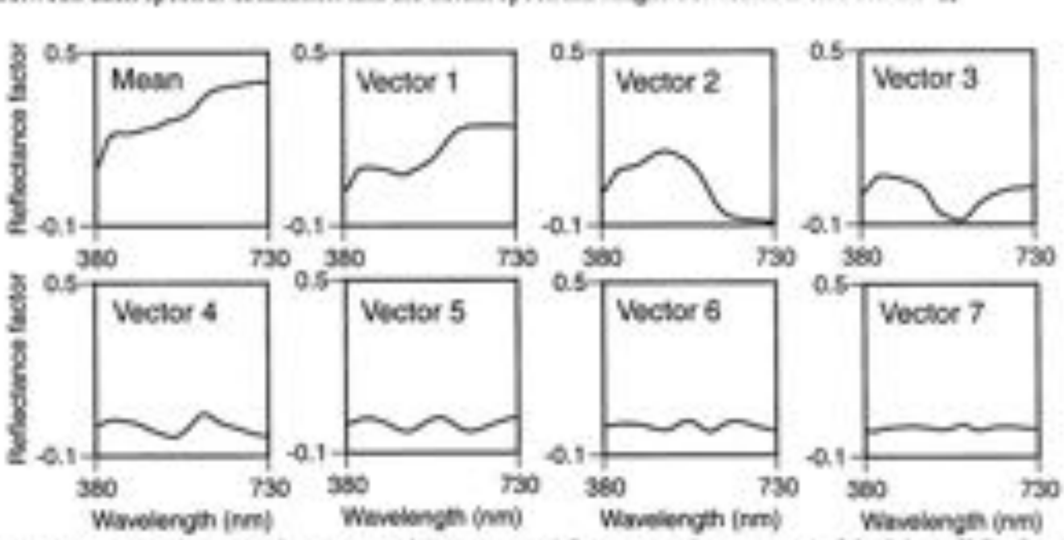


Figure 4. Spectral reflectance factor data of the mean and first seven eigenvectors of the Munsell Student Set.

Table 1. Cumulative percent variance for the principal component analysis of the Munsell Student Set.

Eigenvector	1	2	3	4	5	6	7	8
Cumulative %Variance Explained — $R_λ$	69.15	92.15	97.67	98.91	99.55	99.81	99.88	99.94
Cumulative %Variance Explained — $(K/S)_λ$	67.12	90.17	98.42	99.35	99.74	99.85	99.91	99.94

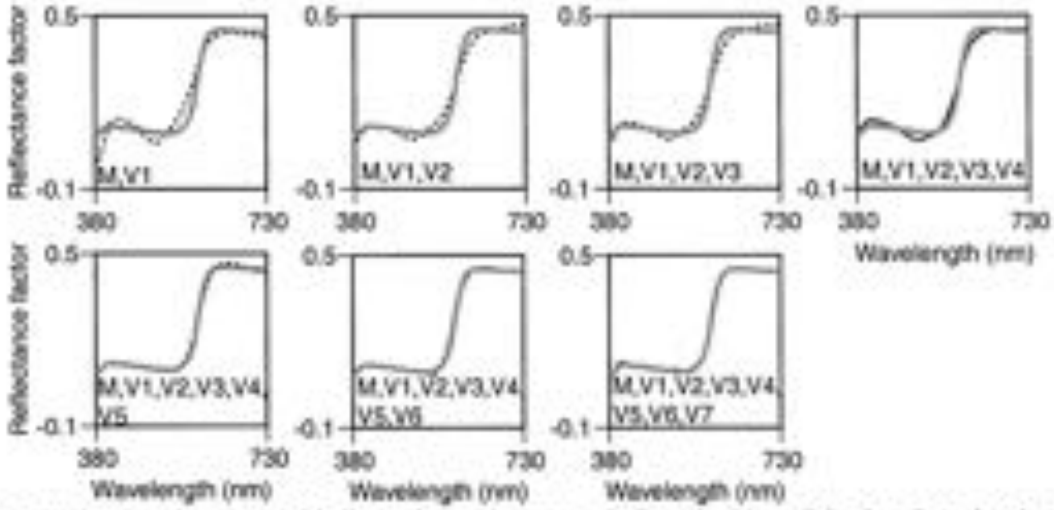


Figure 5. Spectral estimation (dotted thin line) of an arbitrary sample from the Munsell Student Set using the mean, M, and increasingly more eigenvectors, V1, V1+V2,...

Once the number of eigenvectors is determined, each sample's spectral reflectance factor is estimated using the mean and set of eigenvectors. The matching criterion is usually RMS spectral error. The scalars are recorded. The Student Set, arranged as a grid of squares, is imaged using an input device with the same or greater number of channels as the selected number of eigenvectors. The average signal values are recorded for each sample. A transformation is derived, usually statistically, to relate the camera signals with the eigenvector scalars. Commonly least squares (i.e., pseudo-inverse calculation) is used to populate a transformation matrix.

Those familiar with the relationship between colorant amounts and spectral reflectance factor will recognize that a linear model of spectral estimation using reflectance is a crude approximation. Absorption and scattering models such as Kubelka-Munk turbid media theory are more appropriate for spectral estimation. However, as the number of eigenvectors increases, this difference becomes insignificant, shown in Table 1. Depending on the noise properties of the input device, K/S can result in estimated spectra with negative reflectance factors. Conversely, the use of spectral reflectance or transmittance rather than spectral density for the spectral estimation of subtractive systems using only three sensors results in very poor performance. The type of spectral data is an important factor when performing spectral estimation.[14]

5. CONCLUSIONS

Visible-spectrum imaging techniques provide invaluable information: spectral data. Spectral data can be used to estimate color for any observer and illuminant, increase the probability of achieving color reproductions with minimal metamerism, create digital archives with that have physical meaning, and perform forensic evaluations such as pigment identification.

In the future, it is expected that visible-spectrum imaging, spectral color reproduction, spectral color management, and spectral image archives will become commonplace.

6. ACKNOWLEDGMENTS

This research was supported by the R. S. Hunter Professorship in Color Science, Appearance, and Technology.

REFERENCES

1. R.N Colwell,. Ed. *Manual of Remote Sensing Vol I*, 2nd ed, American Society of Photogrammetry, Falls Church, Va (1983).

2. B. Hill, "Optimization of total multispectral imaging systems: Best spectral match versus least observer metamerism," *Proc. AIC Color01 Rochester, 9th Congress of the International Colour Association*, in press (2001).

3. Y. Miyake, H. Haneishi, N. Tsumura, and J. Hayashi, "Gonio-photometric imaging for recording of reflectance spectra of three dimensional object," *Proc. AIC Color01 Rochester, 9th Congress of the International Colour Association*, in press (2001).

4. R. Baribeau, "Spectral estimation from laser scanner data for accurate color rendering of objects," *Proc. AIC Color01 Rochester, 9th Congress of the International Colour Association*, in press (2001).

5. Q. Sun and M. D. Fairchild, "A new procedure for capturing spectral images of human portraiture," *Proc. AIC Color01 Rochester, 9th Congress of the International Colour Association, in press* (2001).

6. M. Hauta-Kasari, J. Lehtonen, J. Parkkinen, and T. Jaaskelainen, "Representation of spectral images in data communications," *Proc. AIC Color01 Rochester, 9th Congress of the International Colour Association, in press* (2001).

7. F. H. Imai and R. S. Berns, "Spectral estimation of artists oil paints using multi-filter trichromatic imaging," *Proc. AIC Color01 Rochester, 9th Congress of the International Colour Association, in press* (2001).

8. R. S. Berns, *Billmeyer and Saltzman's Principles of Color Technology*, 3rd ed., John Wiley & Sons, New York, 2000.

9. Y. Ohno and J. Hardis, "Four-color matrix method for correction of tristimulus colorimeters," *Proc. IS&T/SID 5th Color Imaging Conf.*, 301-305 (1997).

10. Y. Ohno and S. W. Brown, "Four-color matrix method for correction of tristimulus colorimeters – part 2," *Proc. IS&T/SID 6th Color Imaging Conf.*, 65-68 (1998).

11. T. H. James and G. C. Higgins, *Fundamentals of Photographic Theory*, Morgan & Morgan Inc., Hastings-on-Hudson, NY, 1968.

12. R. S. Berns and M. J. Shyu, "Colorimetric characterization of a desktop drum scanner using a spectral model," *J. Electronic Imag.* **4**, 360-372 (1995).

13. *The New Munsell Student Color Set*, text by J. T. Luke, Fairchild, New York, 1996.

14. F. H. Imai and R. S. Berns, "A comparative analysis of spectral reflectance reconstruction in various spaces using a trichromatic camera system," *Proc. IS&T/SID 7th Color Imaging Conference*, 21-25 (1999).

Correspondence: berns@cis.rit.edu; phone:716-475-2230; fax:716-475-5988;www.cis.rit.edu:80/people/faculty/berns/; RIT Center for Imaging Science, 54 Lomb Memorial Drive, Rochester, NY 14623-5604, USA.

Optimization of Total Multispectral Imaging Systems: Best Spectral Match versus least Observer Metamerism

Bernhard Hill

Department of Electrical Engineering and Information Technology
Aachen University of Technology
E-mail: hill@ite.rwth-aachen.de

Abstract

The paper deals with total multispectral imaging systems assembled from a multispectral camera or scanner for capturing color images or natural scenes and a multichannel color image display for image synthesis.The aim of the multispectral technology is to reproduce an approximation to the spectral color stimuli of an original image in order to reduce color mismatches between original and reproduction for every human observer and any illuminant considered. Two system aspects are discussed in more detail: the representation of spectral data by a set of multispectral values at the interface between camera and display and the method of controlling the channels of the multichannel display to reproduce colors at least errors for every human observer. An expansion of spectral stimuli functions into a series of basis functions with weighting coefficients called multispectral values is used for the data representation at the interface. The set of basis functions is either optimized with respect to best fitting the original color stimuli or to produce least observer metamerism. It is shown that observer matched basis functions lead to smaller color errors. Best results for the control of the multichannel display are achieved with an iterative process using stochastic pattern generation. It is shown that maximum color errors for a large test set of spectral color stimuli on one side and 24 different human observers on the other are below 1,6 CIE-ΔE94 units if the experimental spectral characteristics of a 6-channel display are considered.
Keywords: Multispectral color imaging, multispectral camera, multiprimary display, spectral estimation, spectral data encoding, observer metamerism

1. Introduction

The paper discusses problems of spectral data processing in a total multispectral imaging system as sketched in Fig. 1. An original color document or scene is illuminated by a light source with spectral radiant power S_λ. The light reflected from the surface of the original is captured by a multispectral camera. This camera is composed of a greyscale CCD-Sensor (2000 x 2000 elements in the developed system) and a quickly switchable mechanical filter wheel equipped with 16 narrow band interference filters. The 50 % bandwidth of the filters amounts to 20 nm. The centers of the spectral transmittance of the filters are located at wavelengths covering the visible range from 400 to 700 nm.

Before starting the capture of a color image, 16 spectral images of a white reference sheet are taken sequentially while changing the spectral filters in front of the CCD sensor. Afterwards, 16 spectral images of the color original are captured and immediately normalized pixel by pixel with the respective white reference image data. By this way, spatial non uniformities of the illumination or the camera are compensated and the final 16 spectral separations become referenced to illuminant E. Thus, the spectral separations represent the spectral reflectances of the original pixels under the respective angle of color capture. All color separations are recorded at 12 bit of resolution.

The next unit of the system serves to transform the spectral data into an efficient set of multispectral values that represent the relevant spectral information. The task of the unit is to provide a device independent interface from which encoded spectral data can be transmitted to any imaging output device. Some methods of efficient spectral data encoding are discussed in chapter 3. In the laboratory system multispectral data are transmitted to a 6-channel display. This display is composed of two LCD-beamers equipped with narrow band spectral filters. These are installed in the optical pathways so as to achieve color channels of 6 different primary colors superimposed on a screen by back-projection. Methods to control the six channels from spectral data at the input are presented in chapter 4.

First of all however, the fundamental question has to be answered what spectral color reproduction should aim at. A possible method of determining the color quality of a multispectral system is therefore summarized in the next chapter.

2. Color quality of a multispectral system

The color quality of traditional reproduction systems is usually defined by the color difference between the colors of an original document viewed under a given illuminant and the corresponding output colors reproduced with reference to the same illuminant. The color difference might e.g. be defined by CIE ΔE94 and derived for the CIE 1931 standard observer.

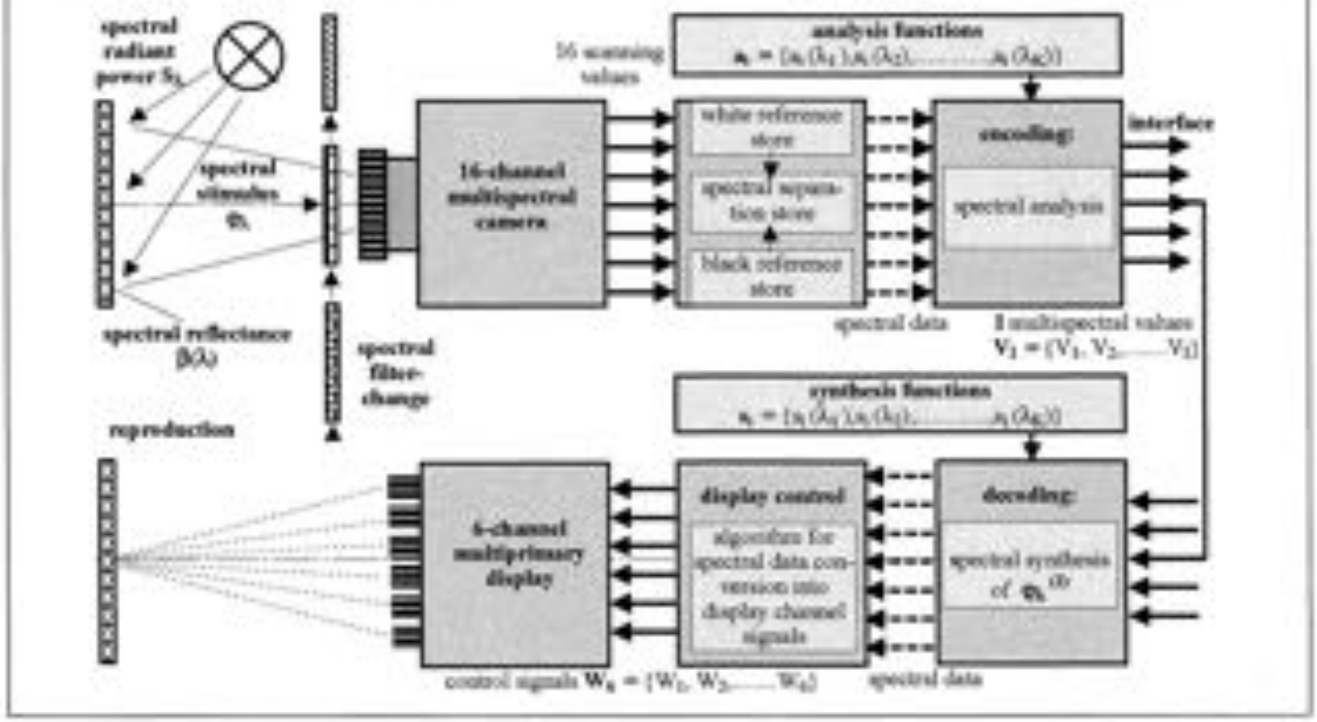


Fig. 1: Structure of the total multispectral imaging system with 16-channel multispectral camera, spectral data encoding unit, open system interface and transmission to a 6-channel display with decoding and control unit

In contrast to tristimulus systems, multispectral systems offer improved color reproduction quality not only for a standard observer but also for any other individual exhibiting normal color vision capability. Normal human observers show color matching functions differing more or less from those of the standard observer and the design of multispectral systems should therefore take those differences into account. Moreover, color perception depends on the viewing angle. The quality of color reproduction is therefore derived from 24 selected human observers with color matching functions taken from measurements of Judd, Stiles and Burch [1], including 2° and 10° observers and the CIE standard deviator (Fig. 2) [2-4]. From the large variety of measured curves available from Stiles and Burch, those showing the largest variation have been selected.

Another essential feature which multispectral imaging systems offer is the basic possibility to reproduce images for any illuminant and to reproduce colors exactly as they would appear under a particular illuminant. This possibility of changing the illuminant without basic loss of quality is particularly important if scenarios using different illuminants are simulated on a display but also when viewing images that are printed from multispectral data. Of course, for the optimization of a system, all these features should be tested for a large number of representative spectra of input colors. The spectral data set published by Vrhel is used for this purpose because it provides a good mixture of natural and technical colors including a selection of Munsell-colors [5]. All combinations of considered illuminants (e.g. D50, D55, D65, C, F2, F11 ect.), test spectra and observers are used to test the reproduction quality of the multispectral system (Fig. 3). The maximum, average and 1 % largest color differences are finally used as quality measures.

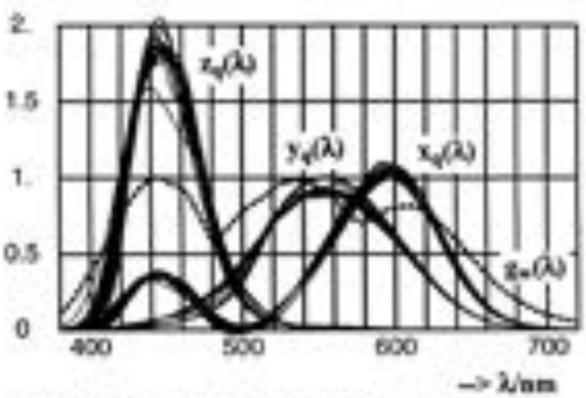


Fig. 2: Color matching functions of 24 observers (solid curves) and spectral weighting function (dotted line, see chapt. 3.2)

3. Spectral data representation at the open interface

The multispectral system under investigation is designed not only for the purpose of image reproduction on a 6-channel display in a closed system architecture but also to provide multispectral input to conventional tristimulus displays or various conventional and future multispectral printers. Therefore, an open system interface for multispectral data has been designed which uses an efficient set of encoded data to describe the spectral information. Two methods are discussed below, one aiming at least errors in the spectral domain, the other at least color errors for different observers.

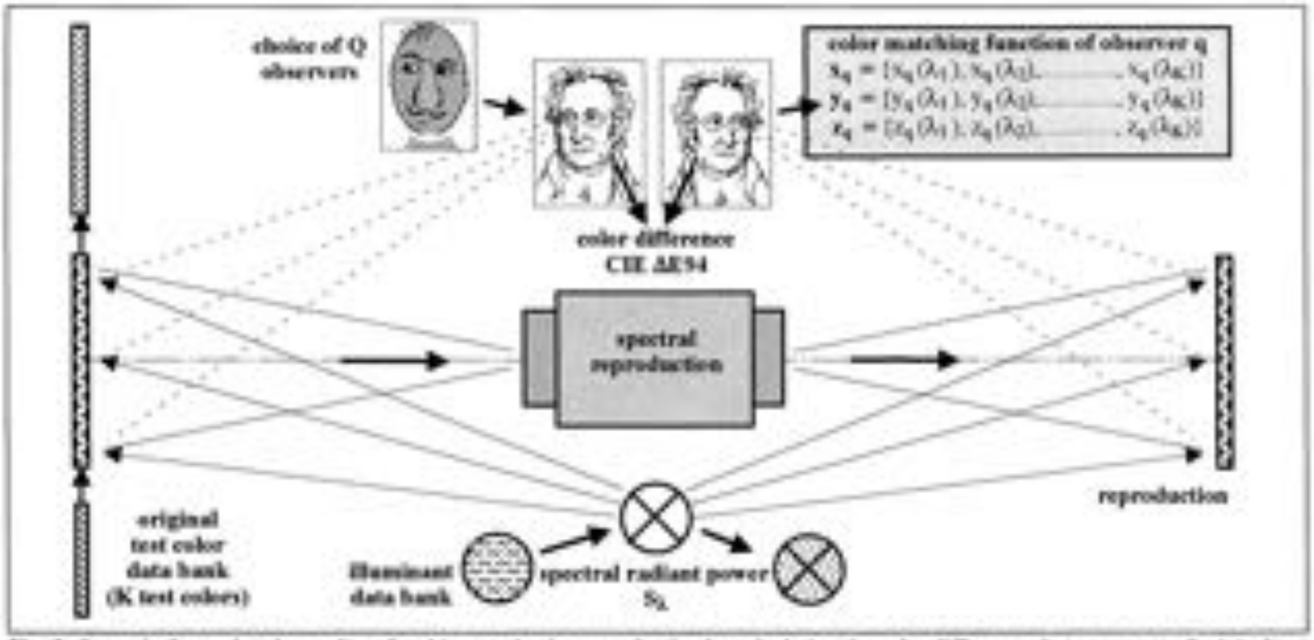


Fig. 3: Scenario for testing the quality of multispectral color reproduction by calculating the color differences between a set of original test spectra of reflective colors irradiated by different illuminants and respective reproductions for different observers (Fig. 2)

In the experimental system, the stimuli of original colors are captured by 16 scanning values. The spectra to be encoded have to be derived from the 16 scanning values of the camera. Therefore, the 16 scanning values are either interpolated using the so called smooting inverse [16] or they are directly mapped onto multispectral values of the linearly encoded data format derived below using an optimized mapping matrix [17].

3.1 Best spectral approximation

Methods to encode the spectral data of surface colors have been proposed in many papers [7-13]. The most common method uses an expansion of spectral data into orthonormal basis functions derived from a principal component analysis (PCA) applied to a spectral test data set. For a particular spectral color stimulus $\varphi_\lambda^{(I)}$ with K spectral components in the visible range the expansion is mathematically described by

$$\boldsymbol{\varphi}_\lambda^{(I)} = \sum_{i=1}^{I} V_i \, \mathbf{a}_i ; \qquad V_i = \boldsymbol{\varphi}_\lambda \cdot \mathbf{a}_i \, ,$$

where the weighting coefficients $\mathbf{V}_i$ of the expansion are called the multispectral values, $\boldsymbol{\varphi}_\lambda$ is the original spectral color stimulus, $\boldsymbol{\varphi}_\lambda^{(I)}$ the respective approximation and $\mathbf{a}_i$ are basis functions with K spectral components within the visible range. ($\boldsymbol{\varphi}_\lambda \cdot \mathbf{a}_i$ means the dot product of vectors). The basis functions are often called spectral analysis functions if they are used to determine the multispectra values from a given stimulus and they are called synthesis functions if they compose the reconstructed stimulus. Numerically, spectral components are defined at 1 nm steps in the range from 380 to 720 nm resulting in K = 341 values. The number I of basis functions influences the accuracy of the synthezised approximation. The PCA applied to a test data set, defines the theoretically best spectral approximation for the average squared error.
Using the test scenario of Fig. 3, the average, maximum and 1% largest color errors of the representation by I multispectral values for illuminants D50, D55, D65 and C have been calculated and plotted in Fig. 4. It is obvious, that maximum errors below 1 unit of ΔE94 can only be achieved, if I = 12 or more basis function are used. The average error is below 1 unit already for I = 6 components. If considering illuminants with less uniformity such as F2, FII, or energy saving lamps, the errors will be at least twice as large.

3.2 Observer matched spectral data encoding

The aim of a multispectral color reproduction system is not necessarily to reproduce the best spectral approximation to a color stimulus but mostly to reproduce minimum color errors for a variety of illuminants and for every human observer. The proposal of an alternative definition of basis functions has therefore been developed. Moreover, the spectral data in multispectral systems of the future should be compatible with conventional tristimulus systems via an easy connection. The compatibility becomes possible if the first three basis functions of a spectral expansion are chosen as linear transform of color matching functions. As sketched in Fig. 5, the definition of basis functions starts from the color matching functions $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$ of the standard observer. The functions are orthogonalized via a 3 x 3 matrix M_{33} and provide the first

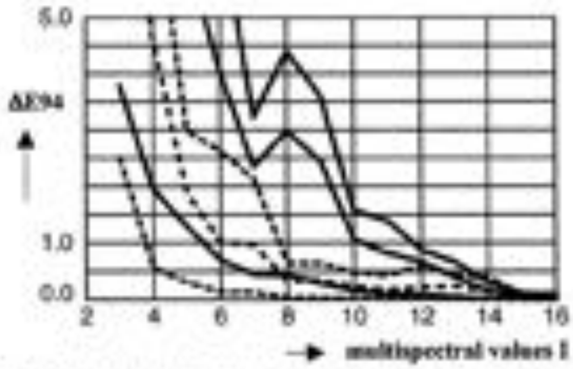


Fig. 4: Color error as a function of the number of multispectral values for basis functions optimized in the spectral domain (solid lines) and observer matched basis functions (dotted lines). Maximum errors (upper lines), 1 % largest errors (medium lines) and average error (lower lines), respectively.

three functions for spectral stimuli analysis. Accordingly, the first three multispectral values (V_1, V_2, V_3) are linear transforms of (X, Y, Z)-values and conventional tristimulus systems can easily be coupled to the first three values of the multispectral data set.

For further encoding of the spectral information the spectral contribution by the first three basis functions is subtracted from the spectral stimulus under test resulting in a spectral difference not visible for the standard observer (black difference spectrum). For all the respective spectral difference functions of the spectral test set, a PCA could now be used to develop a suitable set of further basis functions. An additional improvement will, however be achieved, if the spectral variation of the responsivities of human observers are taken into consideration [15]. For that reason, a spectral weighting function has been derived by calculating the maximum color error introduced by a change of a spectral component at wavelength λ_k of all 24 observers. This is done for the basic color of illuminant E. Afterwards, the square root of this spectral distribution of color errors defines the weighting function sketched in Fig. 2. Further basis functions are now derived by calculating all the black difference functions of the Vrhel data set multiplied by the weighting function in a first step. In the second step, so called observer matched basis functions are determined by applying a PCA to this data set. To encode a spectral stimulus, the contribution of the first three basis functions is analyzed with the result of V_1 ....V_3. Then, the rest of the stimulus function is multiplied by the weighting function and analyzed using the observer matched basis functions to derive multispectral values V_4 .....V_l (Fig. 5).

Data decoding for the purpose of reproducing the spectral stimulus uses the observer matched basis functions divided by the weighting function whereas the first three functions are again the orthogonal color matching functions (Fig. 6). The result of the superposition is finally multiplied by the illuminant considered for reproduction. Multiplication and division by the weighting function can be combined with the application of basis functions resulting in different synthesis and analysis functions (Fig. 5 and 6). In Fig. 4, color errors are given for the observer matched encoding as a function of the number of multispectral values in addition to the results obtained for best spectral fit. It is seen, that there is an essential advantage for the observer matched encoding compared to best spectral fit in the range of multispectral values below 13. This is due to more accurate approximation of color stimuli in the most sensitive spectral ranges of human observers.

The color errors given in Fig. 4 are only caused by the encoding method. Additional errors might be expected from the reconstruction of the spectrum behind the camera from a smoothing inverse [16] or by the method of direct mapping of the 16 scanning values of the camera into l multispectral values as outlined in [17]. Yet, neither the interpolation of the 16 scanning values using a smoothing inverse nor the method of direct mapping of the 16 scanning values into the encoded multispectral values by using an optimized mapping matrix introduce noticeable deterioration of the results compared with those of Fig. 4, if the total process from image capture to interface data is considered. Obviously, the encoding of spectra by a limited number of basis functions introduces the largest errors in the total process. In the experimental system, color errors of the multispectral camera are below 0.5 ΔE94 units.

4. Control of multichannel displays

The model of the multichannel display considers M channels with narrow band spectral characteristics to compose an output color stimulus by the superposition of the light of M channels. For theoretical studies, smooth idealized spectral characteristics are assumed as shown in Fig. 7 on the left hand side for M = 6. The experimental system equipped with two LCD-beamers exhibits the spectral characteristics shown in Fig. 7 on the right hand side. Strong spikes are due to the light source in the beamers. The control of the channels of the display requires a strategy how to transform the spectral data at the input into M control signals in order to produce a spectral output with minimum color errors for every observer. Different methods are possible to solve the problem: e.g. linear mapping [17] or linear programming [18].

Best results have been obtained by an iterative method using stochastic pattern generation. The system starts from an estimated value of M control signals $\mathbf{W_M}$. This is derived from the dot products of each spectral channel characteristic with the input stimulus. Then, a linear spectral model of the display is used to calculate the reproduced colors for the 24 observers and the maximum value is selected. In a second loop, small stochastic patterns are superposed to the control signals and the color errors for 24 observers are calculated again. An internal loop reduces the amplitudes of the superposed stochastic patterns step by step until improvements of the color errors are achieved. Afterwards, the system starts with a new stochastic pattern and so on. It has been found that after 10-20 cycles the results are in the range differing by only 0.1 error units compared to the best results after hundreds of cycles. It has also been found that the criterion of the maximum error to control the iteration provides the most stable and uniform results rather than using the average error. The results are shown in Fig. 8 as a function of the number of idealized channels (Fig. 7 left side) from 3 to 10 and for the 6-channel display with measured spectral characteristics (Fig. 7 right side). The maximum errors for input data of the Vrhel-data set are below 1.6

units for the experimental characteristics and excellent results could be achieved if the idealized characteristics were realizable. An important result is also, that even a number of 6 channels produces acceptable results for multichannel displays

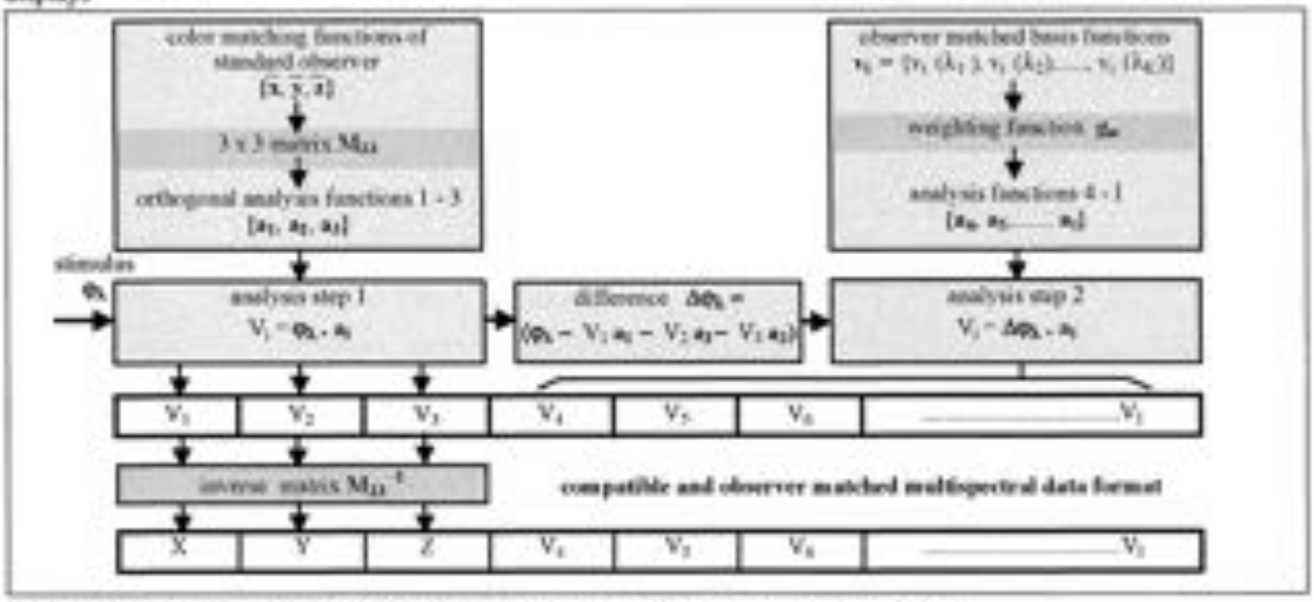


Fig. 5: Structure to compose observer matched multispectral values compatible to tristimulus systems

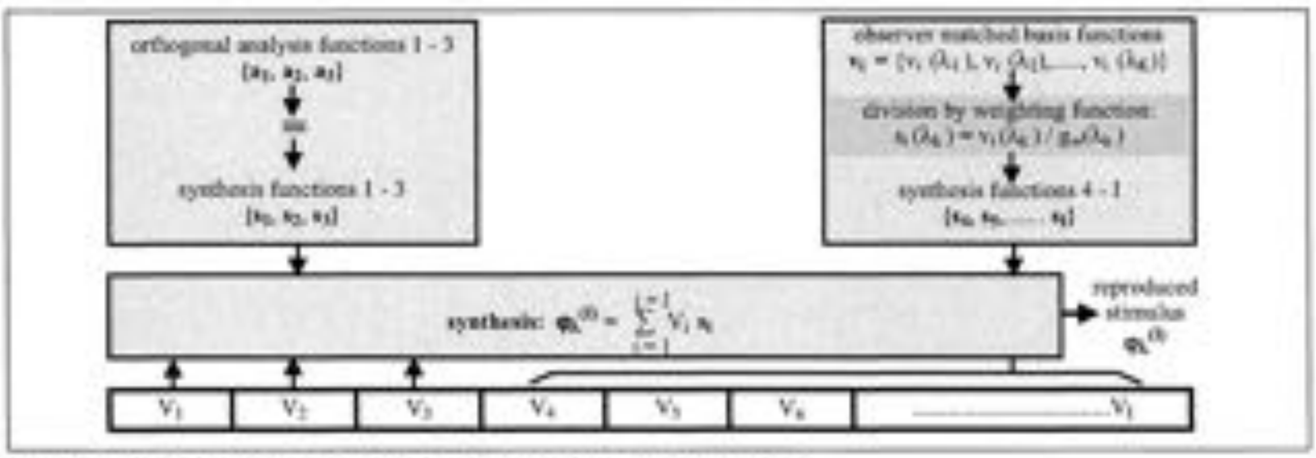


Fig. 6: Reproduction of spectral stimuli from observer matched multispectral values

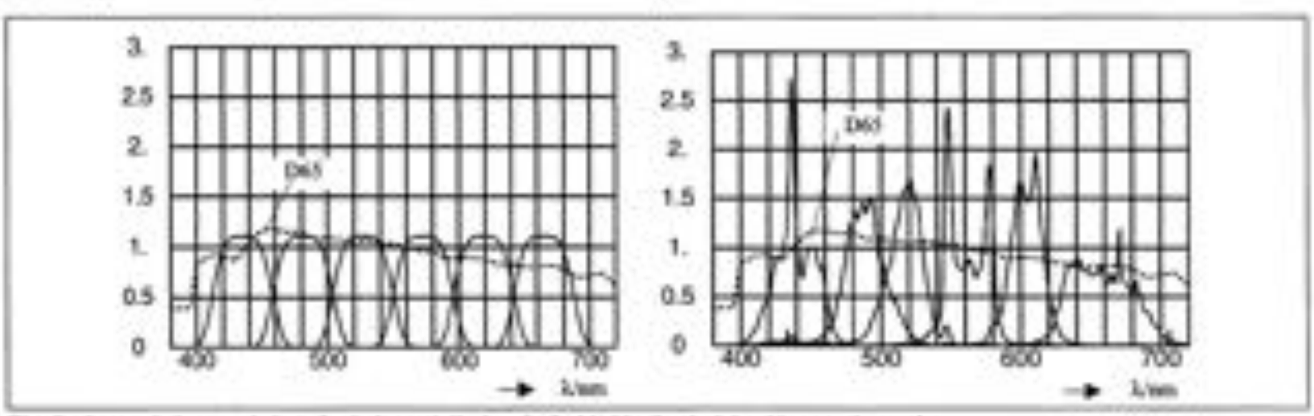


Fig. 7: Spectral characteristics of a 6-channel display. Left side idealized, right side experimental

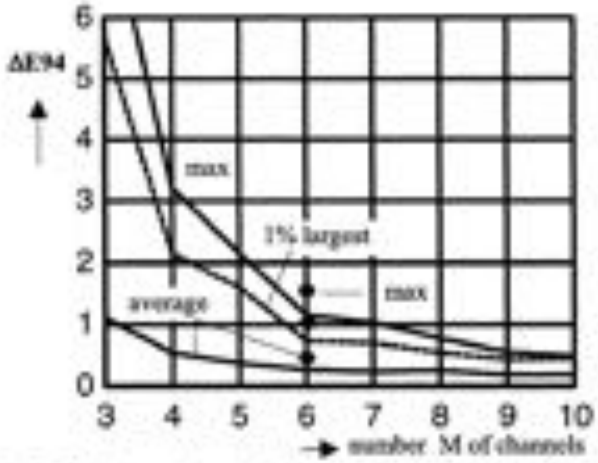


Fig. 8: Maximum (upper solid line), 1 % largest (dotted line) and average reproduction errors of multichannel displays using M idealized channels and respective results for experimental spectral channel characteristics (dots at M = 6).

Conclusions

Multispectral imaging has become a promising technology for high accurate color reproduction. Methods to estimate the original spectral color stimuli from the scanning values of multispectral cameras have been developed and efficient encoding of these data by multispectral values provides open system interface information that can easily be transmitted to any imaging output device. It is shown in this paper, that most efficient encoding is achieved with methods aiming at least observer metamerism rather than best spectral fit. If the data format with 9 coefficients is used, maximum color errors will be below 1 CIE ΔE94 unit for the complete multispectral image capturing and encoding. These theoretical results are in good agreement with the experimental results obtained for the camera with 16 multispectral channels.

A multispectral image display is under investigation. The paper demonstrates the capability of the theoretical model of a multichannel display and an optimized method to control the multitude of input channels from multispectral data. The experimental system does not deliver spectral characteristics suitable to achieve a good spectral fit between the reproduced spectral color stimuli and input stimuli, nevertheless, results of color errors for the control of the system on the basis of stochastic pattern generation show acceptable results even if only 6 channels are available.

References

1. G. Wyszecki, W. S. Stiles, "Color Science", John Wiley & Sons, New York 1982
2. CIE Techn. Report Publ. No. 80 "Special Metamerism Index: Observer Metamerism", 1989
3. Noboru Ohta, "Formulation of a Standard Deviate Observer by a Nonlinear Optimization Technique", Color Res. and Appl. Vol. 10, No. 3, 1985, pp.156 - 163
4. D. C. Rich, J. Jalijali, "Effects of Observer Metamerism in the Determination of Human Color Matching Functions", Color Research and Application, Vol. 20, 1995, pp. 29 - 35
5. M. J. Vrhel, R. Gershon, L. S. Iwan, "Measurement and Analysis of Object Reflectance Spectra", Color Res. Appl. 19, No. 1, 1991, pp. 4 - 9
6. R. W. G. Hunt, "Objectives in color reproduction", The Journal of Photographic Science, Vol. 18, 1970, pp. 205 - 219
7. S. Kawata, H. Komeda, K. Sasaki, S. Minami, "Advanced algorithm for determining component spectra based on principal component analysis", Appl. Spectrosc. 39, 1985, pp. 610 - 614
8. S. Kawata, K. Sasaki, T. Minami, "Component analysis of spatial and spectral patterns in multispectral images", J. Opt. Soc. Am. A4, 1987, pp. 2101 - 2106
9. T. Jaaskelainen, J. Parkkinen, S. Toyooka, "Vector-subspace model for color representation", J. Opt. Soc. Am. A, Vol. 7, No. 4, 1990, pp. 725-730
10. D. H. Marimont, B. A. Wandell, "Linear models of surface and illuminant spectra", J. Opt. Soc. Am. A9, 1990, pp. 1905 - 1913
11. H. J. Trussell, "Applications of Set Theoretic Methods to Color Systems", Color Res. Appl., Vol. 16, No. 1, pp. 31 - 41, 1991
12. W. Praefcke, Th. Keusen, "Optimized Basis Functions for Coding Reflectance Spectra Minimizing the Visual Color Difference", Proc. IS&T/SID's 3rd Color Imaging Conf.: Color Science and Applications, 1995, pp. 37 - 40
13. F. H. Imai, N. Tsumura, H. Haneishi, Y. Miyake, "Principal Component analysis of Skin Color and its Application to Colorimetric Color Reproduction on CRT Display and Hardcopy", J. Imag. Science and Techn., Vol. 40, No. 5, 1996, pp. 422 - 43
14. Th. Keusen, "Multispectral color system with an encoding format compatible with the conventional tristimulus model", J. Imaging Science and Techn., Vol. 40, No. 6, 1996, pp. 510 - 515
15. J. A. S. Viggiano, "The comparison of radiance ratio spectra: Assessing a model's goodness of fit", Proc. IS&T Annual Conference Rochester, N.Y., USA 1990, pp. 222 - 225
16. Patrick G. Herzog, D. Knipp, H. Stiebig, F. König, "Charcterization of novel three and six channel color moiré free sensors", Proc. SPIE Color Imaging Conf. 1999, Vol. 3648, San José, USA, pp. 48 - 59
17. B. Hill, "Aspects of total multispectral image reproduction systems", Proc. 2nd Intern. Symposium on High Accurate Color Reproduction and Multispectral Imaging, Chiba University, Japan, Oct. 2000
18. F. König, K. Ohsawa, M. Yamaguchi, N. Ohyama, B. Hill, "A multiprimary display: Discounting observer metamerism", Proc. 9th Congress of the International Colour Association: AIC Colour 01 Rochester, N.Y., USA 2001

Gonio Photometric Imaging for Recording of Reflectance Spectra of • • •Object

Yoichi MIYAKE*+, Norimichi TSUMURA*, Hideaki HANEISHI* and Junichiro HAYASHI**
(*) Department of Information and Image Sciences, Chiba University, 263-8522, Chiba, Japan
(**) Mitsubishi Electronic Microcomputer Application Software co., Ltd., 617-8550, Kyoto, Japan
(+) E-mai:miyake@ics.tj.chiba-u.ac.jp

Abstract
In recent years, it is required to develop a system for 3D capture of archives in museums and galleries. In visualizing of 3D object, it is important to reproduce both color and glossiness accurately. Our final goal is to construct digital archival systems in museum and Internet or virtual museum via World Wide Web. To archive our goal, we have developed the multi-spectral imaging systems to record and estimate reflectance spectra of the art paints based on principal component analysis and Wiener estimation method. In this paper, Gonio photometric imaging method is introduced for recording of 3D object. Five-band images of the object are taken under seven different illuminants angles. The set of five-band images are then analyzed on the basis of both dichromatic reflection model and Phong model to extract Gonio photometric information of the object. Prediction of reproduced images of the object under several illuminants and illumination angles is demonstrated and images that are synthesized with 3D wire frame image taken by 3D digitizer are also presented.

1.Introduction

The Internet museum, telemedicine, and network shopping on the World Wide Web have increased rapidly in recent years. However, for example in the present Internet museum, color reproduction of the painting and 3D artifact is highly dependent on recording and display devices. Therefore, it is required to record and reproduce the device independent color of the objects.
We have developed high accurate multi-spectral imaging systems[1-2] for recording of reflectance spectra of the object. This system consists of single chip CCD camera (3120x2060 pixels, 14 bits levels) with rotating color wheel comprising five color filters, high quality CRT monitor, and personal computer. Using software Image Digitizer, Image Estimator and Image Reproducer, controls this system. Image Digitizer controls the rotating of filters, focusing of lens, viewing angle and exposure. After taking image, gamma correction, noise reduction and compensation of pixel defect of CCD camera are also processed by using Image Digitizer. Image Estimator is software for estimation of reflection spectra of image based on the principal component analysis and Wiener estimation method from five bands image. Image Reproducer is software to reproduce the color image from estimated reflection spectra of the object under the consideration of CRT monitor characteristics and color adaptation model. The system was significantly applied to record and reproduce of paintings.

In recent years, it is required to develop a system for 3D capture of archives in museums and galleries. In visualizing of 3D object, it is important to reproduce both color and glossiness

9th Congress of the International Colour Association, Proceedings
of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

accurately. Therefore, we have developed Gonio photometric imaging system to record the reflectance spectra of the three dimensional object by using multi-spectral imaging system.

2. Dichromatic reflection model

To record of three 3D objects accurately [6-8], it is necessary to record the reflection spectra, glossiness, texture and shape of the object. In this paper, dichromatic model was introduced to separate surface reflection and diffuse (body) reflection that are corresponding to glossiness and color of the object. As shown in Fig. 1 reflection spectra of the object $\mathbf{f}(\mathbf{r},\theta)$ at coordinate r and illuminant angle θ can be defined by Eq. (1) based on the dichromatic model.

$$\begin{aligned}\mathbf{f}(\mathbf{r},\theta) &= k_s(\mathbf{r},\theta)\mathbf{L}\mathbf{o}_s + k_d(\mathbf{r},\theta)\mathbf{L}\mathbf{o}(\mathbf{r}) \\ &= k_s^{w}(\mathbf{r},\theta)\mathbf{e}_s + k_d^{w}(\mathbf{r},\theta)\mathbf{e}_d(\mathbf{r})\end{aligned} \quad (1)$$

Where, L is spectral radiant distribution of the light source and $O(r)$ is spectral reflectance of the object at coordinate r shown as vector notation.

$$\begin{aligned}\mathbf{L} &= diag\left[l(\lambda_1),\cdots,l(\lambda_n)\right] \\ \mathbf{o}(\mathbf{r}) &= \left[o(\mathbf{r},\lambda_1),\cdots,o_n(\mathbf{r},\lambda_n)\right]^T \\ \mathbf{f}(\mathbf{r},\theta) &= \left[f_1(\mathbf{r},\theta,\lambda_1),\cdots,f_n(\mathbf{r},\theta,\lambda_n)\right]^T.\end{aligned} \quad (2)$$

And,

$$\begin{aligned}\mathbf{e}_s &= \frac{\mathbf{L}\mathbf{o}_s}{\|\mathbf{L}\mathbf{o}_s\|}, \mathbf{o}_s = [1\cdots1] \\ \mathbf{e}_d &= \frac{\mathbf{L}\mathbf{o}(\mathbf{r})}{\|\mathbf{L}\mathbf{o}(\mathbf{r})\|} \\ k_s^{w}(\mathbf{r},\theta) &= k_s(\mathbf{r},\theta)\|\mathbf{L}\mathbf{o}_s\| \\ k_d^{w}(\mathbf{r},\theta) &= k_d(\mathbf{r},\theta)\|\mathbf{L}\mathbf{o}(\mathbf{r})\|.\end{aligned} \quad (3)$$

Here, k_s^w and k_d^w are the intensity of surface reflection and diffuse reflection, and e_s, e_d represents normal vector representing the color of each reflection. In this model, k_s^w and k_d^w depend on the geometry of the illuminant and angle. On the other hand, e_s and e_d are dependent on the wavelength of the illuminant and object. If we can estimate those parameters, surface and diffuse

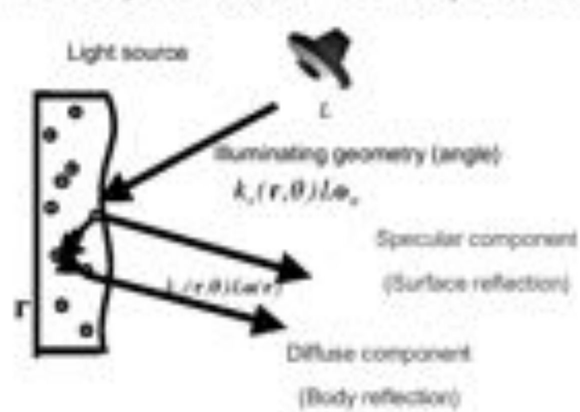


Figure 1 Dichromatic reflection

reflection of the object under the arbitrary spectral distribution and angles can be estimated and reproduced.

3. Gonio photometric acquisition system

In the Eq. (1), e_s and e_d has spectral information from 400nm to 700nm, therefore at the interval of wavelength 10 nm, they have 31 dimensions. On the other hand, k_s^n and k_d^n are continuous functions of angles. We estimated the reflection spectra of the object by using Gonio photometric imaging systems[5] shown in Fig.2. Namely, e_s was estimated by the multi-band image of reference white ($BaSO_4$ plate) and e_d was determined as the most separated direction from the illuminant as the diffuse reflection of the object. Then, Wiener estimation method was used to estimate the reflection spectra of the object from five-band image. Furthermore, we can determine the k_s^n and k_d^n from captured images with different illuminant angles.

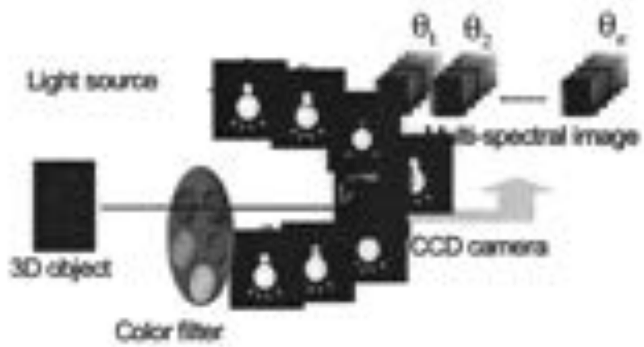


Figure 2 Developed Gonio photometric imaging system

4. Gonio photometric image reproduction by Phong model

In our experiment, five band images were taken with seven different illuminant angles (45•, 60•, 75•, 90•, 105•, 120• and 135•). Therefore, it cannot reproduce the images of 3D object under the illuminant of arbitrary angles. Gonio photometric information of the object, namely intensity of surface and diffuse reflection $\tilde{k}_s(\theta')$, $\tilde{k}_d(\theta')$ can be approximated by continuous function calculated by Phong model defined by Eq.(4)

$$\begin{aligned}\tilde{k}_s(\theta') &= A_1 \cos^{A_2}(\theta' - A_3)\\ \tilde{k}_d(\theta') &= B_1 \cos(\theta' - B_2)\end{aligned} \qquad (4)$$

Where, A_1, A_2, A_3, B_1, B_2 are parameters to represent the Gonio photometric information. These parameters were estimated by the least square method. Figure 3 shows the example of 3D object separated surface reflection image (a), diffuse reflection image (b) and synthesized image (c).

The result shows that the proposed method is significant to reproduce color and glossiness of the 3D object.

(a) Surface reflection (b) Diffuse reflection (c) Synthesized image

Figure 3 Separation of surface reflection image (a), diffuse reflection image (b) and synthesized image (c)

5. Synthesis of Gonio photometric information and shape

Properties of 3D object, namely complexities of the object geometry depend on many factors, such as texture, color or albedo. Many researches have been done on the characterization of surface description such as BRDF (Bi-directional Reflectance Distribution Function) and BTF (Bi-directional Texture Function) models. In section 2, 3 and 4, we only consider the variation on a smooth surface and introduced Gonio photometric method. 3D wire frame image taken by laser projection method (3D digitizer, Minolta VIVID 700) and Gonio photometric images estimated by Eq. (4) were synthesized. Figure 4 shows the image of bottle. (a) shows the wire frame image of Gonio photometric image (Color image) (b). This image can be rotated, and then we can see this bottle image from arbitrary illuminant angles and we can also see the images under the illuminants with different spectral radiant distributions since Gonio photometric information of the object is recorded.

(a) Wire frame image (b) Gonio photometric image

Figure 4 Synthesized image of wire frame and Gonio photometric image

6. Conclusion

In this paper, Gonio photometric imaging method was introduced to record reflectance spectra of t3D object. High accurate five bands CCD camera has been developed and used to Gonio photometric imaging. A method was also presented to synthesize 3D wire frame image taken by 3D digitizer and Gonio photometric image. We consider that the proposed methods are very significant to apply to digital archives for electronic museum, Internet shopping and telemedicine which are required high accurate image recording and reproduction. However, in order to record and reproduce 3D object more precisely, it'll be necessary to analyze the texture of fine scale geometry of the objects.

Acknowledgements

This entire project was made possible by the support of IPA (Information-technology Promotion Agency, Japan). We would like to express many thanks to Mr. K. Tomiho and Mr. T. Honma, graduate course students of our laboratories for their help.

References

[1] Y. Miyake, Y. Yokoyama, H.Haneishi and Tsumura: Development of Multi-spectral Imaging Systems for Recording of Art Paintings, Pros.SPIE, **3468**, 218-225(1999)

[2] N. Tsumura, H. Haneishi and Y. Miyake: Limitation of Color Samples for SpectralEstimation Frpm Sensor Responses in Fine Art Paintings, Optical Review, **6**(1) 57-61(1999)

[3] H. Haneishi, Y Yokoyama, N. Tsumura and Y. Miyake: System Design for Accurately Estimating the Spectral Reflectance of Art Painting, AppliedOptics, **39**(5) 6621-6632 (2000)

[4] S. Shafer: Using color to separate reflection components, *Color Res. and app.*, **10**(4), 210-218 (1985)

[5] Phong Bui-Tuong: Illumination for computer generated pictures, *Communications of the ACM*, **18**, 311-317 (1975)

[6] S. Tominaga and B Wandell: Multichannel vision system for estimating surface and illumination functions, *J. Opt. Soc. Amer.*, **13**, 2163-2173 (1996)

[7] Y. Sato and K. Ikeuchi, Reflectance analysis for 3D computer graphics model generation, *Graph. Mod. and Im. Proc.*, **58**(5), 437-451 (1996)

[8] B. V. Ginneken and J. J. Koenderink: Texture Histograms as a Function of Irradiation and Viewing Direction, J. Computer Vision **31** (2/3), 169-184(1999)

[9] H. Haneishi, T. Iwanami, T. Honma, N. Tsumura and Y. Miyake: Gonio spectral imaging of 3D objects, *IS&T/SID's 6th Color Imaging Conference*, Scottsdale, 173-176 (1998)

Spectral estimation from laser scanner data for accurate color rendering of objects

Réjean Baribeau*, National Research Council Canada

ABSTRACT

Estimation methods are studied for the recovery of the spectral reflectance across the visible range from the sensing at just three discrete laser wavelengths. Methods based on principal component analysis and on spline interpolation are judged based on the CIE94 colour differences for some reference data sets. These include the Macbeth color checker, the OSA-UCS color charts, some artist pigments, and a collection of miscellaneous surface colors. The optimal three sampling wavelengths are also investigated. It is found that color can be estimated with average accuracy $\Delta E_{94} = 2.3$ when optimal wavelengths 455nm, 540nm and 610nm are used.

Keywords: Spectral estimation, color differences, 3D imaging, laser scanner.

1. INTRODUCTON

The recommended practices for measuring the color of reflecting objects require that the complete reflectance spectra be obtained across the visible range. This is then weighted by spectral power distribution of standard illuminants and by color matching functions of standard colorimetric observers to obtain tristimulus values that correlate with the visual perception of color. Many of the modern imaging techniques, either by their nature or for practical reasons, cannot acquire a complete visible spectrum and require that color be estimated from sparse data sets. This is the case for a laser scanner designed at the NRC for the capture of the three-dimensional shape and color of objects. The camera has served to digitize a wide variety of objects including artist paintings and archeological artifacts[1], which were then computer-rendered with fairly high realism. The camera works by projecting a laser spot on the object, which is then imaged on a CCD looking at the scene from a direction slightly different from that of the incoming beam. Spatial coordinates of surface elements are obtained by triangulation. An auto-synchronized scanning mechanism allows full coverage of the scene. The system was initially designed with shape acquisition in mind, but was later modified to allow color capture as well. In this case superimposed red, green and blue laser beams are used for the projection, and the CCD image is split in its three components with a prism. The amplitudes of the three peaks are converted into reflectance values for the three wavelengths by a calibration process[2] that takes into account the particular geometry of illumination and detection at each surface element. While these reflectance values represent true intrinsic properties of the objects, it is often desirable to attribute some perceptual color values to the surface elements. This is the case for virtual reality applications where polygon meshes are reconstructed from the range data and Gouraud shaded according to the color data. This poses the problem of finding the best way to estimate color from the knowledge of only three points on the spectral reflectance curve. While this has no formal solution, this study explores two possible estimation schemes, Principal Component Analysis (PCA) and Spline interpolation, on four sets of spectral data. It is found that spline estimation generally works slightly better and that a set of sampling wavelengths in the vicinity of 455nm, 540nm and 610nm is near-optimal.

2. METHODOLOGY

Two general approaches were considered in this study, Principal Component Analysis (PCA) and Spline interpolation. Calculations of CIE ΔE_{94} were performed with these two methods on four sets of spectral data: the Macbeth ColorChecker, the OSA UCS color charts, twelve artist pigments, and some 289 miscellaneous color surfaces. Unconstrained optimization was finally used determine the best three sampling wavelengths. These topics are now briefly discussed.

1. PCA-based estimation

Given a collection of N spectra uniformly sampled at M wavelengths across the visible, PCA starts by building an M×N matrix $\mathbf{R}$ where R_{ij} is the reflectance of the jth sample at wavelength λ_i minus the average reflectance $\overline{\mathbf{R}}_i$ for the collection at this wavelength. Each column of $\mathbf{R}$ then represents a point in M-dimensional space. $\mathbf{R} \times \mathbf{R}^{\mathrm{T}}$ is the covariance matrix, and its eigenvectors $\mathbf{U}_i$, sorted in descending order of associated eigenvalues, provide a suite of orthogonal directions along

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

which the spread of the distribution of points, in M-dimensional space, is greatest. These are called Principal Components. PCA-based spectral estimation from just three sampling wavelengths (λ_s, λ_m, λ_l) considers that the unknown spectra is best approximated by a linear combination of the first three principal components:

$$\mathbf{R}_{estimated} = \overline{\mathbf{R}} + a_1\mathbf{U}_1 + a_2\mathbf{U}_2 + a_3\mathbf{U}_3 \quad (1)$$

and the sampled reflectances $R_{true}(\lambda_s)$, $R_{true}(\lambda_m)$ and $R_{true}(\lambda_l)$ as well as interpolated values of $\overline{\mathbf{R}}$ and $\mathbf{U}$ are used to solve for (a_1,a_2,a_3):

$$\begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix} = \begin{bmatrix} \mathbf{U}_1(\lambda_s) & \mathbf{U}_2(\lambda_s) & \mathbf{U}_3(\lambda_s) \\ \mathbf{U}_1(\lambda_m) & \mathbf{U}_2(\lambda_m) & \mathbf{U}_3(\lambda_m) \\ \mathbf{U}_1(\lambda_l) & \mathbf{U}_2(\lambda_l) & \mathbf{U}_3(\lambda_l) \end{bmatrix}^{-1} \begin{bmatrix} \mathbf{R}_{true}(\lambda_s) - \overline{\mathbf{R}}(\lambda_s) \\ \mathbf{R}_{true}(\lambda_m) - \overline{\mathbf{R}}(\lambda_m) \\ \mathbf{R}_{true}(\lambda_l) - \overline{\mathbf{R}}(\lambda_l) \end{bmatrix} \quad (2)$$

2. Spline estimation

With this method (cubic spline), third order polynomials are adjusted between each pair of consecutive sampled points in such way that the resulting curve passes through the points and is continuous through the second derivative. The first and last polynomials are used to extrapolate towards the blue and red ends of the spectrum. The simplest variation called *natural cubic spline* , which sets the second derivative to zero at the end-points, is doomed to poorly extrapolate the data. Some rule is needed to keep the extrapolated spectra not-too-far away from the sampled end-points. Two approaches were considered: the first is to impose some value of the first derivative of the interpolating function at the end-points; the second is to do an "educated guess" of the reflectances at 400nm and 700nm and then fit a natural cubic spline through the five points.

3. Color difference calculation

For each sample of a collection the tristimulus values and then the CIE L^*, a^*, b^* are calculated for both the "true" reflectance curve and the estimated one. CIE illuminant D_{65} and 2° observer are assumed. The color difference is then calculated using the CIE94 color difference formula[3] with parametric factors set to 1. With this formula, a difference ΔE_{94}= 1 corresponds roughly to one "just noticeable difference" between the two colors viewed side by side under reference viewing conditions. The mean of the color differences for a whole collection provides a measure of the goodness of the spectral estimation method.

4. Data sets

Data sets consist of reflectance curves obtained with a spectrophometer at 10nm intervals from 400nm to 700nm. A first set is for the 24 color patches of the Macbeth ColorChecker, which is commonly used to check the color rendition of imaging systems. It is a valuable data set because the designer of this chart devoted much effort in achieving reflectances with the same spectral nature as naturally occurring surfaces (human skin, foliage, chicory flower...). The chart covers a wide gamut of chromatic colors, but the neutrals are possibly over-represented with 6 patches out of 24 showing virtually flat spectra. The second set is for the 554 patches of the OSA-UCS color chart, which corresponds to a system where the color difference between adjacent color points is perceptually constant. While it represent a fair sampling of the color space, a drawback is that the chart is realized with a finite set of colorants with no intent to replicate the reflectances of any particular type of surfaces. The third set is for twelve fairly colorful artist colors taken right from the tube and spread on a canvas with a spatula. The fourth set is for 289 miscellaneous common surfaces which were brought to the sample port of the spectrophotometer and measured.

5. Optimization of sampling wavelengths

A function $E_{mean}(\lambda_s, \lambda_m, \lambda_l)$ is implemented that returns the mean ΔE_{94} error over a collection for a given set of three sampling wavelengths and for the particular estimation method considered. The triplet $[\lambda_s, \lambda_m, \lambda_l]$ that minimizes that function is obtained with the Nelder-Mead simplex method[4]. With this method, a small tetrahedron is built in the three-dimensional λ space around some initial estimate. Vertex of the tetrahedron are then moved either away or closer to their opposing faces, or are projected through them, in order to make the function smaller. The tetrahedron eventually shrinks indefinitely around a minimum. The method always converges, but may give only local solutions.

3. RESULTS

The wavelengths for NRC laser scanner are currently 442nm (HeCd), 532nm (laser diode) and 633nm (HeNe). A first calculation was the prediction of the color difference that should be obtained assuming these. The PCA-based method and two variations of the spline method were tested. Results are summarized in Table 1.

	Estimation method		
Data set	PCA-based	Spline1	Spline2
1	4.0	3.5	3.3
2	3.1	3.5	3.1
3	5.4	6.0	5.1
4	4.4	4.3	3.9

Table 1. Mean ΔE_{94} assuming $[\lambda_s\ \lambda_m\ \lambda_l]$ = [442 532 633].

The Spline1 method sets to zero the slopes of the interpolating function at λ_s and λ_l. The spline2 method just replicates the λ_s and λ_l reflectances at both ends (400nm and 700nm) of the visible range. The Spline2 method appears to be the best. Furthermore, it was verified that no meaningful improvement could be obtained with some more fancy setting of the end point conditions of the spline. This was tested using the exact reflectances at 400nm and 700nm and fitting a natural spline through the five points, which resulted in negligible improvement of the mean ΔE_{94}.

Results of the search for the optimal three wavelengths using the simplex method are listed in Table 2.

	Estimation method		
Data set	PCA-based	Spline1	Spline2
1	[452 545 608], 2.2	[435 546 626], 3.0	[454 546 613], 2.1
2	[445 544 608], 1.7	[438 554 617], 2.5	[457 537 607], 2.1
3	[453 537 605], 3.1	[444 557 623], 4.6	[453 543 602], 3.1
4	[453 544 611], 2.5	[441 552 619], 3.1	[454 544 608], 2.4

Table 2. Optimal sampling wavelengths $[\lambda_s\ \lambda_m\ \lambda_l]$ and corresponding mean ΔE_{94}.

Clearly the Spline2 method performs better than the Spline1 method and works about as well as the PCA-based method when optimal wavelengths are used. Furthermore, Spline2 is much more general than PCA as it does not make a-priori assumptions of given sets of principal components. The Spline2 method with sampling wavelengths [455 540 610] appears to be a reasonable choice for general usage. The distribution of ΔE_{94} for the whole aggregated collection (877 spectra) is then the one depicted in Figure 1, with the mean error equal to 2.3.

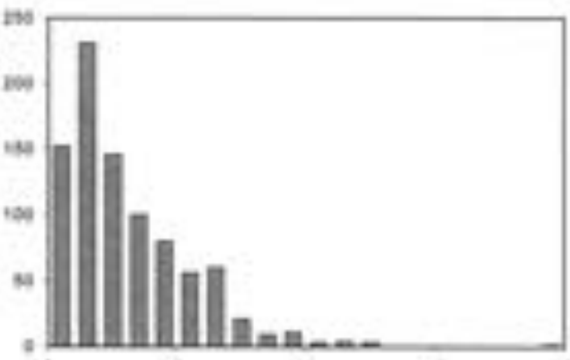


Figure 1: Histogram of the CIE94 error for all-four sets using the Spline2 method with sampling wavelengths [455 540 610].

4. CONCLUSIONS

The NRC laser scanner, with its current three wavelengths [442 532 633], can measure color reasonably well enough for those virtual reality applications where color accuracy is not critical. This study suggest that the color accuracy, as measured by the mean CIE94 color difference formula, can be improved by about 33% with the use of the optimal wavelengths [455 540 610]. This is probably still not enough for the most color-critical applications, which might call for additional sampling wavelengths. The software tools developed for this study are easily expandable to higher dimensions of sampling space. There are two improvements that would be beneficial for this type of study. The first would be the availability of representative data sets for given classes of objects, not just color charts made with limited number of inks. Ideally some weight would be attributed to each sample according to its importance and its frequency of occurrence. A second improvement would be the availability of a formula for the evaluation of color differences between images that would replace the CIE94 formula which was designed for sample to sample comparison.

ACKNOWLEDGEMENTS

The author wish to thank Zoltan Jakab for contributing the huge collection of spectra he captured as part of his Ph. D. work on color perception and physicalism.

REFERENCES

1. R. Baribeau, L. Cournoyer, G. Godin and M. Rioux. "Colour three-dimensional modelling of museum objects", Imaging the Past, British Museum Occasional Paper no. 114, pp. 199-209, Tony Higgins et al. editors.
2. R. Baribeau, M. Rioux et G. Godin. "Color reflectance modeling using a polychromatic laser range sensor". IEEE Trans. Pattern Anal. Machine Int., 14(2):263-269, 1992.
3. R. S. Berns, "Billmeyer and Saltzman's Principles of Color Technology", 3rd edition, John Wiley, New York, 2000.
4. J.A. Nelder and R. Mead. Computer Journal, Vol. 7, pp. 308-313, 1965.

*rejean.baribeau@nrc.ca, phone 1 613 993-9351; fax 1 613 952-1394; National Research Council, Building M-36, Montreal Road, Ottawa, Ontario, Canada K1A 0R6

A New Procedure for Capturing Spectral Images of Human Portraiture

Qun Sun, Mark D. Fairchild
Munsell Color Science Laboratory, Chester F. Carlson Center for Imaging Science
Rochester Institute of Technology, 54 Lomb Memorial Dr., Rochester, NY 14623-5604/USA

ABSTRACT

This paper describes a new procedure of capturing spectral images of human portraiture. The designed imaging system was calibrated directly based on real human subjects and has the capability to provide accurate spectral images of human faces, including facial skin as well as the lips, eyes, and hair, from various ethnic races. The facial spectral reflectances obtained were analyzed by principal components analysis (PCA) method. Based on the results of PCA, spectral images using both three and six wide-band spectral sampling were estimated. The reconstructed spectral images for display based on an sRGB display model are evaluated. The results have proved that this new spectral imaging procedure is successful. The results also show that three basis functions are accurate enough to estimate the spectral reflectance of human faces. The derived spectral images can be applied to color-imaging system design and analysis.

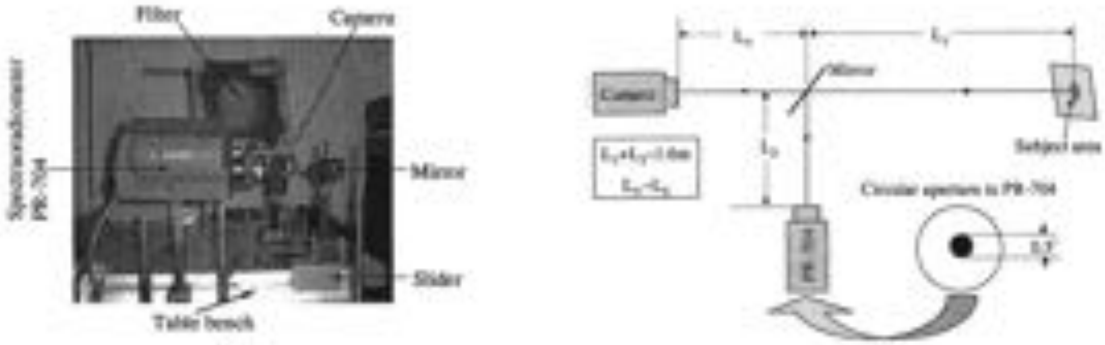
Keywords: Spectral image, multi-spectral image, human face, human portraiture, spectral reflectance, PCA

1. INTRODUCTION

Facial color reproduction is an important aspect of color-imaging system design and analysis. Visible spectral images of human portraits are desired to test color imaging system design via computer simulation. Recent research of spectral imaging on human facial skin[1, 2] showed that three basis functions are sufficiently accurate to describe the spectral reflectances of human skin. Therefore, the spectral reflectance of each pixel of the captured image could be estimated from the values of three color channels and the spectral radiance of the illuminant used. These experiments showed very successful results. However, the spectral reflectance database employed in these experiments was concentrated on a single race and only on skin. The spectral measurement geometry is generally fixed to 45/0 or d/0. Considering the capability of spectral imaging systems for different races of human portraits it seems worth including spectral reflectances of different races and those spectral data should include skin, hair, eyes and lips as well. Since the human face is not a planar but a 3-dimensional object, the spectra of the subjects observed by the camera could vary with any geometry. In other words, to perform an accurate calibration of the spectral imaging system, the spectral database should be with large gamut including various geometric configurations. In addition, previous spectral portrait image researches performed the system calibration based on the painting samples which were the reproductions of the measured spectral reflectance of skin. Those paint samples were not available for us. Moreover, these approaches required very accurate reproductions of skin at a fairly early stage to avoid the errors passed through all the following procedures. According to these considerations, therefore, we proposed a new procedure and designed a new spectral imaging system for human portraiture that has the capability to capture spectral images of various races and describe spectral reflectances of skin, hair, eyes and lips very well. This imaging system would perform system calibration and capture spectral images based on the spectral data directly recorded from the real human subjects with certain lighting and camera conditions. The detail of the experiment procedure is provided. The measured spectral reflectances were analyzed by PCA. Based on the results of PCA, both three wide band and six wide band spectral images were estimated respectively. The results of the reconstructed spectral images for display based on sRGB model are shown and discussed.

3. EXPERIMENT

The imaging system and optical path for system calibration are shown in Fig. 1 as follows:



(a) (b)

Figure 1. Imaging system (a) and optical path (b) for system calibration.

The portrait studio digital camera used for this research is SONY DKC-ST5 Digital Photo Camera that has a three-chip high-resolution CCD with total 1,400,000 pixels. Its output image is 24-bit, 8-bit for each channel, size of 2048x2560 with TIFF format. The lighting system consisted of two lighting heads (Scanlite Digital 1000, Elinchrom) with Halogen Photo Optic lamps (FEL/1000w, 120V). A Photo Research Inc. SpectraScan 704 (PR-704) spectroradiometer was used in the spectral measurement. The wavelength range used in this experiment is in visible region, 400 – 700nm with 2nm interval. A 202 half C.T blue filter, Professional Lighting Filters, Bogen Photo Corp., was chosen to give additional filtered RGB for six-band spectral imaging. The measurement system was calibrated by a high quality white reference, a barium sulfate coated paper with spectrally flat and uniform property. As shown in Fig. 1(b), optical radiation being measured passed through the circular aperture inside PR-704 and then reached the detector for the spectral measurement. A mirror was attached to a slide mounted carrier that could move along the table bench. This system was calibrated so that the pixel positions in the image of a subject that contributed to the spectral measurement in PR-704 were known. The distance between the object to PR-704, L_1+L_2 in Fig. 1(b), was selected in such a way that the uncertainty of calibrated pixel area was less than 2.5% on the assumption that the object surface would move back and forth around the calibrated position within 2cm. The distance we selected was about 1.6m. We could select a longer distance for accuracy purposes. However, the area covered by the aperture of PR-704 would be too large and the spectra measured would be spatially averaged too much. It was estimated that, with ~3% error of subject surface that corresponding to subject moving back and forth about ±3 cm, the color difference was less than 0.08. This proved that the designed imaging-measurement system, theoretically, was quite accurate. During the experiment the subjects were sitting on a chair with their heads against a holder. They were asked to adjust their chair up and down, left and right, until the position of interest fell into the grid box which was shown on the monitor. We first took a picture of the subject, then moved the mirror to its calibrated position and made spectral measurement of the same subject at the same position. The spectral reflectances of various face surfaces of subjects and their corresponding camera responses, digital counts, therefore, could be obtained. Based on this system setting, the spectral measurement would match the different geometries as detected by the camera.

A total 34 of subjects from age 18 to 40, 11 female and 23 male participated in the experiment. The experiment was performed from June to January. The subjects can be categorized into five races, 11 subjects for Pacific-Asian, 8 for Caucasian, 7 for Black, 6 for Subcontinental-Asian and 2 for Hispanic.[3] Each subject provided 16 spectral reflectances which, in general, would contain 10 for facial skin, 3 for hair, 2 for eye and 1 for lips. The locations of spectral measurement were randomly selected considering uniformity of sampling. Therefore, a total 540 of spectral reflectances and their corresponding camera digits were obtained for imaging system calibration and modeling.

4. RESULTS AND DISCUSSION

Applying PCA to 540 spectral reflectances obtained, the basis functions and their coverage percentages were calculated. The cumulative coverage percentages (CCP) for the first six basis functions are shown in table 1. The results in Table 1 indicate that the first three basis functions will cover ~ 99.9% variance for all spectral data of all races. Our further research indicated that the same is almost true for spectral reflectances of individual races and different parts of faces.[4] This suggests that spectral imaging system with three wide bands may provide sufficiently accurate spectral reconstruction for all races. The first three basis functions are shown in Fig. 2. Our further research also showed that different sets of first three basis functions based on spectra of individual races have very similar shapes.[4]

Table 1. Cumulative coverage percentages of first 1~6 basis functions based on all spectra.

No. of PC	1	2	3	4	5	6
%	97.89	98.57	99.89	99.97	99.99	99.99

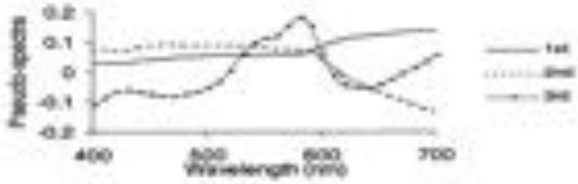


Figure 2. First three basis functions of all spectra.

The mean color differences, metameric indices and spectral root mean square (RMS) errors of the spectral reconstruction for spectra from individual races and different parts of faces based on three basis functions are given in Table 2. The color difference equation applies CIELAB with 2° observer and D50 illuminant. The metameric indices were calculated using illuminations of D50 and A with Fairman's metameric correction using parameric decomposition.[5]

Table 2. Mean color difference, metameric indices and RMS errors of the spectral reconstruction for spectra from individual races and different facial parts. (a) For individual races where PA, C, SA, B, H and AR are abbreviations for Pacific-Asian, Caucasian, Subcontinental-Asian, Black, Hispanic and All Races respectively; (b) for different facial parts

	PA	C	SA	B	H	AR
ΔEab	0.98	0.83	1.28	1.01	0.90	1.10
Index	0.26	0.18	0.34	0.39	0.23	0.28
RMS	0.0034	0.0043	0.0040	0.0043	0.0032	0.0039

(a)

	Skin	Hair	Eye	Lip
ΔEab	0.74	2.37	0.82	1.13
Index	0.18	0.71	0.16	0.22
RMS	0.0042	0.0026	0.0034	0.0049

(b)

The results in Table 2 indicate that three basis functions will provide quite accurate color and spectral reproduction for overall spectra, especially skin and eyes, though there are relatively large errors for spectra of Black subjects and spectra of hair. Our further research indicated that those relatively large errors for spectra of Black subjects are mainly contributed by spectra of hair since spectral reflectances of hair require high order statistics, more basis functions (based on all spectra), to represent them. The biological analysis on this topic is beyond the scope of this research. Since skin spectra are the most important part in spectral imaging of human portraits, the results in Table 2(b) are quite acceptable.

The results of modeling from digital counts to spectral reflectances using 3 and 6 bands are shown in Table 3 where 3P7T and 3P17T represent the use of 3 basis functions with 7 terms (including covariance terms) and 17 terms (with higher order terms) of digital counts involved in calibration regression respectively and similar definition for 6P7T using 6 basis functions. The details of camera system calibration and spectral imaging modeling can be found in references.[1-4]

Table 3. Results of system modeling from linearized digits to eigenvalues using 3 and 6 bands respectively.

Method	ΔEab	Index	RMS
3P7T	2.68	0.73	0.012
3P17T	2.32	0.66	0.011
6P7T	1.78	0.48	0.010

The results in Table 3 indicate that three basis functions will provide acceptable color and spectral reproduction after the calibration. More terms involved in regression of transform matrices or more basis functions used will provide more accurate color and spectral reproduction. On the other hand, however, more terms and more basis functions used, more image noise will be involved.[7] Therefore, in practice, we need to make a compromise. Once transform matrices were determined, the spectral reflectances could be estimated, pixel by pixel, from the original images, hence, obtained the spectral images. For display, the spectral reflectance of each pixel in those spectral images estimated was converted to CRT digits for display using sRGB model and CRT characterization model. For demonstration, some spectral image samples for display are given in Fig. 3. Spectral images for display given in Fig 3 show that, spectral images of 3P7T are little blurred and have small color shift. Spectral images of 6P7T have more image noise. This is partly due to the fact that the camera we used has more noise, especially in blue channel image. Spectral images of 3P17T will be the best with more accurate color and spectral reproduction compared to spectral images of 3P7T, and less image noise compared to spectral images of 6P7T. Image quality research in spectral imaging is currently been carrying on.

(a) (b)

Figure 3.Samples of original images and estimated spectral images for display. (a) Caucasian subject. Images from top to bottom are R, G and B channel images respectively. Images from left to right are original image without filter, original image with filter, 3P7T image, 3P17T image and 6P7T image. (b) Black subject. The same image arrangement as (a).

5. CONCLUSION

A new procedure for capturing spectral image of human portraiture has been proposed. The facial spectral reflectances obtained were analyzed by PCA method. The PCA results indicate that three basis functions will provide quite accurate color and spectral reproduction for facial spectral reflectances from various races and different parts. Three band and six band spectral images of human portraits have been successfully obtained. High order transform matrices will provide more accurate, three-band, spectral images with acceptable image noise. However, for six-band spectral images, transform matrix with low order of 7 terms will give most acceptable results. Due to the limit of image quality of the camera used, the 6-band spectral image did not meet the quality we originally expected. To obtain more accurate, multi-spectral image, a camera with high quality in terms of noise is required. The obtained spectral image can be applied to color-imaging system design and analysis.

ACKNOWLEDGEMENTS

We wish to express our thanks to Eastman Kodak Company for their financial support of this research. We also wish to express our appreciation to those individuals who participated in our experiment.

REFERENCES

1. F. H. Imai, N. Tsumura, H. Haneishi and Y. Miyake, "Principal Component Analysis of Skin Color and Its Application to Colorimetric Color Reproduction on CRT Display and Hardcopy," *J. of Imag. Sci. and Tech.*, **40**, pp. 422-430, 1996.
2. N. Tsumura, M. Kawabuchi, H. Haneishi, Y. Miyake, "Mapping Pigmentation in Human Skin by Multi-Visible-Spectral Imaging by Inverse Optical Scattering Technique," 8th IS&T/SID Color Imaging Conference, pp 81-84, Scottsdale, Arizona, USA, Nov., 2000
3. http://www.whitehouse.gov/omb/fedreg/race-ethnicity.html *Standards for the Classification of Federal Data on Race and Ethnicity*, Office of Management and Budget, The White House, USA, August, 1995.
4. http://www.cis.rit.edu/mcsl/online/Spectral/TechnicalPapers/StatisticalCharacterization_HumanFacialSpectra.pdf. Q. Sun, M. D. Fairchild, "Statistical Characterization of Spectral Reflectances in Spectral Imaging of Human Portraiture", MCSL technical report, 2001.
5. H. S. Fairman, "Metameric Correction Using Parameric Decomposition," *Color Res. Appl.*, **12**, pp. 261-265,1987.
6. R. S. Berns, *Billmeyer and Saltzman's Principles of Color Technology*, 3rd Edition, John Wiley & Sons, 2000.
7. P. D. Burns, Analysis of Image Noise in Multi-Spectral Color Acquisition, Ph.D. Thesis, RIT, 1997.

Representation of Spectral Images in Data Communications

Markku Hauta-Kasari[a], Juha Lehtonen[a], Jussi Parkkinen[a], and Timo Jaaskelainen[b]

[a]Department of Computer Science, University of Joensuu,
P.O.Box 111, FIN-80101 Joensuu, FINLAND
[b]Department of Physics, University of Joensuu,
P.O.Box 111, FIN-80101 Joensuu, FINLAND

ABSTRACT

We present techniques for representing spectral images in data communications. The spectral domain of the images is represented by a low-dimensional component image set, which is used to obtain an efficient compression of the high-dimensional spectral data. The component images are compressed using a similar technique as the JPEG- and MPEG-type compressions use to subsample the chrominance channels. The spectral compression is based on Principal Component Analysis (PCA) combined with a color image transmission coding technique of chromatic channel subsampling of the component images. The component images are subsampled using 4:2:2, 4:2:0, and 4:1:1-based compressions. In addition, we extended the test for larger block sizes and larger number of component images than in the original JPEG- and MPEG-standards.

Keywords: Spectral image, spectral image compression, transmission coding

1. INTRODUCTION

The representation of color in digital images is expanding into new fields due to the new technologies for spectral imaging. These fields include, for example, industrial quality control[1] *e.g.* in food and wood industry, remote sensing, and digital acquisition of art works in museums.[2] It has been realized also in "regular color imaging" that the traditional 3D representation is not always enough for an accurate color realization. These applications include, for example, color images in telemedicine and product advertising in e-commerce. However, many techniques in color image transmission are bound to the traditional 3D color representation. The need of spectral image compression is becoming more and more important in order to be efficiently used in data communications.[3-6]

In color image transmission, there are standards, which are widely used to compress color images based on 3D color representation. A set of standard three-dimensional color image compression methods is formed by different versions of JPEG- and MPEG-type image compression. These standards are based on RGB color images. Usually, the RGB-image is transformed into a YCbCr-coordinate system with a luminance (Y) and two chrominance channels (Cb and Cr).[7] Then, this color information is compressed as follows: the luminance image is used as such and two chrominance images are subsampled either in every second (4:2:2) or in every fourth (4:2:0 or 4:1:1) pixel.

In this study, we are interested to investigate how the spectral images could be compressed by existing standard methods proposed for 3D color images. The preliminary results in this study can be also helpful when the transmission standards can use more than 3 channels.

2. COMPRESSION TECHNIQUES

2.1. Standard JPEG- and MPEG-type subsampling

In JPEG- and MPEG-type compressions the color image- and color video-signals are transformed from RGB to less correlated signals. The transformation is usually done from RGB to YCbCr-coordinates. Based on the studies on Human Visual System (HVS), the chromatic components Cb and Cr can be compressed more than the luminance channel Y. There exist the following standard methods, 4:2:2, 4:2:0, and 4:1:1 called subsampling schemes for sampling every second or every fourth pixel from the Cb and Cr component images.[7]

Further author information: (Send correspondence to Markku Hauta-Kasari)
Markku Hauta-Kasari: E-mail: Markku.Hauta-Kasari@cs.joensuu.fi, WWW: http://cs.joensuu.fi/~mhk, Fax +358-13-2517955
Juha Lehtonen: Email: Juha.Lehtonen@cs.joensuu.fi, Jussi Parkkinen: E-mail: Jussi.Parkkinen@cs.joensuu.fi,
Timo Jaaskelainen: E-mail: Timo.Jaaskelainen@joensuu.fi

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

In the subsampling, the luminance channel Y is kept as such, and Cb and Cr channels are subsampled. The color image is decompressed in the reverse order: two subsampled images are expanded back to the original size by giving the same pixel value for the neighbor pixels (4:2:2 and 4:1:1) or giving the same pixel value for the whole 2×2 pixels block (4:2:0). Then the YCbCr-image is transformed back to RGB-image.

2.2. PCA-based eigenimage subsampling

It has been shown that the spectral images can be efficiently compressed using PCA.[8] Only a few eigenimages form a low-dimensional component image set, which can be used to represent the original spectral image with a sufficient accuracy. When the first three eigenvectors corresponding to the first three largest eigenvalues are used to calculate three eigenimages, then the eigenimages are uncorrelated and they have similar characteristics as the YCbCr-based images. In this study, we applied the subsampling schemes for spectral images. We used also the Independent Component Analysis (ICA)[9] to calculate a low-dimensional component image set for a spectral image. The low-dimensional component image set produced for a spectral image using PCA or ICA is device independent.

We used the low-dimensional component image sets for subsampling-based compression. We extended the test for larger block sizes and larger number of component images than in the original JPEG- and MPEG-standards. In the compression, the component images were subsampled and in reconstruction, resampled component images were used to reconstruct the spectral image.

3. EXPERIMENTS

3.1. Spectral images

In our experiments we used two spectral image databases containing totally 22 spectral images. There were 10 spectral images of coral reef scenes (CORAL) and 12 spectral images of forest scenes (FOREST) measured by Chiao et al.[10] Fig. 1. shows the first three eigenimages for one spectral image (Horshe29) in CORAL-database.

Figure 1. The eigenimages for Horshe29-spectral image in CORAL-database.

Table 1 and 2 shows the results of spectral reconstruction for CORAL- and FOREST-databases, respectively. The error measures are MAX (maximum error), MAE (mean absolute error), MSE (mean square error), MSD (maximum spectral difference), SNR (signal-to-noise ratio), PSNR (peak signal-to-noise ratio), average (ΔE_{avg}) and median (ΔE_{med}) ΔE-errors calculated in CIELAB-color coordinate system, and ΔE errors calculated in S-CIELAB-color coordinate system. S-CIELAB is a spatial extension of CIELAB proposed by Zhang and Wandell.[11]

First, we studied the JPEG-type subsampling of the PCA-based eigenimages. The first eigenimage was kept as such, and the 2nd and 3rd eigenimages were compressed by subsampling them using the methods 4:2:2, 4:2:0, and 4:1:1. The results for both databases are collected in Table 3. Method 4:4:4 means that there is no spatial compression done.

In the following experiments, we used more eigenimages to represent the spectral domain and to keep the compression ratio (CR) in a reasonable level, the block size in subsampling was enlarged to 3×3 pixels. The vector, which represents the 3×3 pixels block was first selected from the center pixel of the block. Also the average vector of the 3×3 pixels block was experimented. The results for the FOREST-database are collected in Table 4. Using the average vector, the reconstruction accuracy was improved. The compression ratios for all performed compressions are shown in Table 5.

Table 1. The spectral reconstruction errors for the CORAL-database containing 10 spectral images. In the first column, k denotes the number of component images used.

k	MAX	MAE	MSE	MSD	SNR	PSNR	ΔE_{avg}	ΔE_{med}	ΔE_{avg} S-CIELAB	ΔE_{med} S-CIELAB	Fidelity
1	1772	6.02	93.58	46.53	16.10	29.50	8.24	7.12	7.43	5.89	99.12
2	987	3.26	25.82	27.06	21.21	34.60	4.60	3.99	3.73	3.15	99.59
3	794	2.29	12.13	18.81	24.33	37.72	3.00	2.47	2.15	1.75	99.75
4	515	1.79	7.17	14.86	26.59	39.98	2.02	1.65	1.29	1.00	99.84
5	380	1.45	4.50	12.09	28.51	41.90	1.51	1.18	0.89	0.66	99.88

Table 2. The spectral reconstruction errors for the FOREST-database containing 12 spectral images. In the first column, k denotes the number of component images used.

k	MAX	MAE	MSE	MSD	SNR	PSNR	ΔE_{avg}	ΔE_{med}	ΔE_{avg} S-CIELAB	ΔE_{med} S-CIELAB	Fidelity
1	1520	4.37	47.23	33.50	17.76	32.40	7.30	6.33	5.57	4.93	99.34
2	1141	2.45	16.41	19.83	22.24	36.88	3.36	2.85	2.44	2.11	99.76
3	661	1.45	6.47	12.44	26.75	41.39	1.53	1.28	1.01	0.82	99.89
4	456	1.03	3.15	8.75	29.94	44.57	1.03	0.87	0.58	0.48	99.94
5	301	0.77	1.70	6.75	32.30	46.93	0.70	0.57	0.34	0.28	99.96

Table 3. The average $\Delta E_{S-CIELAB}$-errors and PSNR in reconstruction for the CORAL-database (10 spectral images) and for the FOREST-database (12 spectral images). The compression was based on an eigenimage subsampling.

CORAL	$\Delta E_{S-CIELAB}$	PSNR	FOREST	$\Delta E_{S-CIELAB}$	PSNR
PCA 4:4:4	2.15	37.72	PCA 4:4:4	1.01	41.39
PCA 4:2:2	2.29	35.58	PCA 4:2:2	1.31	37.94
PCA 4:2:0	2.50	34.18	PCA 4:2:0	1.71	35.87
PCA 4:1:1	2.69	33.44	PCA 4:1:1	2.15	34.97

Table 4. The average ΔE and $\Delta E_{S-CIELAB}$-errors in reconstruction for the FOREST-database containing 12 spectral images. The block size of 3×3 pixels were used in subsampling and the block was repesented by the center vector or the average vector. The results are reported for 3, 4, and 5 eigenimages.

FOREST	3×3 - center			3×3 - average		
Number of eigenimages	3	4	5	3	4	5
ΔE	4.88	4.73	4.67	4.14	3.96	3.91
$\Delta E_{S-CIELAB}$	2.02	1.81	1.73	1.47	1.16	1.04

4. DISCUSSION

We described techniques for spectral image compression in data communications. The technique is developed as a combination of previously known compression techniques. We used first PCA to reduce the number of component images and then the well-known subsampling in JPEG- and MPEG-type color image compression was used for PCA- or ICA-based component images. The PCA- and ICA-based component images are device independent. In our experiments the performance of PCA and ICA were similar.

A drawback in an average vector-based method is that when the eigenimages are resampled, there will be no original values left after resampling. Therefore, after the spectral image reconstruction, there will exist spectra,

Table 5. The compression ratios (CR) for the CORAL- and FOREST-databases used in our experiments. The compression ratios for PCA-based compression are shown.

Number of eigenimages	Method (block size)	CR
3	4:4:4 (2 x 2)	13.3
3	4:2:2 (2 x 2)	20.0
3	4:2:0 (2 x 2)	26.6
3	4:1:1 (1 x 4)	26.6
3	(3 x 3)	32.4
4	(3 x 3)	29.7
5	(3 x 3)	27.5

which are not in original spectral image. However, for the visual purposes, the ΔE-values in this study indicate that the average vector-based method could be better. The experimental results in this study indicate that the spectral images can be transferred by the present data transmission methods proposed for RGB-images. However, for high-accurate spectral image representation, the number of component images should be usually more than 3, and therefore, new techniques for spectral image transmission are needed. The techniques presented in this study can be also expanded for a multispectral video.[12]

ACKNOWLEDGMENTS

The authors are also with the International Centre for Color Analysis (ICCA), which is supported by the EU Regional Structural Fund. Markku Hauta-Kasari was supported by the travel grant from ICCA. We thank Brian Wandell and Xuemei Zhang for S-CIELAB programs and discussions, and Chuan-Chin Chiao for the spectral image databases.

REFERENCES

1. T. Hyvärinen, E. Herrala, and A. Dall'Ava, "Direct sight imaging spectrograph: a unique add-on component brings spectral imaging to industrial applications," in *Proceedings, IS & T /SPIE's Symposium on Electronic Imaging: Science and Technology (EI98), San Jose, California, USA, January 25-30*, vol. 3302-21, 1998.
2. H. Haneishi, T. Hasegawa, N. Tsumura, and Y. Miyake, "Design of color filters for recording artworks," in *Proceedings, IS&T's 50th Annual Conference, Cambridge, Massachusetts, May 18-23*, pp. 369–372, 1997.
3. M. Hauta-Kasari, J. Lehtonen, J. Parkkinen, and T. Jaaskelainen, "Spectral image compression for data communications," in *Proceedings of SPIE, Electronic Imaging 2001, San Jose, California, USA, January 21-26*, vol. 4300, pp. 42–49, 2001.
4. F. H. Imai, M. R. Rosen, R. S. Berns, N. Ohta, and N. Matsushiro, "Preliminary study on spectral image compression," in *Proceedings, Color Forum Japan 2000, Tokyo, Japan, November 16-17*, pp. 67–70, 2000.
5. F. König and W. Praefcke, "Multispectral image encoding," in *Proceedings, IEEE International Conference on Image Processing, ICIP, Kobe, Japan, October 24-28*, vol. 3, pp. 123–126, 1999.
6. W. Kondou, K. Miyata, H. Haneishi, and Y. Miyake, "An evaluation of image quality for compressed multispectral image," in *Proceedings, International Symposium on Multispectral Imaging and Color Reproduction, Chiba, Japan, October 21-22*, pp. 143–146, 1999.
7. C.-H. Wu and J. D. Irwin, *Emerging Multimedia Computer Communication Technologies*, Prentice-Hall, Inc., New Jersey, 1998.
8. A. Kaarna and J. Parkkinen, "Transform based lossy compression of multispectral images," *Pattern Analysis and Applications* **4**(1), pp. 39–50, 2001.
9. A. Hyvärinen, "Survey of independent component analysis," *Neural Computing Surveys* **2**, pp. 94–128, 1999.
10. C.-C. Chiao, T. W. Cronin, and D. Osorio, "Color signals in natural scenes: characteristics of reflectance spectra and effects of natural illuminants," *Journal of the Optical Society of America A* **17**(2), pp. 218–224, 2000.
11. X. Zhang and B. A. Wandell, "A spatial extension of CIELAB for digital color image reproduction," in *Proceedings, Society for Information Display Symposium Technical Digest*, vol. 27, pp. 731–734, SID, 1996.
12. P. Koponen, H. Kälviäinen, and J. Parkkinen, "Multispectral video," in *Proceedings, 15th International Conference on Pattern Recognition, ICPR-2000, Barcelona, Spain, September 3-7*, vol. 3, pp. 190–193, 2000.

Spectral estimation of artist oil paints using multi-filter trichromatic imaging

Francisco H. Imai* and Roy S. Berns*

Munsell Color Science Laboratory
Chester F. Carlson Center for Imaging Science
Rochester Institute of Technology, Rochester, NY, USA

ABSTRACT

A practical and easy way to capture images of oil paintings and estimate their spectral reflectance as a function of position was tested. For the image acquisition, a trichromatic digital camera was used in conjunction with an absorption filter producing six channels. From an *a priori* statistical analysis of common artist oil paints, spectral reflectance was estimated. These experiments showed that it is possible to estimate the spectral reflectance with an accuracy of average ΔE^*_{94} of 1.7 and spectral reflectance rms error of 2.2%. Of particular interest is guidance towards the design of a universal calibration target for imaging paintings.

Keywords: Multi-channel visible spectrum imaging (MVSI), image input, digital image capture, artwork reproduction, multi-spectral acquisition, spectral estimation.

1. INTRODUCTION

In many museums, once an image is captured, deficiencies in the imaging capture system are usually handled through visual adjustments of tone and color balance using tools such as Adobe Photoshop™. Although these adjustments can produce pleasant results, they are not acceptable in terms of color accuracy for applications such as digitally archiving artwork.

Multi-channel visible spectrum imaging (MVSI), also known as multi-spectral imaging, can give a more accurate representation of the image.[1] In order to improve color accuracy, the National Gallery in London, UK has pioneered the development of a multi-spectral imaging system resulting in a colorimetric image archive for their collection.[1] However, colorimetric matching decisions are prone to problems associated with metamerism: intransigence to change in illumination, lack of forgiveness for differences between individuals and the standard observer, and high sensitivity to printer noise and calibration errors. Spectral-based reproduction is far more robust with respect to these limitations. Many researchers have been experimenting with MVSI techniques to capture art paintings.[3,4] These techniques are based on the spectral analysis of the paints. Although spectral information has large dimensionality because the sampling typically from 400 nm to 700 nm in intervals of 10 nm, eigenvector analysis of spectra[5,6] shows that it is possible to reduce the dimension of the spectral information without considerable loss of information due to the smoothness of natural object spectral reflectance curves.

At the Munsell Color Science Laboratory, we have been drawing upon this body of successful work and extending it to produce an end-to-end scene to hardcopy spectral reproduction system. The spectral information provides printed color reproductions that are close spectral matches to the original objects producing high-quality color matching under different illuminations and observers.[7,8] In this paper we are going to concentrate in the input part of system. The first and most direct method to capture spectral data is to increase the sampling increment above the traditional three channels using highly selective, spectrally narrow filtering. The acquisition system becomes a spatial spectrophotometer with appropriate calibration providing a method that is robust for any arbitrary spectral shape. However, we also need to consider other multi-spectral acquisition approaches that would be sufficiently easy, fast, simple to be implemented in museum archival departments, and that provide reasonably accurate spectral reflectance estimation. Considering the smoothness of the spectral curves of the most commonly used pigments, it is possible to reduce the number of channels by means of eigenvector analysis.[9]

Based on these facts we proposed a wide-band image acquisition combined with either a number of colored filters[10] or a number of differently colored light sources. The captured images are converted to a spectral reflectance image

* Contact: 54 Lomb Memorial Drive, Rochester, NY 14623 USA, e-mails: imai@cis.rit.edu and berns@cis.rit.edu.

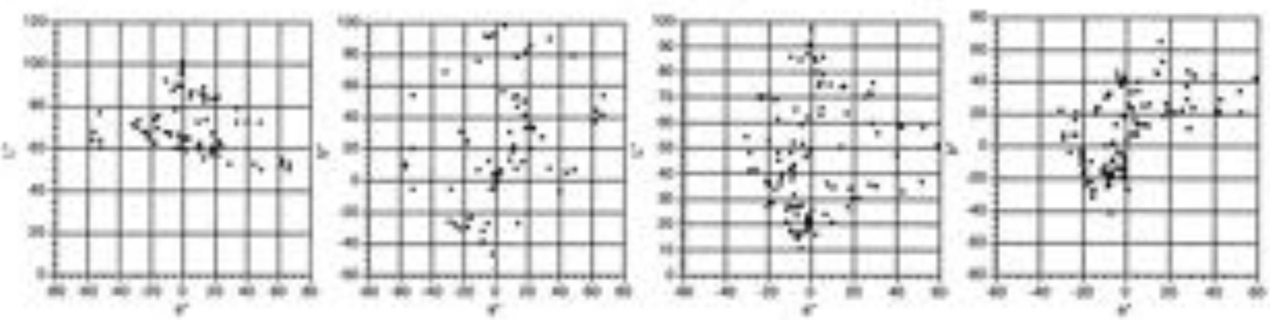
9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

using colorant information known *a priori*. In this case, if the colorants for a particular painting are available it is possible to make targets with the colorants to perform *a priori* spectral analysis. However, generally such information is not readily available without performing either historical or chemical analyses of the paintings. It is necessary to consider the possibility of designing a "universal" oil painting target that can be used when the colorant information is not available.

In this paper we present a method of spectral reflectance estimation for paintings using a transformation from digital signals to reflectance based on *a priori* analysis of a general oil painting target.

2. EXPERIMENTAL

In our experiments we used two oil paint targets. One of the oil painting targets, that we call *Ross target* (painted by Ross Merrill, Head of Conservation at the National Gallery of Art, Washington, DC), was created using 68 pigments dispersed in linseed oil representing blues, greens, yellows, reds, earth colors, browns and radiant colors commonly used by artists. Another oil painting target, called *van Gogh target*,[5] was created by Roy Berns, consisting of 106 patches made from cobalt blue, prussian blue, naples yellow, yellow ochre, cadmium red medium, ivory black, and titanium white, representative of the colors present in one van Gogh self-portrait painted in 1889, part of the Whitney collection at the National Gallery of Art, Washington. The paints chosen for the *van Gogh target* were based on spectral measurements performed on the self-portrait painting. All the spectral measurements were performed using the GretagMacbeth SpectroEye 45/0 spectrophotometer. The color distributions of *Ross* and *van Gogh targets* are shown in Figure 1.



a) Ross target a x L**   *b) Ross target a* x b**   *a) van Gogh target a* x L**   *b) van Gogh target a* x b**

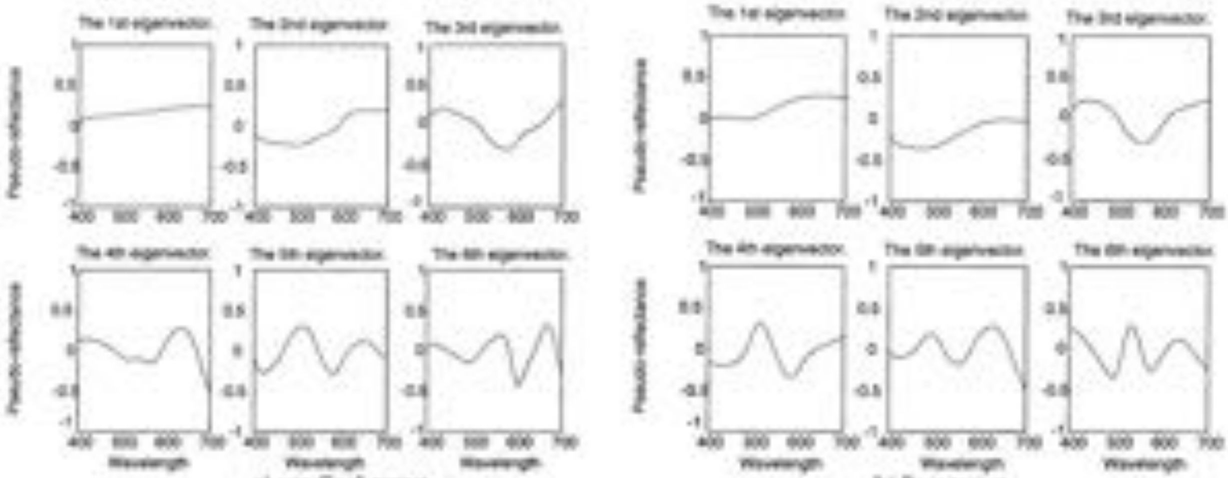
Figure 1. Colorimetric plots for the *Ross* and *van Gogh target* (under D50 illuminant, 2° observer).

Both *Ross* and *van Gogh targets* were imaged using the same illuminants, set of absorption filters, camera system and imaging geometry. For the imaging system we used a medium-spatial resolution trichromatic IBM Pro 3000 digital camera system[8] that consists of a monochrome scanning back and a filter wheel (3,072 x 4,096 pixels, R, G, B filter wheel, dark current corrected 12 bits per channel that has a 45°/0° imaging configuration using tungsten-halogen illumination). Multi-channel images were obtained combining the IBM trichromatic images without external filtering and with a Kodak Wratten filter number 38 (light blue filter). White spatial correction was performed to the captured image to account for spatial non-uniformity of the illumination. The *Ross target* was used as a calibration target. The eigenvectors of the *Ross target* were computed from its measured spectral reflectances. A transformation was derived to convert digital signals to spectral reflectances using the computed eigenvectors. The transformation derived for the *Ross target* was used to estimate the spectral reflectances of the *van Gogh target* from the digital counts of the *van Gogh target*.

The evaluation of the spectral reflectance of the MVSI acquisition system is then subdivided in two parts. At first, eigenvector analysis is evaluated theoretically reconstructing the spectral reflectances from the derived eigenvectors and eigenvalues and comparing the estimated reflectances with the measured spectral reflectances. In the following stage the spectral reflectance is estimated from the eigenvectors and actual digital counts. The estimated spectral reflectances are then compared to the original spectral reflectances.

3. RESULTS

Figure 2 show the first six eigenvectors for the spectral reflectances of both *van Gogh* and *Ross targets*.



a) *van Gogh target* b) *Ross target*

Figure 2. First to sixth eigenvectors of the spectral reflectances for the *van Gogh* and *Ross targets*.

From Figure 2 it is possible to see that the eigenvectors for the *van Gogh target* is very similar to those of the *Ross target*. This indicates that the transformation from digital counts to spectral reflectance derived for our calibration target (in this case *Ross target*) possibly can be used for the pigments of a particular painting (in this case the *van Gogh target*). Therefore we estimated the spectral reflectance of the *van Gogh target* using the eigenvectors and the transformation derived from the *Ross target*; table I shows the colorimetric and spectral performance.

Table I. Cumulative variance contribution and influence of the number of eigenvectors used in the spectral reconstruction of the *Ross target* and *van Gogh target* on the colorimetric and spectral error. ΔE^*_{94} calculated for D50 and the 2° observer of the eigenvectors in reflectance space. (The eigenvectors were derived from the *Ross target* in both cases.)

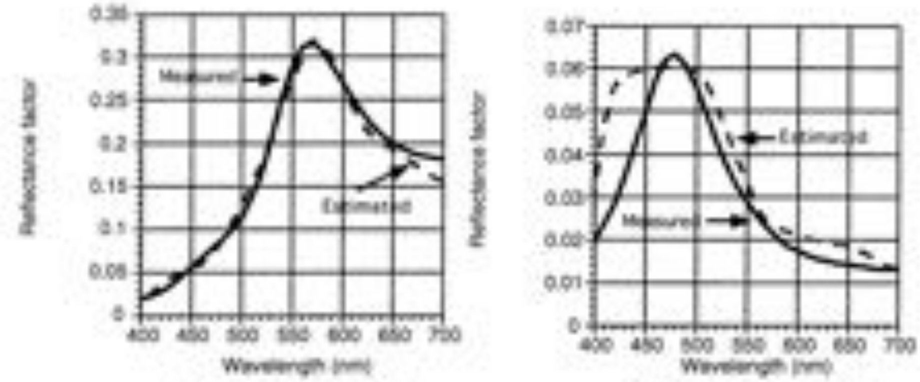
Number of eigenvectors	Cumulative variance contribution (%)	Ross Target		Van Gogh Target	
		Mean ΔE^*_{94} (D50, 2°)	Spectral reflectance rms error factor	Mean ΔE^*_{94} (D50, 2°)	Spectral reflectance rms error factor
3	97.28	2.6	0.022	4.2	0.029
6	**99.61**	**0.7**	**0.011**	**0.6**	**0.010**
9	99.93	0.1	0.005	0.3	0.005
12	99.99	0.03	0.002	0.05	0.002

From Table I it is possible to notice that six eigenvectors can reconstruct the original spectrum with 99.6% accuracy. From the colorimetric and spectral evaluations, we can conclude that the use of six eigenvectors to reconstruct spectra is a good compromise between accuracy and our aim of reducing the number of channels. Theoretically, using six eigenvectors to reconstruct spectra gives colorimetric error less than one ΔE^*_{94} unit and spectral reflectance rms error of approximately 1%. The spectral reflectance of the *van Gogh target* was estimated from its digital counts using the transformation derived for the *Ross target*. The results are summarized in Table II. The metameric index was calculated using the Fairman metameric black method, between standard illuminants D50 and A using ΔE^*_{94} in the calculations.[11]

Table II. Colorimetric and spectral accuracy of van Gogh oil painting target spectral estimation using six signals (R,G,B without filter and with light-blue absorption filter) using transformation derived from the Ross target.

Measure	ΔE^*_{94}(D50, 1931)	reflectance factor rms error	Metameric Index (ΔE^*_{94},D50, 1931)
Average	1.7	**0.022**	**0.3**
Std Dev	1.0	0.016	0.2
Max	4.5	0.091	1.1
Min	0.3	0.004	0.03

From Table II, it is seen that the *van Gogh target* spectral reflectances are reasonably well estimated using the *Ross target* as the calibration target. Figure 3 shows the best and worst spectral matches between the measured and estimated reflectances. The best spectral match was found for a mixture of yellow ochre, naples yellow and prussian blue and the worst match was a very dark mixture of cobalt blue, prussian blue and ivory black. Generally these dark colors are very difficult to match.



a) Best spectral match b)Worst spectral match

Figure 2. Comparison of the spectral reflectances between measured and estimation. (Note scale differences in reflectance factor.)

4. CONCLUSIONS

Our experiments showed that it is possible to estimate spectral reflectance with an average accuracy of 1.7 ΔE^*_{94} and a 2.2% spectral reflectance rms error using a target of commonly used oil paints. These results are encouraging regarding the design a universal target to derive the eigenvectors that are necessary for the spectral estimation. The use of a universal target will be fundamental for the cases in which we do not know the spectral characteristics of the pigments of a particular painting.

REFERENCES

1. B. Hill, Aspects of total multispectral image reproduction systems, *Second International Symposium on Multispectral Imaging and High Accurate Color Reproduction*, Chiba University, Japan, 67-78 (2000).
2. D. Saunders, J. Cupitt, "Image processing at the National Gallery: The VASARI project," National Gallery Tech. Bull. 14, 72-86 (1993).
3. Y. Miyake, Y. Yokoyama, N. Tsumura, H. Haneishi, K. Miyata and J. Hayashi, Development of multiband color imaging systems for recording of art paintings, in *IS&T/SPIE Conference on Color Imaging: Device-Independent Color, Color Hardcopy, and Graphic Arts IV*, G. B. Beretta, and R. Eschbach, Editors, Proc. of SPIE **3648**, Bellingham, WA, 218-225 (1999).
4. H. Maitre, F. J. M. Schmitt, J. P. Crettez, Y. Wu, J. Y. Hardeberg, Spectrophotometric image analysis of fine art paintings, *Proc. IS&T/SID Fourth Color Imaging Conference: Color Science, Systems and Applications*, 50-53 (1996).
5. M. J. Vrhel, R. Gershon and L. S. Iwan, "Measurement and analysis of object reflectance spectra", *Color Res. and Appl.*, **19**, pp. 4-9, 1994.
6. T. Jaaskelainen, J. Parkkinen and S. Toyooka, "Vector-subspace model for color representation", *J. Opt. Soc. A*, **7**, pp. 725-730, 1990.
7. D. Tzeng, R. S. Berns, Spectral-based Six-color Separation minimizing Metamerism, *Proc. of Eighth IS&T/SID Color Imaging Conference*, 342-347, (2000).
8. F. H. Imai, M. R. Rosen, and R. S. Berns, Multi-spectral imaging of van Gogh's self-portrait at the National Gallery of Art, Washington, D.C., Proc. of IS&T's 2001 PICS Conference, IS&T, Springfield, Virginia, 185-189 (2001).
9. S. Baronti, A. Casini, F. Lotti and S. Porcinai, Multispectral imaging system for the mapping of pigments in works of art by use of principal-component analysis, *Applied Optics* **37**, pp. 1229-1309, 1998.
10. F. H. Imai, R. S. Berns and D. Tzeng, A comparative analysis of spectral reflectance estimated in various spaces using a trichromatic camera system, *J. Imaging Sci. Tech.* **44**, pp. 280-287, 2000.
11. H. S. Fairman, Metameric correction using parametric decomposition, *Color Res. Appl.* **12**, pp. 261-265, 1997.

White is Green – New Schematic Diagrams

Hal Glicksman
California State University, Long Beach

ABSTRACT

Two new schematic diagrams are presented here that derive from the study of the value relationships of the primary colors of RGB computer and video color. The first diagram is a "Truth Table" that presents true-false, on-off states of the three colors of RGB so that the colors are presented in the order of their brightness values. The second diagram is a triple Venn diagram based on the perception of color. This diagram is presented as an alternative to the Venn diagrams of additive and subtractive color usually used to explain color.

Keywords: Venn diagram, value relationship, truth table, difference algorithm, Goethe, Ockham

1. INTRODUCTION

The author's original goal was to describe digital color as bits turned on and off for red, green and blue.
What should have been a simple description of additive colors as having one bit on and subtractive colors as having 2 bits on was stymied by the lack of symmetry and reciprocity of the additive and subtractive models of color.

This in turn led the author to a long period of research into the value relationships of the primary colors of RGB color, resulting in the previously published papers on "White is Green"

2. DIGITAL COMBINATIONS OF RGB PRIMARIES

The following chart of RGB color is based on the values of RGB primaries.
The chart resolves the problem of the extreme brightness difference in RGB primaries. (Figure 1)

Bitmap	Green	Red	Blue	Sample	Hue	Brightness
	1	1	1		White	100%
	1	1	0		Yellow	89%
	1	0	1		Cyan	70%
	1	0	0		Green	59%
	0	1	1		Magenta	41%
	0	1	0		Red	30%
	0	0	1		Blue	11%
	0	0	0		Black	0%

Figure 1: Chart of RGB Primaries in brightness order

There are eight possible combinations of three RGB primaries, indicated by a 1 for on and a 0 for off. The first bit is for green because green represents half of the brightness of white. There are four colors with the green bit on. They are white, yellow, cyan and green. With green off, the colors are magenta, red, blue and black. This corresponds to the way a white rectangle appears when viewed through a prism as described by Goethe. Cyan is within the white area and blue is within the black area. Yellow is within the white area, red is within the black area.

Digital information is represented by 1 for yes, on and true. 0 represents no, off, and false. Analog information, such as the brightness of a light source, must be divided into on or off at a threshold level. The threshold for a single bit of data to represent black or white is 50% brightness.

In the chart above, the 50% threshold falls between magenta and green when colors are ranked by brightness. Magenta and all the colors below it would register as black; Green and the colors above it would register as white when the colors are converted to a bitmap.

Red is the second bit in this chart because it is half as bright as green.

Blue is the least significant bit because it is less than half as bright as red. The color chart that results from this order of bits shows RGB colors in their order of brightness.

Red and blue combined are not brighter than green alone. It is important to make this asymmetrical relationship basic to the color model.

The brightness values in the table above were derived by:

- Creating a PICT file of color samples.
- Setting the monitor display to 256 gray
- Creating a screen capture file of the grayscale image
- Reopening the captured grayscale image in RGB color in Photoshop
- Measuring the brightness values in the HSB display in the INFO window.

A grayscale conversion algorithm was not used. Converting red, green and blue to grayscale using the grayscale algorithm in Photoshop yields brightness values that total more than 100%. Blue is especially effected and is converted to a much lighter gray than 11%.

A functioning model of color that can represent all of the 8 combinations of RGB can now be posited on the following conditions of true/false:

1 The presence or absence of brightness
2 The presence or absence of red
3 The presence or absence of blue

In this model green would be brightness=true, red =false, and blue=false.

Using the truth table above, 'white is green' can be argued with Ockham's Razor:
"Pluralitas non est ponenda sine necessitate." Distinctions should not be made that are not necessary.
Green appears as white in the 50% threshold conversion to a bitmap It is not necessary to distinguish white from green with a single bit of data in a bitmap

Figure 2 is a picture of red ground, a green plant, and a blue sky that was created in RGB primaries. It was converted to a grayscale so that the combined brightness of the three colors equaled 100%. Figure 3 is the same image converted to a bitmap at 50% threshold. Only the green plant remains visible.

Figure 2: Green, red and blue in gray values

Figure 3: Green, red and blue converted to bitmap

Figure 3 shows that the logical condition of brightness=yes does not distinguish between white and green.

3. VENN DIAGRAM OF BRIGHTNESS/DIFFERENCE PERCEPTION

The Venn diagrams of additive and subtractive colors that are used to explain color are usually displayed side by side on a screen or printed page. There is an implied reciprocity to this juxtaposition that does not exist. On the printed page the green that is produced by subtracting cyan and yellow ink is much darker than the green of RGB. On the screen, green is much brighter than the green produced on paper by CMYK.

The author wishes to propose a third Venn diagram based on the perception of color. This is a model of vision based on a brightness signal and a test of the brightness signal for the presence or absence of red and blue. The Venn diagram below (figure 4) is a dynamic model of how such a system would work.

The reader is urged to see this model function by reproducing the diagram on a computer and actually creating the color green from white. This is done by generating the diagram in a computer graphics application that has layers and a difference calculation. Each circle of this dynamic triple Venn diagram is on a layer, and the layers are set to calculate the difference from the layer beneath. The background is black. The first layer is transparent with a white circle in the center. The next layer is transparent with a red circle and the top layer is transparent with a blue circle. When the circles are moved on top of each other to create an overlapping Venn diagram, the colors of cyan, green and yellow are generated within the white circle. Viewing the diagram in a static black and white form is less convincing than having the working diagram on a computer screen and moving the circles to see how the color is generated.

The same circle can display both red and its opposite, cyan, by representing the difference between red and the contents of the circle beneath. Red is off (0) in the black layer and red is on (1) in the red layer. The difference is 1, so the condition for the portion of the red circle that is over the black background is on (1) for red.

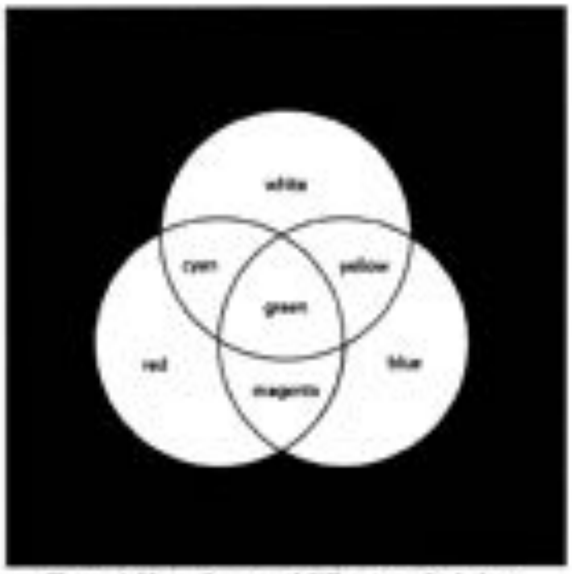


Figure 4: Venn diagram of difference calculations.

The difference between red and white is generated this way: G1 R1 B1 white layer G0 R1 B0 red layer G1 R0 B1 difference cyan	The overlap of red and blue circles and the black background generates magenta. G0 R0 B0 Black Background G0 R1 B0 red layer G0 R1 B0 difference also red G0 R0 B1 blue layer G0 R1 B1 difference magenta	The overlap of the white, red and blue circles generates green by this calculation: G1 R1 B1 white layer G0 R1 B0 red layer G1 R0 B1 difference cyan G0 R0 B1 blue layer G1 R0 B0 difference green

4. CONCLUSION

These diagrams are offered as possible models of color. The author is not a color scientist and cannot speculate on ways that these diagrams could fit existing scientific theories of color perception. The diagrams are offered as a start for developing useful models of color that are based on the value differences of the primary colors of RGB.

BIBLIOGRAPHY:

Boyle, R. 1664. *Experiments and Considerations Touching Colours.* New York: Johnson Reprint Corp., (1964.)

Glicksman, Hal 1997 *White is Green* AIC Color 97, Proceedings of the 8th Congress of the International Color Association, The Color Science Association of Japan, Kyoto

Glicksman, Hal 1999 *White is Green* Proceedings of the International Society for Optical Engineering Volume 3648, SPIE, Bellingham, WA.

Goethe, J. W. 1840; 1970. *Theory of Colors*. Trans. by Eastlake. Cambridge, Mass.: MIT Press.

Ockham, William of; Encyclopedia Britannica Online Edition, 2000, idxfer=412168

Newton, I. 1730;1952. *Opticks*. 4th ed. New York: Dover.

The Paperless or Vanishing Society

Joy Turner Luke

Abstract

In the 1940's color photography became available and within a few years, extremely popular. As people switched from black and white photographs made with the old metallic silver process to the new color films, pictures taken to record their lives and families began a slow disappearing act. The various color processes, coupled with the substrates they were printed on, affected their longevity, but many color photographs taken from the late 1950's through the 1970's, and even into the 1980's, faded not only when exposed to the light, but also when stored in the dark. Henry Wilhelm's excellent book "The Permanence and Care of Color Photographs" documents this history in detail.

Today we are making another transition in the storage of pictures and information. There are questions about the longevity of different types of digital storage, and also of the images printed by various types of inkjet printers, or by laser printers using colored toners. Very expensive and very beautiful works of art produced on Iris printers are appearing in art exhibitions. Some of these are referred to as Giclée prints and are offered on excellent papers. Artists are told the prints will last a lifetime; and if by chance they don't, it is only necessary to make another print.

Henry Wilhelm has begun to test and rate these images for lightfastness; however, his test method was developed for examining longevity in colored photographs. It is of interest to find out how these prints will hold up in the tests required for fine art materials. Thus far companies producing digital inks and printers have not invested the time and money necessary to develop an American Society for Testing and Materials (ASTM) standard method for evaluating the lightfastness of digital prints. However, it is possible to use ASTM D 5383, Standard Practice for Visual Determination of the Lightfastness of Art Materials by Art Technologists, to pinpoint colors that will fade in a short time, even though the test is not as severe as ASTM D 4303, which is used to rate the lightfastness of artists' paint.

Most designers and many artists use computers as part of their work process. The decreasing costs of computers, storage media and printers makes it possible for anyone to create their work, save it and either print it out themselves, or have it printed by a commercial printer or by a printer specializing in art prints. Therefore, the question of longevity arises both in relationship to the storage of images in digital form and also how well prints made with ink jet, solid ink or laser printers will last. As each new digital storage media reaches the market there are claims that it is much more permanent than the media that just preceded it. The lasting qualities of digital media affects also the question of the permanence of printed images since artists are often told that if a print fades, they can just print a duplicate. So what conservators have to say about digital storage is of interest.

In a lecture to conservation students in 1998, Eleanore Stewart, after pointing out that electronic files are not sufficiently archival for preservation, went on to say one possible legitimate use might be scanning a black and white photo collection that is rapidly deteriorating and where funds for traditional film duplication do not exist; then she adds that this is a valid procedure only if the collection is not unique. In other words, putting

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) · 0277-786X/02/$15.00

even black and white graphics in digital form is a temporary expedient when nothing else is possible. (1)

In a letter to the Washington Post Deanna Marcum, president of the Council on Library and Information Sources, said, "We run the risk that digital information will disappear. Indeed, portions of it already have become inaccessible. Either the media on which the information is stored are disintegrating, or the computer hardware and software needed to retrieve it from obsolete digital formats no longer exist. The extent of the problem will emerge as more and more records are requested for retrieval and cannot be read....Military files, including POW and MIA data from the Vietnam War, were nearly lost forever because of errors and omissions contained in the original digital records. Ten to twenty percent of vital data tapes form the Viking Mars mission have significant errors because magnetic tape is too susceptible to degradation to serve as an archival storage medium."

In a 1995 article in Scientific American Jeff Rothenberg (2), a senior computer scientist, estimated both the physical lifetime of various storage media and the length of time before they became obsolete. A 1998 article in U.S. News & World Report, written by Laura Tangley, contrasts the storage time for major and high quality brands (3).

In 1995 the life of magnetic tape was given as a year, while by 1998 it is estimated to be five years, with high quality tape lasting a little over ten years. Rothenberg gives magnetic diskettes a life of five to ten years, but by 1998 they are not mentioned since they were already obsolete. Optical disks, CD-ROMs and CD-Rs, in 1995 were given a lifetime of thirty years, but with obsolescence within ten years. By 1998 the average CD-ROM was given only five years but the lifetime of high quality CD-ROMs was extended to fifty years. The recordable CD-Rs have shorter lifetimes.

The longest period predicted for any digital media is fifty years, not even the lifetime of an individual, and far less the 500 years predicted for high quality paper. There are a number of strategies proposed to make it possible to retrieve information from obsolete media. File conversion programs exist but most of these have drawbacks when considered over very long periods of time, including the necessity of providing, in addition to the bit stream representing the document or graphic, an appropriate application and operating system necessary to interpret the bit stream. It has even been proposed that digital documents be converted into a series of dots on high quality paper.

In addition to artists and collectors who need images that will last, the difficulties listed above increase the importance of the printed image. I have served on the ASTM subcommittee on artists paints and related materials since the late 1970's and one of our main concerns has been the lightfastness of fine art materials. The subcommittee has developed two types of tests to be used in deciding whether a particular color will remain unchanged for many years.

One method, ASTM D 4303, requires instrumental color measurement and two or more exposures, one under glass in natural daylight in south Florida and a second exposure to simulated under glass daylight in a xenon arc instrument. In both cases exposure is continued until a specified amount of irradiation is reached. If the two test results do not give similar results, the colors are tested a third and even a fourth time. The second method, ASTM D 5383, was developed to enable artists and conservators to roughly evaluate the lightfastness of colors without the expense of instrumentation. A study has shown that, whereas D 5383 does not have the controls or require the amount of irradiation as D 4303, all colors in the study that faded when exposed in accordance with D 4303 had at least began to change color when tested in accordance with D 5383. In other words, it offers a way for the individual to determine whether a material is fugitive, inferior, fair or good, but cannot determine if it is lightfast or predict its appearance after a very long period of time.

At Studio 231 there are interior exposure racks hung one foot below a south facing skylight in a room that is air-conditioned. Although the racks get hot, neither the heat or humidity is extreme. I have been using D 5383 to test inks used in ink jet printers, along with other art materials, for four years. I chose to test inks first because so many artists and photographers I knew were using Epson printers and because inks are also used in the expensive Giclée prints made on Iris printers. I occasionally serve as a judge for art exhibitions and I have seen a constant increase in the number of Iris prints submitted. They make beautiful prints and the inks used are constantly being improved.

Before describing the test and test results further, a few words should be said about lightfastness tests in general. The ultra-violet spectrum is divided into three sections, UVA, UVB, and UVC. The shortest, most destructive wavelengths, UVC, never reach the earth, the UVB wavelengths do not pass through window glass and, therefore, do not affect materials kept indoors. It is the UVA wavelengths and, in some cases, the shorter wavelengths of visible light that destroy colors, i.e., from about 300 nm in the ultra-violet through the violet and blue wavelengths to about 500 nm.

The more permanent colors fade only in ultra-violet illumination, it is the fugitive colors that fade in visible light. The colorant itself is only affected by the wavelengths it absorbs, so under a light source that contained only red wavelengths, a red color would never fade. However, the absorption of photons is just the first step in the deterioration process. This primary absorption process is not affected much by temperature, but varies a great deal in effectiveness. The secondary chemical reactions are often effected by heat and moisture. Usually the principle of reciprocity means that the total photochemical action is the product of the intensity of irradiation multiplied by the length of exposure; however, in some cases reciprocity does not hold. (4)

Not all absorption results in damage because not all absorption results in changes in the material. It may not be the absorption by the pigment or dye that is responsible for deterioration, it may be absorption by chromophoric groups in a trace impurity that activates the vehicle and results in the degradation of the colorant. (4) The wavelength by wavelength power distribution of the light source combined with the sensitivity of the material to particular wavelengths determine what happens during exposure. The first two slides serve as a cautionary statement for the rest of the slides and should be borne in mind when when looking at results from any accelerated lightfastness test.

The blue line on the first slide represents the spectral power distribution of a particular phase of natural daylight and the red and green lines represent the spectral power distribution of two special full spectrum fluorescent lamps, such as are used in color matching. The second slide illustrates this fact. Two prints were made at the same time on the same paper with an Epson printer. One was exposed to sunlight coming through a skyfight onto an exposure rack; and the other was hung in the same building but on a back wall away from a window. They were both illuminated largely by natural daylight, although there was occasionally fluorescent illumination in the room. The main differences were between direct sunlight exposure with its attendant heat, and sunlight reflected within the room. The skylight exposure took three and half months to fade the control, Blue Wool 6. The other print has been exposed on the wall for five years.

Both exposures show that the colors fade badly, but there are definite differences between the two exposures, particularly what happened to the yellow shades. Under the skylight the yellow shades took on a green cast, but they not in indirect light. The cyan faded more in the indirect room light, while the red has faded much more in the skylight exposure. The point is that while accelerated exposures can indicate which colors are lightfast, it does not necessarily tell you how their appearance will change over time. This is even more true when the material is exposed to different types of light source.

The ASTM standard, D 5383, which was followed in testing these various inks, requires that test specimens be exposed to natural daylight along with a set of eight ISO Blue Wool References. Each of these references are about twice as lightfast as the one that precedes it in the series. Materials that do not show a color change when Blue Wool Reference 8 fades have excellent lightfastness; however, it takes longer to reach this point than artists will wait for results. As mentioned above a study has shown that by the time Blue Wool 6 fades colors that fade significantly when Blue Wool 8 fades, will have show some color change. Therefore, although exposing a test specimen until Blue Wool 6 fades will not tell whether it has excellent lightfastness, it does indicate whether it has good lightfastness.

Blue Wool 6 is a dark color and it is difficult to detect visually when it has began to change color. At the time Blue Wool 6 is beginning to fade, Blue Wool 3 is changing rapidly, making a visual evaluation easier, so exposure continues until Blue Wool 3 matches two blue chips on a mask and a color change can also be seen in Blue Wool 6. The test specimens are then rated by at least three experienced observers who compare each specimen's color change with the amount of fading in the Blue Wool References. Those ratings averaged. The tables report the effects of the substrate on lightfastness, the effect of covering the colors with UV absorbing glass and improvemts due to the introduction of new inks.

1. *Why Library Preservation should Plan for a Digital Future*, Eleanore Stewart, The Abby Newsletter, v. 22 #3 P. 33, 1998

2. *Ensuring the Longevity of Digital Documents*, Jeff Rothenberg, Scientific American, January 1995.

3. *Whoops, there goes another CD-ROM*, Laura Tangley, U.S.News & World Reoport, February 16,1998.

4. "Accelerated Aging: Photochemical and Thermal Aspects," Robert L. Feller, The Getty Institute, 1994.

Different Papers - Epson Stylus 500 Printer, Epson SO20097 Ink

Strathmore Pro Paper acid free 100% Cotton	Cyan	2.3 Inferior	Strathmore Artists Ink #24	Cyan	2.7 Inferior
	Magenta	1.8 Fugitive		Magenta	1.8 Fugitive
	Yellow	2.6 Inferior		Yellow	3.8 Inferior
	Red	2. 5 Inferior		Black	2.0 Fugitive
	Green	2.3 Inferior		Red	2.0 Fugitive
	Blue	2.7 Inferior		Green	2.3 Inferior
				Blue	2.3 Inferior
Hammermill Ultra Gloss	Cyan	3.0 Inferior	Hammermill Inkjet Ultra	Cyan	3.3 Inferior
	Magenta	2.0 Fugitive		Magenta	2.0 Fugitive
	Yellow	3.0 Inferior		Yellow	3.0 Inferior
	Red	3.0 Inferior		Red	2.8 Inferior
	Green	3.3 Inferior		Green	3.3 Inferior
	Blue	2.7 Inferior		Blue	3.3 Inferior

Epson Stylus Photo 870, Epson T008 Ink

Epson Photo Quality Glossy Paper	Red	2.0 Fugitive	Epson Matte Heavy Weight Paper	Red	4.2 Inferior
	Yellow	4.3 Inferior		Yellow	4.2 Inferior
	Blue	2.8 Inferior		Blue	4.0 Inferior
	Cyan	2.5 Inferior		Cyan	4.0 Inferior
	Magenta	2.5 Inferior		Magenta	3.7 Inferior
	Green	4.3 Inferior		Green	4.3 Inferior
	Black	3.2 Inferior		Black	2.7 Inferior
	Gray	3.0 Inferior		Gray	3.3 Inferior
	Brown	2.5 Inferior		Brown	2.8 Inferior
	Orange	3.0 Inferior		Orange	3.0 Inferior
	Purple	2.8 Inferior		Purple	3.0 Inferior
Epson High Quality Paper	Red	2.0 Fugitive	**New** Premium Glossy Photo Paper	Red	6.2 Good
	Yellow	3.2 Inferior		Yellow	7.0 Good
	Blue	2.3 Inferior		Blue	4.8 Inferior
	Cyan	2.0 Fugitive		Cyan	3.7 Inferior
	Magenta	2.0 Fugitive		Magenta	4.7 Inferior
	Green	3.0 Inferior		Green	4.2 Inferior
	Black	2.0 Fugitive		Black	6.0 Fair
	Gray	2.3 Inferior		Gray	3.8 Inferior
	Brown	2.0 Fugitive		Brown	3.7 Inferior
	Orange	2.2 Inferior		Orange	4.5 Inferior
	Purple	2.0 Fugitive		Purple	3.7 Inferior

Lumijet Platinum Inks, Epson Stylus Photo

Epson Photo Quality Gloss Paper	Black	6.8 Good
	Yellow	4.6 Inferior
	Cyan	5.0 Inferior
	Magenta	4.3 Inferior
	Blue	5.2 Inferior
	Green	4.3 Inferior
	Red	6.3 Good

Rating: 1 - 2 Fugitive (bleached)
2.1 - 5.4 Inferior
5.5 - 6.0 Fair
6.1 - 7 Good

Epson 2000P Photo Printer, Epson T016201 Ink

Archival Matte Paper	Red	7.0 Good
	Yellow	7.0 Good
	Blue	7.0 Good
	Cyan	5.5 Fair
	Magenta	5.8 Fair
	Green	7.0 Good
	Black	7.0 Good
	Gray	7.0 Good
	Brown	6.8 Good
	Orange	6.8 Good
	Purple	6.7 Good

Lumijet Preservation Silver Inks with Epson Stylus Photo Printer

Lumijet Gallery Gloss	Cyan	6.0 Fair	Epson Glossy SO41124	Cyan	4.0 Inferior
	Yellow	6.3 Good		Yellow	2.6 Fugitive
	Black	2.3 Inferior		Black	1.7 Inferior
	Red	4.0 Inferior		Red	4.0 Fugitive
	Blue	4.3 Inferior		Blue	4.3 Fugitive
	Green	4.3 Inferior		Green	3.6 Inferior
Lumijet Canvas Cloth	Cyan	6.3 Good	Hammermill Inkjet Ultra	Cyan	3.3 Inferior
	Yellow	5.3 Fair		Magenta	2.0 Fugitive
	Black	3.3 Inferior		Yellow	3.0 Inferior
	Red	6.3 Inferior		Red	2.8 Fugitive
	Blue	3.3 Inferior		Green	3.3 Inferior
	Green	2.7 Inferior		Blue	3.3 Inferior
Hammermill Jet Print Ultra Gloss Paper	Cyan	3.0 Inferior	Polaroid Ink Jet Photo Paper	Cyan	2.3 Inferior
	Magenta	2.0 Fugitive		Magenta	1.8 Fugitive
	Yellow	3.0 Inferior		Yellow	2.8 Inferior
	Red	3.0 Inferior		Red	1.8 Fugitive
	Green	3.3 Inferior		Green	2.7 Inferior
	Blue	3.7 Inferior		Blue	3.0 Inferior
Epson 720 dpi Ink Jet	Cyan	2.2 Inferior	Weber Valentine JPG170	Cyan	3.6 Inferior
	Magenta	1.3 Fugitive		Yellow	3.6 Inferior
	Yellow	1.7 Fugitive		Black	2.3 Inferior
	Red	1.8 Fugitive		Red	4.0 Fugitive
	Green	1.8 Fugitive		Blue	4.0 Inferior
	Blue	2.5 Inferior		Green	4.0 Inferior
Lumijet Belgian Linen	Cyan	4.0 Inferior	Lumijet Silver Foil	Cyan	7.0 Good
	Yellow	5.7 Fair		Black	7.3 Good
	Black	3.3 Inferior		Yellow	7.3 Good
	Red	6.3 Good		Red	7.3 Good
	Blue	5.0 Fair		Green	7.3 Good
	Green	4.7 Inferior		Blue	7.3 Good

Lumijet Preservation Silver Inks, Stylus Photo Printer, Under UV Absorbing Glass

Lumijet Gallery Gloss	Cyan	6.2 Good	Epson Glossy SO41124	Cyan	5.8 Fair
	Yellow	6.0 Fair		Yellow	5.8 Fair
	Black	4.3 Inferior		Black	3.0 Inferior
	Red	5.5 Fair		Red	6.0 Fair
	Blue	5.2 Inferior		Blue	5.7 Fair
	Green	5.0 Inferior		Green	4.7 Inferior
Lumijet Canvas Cloth	Cyan	5.3 Inferior	Weber Valentine JPG170	Cyan	4.3 Inferior
	Yellow	5.6 Fair		Yellow	4.3 Inferior
	Black	4.0 Inferior		Black	3.3 Inferior
	Red	5.5 Fair		Red	4.3 Inferior
	Blue	5.3 Inferior		Blue	5.0 Inferior
	Green	5.5 Fair		Green	4.7 Inferior

Development of the Uniform Color Scales by The Optical Society of America and the Introduction of Color Cleaver™ to Make the Colors Accessible

Joy Turner Luke

After the end of World War II, R.C. Gibbs, former president of the Optical Society of America (OSA) and at that time chairman of the Division of Physical Sciences at the National Research Council, asked Dr. Deane B. Judd to suggest an important research project unrelated to war and armaments. Deane Judd spent 43 years as a staff member of the Photometry and Colorimetry Section of the National Bureau of Standards (now National Institute of Standards and Technology) and served as Director of the Technical Secretariat of the International Commission on Illumination (CIE), from 1948 - 1955. He was the premier figure in color science in the United States at that time.

Judd suggested a study of uniform color scales. A perceptually uniform color space was important to both industry and the arts. Among other advantages, industrial color tolerances could be established more easily in a uniform color space. Studies leading to improvement of the uniformity of the Munsell color system had been completed a few years earlier. The individuals who worked on this project knew that since the Munsell color system is based on radiating polar coordinates, it can never be completely uniform.

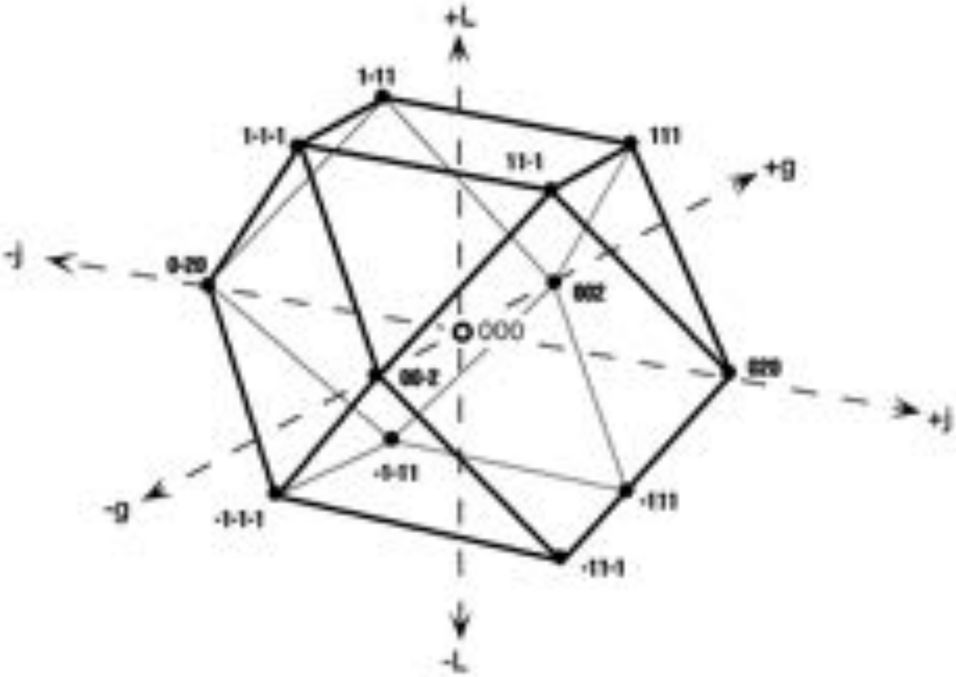
This group believed that there should be a fresh start with the single goal of achieving a three-dimensional color space based on uniform color differences between color samples. A formal conference was held at the National Academy of Sciences on June 20, 1947, a detailed research program developed, and the Optical Society of America (OSA) Committee on Colorimetry undertook the project with Dean Judd as chairman. The 1947 OSA committee included most of the major names in color science. Each of these individuals had been responsible for important contributions to modern color science. Together they comprised the most knowledgeable and prestigious group of color scientists in the United States.

On the advice of Carl Foss was decided that color samples exemplifying the proposed system would be placed at the vertices of a family of regular tetrahedra. When tetrahedra fill three dimensional space they produce a complicated but interesting arrangement of points. This arrangement is one of two types of 'closest packing,'and is known as face centered cubic. The interest for the committee was that each point in this space is surrounded by twelve equally spaced neighboring points. Placing colors at these points is the most rigorous test of uniformity possible. If the arrangement is looked at from the perspective of a color and its twelve neighbors, the primary unit is a cuboctahedron. The cuboctahedrons are repeated to fill reproducible color space.

This arrangement is also sometimes referred to as a rhombohedral lattice because the triangles

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

join to form parallel rhombohedral lattices lying at an angle in space and crossing one another from four directions. Colors displayed on these lattices change regularly in all three color attributes resulting in unusual and beautiful color sequences.



Following many studies 1966 the committee became convinced that a perfectly regular "sampling of color space does not exist for any fixed background." Nevertheless, everyone agreed that the beautiful color sequences inherent in the system would interest people in the art, design and education fields and it was worthwhile to see how close an approximation to complete uniformity could be achieved. In its 20th year the committee agreed to produce the best approximation possible using a neutral value 6/ background.

Deane Judd became ill with cancer and the committee, knowing how much he wanted to live to see the production of color samples representing the color system, waited impatiently for the last reports by committee members. In January of 1971 MacAdam sent Judd photographs of 21 charts assembled from colors produced by color photography linked to a computer and based on the adjusted formulas that had been developed over the years. The charts showed several examples of the main seven cleavage planes in the system. Judd wrote, "I have spent about four hours studying those charts and I expect to spend many more…Most of these series are novel, and should be of great interest to color coordinators. Most of these colors are shown surrounded by six nearest neighbors… each color of the set appearing to differ from the central color by approximately the same amount. This property of the colors should make the collection of colors very interesting to those who have to set color tolerances."

There were delays and by September 1972 Judd knew he would be unable to complete the committee work. He telephoned Dr. David MacAdam and asked him to take over the committee. Deane Judd died October 15, 1972.

MacAdam's article, "Uniform Color Scales," was published in the December 1974 issue of the Journal of the Optical Society of America (Vol. 64, No. 12,1691-1702). This article describes the work and the color system in detail and should be read by anyone who wants to understand the foundation of the system. In 1976 the Optical Society announced availability of sets of two inch square samples of the 558 colors formulated in a glossy automotive acrylic finish and placed in plastic side holders in a large notebook. The system is referred to as the Optical Society of America's Uniform Color Scales or the OSA-UCS color system.

It had taken thirty years for a committee made up of the most knowledgeable color scientists to create a color system which, although not perfectly uniform, was the best that could be found. Everyone was impressed with the unusual beauty of the color scales. And then, except for scientific papers, the OSA-UCS system sank from sight.

There were several reasons for this. After thirty years most of the individuals active in developing the OSA-UCS system, who were at the peak of their careers as they began the work, were either retired or dead. The next generation of color scientists, while respectful of their work, had their attention focused elsewhere. Also in 1976 the CIE approved a mathematical transformation of the wildly nonuniform (demonstrated by MacAdam's famous ellipses) CIE Chromaticity Diagram to produce a more uniform color diagram along with the CIELAB and CIELUV formulas that represent approximately uniform color differences.

Artists and designers did not recognize the advantages of the system because the OSA-UCS color chips were inserted in a way to fill all the pockets in plastic slide holder sheets. In this scrambled array, the beauty of the color scales disappeared. No one from the arts who looked at the pages in the OSA-UCS set would want to purchase the system.

While the Optical Society offered the sets for sale to their members, they were not advertised outside the Society and, although the system was in the public domain, no company undertook to produce and market samples exemplifying the system. With few exceptions, the set of colors has been used only in vision research.

Today when the widespread use of computers has added an extra dimension to the already difficult problem of color reproduction, it is worthwhile to look again at the OSA-UCS system. The Hue, Saturation, Value (HSV) and Hue, Lightness and Saturation (HLS) color systems used to display and select colors on computer monitors are definitely not perceptually uniform; and, in spite of their names, which sound as though the three colors attributes are separate, they are not. There is a variation in perceived lightness on a single Lightness or Value plane. This makes it difficult for the user to adjust colors. The widely used Pantone™ colors are a collection of colors based originally on intermixtures of inks. They represent a colorant system, as distinct from a true color system. They are not based on perceptually uniform spacing and, although they have been adapted for use on color monitors and are in wide use, they do not offer the advantages of a true color system.

The OSA-UCS system provides colors as uniformly spaced as it was possible to achieve. In addition, while spacing in the OSA-UCS system and CIELAB are not the same, OSA-UCS colors are also defined in terms of the CIELAB system, so companies that produce colors to CIELAB specifications can reproduce OSA-UCS colors exactly. The OSA-UCS notational sytem is based on the fact that humans have an opponent color visual system, i.e., the brain receives either a red or green signal and either a blue or yellow signal; but never a combination of red and green or combination of yellow and blue. Therefore, the notation needs only a term for lightness, one for red or green, and one for yellow or blue (L, j,and g).

Color Cleaver™

Color Cleaver™ is computer software developed to enable artists and designers to use the OSA-UCS color system. The patented program is complete and available for study, but is not yet commercially available.

The user enters two colors of interest into the program, using any of three different methods. These two colors form a color key and based on that key, Color Cleaver™ splits this many faceted system into between 50 and 200 palettes of colors, depending on the pair of colors entered. The user scrolls through thumnail versions of the palettes looking for the right color combination for the project. The palettes progress, one after another through the OSA-UCS color space. Each palette includes the original two colors and a number of unique colors that harmonize with them. The colors in the palettes are beautiful because a natural relationship between them retained.

When a color palette seems suitable, it can be enlarged to become a work chart. Individual colors can be moved, resized and placed behind one another to assist in studying how they will look at different sizes and in different relationships in the user's project. Color Cleaver™ also includes a way for the user to intermix the 2085 colors in its color gamut; and therefore, offers the user a limitless number of colors. Each color can be selected, enlarged again and its tristimulus values, CIELAB and RGB notations displayed to aid in color communication.

The palettes are not color sequences found by intermixing paints or dyes. They represent the type of related colors that are seen in nature. Colors are arranged in the palettes as though you were looking at a slice of color space. The distance between colors on the palette indicates the amount of contrast between them.

It is envisioned that Color Cleaver™ will be used in conjunction with drawing, painting and image editing programs. Once the correct colors for a job are found they can be moved into these other programs for use in art and design works. Interior designers and others can also print color samples if their monitor and printer are properly calibrated and they have a reliable color management system.

Further information:

"Colorimetric data for samples of the uniform color scales," David MacAdam, *Journal of the Optical Society of America* (Vol. 68, No. 1, 121-130), 1978

The whole issue of *Color Research and Application* (Vol. 6, No. 1),1981, was devoted to articles on the Uniform Color Scales, including Dorothy Nickerson's description of the system, Hugh Davidson's formulations for the color samples, and David MacAdam's article on changes in the appearance of the OSA-UCS samples under different light sources and between the 10° and 2° observer. Fred Billmeyer, Jr. contributed a note on the geometry of the OSA Uniform Color Scales and Richard and Marjorie Ingalls described the reproduction of some OSA-UCS color planes for the journal.

Information on Color Cleaver™: Bronson Color company, 93 Bronson Lane, Sperryville, Virginia, USA, 22740. Phone: (540) 876-8386; Fax: 540-987-3353; Email: jtluke@summit.net.

Accurate colour images: from expensive luxury to essential resource

David Saunders and John Cupitt, Scientific Department, The National Gallery, Trafalgar Square, London WC2N 5DN, UK

ABSTRACT

Over ten years ago the National Gallery in London began a programme to make digital images of paintings in the collection using a colorimetric imaging system. This was to provide a permanent record of the state of paintings against which future images could be compared to determine if any changes had occurred. It quickly became apparent that such images could be used not only for scientific purposes, but also in applications where transparencies were then being used, for example as source materials for printed books and catalogues or for computer-based information systems.

During the 1990s we were involved in the development of a series of digital cameras that have combined the high colour accuracy of the original 'scientific' imaging system with the familiarity and portability of a medium format camera. This has culminated in the programme of digitization now in progress at the National Gallery. By the middle of 2001 we will have digitized all the major paintings in the collection at a resolution of 10,000 pixels along their longest dimension and with calibrated colour; we are on target to digitize the whole collection by the end of 2002. The images are available on-line within the museum for consultation and so that Gallery departments can use the images in printed publications and on the Gallery's web-site.

We describe the development of the imaging systems used at National Gallery and how the research we have conducted into high-resolution accurate colour imaging has developed from being a peripheral, if harmless, research activity to becoming a central part of the Gallery's information and publication strategy. Finally, we discuss some outstanding issues, such as interfacing our colour management procedures with the systems used by external organisations.

Keywords: Accurate, colour, images, paintings, conservation, analysis, printing, reproduction

1. INTRODUCTION

Interest in colour digital imaging at the National Gallery, London began in the late 1970s when these systems were investigated as a non-contact means of making colour measurements of the surface of paintings. The advantage of a digital imaging system was that it provided a method of making measurements across the whole surface of the painting, as opposed to the spot measurements being made at that time with a custom-built spectrophotometer developed by Professor W.D. Wright from Imperial College, London.[1] Our predecessors presented the prototype colour imaging system for paintings at the International Institute for Conservation (IIC) conference in Washington DC in 1982.[2] This system was based on an analogue TV camera, a frame grabber in a DEC LSI-11 computer and a set of three Kodak *Wratten* colour separation filters. The instability of the analogue camera led to the development of a second generation image processing system during the mid-1980s, this time incorporating a solid state camera.[3] However, both systems relied on uncalibrated RGB colour separation and produced images that were 256 x 256 pixels in size.

When we came to assess the future of this project in the late 1980s we concluded that to make accurate colour images of paintings, against which future images could be compared to determine if any changes had occurred, we would need to increase the image resolution markedly and use a standard colour space. Although we accepted that the colour accuracy of our new system would not be as good as that of a spectrophotometric method, we felt that the ability to detect colour change anywhere on the surface was more important. After discussions with colleagues in other museums, we concluded that none of us had funding to support such a project. Although many museums, including the National Gallery, were looking to use digital images for their visitor information systems, these images were of far lower resolution and colour quality than we required. In 1989 we were fortunate to secure European community funding for a collaborative project to build the imaging system we wanted, and the VASARI (Visual Arts: System of Archiving and Retrieval of Images) project was born.

2. THE VASARI PROJECT

Although it didn't seem that way at the time, the VASARI consortium, including three museums and two university research laboratories, worked surprisingly well. After three years, we had managed to build two systems which matched our original specification. As the details of these scanners have been published previously,[4-6] only a brief description is given here as a background to the discussion of properties of the images they produced.

As this was a colour measurement exercise, we decided to record colour in the CIELAB colour space, to the best accuracy we could manage. In theory, it is possible to get accurate CIELAB measurements with just four colour channels.[7] In practice, filters with the correct transmission are very hard to manufacture and, from studies of the spectra of artists' pigments, it was concluded that a set of seven commercially-available broadband interference filters should give a colour accuracy of approximately $1\Delta E_{ab}$. For practical reasons discussed in previous publications, we placed the filters in the optical path between the light source and the painting, using fibre-optics to illuminate an area in front of the camera. While the painting is held stationary on a vertical easel, the camera and lighting system move on a large positioning frame to build up a high resolution image, with up to 20 pixels per millimetre. A calibration for lighting homogeneity and dark current was applied and a simple least-mean-squares 'black-box' calibration, using a Macbeth Color Checker as a colour standard, was used to give CIELAB data (with reference to illuminant D65) for the images of paintings.

The images fulfilled our expectations in terms of resolution and colour accuracy. We achieved an average ΔE_{ab} of around two for the 24 colours on the Macbeth chart by the end of the first phase of the project and have steadily improved this colour accuracy over the years by refining the calibration procedure and upgrading the camera and lighting systems. Typically, we now achieve an average colour difference of 1.1 ΔE_{ab} units, with a maximum colour difference of less than 5 ΔE_{ab} units. By the end of the initial project in 1993, we had scanned around 30 paintings and, while waiting for sufficient time to elapse to evaluate digital images of a painting recorded at different times, we compared the CIELAB data from images with those produced by the Wright spectrophotometer five years previously.[8]

During the VASARI project, we began to explore other uses for the digital images. Our traditional method of recording paintings is through large-format transparencies (up to 10 x 8") which have excellent resolution but not accurate colour, and which gradually deteriorate over time. We hoped that making digital images might overcome the need to re-photograph regularly to replace old transparencies. We also began to think about using the images in those applications where transparencies were then being used, for example as source materials for printed books and catalogues or for computer-based information systems. At the time, we did not have a colour printer on the premises, so a few trials were conducted, sending out images to a commercial reprographics company.

The results were encouraging, but it was clear that if we were to use high-quality digital images for reproductions or display, we needed a method other than the VASARI scanner to capture the data. The main drawbacks of the VASARI scanner were that it was bulky, immovable, and could only image paintings less than 1.5 by 1.5 metres. In addition, the fibre optic lighting system gave all paintings a uniform 'flat' look (this looked particularly odd in paintings with gilded areas, mainly because of the moving optical axis). Finally, the system could not be operated by a photographer and could realistically only image one painting per day. We were not, however, willing to accept the colour quality and resolution available from commercially-available digital cameras at the time (1993). The commercial partners in the VASARI project shared our feelings and together we secured follow-on funding (with a slightly altered consortium), for the MARC (Methodology for Art Reproduction in Colour) project.

3. THE MARC PROJECT

The MARC project built on the results from VASARI, but was specifically targeted towards producing high-quality printed colour reproductions of paintings, a valuable source of income for the museum partners. MARC required two developments: a new imaging system suitable for use by photographers, and a system for calibrating a conventional offset printing press to receive the images.[9]

The principal innovation in the MARC camera was to move the chip within the camera rather than move the entire camera and lighting system. By moving the CCD across the focal plane of the lens we were able to produce an image of up to 20,000 by 20,000 pixels.[10] As it was not possible to light an entire painting through the interference filters used in VASARI, the MARC camera used white lights and filtered the light in the camera using a conventional three-colour mosaic filter on the surface of the chip. Although this reduced the colour accuracy compared with VASARI, by a careful choice of filters, the MARC camera, with its 12-bit output, still managed a respectable 3 ΔE_{ab} units average colour error. We felt that the benefits of unlimited painting size, fast scanning, and photographic lights were worth it. We also worked hard on the camera interface, to make it useable by non-scientists.

The other aspect of MARC was offset press calibration, so that we could produce accurate colour images of paintings in printed catalogues. The process was to print a colour chart on the target press (getting as close to final print settings as possible), and then to use a calibration module developed by Crosfield Electronics in the project to generate a large look-up table that converted from stored CIELAB to CMYK dot-percent values.[11] To demonstrate the technical results from the final MARC system, in 1995 the consortium published a catalogue of Flemish Baroque Painting in which all 80 colour plates were made from digital images that had been acquired in one of the collaborating museums using the MARC camera.[12] Most of the problems that were encountered in producing this book were associated with adapting to the working practices of the printing business and persuading them to use the methods we had developed, even when the results appeared, to their eyes, to be unsatisfactory. Nevertheless, we eventually managed to calibrate the press in Switzerland used for the book and persuaded the operators not to alter the settings once they had been set. Five of the images were proofed and the remaining images were then printed with no conventional proofing. When we took the finished book into the galleries to make a direct comparison, it was clear that although the matches were on the whole very good, there were a few minor unresolved problems, particularly in the dark areas.

4. MARKING TIME

We hoped that once the MARC book was finished we would go on to use digital images as the basis for further publications, but this was not straightforward. Within MARC we had been in the privileged position of having the publisher (Hirmer Verlag) and printer (Schwitter AG) as partners in the project, with many of the costs of book production offset by the research grant. We were thus able to 'buy' the press for the time it took to go through lengthy calibration procedures and to subsidise production costs that would otherwise have rendered the book too expensive to sell. Another potential problem for future book or catalogue production was that although the MARC camera was easily usable by photographers, based as it was on a standard Bronica 6 x 6cm plate camera, the time taken to produce an image was too long. While the acquisition time was around 40 minutes (no more than required to make and check a transparency) calibration and storage needed several more hours. As a result, any problems with the acquisition might not be apparent until the painting had left the studio and returned to display.

Nevertheless, we continued work to improve the MARC camera and acquisition procedure and by 1997, had handed the day-to-day task of imaging paintings to our photographic department. The lighting was changed from tungsten-halogen to HMI. Because the HMI lights were more powerful, but did not generate so much heat, we were able to increase the light level during imaging without desiccating the painting; the increase in light level allowed the lens aperture to be closed slightly, giving better depth of focus while still reducing the exposure time, an important consideration for the conservation of the paintings given the increased illuminance. The colour temperature of the HMI lights is closer to our reference illuminant (D65) than the previous lights and we immediately obtained improved colour accuracy, with an average colour difference for the Macbeth chart of around 2 ΔE_{ab} units. As images of more paintings became available, so interest in using the images, for example in short-run applications like poster and leaflet production, became greater and requests began to be made for particular paintings to be imaged. Requests also came from colleagues in the Conservation Department to have full-size prints of images to use alongside the original during restoration.

Digital images from the VASARI and MARC systems had not been used in the Gallery's visitor information system, the *MicroGallery*, nor in the web-site, partly because neither of these could handle image files of the size generated by the system and partly because VASARI/MARC images were only available for a small proportion of the collection. More telling was the decision not to use the images that were available, as even at reduced resolution they were of such high quality that the images produced from scanning transparencies looked poor alongside. This favourable comparison was reinforced by some experiments in which we sent digital images out to be written as large format transparencies. These 'digital transparencies' were compared with transparencies made directly from the painting by conventional means and were felt by our photographers to be clearly better, in terms of colour accuracy and tonal range.

As mentioned above, a major obstacle to the use of the high-resolution images as our principal source of visual information was the image file size, as a consequence of which huge storage space was required and transmission across the Gallery, or external, networks would have been painfully slow. As part of another European–Canadian project (VISEUM) we had developed a means of browsing very large colour accurate-images across the commercial internet, at reasonable speed and without loss of quality.[13,17] We reasoned that if this worked on the internet, then we could certainly gain very rapid internal access to our MARC image collections using the fast network being installed in the Gallery at the time.

5. MARC II : THE SCANNING INITIATIVE

The final element in the decision to go ahead with a comprehensive colour-accurate high-resolution imaging programme within the Gallery was the availability of an improved version of the MARC camera. This camera had been developed by CCD Videometrie, the makers of the original MARC camera, for use at the Library of Congress in Washington DC. The new MARC II camera is based on a higher resolution CCD (1300 x 1030 elements), again using micro- and macro-positioning to increase this resolution to around 10,000 by 10,000 pixels. The greater sensitivity of the CCD allows the exposure time to be significantly reduced which, combined with faster movement of the chip and more efficient data read-out, reduces the time required to acquire, calibrate and store an image of a whole painting to less than three minutes. In common with the VASARI and original MARC systems, each image is calibrated by first imaging the Macbeth chart and converting the raw camera signals to CIELAB data. A very low dark current, 14-bit A/D conversion, and a system whereby the positioning electronics shut down during image read-out to reduce cross-interference, yield high quality images of up to 10,000 by 10,000 pixels.

The Gallery thus made a decision to go ahead with an ambitious project — to scan all the so-called 'main floor' paintings over a period of eighteen months; the main floor paintings include all the important paintings in the Collection. This scanning initiative would run alongside the development of the Gallery's new collection management system (VERMEER), so that the images could be integrated into the system. For the first time, the Gallery committed its own funds to high-quality digital imaging, although the cost of one of the MARC II cameras was met by a sponsor. As well as the cameras and computer equipment required for the project, extra staff were needed. A digital photographer, an assistant to process and store the images and an administrator were employed by the photographic department and extra staff were taken on by the art-handling department to cope with the increased number of paintings that would need to be taken from display and removed from their frames for imaging. As important as the quality of the images produced has been the administration of the flow of paintings through the studio. In contrast to the VASARI and original MARC systems, where the speed of imaging was the critical factor, the rate at which images are made with the MARC II camera is determined by the practicalities of delivering paintings to the studio and, to a lesser extent, the rate at which the images can be stored as multiple copies on CD-ROM.

As the National Gallery collection is modest in size, the VERMEER system can contain not only the images, but all the textual information for each painting, ranging from the label text used in the Gallery to bibliographic details and the full entry from the scholarly catalogues. Thanks to the donation of large server by Hewlett Packard, we have been able to store high-resolution versions of the images on-line. For each painting, the 'parent' image, the highest resolution CIELAB image in a 32-bit format, is stored off-line, although now the system has been upgraded from 1.0 to 1.7Tbytes these will soon be available for specialist use. From the 'parent' image full resolution and reduced resolution TIFF images of *c*.200 and 30Mbyte respectively, are created as well as reduced resolution and 'thumbnail' JPEG images for use on the web-site. The first target is to image 928 paintings by the end of June 2001; it is expected that *c*.950 paintings will be imaged by this date. Funding having now been secured for the second phase of the imaging initiative, we are on target to image the entire Collection (*c*.2250 paintings) by the end of 2002.

6. PRINTING REVISITED

With many of the important paintings now on-line as high-resolution images from the MARC II camera, there has been renewed interest in printing directly from digital files. In the period since we last actively explored using offset presses, immediately after the MARC project, we have been fortunate enough to be given several large-format inkjet printers by Hewlett Packard as part of a continuing research collaboration. We are now using the procedure that we developed for accurate reproduction on the inkjet printer in trials with offset presses, having failed to resolve the outstanding issues with the MARC calibrator module, including the black-point problem.

The method we now use applies a set of simple linear transformations to the stored CIELAB data to match the input requirements of the reproduction technique; either one of our in-house inkjet printers or one of the repro houses used by the Gallery. We use the 24 colours of the Macbeth chart plus a twenty step grey scale to develop this transform. The three transformations that we apply are:

1. Linear scale and offset of L*: this transforms the absolute colorimetric values used for storage with respect to the paper white, surface finish and the black point of the print system (we have found that the inkjet printers give a better black than the offset press).

2. For each L* value a lookup table provides an a* shift and a b* shift: this compensates for the colour cast of the paper and partly compensates for the difference in colour temperature between the calibration illuminant and the viewing illuminant. This ensures that the grey scale remains neutral throughout its entire length. For the offset press under study, we have found that the a* and b* shifts are independent of L*, whereas inkjet printers often show a dramatic change in colour along the grey scale.

3. The a* and b* values are scaled to adjust the saturation: this compensates for the effect of the surface finish of the paper and makes a simple compensation for gamut-mapping effects.

The results to date from this very simple model are promising. Images that we have sent to the printers (as LABTIFF files) after 'tweaking' our CIELAB data have reproduced well on both an offset press and a high-quality (IRIS) proofing press, as the profiles for the devices have been set up to give a good match. Based on the quality of the reproduction of the colours from the Macbeth chart, the colour difference (from original object to final reproduction) is as low as 2.6 ΔE_{ab} units for inkjet prints and 4.1 ΔE_{ab} units from the offset press.

We have chosen to keep our own camera calibration system to produce CIELAB data, rather than use the ICC profile mechanism since, as a research group, wee feel that we need complete control over colour measurement process. Even were we to use ICC profiling to characterise the input and output devices, it would still be necessary to make fine adjustments of the type described above to account for differences in surface finish between original object and print, and to control the gamut mapping and colour temperature match.

In the next year or so we hope to improve our colour matches by using a larger colour chart, the Macbeth DC chart, and by incorporating a more sophisticated conversion between illuminant colour temperatures, to account for the preference for D50 in the reprographics field.

7. CONCLUSIONS

Eighteen years after the prototype system for colour measurement by image processing was presented at the IIC in Washington DC, two of the museums from the original VASARI consortium who are still collaborating together, the National Gallery and the Bayerischen Staatsgemäldesammlungen, presented a joint paper to the IIC conference in Melbourne,[16] reviewing the past ten years' research and presenting recent results in the technical examination of paintings using image processing. We have continued to improve the VASARI system for making scientific images, incorporating a new camera, lighting system and easel. We now acquire 12-band images, having extended the spectral range into the near infrared.

Getting the images onto disk has proved to be the easy part, although we could not have predicted this at the outset; controlling the quality of any output, particularly when responsibility for reproduction passes outside the Gallery, has proved much more difficult and remains one of our main challenges for the future.

ACKNOWLEGEMENTS

The MARC and VASARI projects were funded by the European Commission's ESPRIT programme. VASARI involved: The Doerner Institut, Brameur Ltd., Birkbeck College London, Telecom Paris/ENST, Thomson-CSF LER, and TÜV-Bayern. The ESPRIT III project MARC also involved: CCD Videometrie, Thomson Broadband Systems, Crosfield Ltd., Hirmer Verlag, and Schwitter AG. We are grateful to Hewlett Packard Laboratories for an ongoing external research grant and numerous donations of equipment.

REFERENCES

1. W. D. Wright, "A Mobile Spectrophotometer for Art Conservation", *Color Research and Applications* **6**, 1981, pp. 70–4.
2. G. Thomson and S. Staniforth, "Identification and Measurement of Change in Appearance by Image Processing", *Science and Technology the Service of Conservation*, ed. N.S. Brommelle and G. Thomson, IIC, London, 1982, pp. 159–61.
3. D. Saunders, "Detection and measurement of color change in paintings by digital image processing", *Proceedings of the Society of Photo-Optical Instrumentation Engineers* **1075**, 1989, pp. 405–15.
4. K. Martinez, J. Cupitt, and D. Saunders, "High Resolution Colorimetic Imaging of Paintings", *Proceedings of the Society of Photo-Optical Instrumentation Engineers* **1901**, 1993, pp. 25–36.
5. D. Saunders and J. Cupitt, "Image processing at the National Gallery : The VASARI project", *National Gallery Technical Bulletin* **14**, 1993, pp. 72–85.
6. A. Burmester, J. Cupitt, H. Derrien, N. Dessipris, A. Hamber, K. Martinez, M. Müller, and D. Saunders, "The Examination of Paintings by Digital Image Analysis", *3rd International Conference on Non-Destructive Testing, Microanalytical Methods and Environmental Evaluation for Study and Conservation of Works of Art*, Viterbo, 1992, pp. 201–214.
7. J. E. Farrell, J. Cupitt, D. Saunders, and B. A. Wandell, "Estimating Spectral Reflectances of Digital Images of Art", *Proceedings of the International Symposium on Multispectral Imaging and Colour Reproduction for Digital Archives*, Society of Multispectral Imaging of Japan, Chiba., 1999, pp. 58–64.
8. D. Saunders, H. Chahine, and J. Cupitt, "Long-term Colour Change Measurement: Some Results After Twenty Years", *National Gallery Technical Bulletin* **17**, 1996, pp. 81–90.
9. J. Cupitt, K. Martinez, and D. Saunders, "Methodology for Art Reproduction in Colour: the MARC project", *Computers and the History of Art*, **6**, 1996, pp. 1–20.
10. R. Lenz, R. Beutelhauser, and U. Lenz, "A microscan/macroscan 3 x 12 bit digital color CCD camera with programmable resolution up to 20,992 x 20,480 picture elements", *Proceedings of the Commission V Symposium: Close range techniques and machine vision, Melbourne, Australia, International Archives of Photogrammetry and Remote Sensing* **30**(5), 1994, pp. 225–30.
11. L. W. MacDonald, J. M. Deane, and D. N. Rughani, "Extending the Colour Gamut of Printed Images", *The Journal of Photographic Science* **42**, 1994, pp. 97–9.
12. A. Burmester, L. Raffelt, K. Renger, G. Robinson, and S. Wagini, *Flämische Barockmalerei: Meisterwerke der Alten Pinakothek München; Flemish Baroque Painting: Masterpieces of the Alte Pinakothek München*, Hirmer Verlag, München, 1996.
13. K. Martinez, J. Cupitt, and S. Perry, "High resolution Colorimetric Image Browsing on the Web", *Computer Networks and ISDN Systems*, **30**, 1998, pp. 399–405.
14. D. Saunders, J. Cupitt, R. Pillay, and K. Martinez, "Maintaining Accurate Colour in Images Transferred Across the Internet", *Colour Imaging in Multimedia*, Derby, 1998, 227–36.
15. K. Martinez and S. Perry and J. Cupitt, "Object browsing using the Internet Imaging Protocol", *Computer Networks*, **33**, 2000, pp. 803–10.
16. D. Saunders, A. Burmester, J. Cupitt, and L. Raffelt, "Recent applications of digital imaging in painting conservation: transportation, colour change and infrared reflectographic studies", *Tradition and Innovation: Advances in Conservation*, ed. A. Roy, and P. Smith, IIC, London, 2000, pp. 170–6.

Color Strategies for Image Databases

Sabine Süsstrunk*, Audiovisual Communications Laboratory,
Swiss Federal Institute of Technology (EPFL), Lausanne, Switzerland

ABSTRACT

In this paper, color encoding strategies for different image database applications are discussed. The color image workflow is examined in detail, and master and derivative file encoding strategies are outlined in relation to capture, maintenance, and deployment of image files. For the most common image database purposes, recommendations are given as to which type of color encoding is most suitable. Advantages and disadvantages of sensor, input-referred, output-referred, and output device specific color encodings are discussed in relation with image usage. The role of ICC color management in an image database environment is also considered.

Keywords: Image Databases, Master and Derivative Image Files, Color Image Workflow, Color Encoding, ICC

1. INTRODUCTION

Image database is a very general term for describing a repository of digital images, deployable for various purposes. An image database may contain any number of images, from a few hundred to millions of image objects. These image files can either *represent* digital reproductions of original artwork, such as photographs or paintings, or can *be* the original digital artwork, such as if an original scene was captured with a digital camera. The purpose of image databases vary: they can either contain digital image files that represent scenes or replace original artwork; they can contain digital image files that only represent a reproduction of the scene or original artwork, optimized for a given use and workflow; or they can contain a combination of both. It is usually implied that images should be accessible and usable over a long time frame, and should keep their value to the user indefinitely. The database should also be easy to manage, i.e. digital images should be deployed, processed, converted, and transmitted automatically. All this implies that certain strategies of initial image capture and processing techniques and a certain standardization of the workflow should be well defined before an image database project begins.

The usage of the digital image files ultimately dictates image quality and the necessary processing steps to be taken before archiving and delivering images. The higher the quality, the more expertise, time, and cost are associated to the generation, processing and storage of image files. While this paper focuses primarily on color issues relating to the capture, maintenance, and deployment of digital images in a database, the same applies, of course, to other image database issues, such as capture and maintenance of text and administrative metadata, storage issues like file format and media, and other image processing steps like noise filtering and sharpening. Following are three cases of most common digital image usage that define quality criteria [1]:

The digital image is only used as visual reference: the required digital image quality is low, both in terms of spatial and color resolution content. The display is limited to a screen or a low-resolution print device. Exact color reproduction is not critical; the image has only to "resemble" the original artwork or scene. Images are usually compressed to save storage space, but primarily delivery time. For cases where original artwork is digitized, it suffices to use existing photographic duplicates of the originals and low-resolution scanners. Analog, low-cost digital cameras can be employed when capturing scenes.

The digital image is used for print reproduction: the requirements for the digitizing system depend on the desired reproduction quality. Limiting output to certain spatial dimensions and a certain color encoding will define the digitizing devices and initial processing. Commercial digital image archives, such as Corbis Corporation [2,3] and Getty Images, Inc. [4], and many cultural institutions digitize their analog image collections with this purpose in mind. Similarly, professional photographers who use digital cameras will build a collection of such images, and therefore an image database, over time. Commercially available scanners, digital cameras, and imaging software can produce image files for such applications.

The digital image represents a "replacement" of the original in terms of spatial and color information content: this goal is the most challenging to achieve. The information content in terms of pixel equivalency varies from original to original. In terms of scanning original photographs, for example, it is not only defined by film format, but also by emulsion type, shooting conditions and processing techniques. Color information can only be captured adequately if the digitizing device supports the originals' color gamut in terms of encoding bit-depth and lack of metamerism. Such image library applications can be found in museums and other collections, where colorimetrically accurate capture is important, and/or the physical artwork is too fragile to be handled daily, or is already deteriorating so that the image content as seen today needs to be preserved. Producing these files usually requires specialized hardware and software.

Each of the usages outlined above will determine the quality of the *digital master* to be archived. It represents the highest quality file that has been digitized [5]. Since it represents the information that is supposed to survive long term, the encoding has to be appropriate for all current and future–as yet unknown–usage. The choices made in the initial digitization and processing of images are final and can usually not be reversed, and therefore great care should be given in designing the technical specifications of the initial capturing process. For daily use, *derivatives* of digital master files can be created, which are encoded according to their purpose. In many image databases, various image derivatives are found, each appropriate for a different application [6]. See Table 1 for a comparison of different image database usage and recommended encoding specifications.

Table 1: Comparison of different image database purposes and recommended encoding specifications.

Master file	Visual Representation	Print Reproduction	Replacement of the Original
Purpose of the image database	• Consumer (digital camera files, print scanning) • On-line visual representation (electronic catalogues, image kiosks, insurance databases) • Low-end print representation (prints up to 4 x 6 inch)	• Commercial image libraries (picture agencies, publishing houses, news agencies) • Professional photographers • Museums, cultural, and government institutions • Consumer printing (8 x 10 inch)	• Museums, cultural, and government institutions with high quality demand and/or fragile original artwork.
Derivatives	• Screen resolutions • Thumbnails	• Lower print resolutions • Screen resolutions • Thumbnails	• Print resolutions • Screen resolutions • Thumbnails
Spatial Resolution[1] (for one dimension)	• Thumbnails: ≤ 250 pixels • Screen resolution: ≤ 1600 pixels	• Dependent on the reproduction intent, the size and quality of the original artwork, and/or limited by the maximum spatial resolution of the digitizing device. • ~ 2000 to 7000 pixels	• Dependent on the size and quality of the original artwork, and/or limited by the maximum spatial resolution of the digitizing device.
Image encoding of master file	Output-referred	Output-referred	Sensor Input-referred
Compression of the master file	None, lossless, or lossy (JPEG, JPEG2000)	None or lossless	None or lossless
File Format of the master file	Exif, TIFF, JFIF, JP2	EXIF, TIFF, JPX	TIFF, JPX

[1]Note that pixel dimension is only one parameter describing the spatial resolution of a digital image file. Other factors, such as the size, resolution and sharpness of the original, the spatial frequency response of the digitizing system, the quality of pixel reconstruction and interpolation algorithms, and the resolution of the output device all influence the resolution and apparent sharpness of the image reproduction [7,8].

2. DIGITAL IMAGE COLOR WORKFLOW

The color workflow of a digital image can be generalized as follows (see Figure 1). An image is captured and encoded into a sensor or source device space, which is device and image specific. It may then be transformed into an input-referred image representation, i.e. a color encoding describing the scene's or original's colorimetry. In most workflows, however, the image is directly encoded from source device space into an output-referred image representation, which describes the image appearance on some real or virtual output. If the output-referred color space describes a virtual output, then additional transforms are necessary to encode the image into output coordinates, which are dependent on the specific device [9,10].

According to the CIE, a *color space* is a geometric representation of colors in space, usually of three dimensions [11]. The basis functions are color-matching functions, usually CIE color matching functions. Spectral spaces are spanned by a set of spectral basis functions. The set of color spaces is therefore a subset of the set of spectral spaces. However, in practice, the difference is often neglected, and all representations of color in space are called a "color space." *Color encoding*, on the other hand, refers to a quantized numerical representation of an image in a color space including any associated data required to interpret the color appearance of the image [12]. A color space can have more than one color encoding associated with it. For example, CIE XYZ is a color space, but the encoding of images within the color space, and the image appearance associated with it, is determined by the color encoding specifications such as viewing conditions, transformation from device encoding and quantization. These color encodings are also often called "color spaces," which leads to some confusion in the imaging literature and industry. Note also that color reproduction quality is not necessarily defined by the color space an image is encoded in, but by the quality of the transformation applied to the image data to encode the image into a given color space.

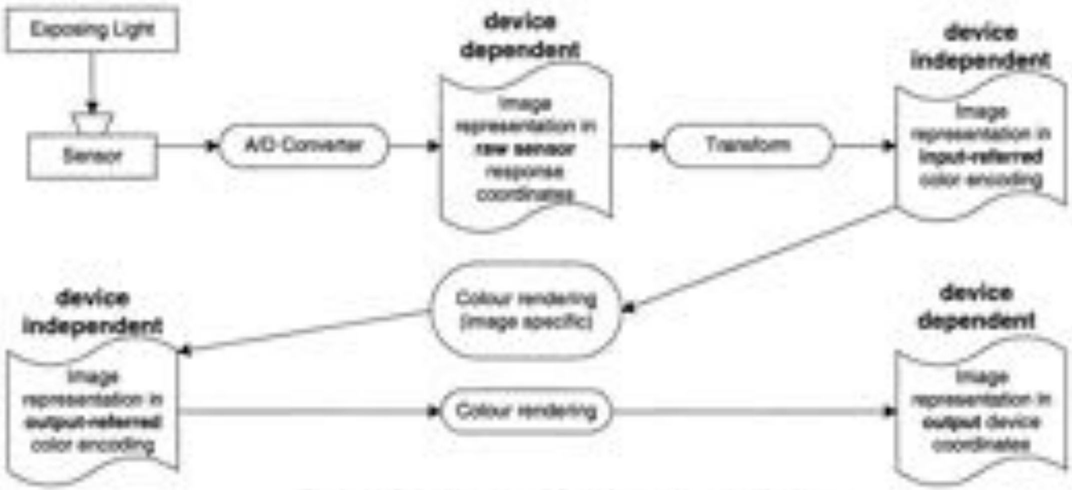


Figure 1: Color image workflow from capture to display.

2.1 Sensor Encoding

When a scene or original is captured, either by a scanner or by a digital camera, its first color encoding is device and scene specific, defined by illumination, sensor, exposure, and filters. In the case of scanners, the illuminant should be nominally constant for each image. With natural scenes captured by digital cameras, the illumination can vary from scene to scene, and even within a scene, and usually has to be estimated. The spectral sensitivities of the filters for a digitization device should be chosen, if possible, according to the original. When scanning color negatives, for example, the filters used should be optimized to the film dye spectral sensitivities. Filters for scanning color positives, as well as digital camera filters, are usually broader and overlap. Out of image system considerations such as noise and speed, it is rare to find filters in commercially available capturing devices that match the color matching functions of the human eye. As a result, device metamerism can occur, i.e. two different colors that can be distinguished by the human eye can be encoded to the same digital values and vice versa. Depending on the application and originals, that effect is more or less negligible. If very precise color reproduction is required, the use of a multi-spectral capturing system is appropriate. Such systems are usually employed in a museum environment where original paintings are scanned. Depending on the system, they consist of six to eight filters with varying bandwidth and peak spectral sensitivities [13,14,15]. XYZ tristimulus values can then be calculated from the different channels for a colorimetric representation of the original.

When images are archived in sensor space, camera or scanner characterization data, such as device spectral sensitivities and illumination data have to be maintained so that further color and image processing is possible. Additionally, it has to be clearly noted which processing has already been applied to the image. The image should be saved in a standard file format, such as TIFF, whose encoding specifications are widely published [16], and libraries are available. The International Organization for Standardization (ISO) has developed a specific TIFF format called TIFF/EP [17], which has defined tags for the necessary information that has to be stored to further color process images from digital cameras, such as spectral sensitivities, sensing method, illuminant, opto-electronic conversion function (OECF), color-filter array pattern, and more. TIFF/EP can also store tags about the camera shooting condition that are used to determine noise filtering, sharpening, and preferred reproduction algorithms. Similar tags can easily be developed for scanning applications. It is also advantageous to store as much information as possible about the original artwork, such as original size, reflection characteristics, and film emulsion type in case of photographs. In general, it is always advisable to archive more, rather than less, information about the original scene or artwork, the digitizing system, and the lighting conditions.

If the capturing conditions are always the same, it might be advantageous to store the color metadata not in the file, but in a separate database, which allows the creation and definition of the tags necessary for an individual application. However, in real situations it can occur that the image data and metadata are de-synchronized, usually due to human error. Storing image metadata in a database and in the master file can prevent that this has a negative effect on future automated processing.

Images encoded in raw-data, or sensor space, are not viewable without further processing. However, they represent the true archive files necessary for many high-end image database applications. Any further processing can degrade the image, as algorithms are based on today's know-how and might be improved in the future. Additionally, these transforms are not always reversible, even when stored with the image files. In most cases, the hardware and software necessary to create and archive such master files is not commercially available and has to be developed in-house or with academic or industrial partners [18,19].

2.2 Input-Referred Image Encoding

The transformation from raw data to input-referred, device-independent color encoding is image and/or device specific and includes the following steps: linearization, flare correction and pixel reconstruction (if necessary), white point selection, followed by a transformation to the input-referred color space.

The purpose of input-referred image encoding is for the image to represent an estimate of the scene's or the original's colorimetry. An input-referred encoding maintains the relative dynamic range and gamut of the scene or original. A scene-referred encoding describes the input-referred encoding of an original scene, where as an original-referred encoding describes the input of original artwork. Scene-referred encodings usually need to support a higher dynamic range.

The quality of the colorimetric estimate depends on the ability to choose the correct scene illuminant, and the correct transformations from device RGB to standard input-referred color encodings. The transformation is usually based on minimizing an error criteria, such as minimizing CIE XYZ, CIE ΔE_{Lab}, CIE ΔE_{Lab94}, or CIE ΔE_{Luv} [20]. The choice of which error criterion to use, and therefore the method of calculating the transform, is input system and application dependent [21]. If the illuminant spectral power distributions, the reflection spectra of the original artwork, the spectral sensitivities of the filters and CCD, and the OECF of the digitizing system are known, the transform can theoretically be calculated. However, because digitization devices have spectral responsivities that are usually not equivalent to a set of color-matching functions, this transform cannot be perfect for all possible original stimuli. In practice, it is therefore advisable to image a test chart that has similar or identical reflection or transmission spectra as the original's to be digitized. For many applications, the commercially available MacBeth ColorChecker™ [22] is used as target. For photographic slide and print scanning, an IT-8 [23] target on the same film or print material can be imaged. When paintings are digitized, a target with representative color samples should be used so that the transform is based on realistic reflection spectra.

Examples of color encodings that are used to encode an estimate of the scene's or original's colorimetry are CIE XYZ, CIE Lab, CIE Luv, Photo YCC [24], and RIMM RGB [25]. Input-referred image encodings can be used for archiving master image files when it is important that the original colorimetry is preserved so that a facsimile can be created at a later date, and the transformation from sensor encoding to input-referred encoding is unambiguous. Another advantage of input-referred encodings, especially if the images are encoded in higher bit-depth, is that they can always be tone and color processed for all kinds of different rendering intents and output devices at a later date, without having to maintain all the device characterization data necessary to process a raw sensor data encoded image.

2.3 Output-Referred Image Encoding

Output-referred image encodings refer to image representations in color spaces that are based on the colorimetry of real or virtual output characteristics. Images can be transformed into output-referred encodings from either source or input-referred image encodings. The complexity of these transforms varies: they can range from a simple gamma-function, such as is employed by video encoding [26] to complicated image dependent algorithms. The transforms are usually non-reversible, as some information of the original scene encoding is discarded or compressed to fit the dynamic range and gamut of the output. The transforms are image specific, especially if pictorial reproduction modeling is applied.

Most commercially available scanners and digital cameras, except for the high-end models, automatically apply some preferred pictorial reproduction model and deliver files in an output-referred encoding. With scanners and high-end digital cameras, the user can additionally "manipulate" the model by changing color, saturation, contrast, etc. As the transform algorithms – and the resulting image reproduction quality – are the differentiating factors between manufacturers and their devices, it is hard to obtain much information about them. Additionally, these transforms can never be standardized, as most images are subjectively evaluated, and preference varies between observers. It is also difficult to commercially obtain software that automatically applies preferred reproduction models to sensor or input-referred encoded images, especially if the images are encoded with higher than 8-bits/channel. The closest to such applications are high-end scanner and digital camera drivers that allow importing high bit-depths data files. However, they are usually only capable to interpret the image files coming from their own devices, as the device metadata is stored in the driver and not in the image file. This is the main reason that commercial image archives, as well as many cultural institutions, archive their master files in an output-referred encoding. It is to be expected that the imaging industry will soon address this missing piece in the image production pipeline.

Output-referred color encodings, based on real or virtual output devices, are e-sRGB [27], sRGB [28], ICC PCS [29], ROMM RGB [30], Adobe 98 RGB [10], and SWOP CMYK [31]. Output-referred image representations can also be encoded in other color spaces, such as CIE Lab, CIE Luv, Photo YCC [24], YUV [32], and YCrCb [32].

Archiving images in output-referred encoding is appropriate for image libraries that archive primarily master files whose purpose is to be a reproduction of the original, and not a representation. Most current image libraries fall into this category, as commercial hardware and software are available for this task. The choice of which output-referred color encoding is appropriate for the master file and its derivatives depends on the database applications. However, whenever possible, the same encoding should be chosen for the master files, especially when large number of images are processed to derivatives at a later date. In general, all image library derivatives are encoded in output-referred representations.

2.4 Output Device Specific Encoding

Transforms from output-referred encodings to output coordinates are device and media specific. If an output-referred color space is equal or close enough to the real device characteristics, such as "monitor" RGBs, no additional transformation to device specific digital values is needed. For other output applications, such as print, there is a need for additional conversions. This can be accomplished using the current International Color Consortium (ICC) color management workflow [29]. An "input" profile maps the reproduction description in the output-referred space to the profile connection space (PCS), and the output profile maps from the PCS to the device and media specific values. However, if the gamut, dynamic range, and viewing conditions of the output-referred encoding are very different from those of the actual output, it might be more advantageous to use a reproduction model that allows image specific transforms than to use the current ICC color management systems that only contains "device-to-device" mapping. Adjusting for different viewing conditions and dynamic range often are not implemented in current applications, and out of gamut colors require image dependent mapping for optimal reproduction.

Apart from some graphic arts applications, it is rare today that images are archived in output coordinates, such as device and media specific RGB, CMY, or CMYK spaces. However, there are many legacy master files, such as CMYK separations and RGB monitor specific images that need to be color managed so that they can be viewed and printed on other devices. If the color encoding is known and sufficiently characterized, it is possible to "reverse"-transform these images to another, better suited color encoding. If the two color encodings are similar and the viewing conditions assumed to be the same, for example Apple RGB and sRGB, the reverse transform can simply be executed by applying the inverse of the first non-linear encoding transfer function, followed by chromatic adaptation transform (if necessary), followed by a linear matrix conversion to the new color space, and then again perceptual encode using the new non-linear transfer function. This simple transform will clip colors that are outside of the destination gamut. Therefore, if the gamuts of the two encodings have a different shape, gamut mapping should be applied to map from one encoding to another. This can be accomplished using an ICC profile. However, if the gamuts, white-point, and viewing conditions are very different, an image dependent reproduction model might be more appropriate. Each transformation and resulting new quantization can introduce visible artifacts. It is therefore recommended that only new derivatives are "reverse"-transformed, and a copy of the original master file is kept. If, in a few years, other "standard" output-referred encodings based on new output devices become popular, then new derivatives can be created from these master files.

3. COLOR SPACES AND COLOR ENCODINGS

The correct color space and the correct color encoding parameters depend on the particular image application. The following parameters need to be considered [12]: extent of color gamut, perceptually linear tone-scale encoding to minimize the bit-depth needed to encode an image, dynamic range, illuminant white-point, viewing conditions, quantization efficiency, and compression. Table 2 summarizes the most important attributes of input referred and output-referred color encodings.

Table 2: Attributes of input-referred and output-referred color encodings.

	Input-referred encoding	**Output-referred encoding**
Image representation	Colorimetric estimate of a scene/original	Colorimetric estimate of a reproduction
Color gamut	Large enough to encompass most scene/original colors	Large enough to encompass most output devices
Perceptual uniformity (transfer function)	Data is optionally encoded using a transfer function for approximate perceptual uniformity (invertability desired)	Data is optionally encoded using a gamma-type power function to approximate perceptual uniformity on the output device (invertability desired)
Dynamic range	Must handle a scene luminance ratio of at least 10 000:1, or the luminance ratio of the original	Must handle an image luminance ratio of at least 1000:1
White point	Should accommodate floating white points or chromatic adaptation to a fixed white point	Fixed white point determined by reproduction viewing conditions (D50, D65)
Viewing conditions (linkage to color appearance)	Luminance level, viewing surround, adapted white point, and viewing flare, as typical of outdoor environments for scene-referred encodings, typical of original viewing conditions for original encoding	Luminance level, viewing surround, adapted white point, and viewing flare, as typical of indoor environments
Quantization/ Encoding	Quantization errors not visible on smooth, noiseless ramps Extended bit-depths encoding desired (10, 12, 16-bit per channel)	Quantization errors not visible on smooth, noiseless ramps. 8, 10, 12 or 16-bit encoding (8-bit for applications)
Compressibility	Not very important	Importance dependent on the imaging application (easy conversion to YCC color encoding)
Usual color encodings	CIEXYZ, CIELAB, CIELUV, RIMM RGB, Photo YCC	e-sRGB, sRGB, ROMM RGB, Adobe RGB 98, YCbCr, Photo YCC (legacy: Apple RGB)
Applications	Master files for high-end applications (replacement of the original)	Master files (for print reproduction): e-sRGB, ROMM RGB, Adobe RGB 98, Photo YCC Master files (for screen viewing): sRGB, YCbCr Derivatives for print reproduction or screen viewing

3. THE USE OF ICC COLOR MANAGEMENT IN IMAGE DATABASES

The use of ICC profiles in image database production and deployment can be manifold, and its usage needs to be discussed in the right content. It is not recommended for image libraries to archive master files with only ICC profiles to characterize the color encoding. Current ICC profiles do not contain device characterization data, they only contain the transformation from a device specific space to the PCS. For example, it is impossible to determine the sensor spectral characteristics of a scanning system from a scanner profile, as the sensor data was transformed to an output referred encoding and the specific transforms not retained. The image encoding is therefore determined by the device and non-standardized, and the only clue about its characteristics is given by the profile. Additionally, the profile and PCS specifications have evolved, and will continue to evolve. While it is reasonable to assume that applications are capable of reading older version profiles for two to three generations, accurate processing of these older profiles in combination with newer profiles is not guaranteed. In an image database environment where color transformation accuracy and longevity are important, updating all the different profiles associated with different devices and originals can be difficult to manage. It is therefore recommended that output-referred master files be archived in a well defined, if not standard color encoding. In that case, only one profile needs to be updated when profile specifications change. An ICC profile of the color encoding can be kept separately in a database, and can easily be updated when the specifications change.

The ICC profile associated with an output-referred master file encoding can be used to create derivatives files in other output-referred encodings, or it can be used to directly map to the output device coordinates. Practically, ICC profiles certainly facilitate the production workflow of images, such as for previewing and soft-proofing on a monitor and printing. Therefore, all derivative image files intended for print reproduction should be deployed with an ICC profile. Most pre-press and professional image manipulation programs can read and process them. While using ICC color management does not always guarantee perfect color reproduction, it does communicate an encoding intent. It is up to the user of the derivative files to additionally process the image if so desired.

Thumbnail and screen resolution images should be encoded so that they do not need to be color managed, i.e. their encoding should closely resemble the intended output device. It is not reasonable today to assume that a user's systems and applications are color managed. Indeed, many viewing applications assume today that if no profile is attached to an RGB image file, the file is encoded in sRGB and is displayed as such. If the applications are color management enabled, i.e. most printer drivers for desktop printers, they will transparently transform the image to device specific values.

4. SUMMARY

It is not possible today to give a general color encoding "recipe" for image databases, as the most suitable color encoding is strongly dependent on the purpose of the database, and these vary greatly. In theory, every image database can design its own color encodings optimized for the applications of master and derivative image files. The encoding would either be based on CIE XYZ, CIE Lab, CIE Luv, RGB, YCC or n-channel space. The encoding specifications need to be stored so that future processing – to new derivative files or to create new ICC profiles – can always be guaranteed. However, while an application-specific encoding might be desirable for the master archive file, it is not usually reasonable to use non-standard image encodings for derivatives files. In practice, commercial applications drive most image production workflows and display, and are therefore the recipients of image database derivative files. They only understand a limited number of color encodings, and it is advantageous considering productivity and image quality to keep derivative files in a standard output color encoding. If a (higher quality) master file is available, new derivatives with different encodings for different output-driven purposes can always be generated from these archive files.

REFERENCES

1. F. Frey and S. Süsstrunk, "Image Quality Issues for the Digitization of Photographic Collections," *Proc. IS&T 49th Annual Conference*, pp. 349-353, 1996.
2. Corbis Corporation, www.corbis.com
3. S. Süsstrunk, "Imaging Production Systems at Corbis Corporation," *Proc. ICPS'98*, pp. 232-234, 1998.
4. Getty Images, Inc., www.gettyimages.com
5. J. Holm & N. Judge: "Electronic Photography at the NASA Langley Research Center," *Proc. IS&T 48th Annual Conference*, pp. 436-441, 1995.
6. F.S. Frey and J.M. Reilly, *Digital Imaging for Photographic Collections*, Image Permanence Institute, RIT, 1999. Available at http://www.rit.edu/ipi.
7. ISO 12233: 2000 Photography - *Electronic still picture cameras - Resolution measurements*
8. ISO 16067-1 CD Photography - *Electronic scanners for photographic images – Spatial resolution measurements – Part 1: Scanners for reflective media*
9. J. Holm, "Integrating New Color Image Processing Techniques with Color Management," *Proc. IS&T/SID 7th Color Imaging Conference*, pp. 80-86, 1999.
10. S. Süsstrunk, R. Buckley, and S. Swen, "Standard RGB Color Spaces," *Proc. IS&T/SID 7th Color Imaging Conference*, pp. 127-134, 1999.
11. CIE Publication N. 17.4 – 1987, *International Lighting Vocabulary*
12. ISO 22028-1: Photography - *Electronic still picture cameras – Extended colour encoding for digital still image storage, manipulation and interchange* (Draft 1, March 2001).
13. K. Martinez, J. Cuppit, and D. Saunders, "High resolution colorimetric imaging of paintings," *Proc. SPIE*, vol. 1901, pp.110-118, 1993.
14. P.D. Burns and R.S. Berns, "Analysis Multispectral Image Capture," *Proc. 4th Color Imaging Conference*, pp. 19-22, 1996.
15. H. Sugiura, T. Kuno, N. Watanabe, N. Matoba, J. Hayashi, Y. Miyake, "Development of Highly Accurate Multispectral Cameras," *Proc. International Symposium on Multispectral Imaging and Color Reproduction for Digital Archives*, Society of Multispectral Imaging of Japan, pp.73-80, 1999.
16. *Tagged Image File Format*, specifications 6.0, Adobe, 1995. available at http://partners.adobe.com/asn/developer/pdfs/tn/TIFF6.pdf

17. ISO 12234-2 FDIS Photography - *Electronic still picture cameras – Removable memory - Part 2: Image data format - TIFF/EP*.
18. S. Granger, D. Saunders, K. Martinez, J. Cupitt, "From Vasari to Viseum: the development of methods and systems for the acquisition, display, publishing and transmission of high resolution colourimetric digital images of works of art," available at <http://dn.dial.pipex.com/stewartg/vasari.html>.
19. F. Mintzer, "Developing Digital Libraries of Cultural Content for Internet Access," *IEEE Communications Magazine*, vol 37(1), pp. 72-78, 1999.
20. R.W.G. Hunt, *Measuring Colour*, 3[rd] ed., Fountain Press, 1998.
21. J. Holm, I. Tastl, S. Hordley, "Evaluation of DSC (Digital Still Camera) Scene Analysis Error Metrics - Part 1," *Proc. IS&T/SID 8th Color Imaging Conference*, pp. 279-287., 2000.
22. C.S. McCamy, H. Marcus & J.G. Davidson, "A Color Rendition Chart," *Journal of Applied Photographic Engineering*, vol. 2, p. 95-99, 1976.
23. ISO 12641: 1997 Graphic technology - *Prepress digital data exchange – Colour targets for input scanner calibration.*
24. E.J. Giorgianni and T.E. Madden, *Digital Color Management – Encoding Solutions*, Addison-Wesley, 1998.
25. K.E. Spaulding, E.J. Giorgianni and G.Woolfe, "Reference Input/Output Medium Metric RGB Color Encoding (RIMM/ROMM RGB)," *Proc. PICS 2000*, pp. 155-163; 2000.
26. ITU-R Recommendation BT.709-3: 1998, *Parameter values for the HDTV standards for production and international programme exchange.*
27. PIMA 7667, WD 3.0 – Photography – Electronic Still Picture Imaging – Extended sRGB color encoding, e-sRGB, February 2001.
28. IEC 61966-2-1 (1999): Multimedia systems and equipment – *Colour measurement and management – Part 2-1: Colour management – Default RGB colour space – sRGB.*
29. Spec ICC.1:1998-09, *File Format for Color Profiles*, International Color Consortium. Available at www.color.org
30. PIMA 7666: 2001 Photography – *Electronic Still Picture Imaging – Reference Output Medium Metric RGB Color encoding: ROMM-RGB*
31. ANSI/CGATS TR 001 (1995): *Graphic Technology - Colour Characterization Data for Type 1 Printing.*
32. C. Poynton, *A Technical Introduction to Digital Video*, John Wiley & Sons, Inc., 1996.

* e-mail: sabine.susstrunk@epfl.ch; phone: +41 21 693 66 64; fax: +41 21 693 43 12; mail: EPFL/DSC/LCAV, Ecublens INR-140, CH-1015 Lausanne, Switzerland

Digital Slide Reproduction using Densitometry

Peter R. Fornaro, Rudolf Gschwind, Lukas Rosenthaler [a] , and Pip Laurenson [b]

[a] University of Basel, Institute of Media Sciences
[b] Sculpture Conservator for Electronic Media and Kinetic Arts, Tate, London

ABSTRACT

Many contemporary art collections contain important art installations where artists have used 35mm slides as the primary medium. The number of hours these works are on show makes it necessary to regularly change the slides due to light fading [1]. With funding from the Henry Moore Foundation the conservation department at Tate initiated a project to examine ways in which digital technology could be used to aid the conservation of these works. The aim of the project was to place the original slides in cold storage and explored the possibility of using digital technology to make duplicate sets for display in the gallery [2]. The reproductions needed to be of very high quality both in terms of resolution and colour management.
This paper discusses the use of densitometry to calibrate both device dependent and device independent systems for digitally reproducing 35mm slides using a scanner and a film recorder and the effect of metamery when using slide films which employ different dyes.

Keywords: Densitometry, metamery, slide duplication

1. INTRODUCTION

To duplicate photographical color slides by digital imaging, at least a scanner and a film recorder is needed. All those components do have a characteristic transfer function $f(x, y, z)$. Without any calibration, a difference in hue, saturation and brightness between original and copy must be expected. If the system used can be described completely, it is possible to compensate those changes, which are the result of the duplication process. The aim is to find this function f and its inverse f^{-1}. With this knowledge it is possible to correct the digital data correlating to the original image. The mathematical description of the 3-dimensional transfer function in this study is done by using cubic, 3-dimensional lookup-tables. In this case triangulation is relatively simple and if the size of the lookup-table is large enough (> 9x9x9), simple trilinear interpolation can be used.

2. CLOSED SYSTEM

The simplest case of a duplication process is done within a closed system, i.e., a setup where the system components are not calibrated individually but as a whole (Scanner, Photographic Film, Recorder). We get the knowledge of the system from a calibration process, from where we determine the transfer function of the combined components.

The calibration procedure is done in the following manner:

Synthetically generated test images are produced, which contain patches of known color, i.e., a (9x9x9) or (17x17x17) RGB cube. These test images are exposed onto film with a filmrecorder. These slides are scanned and the R'G'B' values are compared with the originally generated RGB values, which describes the transfer function of our system (Figure 1). The forward interpolation from RGB ⇒ R'G'B' by trilinear interpolation is straightforward. If we have a point P_{ijk} within a cube (indices ijk: 0 0 0 .... 1 1 1), we can define (e : unit color vector), see Figure 2

$$P_{new} - P_{ijk} = k_r e_{red} + k_g e_{green} + k_b e_{blue} \qquad (1)$$

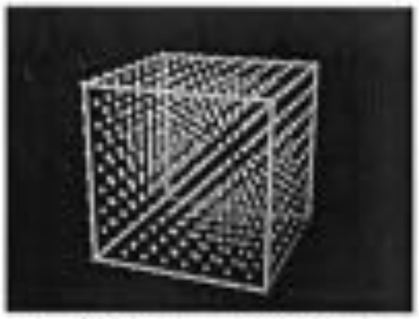
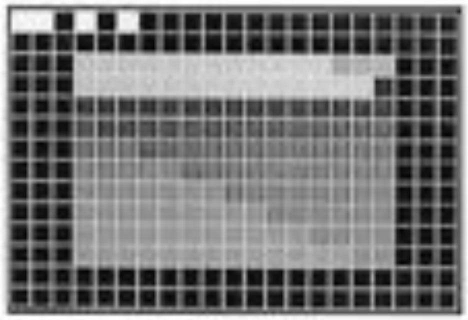
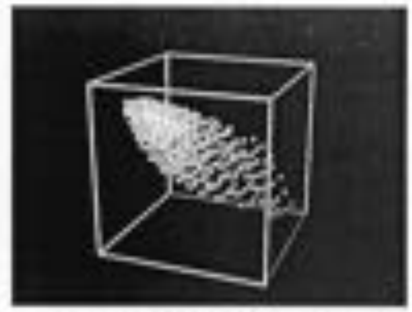


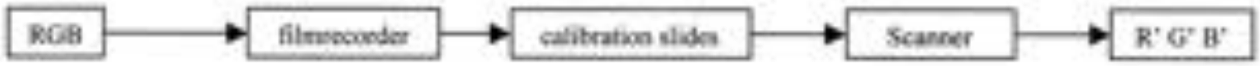
Fig. 1 Synthetically generated color cube



Test patch with reference colors



Band colors after transfer through system



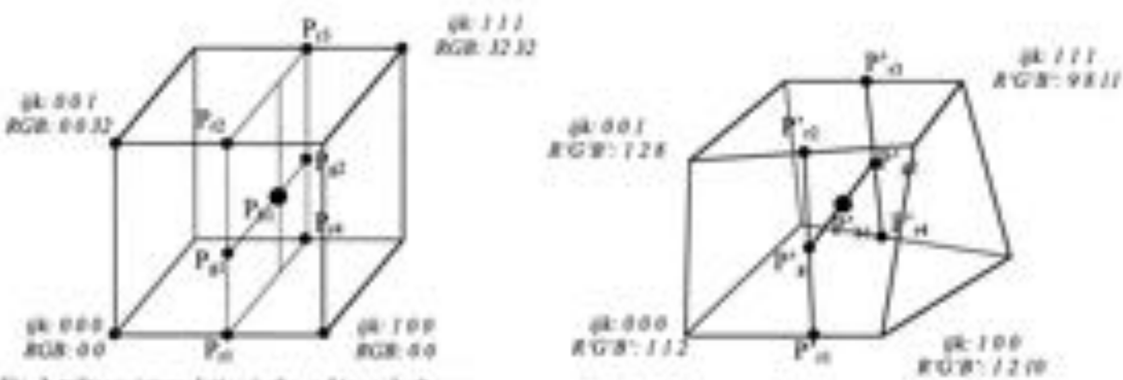


Fig. 2 trilinear interpolation in the cubic „color" space

The point P'_{b1} is calculated in the following way: First we calculate the 4 points P'_{r1} ... P'_{r4} (we begin arbitrarily with the red vector)

$P'_{r1} = k_r\,(P'_{(1,0,0)} - P'_{(0,0,0)})$ .... and the same until P'_{r4} (2)

Now we determine P'_{g1} ... P'_{g2}

$P'_{g1} = k_g\,(P'_{r2} - P'_{r1})$ and
$P'_{g2} = k_g\,(P'_{r3} - P'_{r4})$ (3)

and

$P'_{b1} = k_b\,(P'_{g2} - P'_{g1})$ (4)

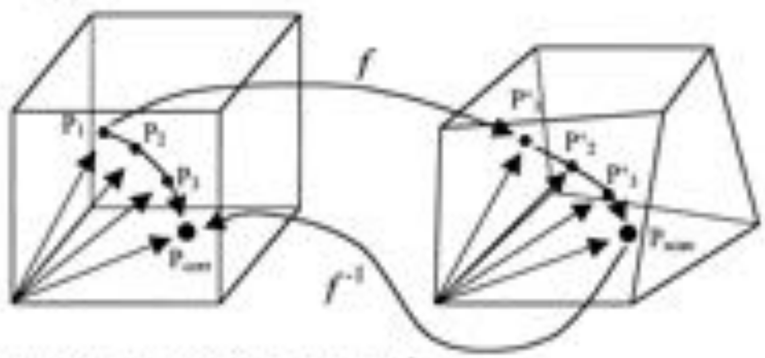


Fig. 3 stepwise, nonlinear optimization to apply f'

The problem is, that we have to do the inverse (backward) calculation during the correction process. After scanning we got a value P' which is within the "distorted" color space and we have to determine the corresponding point P. Whereas (R'G'B') = f(RGB) is straightforward (trilinear interpolation), the inverse function[1] (RGB) = f^{-1}(R'G'B') must be solved iteratively by a nonlinear optimization procedure, e.g., steepest descent algorithm (see figure 3).

[1] The inverse function leads to a equation of 3[rd] order and with mixed terms, which cannot be solved analytically.

To find the corresponding sub volume, a simple search is done. We calculate the distance between the scanned R'G'B' color and every single index point (the base of the "cube") until we find the closest base point in the R'G'B' space. If we know the closest base point (index ijk), we know that the scanned color point must be an element of one of the eight surrounding sub volumes around the base point (see figure 4). Every arbitrary R'G'B'-point, can be described as a linear combination of our base vectors:

$$p_{new} - p_{ijk} = k_r e_{rot} + k\, e_{grün} + k\, e_{blau} \qquad (5)$$

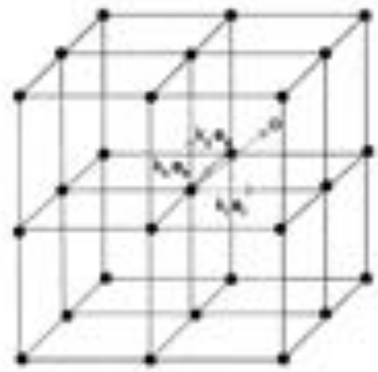


Fig.4 Nearest color point and 8 subvolume

We do this for all 8 sub volumes and test if all 3 coefficients are in the range between $0 < k_{(r,g,b)} < 1$.

3. OPEN SYSTEM USING OPTICAL DENSITIES

A closed system is very simple to calibrate, but has the disadvantage, that if one ore more components are replaced, a new calibration is necessary. A closed system is by definition a "device dependent" system. In the case of museums or archives, the goal of making "digital duplicate" will be the long-term replacement of the original slide, hence, a future replacement of equipment and slide films will be inevitable. We have therefore to use methods of color management which are "device independent". We need a description of the slide colors, i.e., "color coordinates", which is independent of the imaging devices and which can be measured by reproducible, physical methods. In an open system each device has to be calibrated, that is the relationship between the "device independent color coordinates" of the photographic film and the corresponding RGB-values of the scanner or the filmrecorder has to be known (see fig 5).

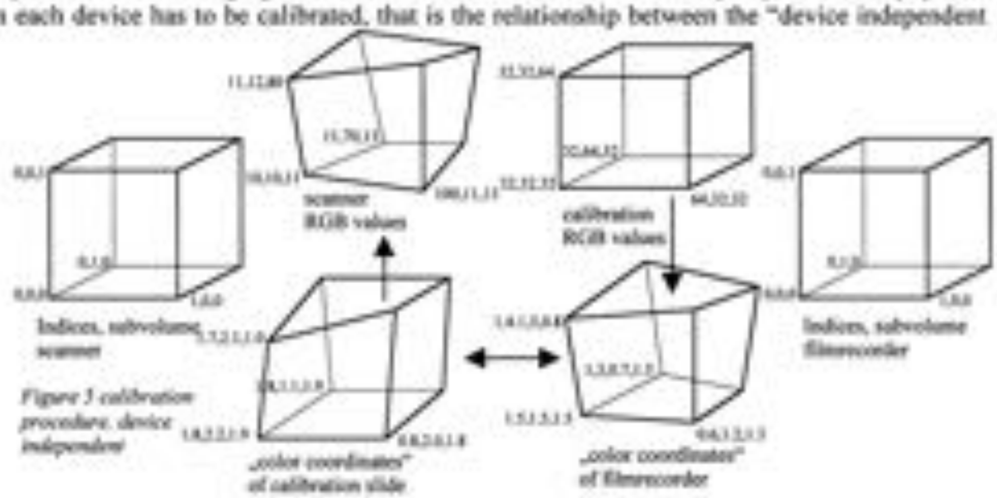


Figure 5 calibration procedure, device independent

A wide variety of such measurements would be possible: Optical Densities, e.g., Status A ("standard" densities in color photography) , scanner-"printing densities", Equivalent Neutral Densities (END) [3] or colorimetric color coordinates, e.g. CIELAB [4]. The ultimate case would be a multispectral measurement.

To understand, which color system is suitable, the color reproduction process of photographic color film and of digital scanner system have to be looked at carefully. Fig. 6 (left) shows a schematic diagram of the photographic color reproduction system [5-8]. The input of the model is the spectrum of an original color (step A). The model considers the effect of the exposure illuminant (step B), the camera , i.e., flare, optics, filters (step C), spectral sensitivity of the film (step D), the characteristic curve (step E), inter-image effects (step F), the dyes (step G), and eventually the relation between reflection density and transmission density, which result in the spectrum of the reproduced colorants (step H). As a comparison color-coordinates of the same original color as viewed by a human observer are calculated (steps I,J,K) . This yields the color differences (step L) between the photographic and the direct view case for a specific color in LAB space CIE (1976) L*,a*,b*= CIELAB. The first step, the scene object (shown as an example for a blue color in the small box), is characterized by the spectral reflection or transmission curve R (λ) or T (λ), and in the second step, light source exposition (here daylight), by the spectral radiance J(λ). A certain amount of flare (f) may be added in step C, if necessary. The light impinging on the film has the intensity :

$I(\lambda) = (R(\lambda) + f) * J(\lambda)$........(6)

From the three sensitization curves $S_j(\lambda)$(j=1,2,3 = blue, green, red) the relative logarithmic exposure densities H_j (j=1,2,3) are obtained. The generated dye densities are derived from the characteristic curve, inter-image and mask

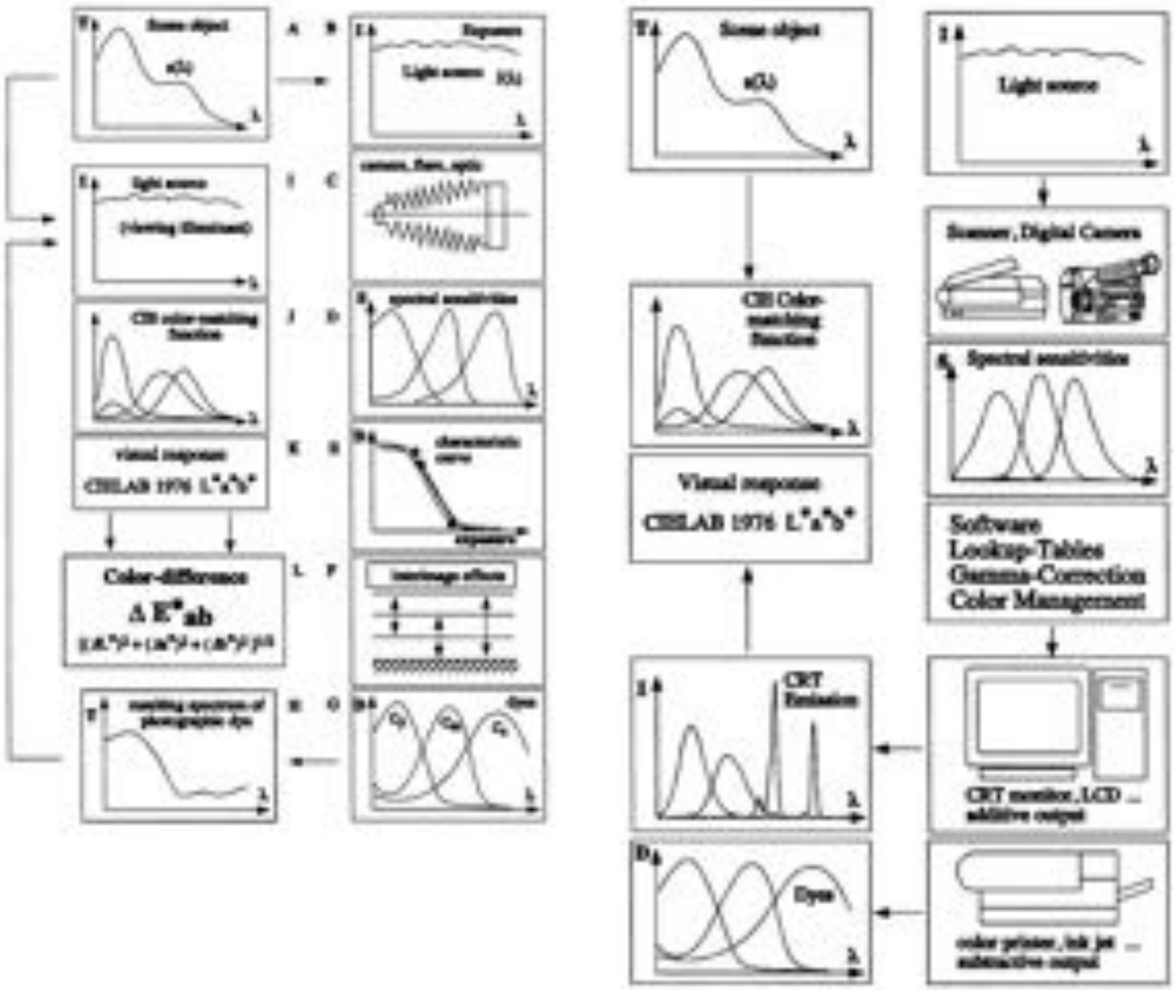


Figure 6: Schematic diagram of the photographic color reproduction system (left) and of a electronic color imaging system (right)

effects. Inter-image effects and masking play an important roll in color photographic system [9,10]. They may be used to partly correct the undesired secondary absorption of photographic colorants and to enhance the color gamut. The resulting dye concentrations Cy, Cm and Cc represent analytical densities

In Figure 6 (right), the corresponding schematic model for a electronic imaging system is shown. Compared to photographic material, input (scanner, digital camera ...) and output device (printer, monitor ...) are physically separated by the computer. Hence, the image data can be manipulated. If the goal is a faithful reproduction of the original colors, the colorimetric color reproduction, color management software must minimize the ΔE*ab between the input- and output colors.

If we look at each step in the color reproduction, we see that all steps are unequivocal, i.e., for each step an inverse function exists, with the exception of step D, where the three-color imaging device transforms the n-dimensional spectrum in a three-dimensional signal. The same argument holds for the calculation of color co-ordinates, where the light spectrum is weighted, i.e., integrated with the three tristimulus functions X, Y and Z. These steps are not reversible, hence it is not possible to calculate back the spectrum of the scene object from the three exposure values. Therefore the problem *Is it possible to calculate back the original color of an object from the reproduced color on the photography?* can be solved only in one case: The spectral sensitivity for the imaging device (or photographic film) must be the same (i.e., linearly dependent) as the tristimuli function X, Y, Z . In all other cases, more or less metamerism is the result.

4. METAMERY OF DIFFERENT COLOR DYES

If we work with the same type of photographic material, as was used in the "original" slide, in the calibration procedures and use this for the duplication itself, the choice of the color description (color coordinates) is irrelevant, as all systems would work equally well. There is no metamery, because we have the same spectral 3-component system. But in an archival environment, the originals are often older photographic material, which is nolonger manufactured. However, the scanner is calibrated with new material, e.g. with "Ektachrome" slide film and finally the digital duplicates may be recorded on a lightfast film material. Problems will arise because all 3 film types are spectrally different.

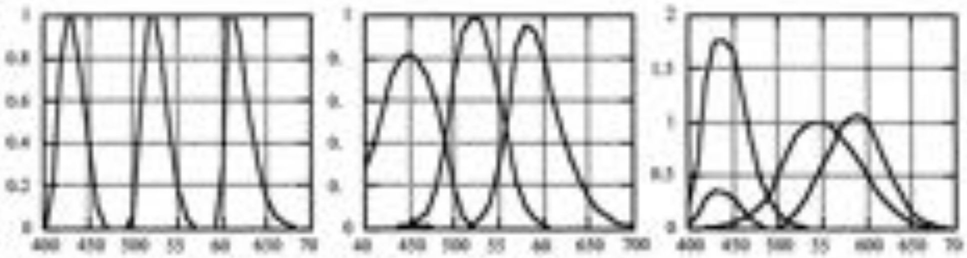


Figure 8 rel. spectral sensitivities: status A, color CCD camera, XYZ

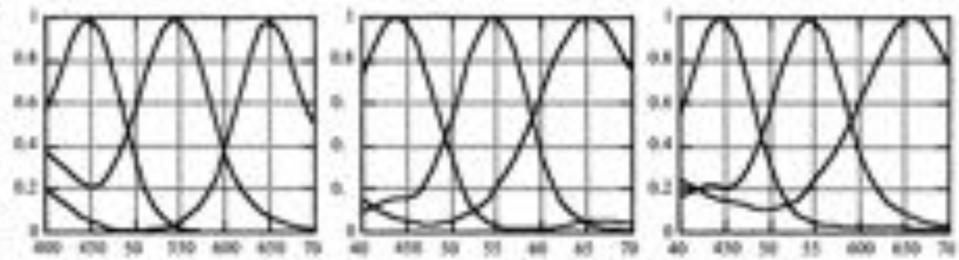


Figure 9 spectral absorption of photographic dyes: Kodachrome, Ektachrome, Fujichrome

To investigate the influence of different photographic dyes and color measuring devices with different spectral sensitivities, a simulation was done. Grey scales (CIELAB coordinates: L = 10 ... 90, a,b = 0) were simulated, using the "dyes" with the spectral absorptions of some common color slide films (see figure 9). From these colors we calculate the corresponding "printing densities" POD, i.e., the integrated optical densities, simulating devices (densitometer) with different spectral sensitivities: A Status-A densitometer (commonly used in color photography) [11], a typical color CCD device and a "colorimeter" with sensitivities based on the CIE XYZ tristimuli values.

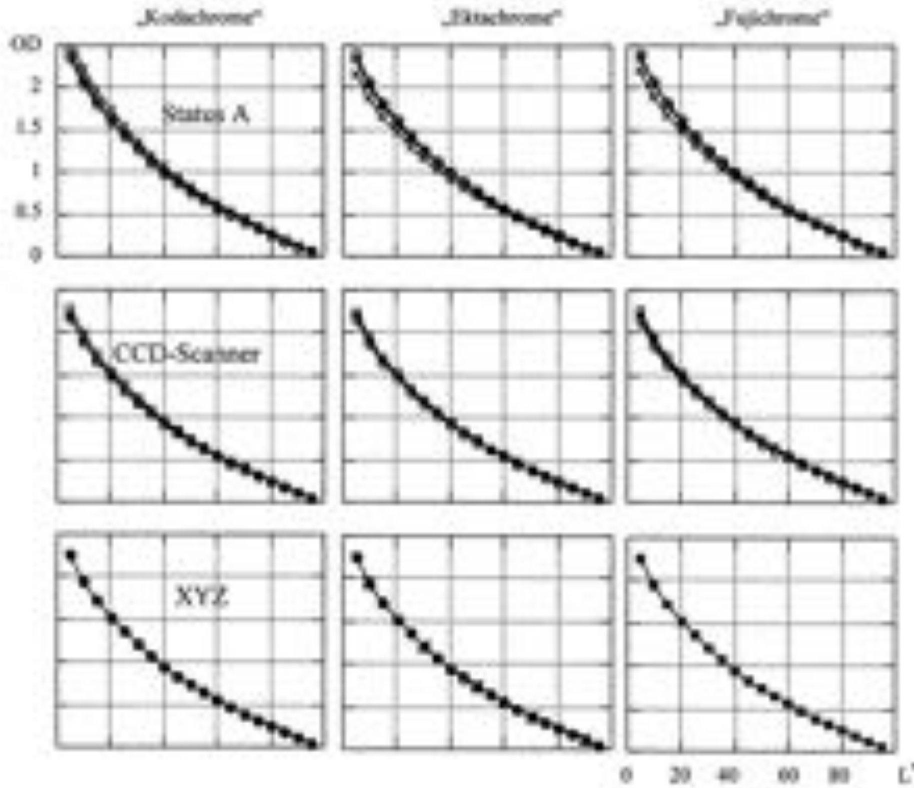


Fig 10 „printing densities" of different photographic material with same LAB-grey values

The results are shown in figure 10. In the case of a Status A densitometer, the density-curve is different for each photographic film and the deviation of the three colorants Yellow, Magenta and Cyan is quite significant. The relatively narrow-banded spectral sensitivities are the reason of this behavior. On the other hand, a densitometer with XYZ spectral sensitivities gives the same curves for all three films and dyes. This is no surprise, as the CIELAB coordinates are based on CIE XYZ tristimuli values! A densitometer with spectral sensitivities of a typical CCD color camera give results, where the curves for all films are different, but to a much less extend than in the case of Status A. The spectral sensitivity curves are much broader than Status A sensitivities and correspond more to the XYZ curves.

5. DISCUSSION AND CONCLUSION

Within a closed system and using always the same photographic filmmaterial, an identical color reproduction can be reached. This is true, as long as the color gamut of the filmrecorder is larger than the color gamut of the original slides. In a open system a color match is only possible under one of the following conditions:

- scanner and calibration devices (densitometer, colorimeter) must work in a true colorimetric way, i.e., the spectral sensitivities must correspond the XYZ tristimuli values
- The spectral characteristics of all components (inclusive photographic materials) is known. Only in this case we can transform a "color space" in a true colorimetric one, i.e., CIELAB.

6. SYMBOLS USED

CIELAB	= CIE (1976) L*,a*,b* color co-ordinates
ΔE	= [(ΔL*)**2 + (Δa*)**2 + (Δb*)**2]**$^{1/2}$
	= ΔE*Lab , total color difference ref [6]
J(λ)	= spectral radiance of light
Sj(λ)	= spectral sensitization, j = 1,2,3 (B,G,R)
R(λ), T(λ)	= reflection or transmission spectrum
PODj	= printing density, j=1,2,3 (B,G,R)

$$= -\log 10 \frac{\int (T(\lambda)\, J(\lambda)\, S_j(\lambda))}{\int (J(\lambda)\, S_j(\lambda))} \Delta\lambda$$

7. REFERENCES

1. F. Frey and R. Gschwind, Mathematical bleaching models for photographic three-color materials, J. of Imaging Science and technology, 38(6), p. 513, 1994
2. L. Rosenthaler, R. Gschwind and F. Frey, The Digital Age in long-term Image Archive – Opportunities and Risks; Paper delivered at the 12th Triennial Meeting of the International Council of Museums Commitee on Conservation (ICOM-CC), Lyon, 1999, vol II, 572-578, ISBN 1 873936 92 3
3. P. Kowalisky, Applied Photographic Theory, John Wiley & Sons, London, 1972
4. G. Wyszecki and W.S. Stiles,1982, Color Science, p. 164, J. Wiley and Sons,
5. R.W.G.Hunt, 1970, J.photogr. Sci. 18, 205.
6. R. Gschwind, E. Baumann and R. Hofmann; Simulating and Optimizing the Colour Reproduction of Photographic Materials; Colour Imaging Systems RPS Symposium Camebridge, 22.-26.09.1986, M.R.Pointer ed. publ. 1987
7. F.R.Clapper, 1977,"Color Reproduction" in "The Theory of the Photographic Process" (T.H.James ed.), p.561, Macmillan Publishing Co.,Inc., New York.
8. .R. Gschwind and G. Di Pietro: "Metamerism in Colour Imaging Systems and "Reverse" Colour Reproduction"", in: ICPS'98 (The International Committee on the Science of Photography), International Congres on Imaging Science, Antwerp, 7-11 Sept. 1998,Vol 2, p. 11-14
9. R. Gschwind, A. Rosselet, H.J. Buser and E. Baumann; Investigation and quantification of inter-image effects ; The Journal of Photographic Science, 41, 86, 1993, Inc, New York.
10. G.G.Attridge, R.E.Jacobson, P.Newman, J. Roychoudhury, 1983, J.photogr. Sci. 31,197.
11. COLOR: Theory and Imaging Systems, Raymond A. Eynard Ed., SPSE, 1973

SPACES OF PROBABILITY DISTRIBUTIONS AND THEIR APPLICATIONS TO COLOR BASED IMAGE DATABASE SEARCH

Linh Viet Tran, Reiner Lenz

Media Group, Department of Science and Engineering
Campus Norrköping, Linköping University, 601-74 Norrköping, Sweden
Email: {lintr,reile}@itn.liu.se

ABSTRACT

We present a framework to compute the distance between color distributions based on differential geometry. We investigate more detailed the case when color distributions are described as linear combinations of a set of pre-computed basic functions. Experiments in our color based image retrieval system, which were done on 1000 images from Corel image database, show the advantage of our method based on the new distance measure and color descriptor.

1. INTRODUCTION

Almost all image database retrieval systems provide color as a search attribute. This can be used to search for images in the database which have a color distribution which is similar to the color distribution of a given query image. In most systems the color histogram is used to represent the color properties of an image. However, the color histogram is not a very efficient representation due to its large memory requirement. Recently many methods have been proposed to overcome this problem [7, 2, 3, 4, 8].

Once a description of the distributions has been chosen the next problem in image database applications is the definition of a distance measure between two such distributions and its computation from their descriptions. Ideally the distance measure between color distributions should have the following basic property: (1) it should describe perceptual similarity (ie. the feature distance between two images is large only if the images are not "similar" and small if the images are "similar"), (2) it should be easy to compute, and (3) it should be a metric. Many histogram based distance measures are derived heuristically and they may violate some of these properties. In this paper we propose a framework to compute the distance between color distribution based on differential geometry [1]. This distance takes into account all the properties mentioned above. It will be applied to derive new color descriptors for color based image retrieval applications.

The paper is organized as the follows: the framework is presented in the next section and illustrated with the simple example in the space of normal distributions. Section 3 presents an application to image retrieval where color distributions are described as linear combination of basic functions. There we also describe how to compute the basic functions and illustrate the approach with some experiments. Finally, in section 4 we summarize the paper and propose some directions for future work.

2. DISTANCE BETWEEN COLOR DISTRIBUTIONS

Suppose that a color distribution p can be represented by a set of r $(r \geqslant 1)$ parameters. We then denote the parameter vector by $\theta = (\theta_1, \theta_2, ..., \theta_r)$, the parameter space by Θ and $\{p_\theta, \theta \in \Theta\}$ is a family of color distributions. We now want to measure the distance $dist(p_\alpha, p_\beta)$ between the two color distributions p_α and p_β, with parameter values $\alpha = (\alpha_1, \alpha_2, ..., \alpha_r)$ and $\beta = (\beta_1, \beta_2, ..., \beta_r)$ in the parameter space Θ.

To get a distance measure in the parameter space Θ, its metric has to be defined. Consider a color distribution p_θ and its neighboring $p_{\tilde{\theta}}$ in the space Θ where $p_{\tilde{\theta}} : \tilde{\theta} = (\theta_1 + d\theta_1, \theta_2 + d\theta_2, ..., \theta_r + d\theta_r)$. For discrete distributions the distance between the two neighboring distributions can, locally, be well approximated by

$$ds^2 = dist^2(p_\theta, p_{\tilde{\theta}}) = (p_\theta - p_{\tilde{\theta}})^T M (p_\theta - p_{\tilde{\theta}}) \quad (1)$$

where $M = [m_{ij}]$ is a symmetric, positive definite matrix defining the properties of the color space. Each entry m_{ij} captures the perceptual similarity between colors represented by bins i and j. Some reasonable choices of m_{ij} are:

$$m_{ij} = 1 - d_{ij}/d_{max} \quad (2)$$
$$m_{ij} = exp(-k(d_{ij}/d_{max})) \quad (3)$$
$$m_{ij} = exp(-k(d_{ij}/d_{max})^2) \quad (4)$$

This work was supported by the VISIT program of the Swedish Foundation for Strategic Research.

for some positive constant k. Here d_{ij} is the Euclidean distance between color i and j in some uniform color space like CIELab or CIELuv and $d_{max} = \max_{ij}(d_{ij})$ (see [6] for more details)

To the first order, the differential distance ds summarizes the effect of replacing p_θ by $p_{\hat{\theta}}$ and is given by

$$ds^2 = dist^2(p_\theta, p_{\hat{\theta}}) = (\sum_{i=1}^{r} \frac{\partial p_\theta}{\partial \theta_i} d\theta_i)^T M (\sum_{i=1}^{r} \frac{\partial p_\theta}{\partial \theta_i} d\theta_i) = \sum_{i=1}^{r} \sum_{i=j}^{r} (\frac{\partial p_\theta}{\partial \theta_i})^T M \frac{\partial p_\theta}{\partial \theta_j} d\theta_i d\theta_j = \sum_{i=1}^{r} \sum_{i=j}^{r} g_{ij} d\theta_i d\theta_j \quad (5)$$

in which M defines the global metric in the histogram space $\mathbb{H}$ and $\{g_{ij}\}$ defines the metric locally around point θ in space Θ, which is a projection of the full histogram space $\mathbb{H}$.

Suppose now we have two color distributions represented by the two points p_α and p_β. Let $\theta(t)$ be an arbitrary curve connecting the two points in Θ, $\theta(t_1) = p_\alpha$ and $\theta(t_2) = p_\beta$. In Riemannian geometry, the distance $s(p_\alpha, p_\beta)$ along the curve between p_α and p_β is given by

$$s(p_\alpha, p_\beta) = \int_{t_1}^{t_2} \sqrt{\sum_{i,j=1}^{r} g_{i,j}(\theta) \frac{d\theta_i}{dt} \frac{d\theta_j}{dt}} dt \quad (6)$$

The distance between two distributions is then defined as the geodesic distance or the distance along the shortest curve between the two distributions. It is computed by minimizing $s(p_\alpha, p_\beta)$ with the help of the calculus of variation.

$$dist(p_\alpha, p_\beta) = \underset{\text{all } \theta(t)}{\text{minimize}}(s(p_\alpha, p_\beta)) = \underset{\text{all } \theta(t)}{\text{minimize}}(\int_{t_1}^{t_2} \sqrt{\sum_{i,j=1}^{r} g_{i,j}(\theta) \frac{d\theta_i}{dt} \frac{d\theta_j}{dt}} dt) \quad (7)$$

A very simple example is the space of normal distributions $N(\mu, \sigma)$

$$p(\mu, \sigma) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{1}{2}(\frac{x-\mu}{\sigma})^2}$$

where a color distribution (e.g. a homogenous color region in HSV color space) can be described by three independent normal distributions. If we use the exponential kernel in (4) with $k = d_{max}^2$, the metric $\{g_{ij}\}$ and the distance between two normal distributions is given by

$$\{g_{ij}\} = G(\mu, \sigma) = \begin{bmatrix} 2(1 + 4\sigma^2)^{-3/2} & 0 \\ 0 & 12\sigma^2(1 + 4\sigma^2)^{-5/2} \end{bmatrix} \quad (8)$$

$$d(p_1(\mu_1, \sigma_1), p_2(\mu_2, \sigma_2)) = \sqrt{3[(1 + 4\sigma_1^2)^{-1/4} - (1 + 4\sigma_2^2)^{-1/4}]^2 + 2\sqrt[4]{2}[\sqrt[4]{\mu_1} - \sqrt[4]{\mu_2}]^2} \quad (9)$$

3. APPLICATION TO IMAGE RETRIEVAL

In this section we describe a color histogram as a linear combination of pre-computed basic vectors. We describe two ways to compute optimal basis systems and investigate their properties in color image retrieval applications.

3.1. Linear representations of color distributions

For a given set of N basis vectors h_i, a histogram h with N bins can be parameterized by the N parameters $\{p_i\}$ defined by the description

$$h = \sum_{i=1}^{N} p_i h_i \quad (10)$$

Different ways to compute b_i define different representation methods of color distributions. By using the framework in the previous section, the metric $\{g_{ij}\}$ of the histogram space in (10) and the distance between two distributions in this space are given by

$$g_{ij} = b_i M b_j \quad \text{and} \quad dist(h_1, h_2) = \sum_{i}^{N} \sum_{j}^{N} g_{ij} \Delta p_i \Delta p_j \quad (11)$$

For large image databases it is desirable to project the histograms to a lower dimensional space. To obtain good retrieval properties such a projection should preserve the distances between images in the database as much as possible.

Given the distance measure in (11) for the general descriptor in (10) and a fixed number K, we want to find a subspace $\mathbb{K}$, spanned by a set of K basic vectors $\{h_i\}_K$ such that the projection of the space of full color histograms $\mathbb{H}$ on $\mathbb{K}$ has a minimum mean least squared distance to the original histograms.

Selecting the K–basis vectors $\varphi_k, (k = 1, \ldots, N)$ we approximate h by $\tilde{h}_K = \sum_{k=1}^{K} x_k \varphi_k$ with an approximation error given by $\varepsilon_K(h)$

$$\varepsilon_K(h) = h - \tilde{h}_K = h - \sum_{k=1}^{K} x_k \varphi_k = \sum_{k=K+1}^{N} x_k \varphi_k \quad (12)$$

In our first approach we use the standard Karhunen-Love transform in the histogram space $\mathbb{H}$ and select the basis functions φ_k such that the mean squared error is minimized:

$$\varepsilon_M^2 = E\{d(\varepsilon_K(h), \varepsilon_K(h))\} \quad (13)$$

The basis with the lowest error can be found using Singular Value Decomposition (SVD). It can be computed by transforming the histograms h using the invertible matrix U, where $M = U^T U$, and then applying ordinary SVD (see [5]). In the first step the eigenvectors ψ_k of the correlation matrix $\Sigma_M = E(U^T h^T h U)$ are computed. From them the basis functions φ_k are obtained as:

$$\varphi_k = U^{-1}\psi_k \tag{14}$$

The expansion coefficients and the approximation are given by $x_k = \varphi_k^T h$ and $\tilde{h}_K = \sum_{k=1}^{K} x_k \varphi_k$ where the corresponding basis vectors φ_k $(k = 1, \ldots, K)$ are the eigenvectors belonging to the largest eigenvalues. Ordinary KLT is a special case where the relations between color bins is ignored (M = identity). When the correlations between the input images in the database are ignored the solution is identical to [6].

Given two color images I_1, I_2 described by their coefficient vectors $(f_{n1}, \ldots, f_{nK})$, $(n = 1, 2)$ the distance between them can now be computed as:

$$\begin{aligned} d(I_1, I_2)^2 &\approx (\tilde{h}_1 - \tilde{h}_2)^T M (\tilde{h}_1 - \tilde{h}_2) = \sum_k^K \sum_j^K (f_{1k} - f_{2k})(f_{1j} - f_{2j}) \phi_k^T M \phi_j \\ &= \sum_k^K (f_{1k} - f_{2k})^2 = \sum_k^K (f_{1k})^2 + \sum_k^K (f_{2k})^2 - 2 \sum_k^K f_{1k} \cdot f_{2k} \end{aligned}$$

The first two terms are computed only once. The computation of the distance in the retrieval phase involves therefore only K multiplications.

A different way to use KLT-based techniques in color-based image retrieval is based on the differences between color histograms. We consider the space of all local differences between two histograms in the space of histograms $\mathbb{H}$. When we are searching using similarities we are only interested in local distances. Then we define for (small) constants δ the space $\mathbb{D}_\delta$ of local

histogram differences as:

$$\mathbb{D}_\delta = \{\Delta h = h_1 - h_2 : h_1, h_2 \in \mathbb{H}, d(h_1, h_2) \leq \delta\}$$

KLT-techniques are then used as before with the only difference that now they are operating on the space $\mathbb{D}_\delta$ instead of the histogram space $\mathbb{H}$.

3.2. Experiments

For most image retrieval applications it is sufficient to use histograms with 8x8x8 bins in the CIELab color space. We use the CIELab color space since its metrical properties are well adapted to human color difference judgments. This is very important in the present context since we use distance measures based on quadratic forms.

In our experiments we estimate the influence of the different approximations by comparing the retrieval results of the approximation based methods to the retrieval results achieved when the full histogram is used. In the experiments we use 1000 images from a Corel image database. In the first processing step we compute different descriptions of the color distribution of an image. These descriptions include full histograms, dominant-color based descriptions and the PCA-based methods presented in the previous subsection. In the second step we then use these descriptions to approximate the quadratic form based distance measure. In the retrieval simulation we use every image in the database as a query image and search against the database using different distance measures. The result is then compared to the standard method based on the full histogram. This allows us to evaluate the approximation performance of different methods in the context of color image retrieval. For a given approximation order we say that method A is better than method B if (on average) the number of identical images found by method A and the standard method is larger than the images found by method B and the full histogram method simultaneously. Specifically, we use *precision*, which is defined as the number of relevant images retrieved relative to the total number of retrieved images, as criteria to evaluate the performance between different method compared to the standard method based on using full histogram.

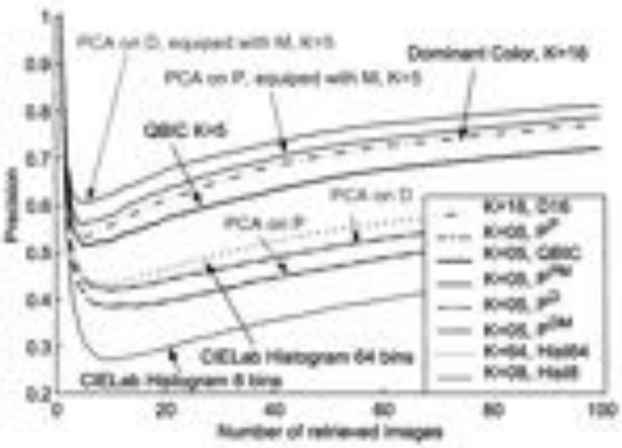


Fig. 1. *Search results using full histogram of 512 parameters (standard method) are compared to other methods of representation of color distributions: Histogram with fewer bins, Dominant colors based methods [7, 4], method presented in [6] and our proposed methods. Here K denote the number of parameters. It shows that our methods give a better compact representation. For example the PCA based methods equipped with M using only 5 parameters gives more correlated search result to standard method than dominant colors based method using 16 parameters.*

The performance of the quadratic form based indexing method depends on the similarity matrix M, and to our best understanding, there is no published result about which M is the best choice in color based image retrieval. Thus we did

Fig. 2. *An example of the search in our image retrieval system. More examples and the color version of the paper can be found at http://www.media.itn.liu.se/publications/aic2001*

some experiments with different matrices M given by different values of k in (4). One of them is illustrated in Figure [1] (We refer [8] for more detailed information).

The results from our experiments show that:

- Incorporating information from the metric of the color space and applying PCA on the space of differences between neighboring histogram make the search results on the approximated feature space more correlated to the original full histogram method. The proposed method PCA^{DM}, which combines the two proposed ideas described above, gives the best performance compared to the other methods in all cases.
- For large values of $K (K \geq 15)$, results of PCA based methods which incorporate the color metric M converged to the standard method faster than PCA^{QBIC}.
- When the similarity between color bins has lower weights, or when the value of k in (4) is large, the performance of PCA^{QBIC} is reduced compared to PCA^{DM} and PCA^{PM} methods which are not solely based on the matrix M.
- The dominant color based method is fairly good while simple PCA and coarse histogram based methods show poor results.

4. CONCLUSION

We have proposed a framework to compute the distance between color distributions based on differential geometry, in which the color properties of color space is taken into account. We show that the distance is the minimal cost to transform one distribution to another one. Two examples are presented and applied in deriving new color descriptors for image retrieval applications. Experiments show that the proposed descriptors give a better compact representation of color distribution compare to other existing methods. Since the framework is general, one can apply and extend it to other representation based on color, texture, shape ... However the difficulties in solving (7) limit the application of the framework.

5. REFERENCES

[1] S.-I. Amari. *Differential geometrical methods in statistics.* Springer, 1985.

[2] D. Androutsos, K. N. Plataniotis, and A. N. Venetsanopoulos. A novel vector-based approach to color image retrieval using a vector angular-based distance measure. *Computer Vision and Image Understanding*, pages 46–58, 1999.

[3] J. Berens, G.D. Finlayson, and G. Gu. Image indexing using compressed colour histogram. In *IEE Proc.-Vis. Image Signal Process.*, pages 349–353, 2000.

[4] Y. Deng, B.S. Manjunath, C. Kenney, M.S. Moore, and H. Shin. An efficient color representation for image retrieval. *IEEE Trans. on Image Processing*, pages 140–147, 2001.

[5] K. Fukunaga. *Introduction to Statistical Pattern Recognition.* Academic Press, 1990.

[6] J. Hafner, H.S. Sawhney, W. Equitz, M. Flickner, and W. Niblack. Efficient color histogram indexing for quadratic form distance functions. *IEEE Trans. PAMI*, pages 729–736, 1995.

[7] W.-Y. Ma. *Netra: A Toolbox for navigating Large Image Databases.* PhD thesis, Department of Electrical and Computer Engineering, University of California at Santa Barbara, 1997.

[8] L.V. Tran and R. Lenz. PCA-based representation of color distributions. Technical Report LiTH-ITN-R-2001-1, Department of Science and Engineering, Linköping University, 2001.

CIE: Vision, Colour and Imaging

Michael R. Pointer
National Physical Laboratory, Teddington, TW11 0LW, UK

ABSTRACT

Historical achievements of CIE Divisions 1 *Vision and Colour* are described and a review of current technical committee activity presented. An overview of the work of CIE Division 8 *Image Technology* is also presented.

Keywords: Colour, vision, colour-difference, adaptation, appearance, imaging

INTRODUCTION

The International Commission on Illumination - abbreviated as CIE from its French title Commission Internationale de l'Eclairage - is an organisation devoted to international co-operation and exchange of information on all matters relating to the science and art of lighting. Since its inception in 1900, the CIE has been accepted as representing the best authority on the subject and as such is recognised by the ISO as an international standardisation body. CIE is a technical, scientific and cultural non-profit organisation whose primary objective is to provide an international forum for the discussion of all matters relating to the science, technology and art of light and lighting, and for the interchange of information in these fields between different countries. This it seeks to do by developing and publishing basic standards and procedures for metrology. It is important to note that light and lighting is meant in its broadest sense and thus includes the fundamental aspects of vision, photometry and colorimetry, as well as the more applied aspects of lighting installations and image technology.

CIE TECHNICAL COMMITTEES

The success of an organisation such as the CIE depends upon the effectiveness of its technical committees. Each major subject of interest has been assigned to one of seven Divisions. Division 1: *Vision and Colour* studies visual responses to light and establishes standards of response functions, and models and procedures of specification relevant to photometry, colorimetry, colour rendering, visual performance and visual assessment of light and lighting. Other Divisions deal with Measurement of Light and Radiation (Division 2), Interior Environment and Lighting Design (Division 3), Lighting and Signalling for Transport (Division 4), Exterior Lighting and Other Applications (Division 5), Photobiology and Photochemistry (Division 6), and Image Technology (Division 8).

COLOUR SCIENCE

At the 6th session of the CIE, held in Geneva in 1924, it was decided to set up a Study Group on Colorimetry. This was in response to the fact that the measurement of colour had become an important factor in several industries and scientific laboratories but none of the systems of colour specification that existed at that time could be considered satisfactory for general practice. At the 7th Session of the CIE held in Saranac, New York, USA in 1928, a working programme was proposed to establish suitable basic standards that would put colorimetric practice on a unified basis. In particular, it was agreed that efforts should be made to reach agreement on colorimetric terminology, a standard daylight and "sensation curves" of the average human observer with normal colour vision.

At the 8th Session of the CIE held in Cambridge, England in 1931, a number of recommendations were made which laid the basis for modern colorimetry: the CIE 1931 Standard Colorimetric Observer, the CIE x, y colorimetric co-ordinate system, three standard sources (A, B and C), standard illuminating and viewing conditions for measuring reflecting surfaces and the standard of reflectance in the form of a magnesium-oxide surface. Apart from minor adjustments, these recommendations have stood the test of time right up to the present day. Every other recommendation can be considered as an enhancement or an addition to these basic recommendations. At the 14th Session of the CIE held in Brussels, Belgium in 1959 a proposal was made to adopt the MacAdam uniform chromaticity scale diagram, the u,v diagram, to provide a more uniform representation of chromaticity differences. In this system a measure of the perceived size of the difference between two colours is obtained by the square root of the sum of the squares of the differences between corresponding co-ordinates U*, V*, W*. This recommendation was put forward in an attempt to unify the many diverse practices of calculating colour differences.

At the 15th Session of the CIE held in Vienna, Austria in 1963, agreement was reached on what became known as the 1964 supplementary standard observer, based on colour-matching data obtained using a 10 degree field. It was also at this meeting that the standard daylight distributions were given special attention with the recommendation that the spectral power distributions of the D illuminants be calculated at any correlated colour temperature required. In practice, D50, D55 or D65 have been the usual choice. 1971 saw the publication of CIE Document 15, *Colorimetry*. At the 18th Session of the CIE held in London, England in 1975, the CIE recommended the adoption of two new colour spaces and associated colour-difference formulae, known as CIELAB and CIELUV. The latter was an improvement of the previously recommended U*,V*,W* space. 1986 saw the publication of CIE Document 15.2, Colorimetry. At the 1997 meeting of Division 1, held in Kyoto, a colour appearance model, CIECAM97s, was recommended for the first time.

The following Technical Committees are now active in Division 1; they are grouped by subject rather than numerical or chronological order:

Colour Appearance
TC1-52, *Chromatic Adaptation Transforms* has issued a draft technical report reviewing a number of studies on the subject. The topics include experimental techniques, experimental data sets, chromatic adaptation transforms and the results of testing the performance of those transforms. It is proving difficult to reach a decision as to the best transform due to the closeness of their performance in predicting different experimental data sets.

Colour Difference
TC1-47, *Hue & Lightness Dependent Correction to Industrial Colour Difference Equation* has investigated the hue and lightness inter-dependence of industrial colour differences and has now produced an improved version of the CIE94 colour-difference equation; a Technical Report will be issued soon. TC1-55, *Uniform Colour Space for Industrial Colour Difference Evaluation*, is looking at methods of improving CIELAB colour space to enable a more uniform space to be recommended. This will enable colour differences to plotted in a uniform space, something not possible with CIE94 colour differences because they are based on CIELAB coordinates.

Colour Imaging
TC1-27, *Colour Appearance for Reflection/VDU Image Comparison*, is studying and will make recommendations on how to specify a colour appearance match between a reflective image and a self-luminous display image.

Sources
TC1-44, *Practical Daylight Simulators for Colorimetry*, is carrying out an inter-comparison between existing daylight simulators for color measuring instruments and color matching booths and on the basis of that inter-comparison will recommend practical methods for simulating daylight sources.

Applied Colour Vision
TC1-36, *Fundamental Chromaticity Diagram with Physiologically Significant Axes*, is seeking to establish a chromaticity diagram where the coordinates correspond to physiologically significant axes and that will be of value to vision scientists. TC1-37, *Supplementary System of Photometry* will recommend a system of photometry to assess lights in terms of their comparative brightness relationships at any level including the mesopic and scoptic levels. TC1-43, *Rod Intrusion in Metameric Colour Matches*, is investigating a procedure for calculating the effect of rod intrusion on typical industrial metameric colour matches. TC1-48, *Revision of Document 15.2 Colorimetry*, is producing a revision of this document that will reflect current thinking on the basic principles of colour measurement. TC1-51, *Visual Acuity*, is surveying the literature in order to provide a specification for a human spatial contrast sensitivity function under defined viewing conditions (luminance level, surround,

adaptation state, geometry, etc.). TC1-54, *Age-related Change of Visual Response*, is investigating currently available data in order to recommend the spectral luminous efficiency, visual acuity, and contrast sensitivity functions as a function of age. TC1-56, *Improved Colour Matching Functions*, is comparing the current CIE colour matching functions with those proposed other workers. TC1-58, *Visual Performance in the Mesopic Range*, is investigating performance based photometry and colorimetry in the mesopic range. TC1-59, *Standard Photometric 10° Observer* is considering the use, or not, of the 10° $Y(\lambda)$ function as a spectral luminous efficiency function for that observer.

Standards

TC1-53, *A Standard Method for Assessing Daylight Simulators*, is writing an CIE/ISO Standard based on the CIE method of assessing the quality of daylight simulators. TC1-57, *Standards in Colorimetry*, is considering the preparation of a number of ISO Standards to cover the calculation of tristimulus values and chromaticity coordinates, uniform colour spaces, and a colour difference formula.

IMAGE TECHNOLOGY

TC8-01, *Colour Appearance Modelling for Colour Management Applications* is seeking to develop and recommend methods for the application of a colour appearance model based on CIECAM97s for use in digital colour management. TC8-02, *Colour Difference Evaluation in Images*, is studying methods for evaluating colour differences for images. TC8-03, *Gamut Mapping* is seeking an optimal solution for cross-device and cross-media image reproduction. TC 8-04, *Adaptation Under Mixed Illumination Conditions*, is investigating the state of adaptation of the visual system when comparing soft-copy images on self-luminous displays and hard copy images viewed under various ambient lighting conditions. TC 8-05, *Communication of Colour Information* is looking to standardise a minimal set of techniques that enable unambiguous and efficient communication of the colour information in images. TC8-06, *Terminology* is bringing together the colour and imaging terminology necessary to communicate in this inter-disciplinary area.

In addition, both Division 1 and 8 have a number of active Reporters investigating the potential for new work.

Status of CIE Color Appearance Models

Mark D. Fairchild*
Rochester Institute of Technology, Chester F. Carlson Center for Imaging Science,
Munsell Color Science Laboratory

ABSTRACT

In meetings just prior to the 1997 AIC Congress in Kyoto, CIE TC1-37, chaired by M. Fairchild, established the CIE 1997 Interim Colour Appearance Model (Simple Version), known as CIECAM97s. CIECAM97s was formally published in 1998 in CIE publication 131. CIE TC1-37 was dissolved shortly after publication of CIECAM97s at which time, a reportership, R1-24 held by M. Fairchild, was established to monitor ongoing developments in color appearance modeling and notify CIE Division 1 if it became necessary to form a new TC to consider revision or replacement of CIECAM97s. In the four years between AIC Congresses, there has been much activity, both by individual researchers and within the CIE, aimed at furthering our understanding of color appearance models and deriving improved models for consideration. The aim of this paper is to summarize these activities, report on the current status of CIE efforts on color appearance models, and suggest what the future might hold for CIE color appearance models.

1. BACKGROUND: THE FORMULATION OF CIECAM97s

The history of modern color appearance models dates back approximately 20 years to the time the earliest versions of the Hunt and Nayatani color appearance models were published.[1] It is important context to recall that these early models were suggested only about 5 years after the CIE recommendation of the CIELAB and CIELUV color spaces for color difference specification. Many fascinating and significant advances were made by Hunt, Nayatani, and many other researchers in the ensuing two decades. This work culminated in the spring of 1997 when many of these researchers converged in Kyoto and agreed upon the formulation of CIECAM97s, the first CIE color appearance model.

The formulation of CIECAM97s represents a highlight in the history of CIE (which is littered with highlights). The CIE was able to respond to the needs of the imaging industry and recommend a single color appearance model in a very short time frame (approximately 1 year from start to finish!). Perhaps most amazing, was that CIE TC1-34, which formulated the model, included members who had personally derived no fewer than eight distinct color appearance models. However, all the committee members saw the greater need and the greater good that the CIE could do and unanimously agreed on a single model that represented the best of many previously published models and could be used to focus both industrial applications and future research. Those interested in learning more about the formulation of CIECAM97s are referred to CIE publication 131,[2] a draft of which can also be obtained on the CIE TC8-01 web site.[3]

TC1-34 was under no delusion that CIECAM97s was the ultimate color appearance model, would be flawless, or would solve all problems thrown its way. However, the committee was confident that they had produced a model that performed at least as well as all previously published models across a wide variety of viewing situations. This philosophy is best indicated by the name of the model itself which includes both the word "Interim" and the date "1997". Both were included to make it clear that it was fully expected that improvements in the model would become evident through future research and that the CIE would likely publish an updated model at some point in the future. This parallels the recommendations of CIELAB and CIELUV, which both include the date "1976" in their full designations and are both considered interim recommendations. (In fact, the CIE94 and CIE2000 color difference equations represent the result of this philosophy of continuous improvement and recognition that color science is complicated and not likely to ever be fully understood.)

---

* mdf@cis.rit.edu; phone 1 716 475 2784; fax 1 716 475 5988; http://www.cis.rit.edu/fairchild; Rochester Institute of Technology, Chester F. Carlson Center for Imaging Science, Munsell Color Science Laboratory, 54 Lomb Memorial Drive, Rochester, NY, USA 14623

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

In hindsight, it is clear that CIECAM97s can be considered an unequivocal success. Not so much because it has solved all of the industrial problems with respect to color appearance (it hasn't and, in fact, no model could), but because it has successfully provided a focal point for both researchers and practitioners interested in problems of color appearance. Currently, anyone doing research and testing on color appearance models is sure to include a comparison of their results with the predictions of CIECAM97s or a comparison of suggested improvements with the original model. This focused approach to research, facilitated by the CIE's adoption of CIECAM97s, has accelerated the pace of understanding and the potential for practical solutions in color appearance to a point where significant industrial impact can be foreseen.

As soon as CIECAM97s was published, a number of studies were carried out and quickly reported that indicated areas for improvement in the model. These have been recently summarized by Fairchild[4,5] The rapid rate at which these improvements have been formulated and reached general consensus in the field provides direct evidence of the effectiveness of CIECAM97s. These efforts have found a natural home in the activities of CIE TC8-01, which are discussed in further detail below. There are also several other CIE efforts, described in the next section, that have an impact on the formulation and use of color appearance models.

2. SOME CURRENT CIE ACTIVITIES

Ongoing CIE activities on color appearance modeling are taking place mainly within the purview of 3 active technical committees and one reportership. These are TC1-27, *Specification of Colour Appearance for Reflective Media and Self-Luminous Display Comparisons*, chaired by P. Alessi, TC1-52, *Chromatic Adaptation Transforms*, chaired by M.R. Luo, TC8-01, *Colour Appearance Modeling for Colour Management Applications*, chaired by N. Moroney, and R1-24, *Colour Appearance Models*, M. Fairchild.

TC1-27 is in the process of completing a final round of visual experiments designed to evaluate the performance of various color appearance models (including CIECAM97s and suggested improvements) for cross-media color reproduction applications. Results of earlier experiments confirmed the expectations of TC1-34 that CIECAM97s would work at least as well as the best-performing models in each type of experiment. It should, however, be noted that other models often perform as well as CIECAM97s. These experiments have also served very well to help clarify the difficulties in understanding and predicting the effects of surround relative luminance levels on the perceived lightness contrast of images. While the effects are well known, predicting their magnitude is extremely complex and depends on variables such as the image field of view, observer task, image content, *etc.* It is anticipated that TC1-27 will wrap up its work in the very near future.

TC1-52 was established with the goal of recommending a CIE chromatic adaptation transform. Chromatic adaptation transforms are one component of color appearance models, but often find use independent from the full appearance models. For example, chromatic adaptation transforms are often used in the calculation of indices of metamerism or in simple white-point transformations for image reproduction. To date, TC1-52 has been unable to agree upon a single adaptation transform for recommendation. This is because there are several transforms that have been proposed with similar predictive performance. It should also be noted that the performance of these transforms is not significantly different from the performance of the transform incorporated into CIECAM97s when the uncertainty in the visual data is considered. While it was hoped that TC1-52 would come to a conclusion consistent with the recommendations of TC1-34, the inability to do so has been productive in highlighting potential revisions and simplifications of CIECAM97s model. This result provides hope for the future possibility of consistent CIE recommendations for a chromatic adaptation transform and a color appearance model. It is apparent that TC8-01 will recommend a revision to CIECAM97s with a simplified chromatic adaptation transform. Perhaps this result will provide some useful data for TC1-52.

TC8-01 is working to make CIECAM97s useful in practical imaging applications. As part of this endeavor, TC8-01 has been examining possible corrections, refinements, and simplifications of the model. These range from a few simple changes to the model to logically improve its performance to reformulation of the embedded chromatic adaptation transform and chroma scale. The main objective in considering modifications to the model has been to make it more useful in practical applications while improving, or at least not changing, the model's performance. The committee seems to be coming to a consensus on the general structure of changes to be proposed and is currently working on formulating a detailed recommendation. A review of many of these proposed revisions and a general structure for a revised model have been summarized in a paper prepared for TC8-01 and recently accepted for publication in Color Research and Application.[4,5] In addition, Hunt *et al.* have recently suggested additional refinements for model reformulations.[3,7] It is likely that TC8-01 will suggest a revised model that includes aspects of both of these proposals (which are more similar than different). The following section of this paper provides some more details on the proposed revisions to CIECAM97s and the outlook for their adoption.

Finally, R1-24 continues to collect information on activities in the area of color appearance modeling and report them to Division 1. At this point in time, all of the relevant activities seem to be under consideration of the various TCs mentioned above. If and when the time arises, R1-24 will make a recommendation to Division 1 to form a new committee to consider revision of the CIECAM97s model. One important consideration in this activity will be an effort to assure that any model proposed by Division 8, through TC8-01, is consistent with future recommendations from Division 1. This paper can be considered one of the activities of R1-24.

3. REVISION OF CIECAM97s

As part of its activities, CIE TC8-01 has begun the process of preparing a revision of CIECAM97s to address a number of known flaws, include improvements, and enhance usability in practical applications. A number of such improvements have been suggested by various researchers. At the meeting of TC8-01 in April, 2000, it was decided that many of these suggestions had reached a level of consensus that would allow the task of formulating a revised model to begin. All of the agreed upon revisions along with a few additional suggestions were collected in a single paper to facilitate the work of TC8-01.[4,5]

Among the most important of the revisions discussed was the simplification of the chromatic adaptation transform embedded within CIECAM97s. CIECAM97s includes a modified form of the Bradford chromatic adaptation transform that is similar to a simple von Kries scaling for the red and green channels, but includes an adaptation-level-dependent nonlinearity on the blue channel. The form of this nonlinearity renders exact inversion of CIECAM97s (a necessity for many applications such as color reproduction) impossible and makes even approximate inversion difficult. A number of researchers (including Li, Luo, Fairchild, Süsstrunk, Finlayson, *et al.*; see ref. 4) have found that the nonlinearity in the chromatic adaptation transform can be eliminated without adversely affecting model performance (and in some cases improving it) as long as the matrix transformation from XYZ to RGB was also optimized. Including such a linear chromatic adaptation transform (essentially a von Kries transform) in a revised color appearance model would make it significantly easier to use in many situations and is seen as a major advantage. CIE TC8-01 agreed that such a linear adaptation transform should be included in a revision, but is still working to decide exactly which of several proposed XYZ-to-RGB transformation matrices to utilize. It is worth noting that all of the proposed models are capable of predicting available visual data on chromatic adaptation to within experimental uncertainty. The various proposed matrices are discussed and compared in references 4 and 5, drafts of which can be found at reference 3.

Fairchild[4] summarized the proposals for revision of CIECAM97s that were discussed within TC8-01 and proposed a revised model as a starting point for the committee's work. The changes suggested include:

1. Linearized Chromatic Adaptation Transform,
2. Correction of Anomalous Surround Compensation,
3. Correction of Lightness Scale for Perfect Black Stimuli,
4. Correction of Chroma-Scale Expansion for Low-Chroma Stimuli, and
5. Formulation of Continuously-Variable Surround Compensation.

At the time this paper was written it appears clear that items 1, 2, 3, and 5 from the list above will be included in any proposed model generated by TC8-01. However, the precise formulation of the linear adaptation transform is still a topic of discussion. Item 4 has found support from a few distinct studies and has a reasonable chance of being included in a revised model.

Hunt *et al.* recently suggested further changes in a paper that has been submitted to *Color Research and Application*[5] and also distributed to TC8-01.[3] In it, they suggest adoption of items 1, 2, 3, and 5 with a few slight changes in the specific constants used. In addition, they propose revised predictors of chroma, colorfulness, and saturation. At this time, it is unclear whether these additional proposals will be included in a TC8-01 model, however they will be thoroughly considered. It should be noted that the Hunt *et al.* chroma scale is inconsistent with item 4 in the above list, so a decision on which form to follow will have to be made within TC8-01. However, rather than focusing on the one significant difference, it is important to point out that most of the substance of the proposed changes has been agreed upon and the potential for TC8-01 to be able to work out the fine details and produce a useful, and significantly improved, revision of CIECAM97s is very high.

Currently a subgroup of TC8-01, led by committee chair N. Moroney, is in the process of working through all of the proposed revisions to come up with a single formulation to suggest for committee, and ultimately CIE, approval. At the time of this writing it is impossible to predict the precise formulation of this model. The committee's plans call for discussions of the revisions during meetings after the AIC congress in Rochester in June 2001 with a draft model prepared by autumn, 2001. If all goes well, and CIE divisions 1 and 8 ratify this work, it is entirely feasible that the world will see CIECAM01s (or maybe CIECAM02s) in the very near future. Such a happy event will only serve to improve color appearance research and applications in the years to come.

4. FUTURE DIRECTIONS

As suggested in the previous section, reporter R1-24 (also the author of this paper) will suggest to Div 1. that the model to be proposed by TC8-01 be considered a revision of the CIE interim color appearance model and not a separate entity. In so doing, this is equivalent to suggesting that TC8-01 be given the charter to author what likely will become the CIECAM01s to avoid any possible confusion. It is worth noting that the comprehensive version of the model, to be designated CIECAM97c, was never formulated and appears not to be an urgent need. However, it is suggested that the "s" and "c" designations be retained since a more comprehensive model might become necessary in the future.

The CIECAM97s model has been successful in focusing research and development activities on a single model. This focus has allowed for significant new gains in knowledge over the past four years. As originally intended, CIECAM97s is an interim model and it is becoming increasingly clear that consensus will soon be reached on several evolutionary improvements to the model that also make it easier to use. With this in mind, there is reason to be optimistice about the publication a new version of the CIECAMXXs model in the coming years.

REFERENCES

1. M.D. Fairchild, *Color Appearance Models*, Addison-Wesley, Reading, 1998.
2. CIE, *The CIE 1997 Interim Colour Appearance Model (Simple Version), CIECAM97s*, Vienna, CIE Pub. 131 (1998).
3. http://www.colour.org/tc8-01
4. M.D. Fairchild, A revision of CIECAM97s for practical applications, *Color Res. Appl.* **26** in press (2001).
5. R.W.G. Hunt, C.J. Li, L.G. Juan, and M.R. Luo, Further improvements of CIECAM97s, *Color Res. Appl.* submitted (2001).

The CIE 2000 colour difference formula: CIEDE2000

M. R. Luo, Colour & Imaging Institute, University of Derby

ABSTRACT

The CIE Technical Committee TC 1-47 *Hue and Lightness Dependent Correction to Industrial Colour Difference Evaluation* was established in October 1998 and its aim was to improve the performance of the *CIE94* colour-difference formula. As a result of close collaboration between the TC members, the CIE 2000 colour difference formula, *CIEDE2000*, was developed within two years. This paper describes the development of this formula.

Keywords: Colour difference formula, CIELAB, CMC, CIE94, BFD, LCD, CIEDE2000, Lightness, chroma, hue weighting functions and parametric factors.

1. INTRODUCTION

Colour difference is one of the important research fields in colorimetry with the goal of developing a single number pass/fail formula for industrial applications, i.e. the same colour difference predicted by the formula for pairs of samples located in different colour regions gives the same perceptual differences. Many colour scientists have striven to achieve this since the earliest colour difference formulae in the 30s. Undoubtedly one of the major contributions of the CIE in this century is the development of the CIE 2000 colour difference formula (*CIEDE2000*). The work was led by Alman, the chairman of CIE TC1-47 *Hue and Lightness Dependent Correction to Industrial Colour Difference Evaluation*. The first TC meeting was held at Baltimore in 1998. Various tasks were identified and assigned to TC members. It was agreed that the work should focus on the modification of the *CIELAB* formula following the lines of *CIE94* [1] and *CMC* [2] rather than on the development of a uniform colour space. The final structure of the formula is given in Equation (1).

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)} \qquad (1)$$

There are four enhancements to the *CIE94 formula*: a modification of the CIELAB a^* scale, which resulted in the new $\Delta C'$ and $\Delta H'$ terms in Equation (1), a new lightness-difference weighting function (S_L), for which $\Delta L' = \Delta L^*$, a hue-chroma interactive term (R_T) and a new hue-difference dependent function (S_H). The S_C function is the same as that in *CIE94* and the k_L, k_C and k_H are the parameters for taking into account parametric effects.

This paper describes the development of *CIEDE2000* and explains the reasons for these enhancements. Although it was an iterative process, the following sections are arranged according to the sequence of development. (The symbols used in Equation (1) and following equations correspond to those in the final CIE report. Each weighting function in the *CIEDE2000* is calculated using the arithmetic mean of the coordinates of the standard and sample to avoid different results when they were exchanged.)

2. DATASETS AND MEASURE OF FIT

The first task for developing a colour difference formula was to determine what experimental datasets were to be included. Four datasets considered to be the most reliable were accumulated: RIT-DuPont [3], Witt [4], Leeds [5] and BFD-Perceptibility [6] including 156, 418, 307 and 2776 colour-difference pairs. They have a mean ΔE^*_{ab} of 2.7. These datasets were merged to form a combined dataset, called COM. This was considered to be advantageous because fitting a formula to one dataset rather than fitting a formula to each individual dataset results in a single formula. The visual differences (ΔV) in each individual dataset were adjusted to have the same visual scale as that of the BFD-Perceptibility dataset. Finally, the pairs in each dataset were weighted 18, 7, 9 and 1 times for the RIT-DuPont, Witt, Leeds and BFD-Perceptibility datasets respectively. This was done to avoid too much weight for the BFD-Perceptibility dataset when developing a formula.

The *PF/3* given in Equation (2) was used by Guan and Luo [7] as a measure of fit for deriving colour difference formulae.

$$PF/3 = 100\,[(\gamma\text{-}1)+V_{AB} + CV/100]/3 \qquad (2)$$

where the coefficient variation *(CV)* and γ, were described by Alder *et al* [8] and V_{AB} derived by Schultz [9]. For a perfect agreement between the ΔE values predicted by a particular formula and visual results, ΔV, *PF/3* should equal zero. A *PF/3* of 30 indicates a disagreement of about 30%.

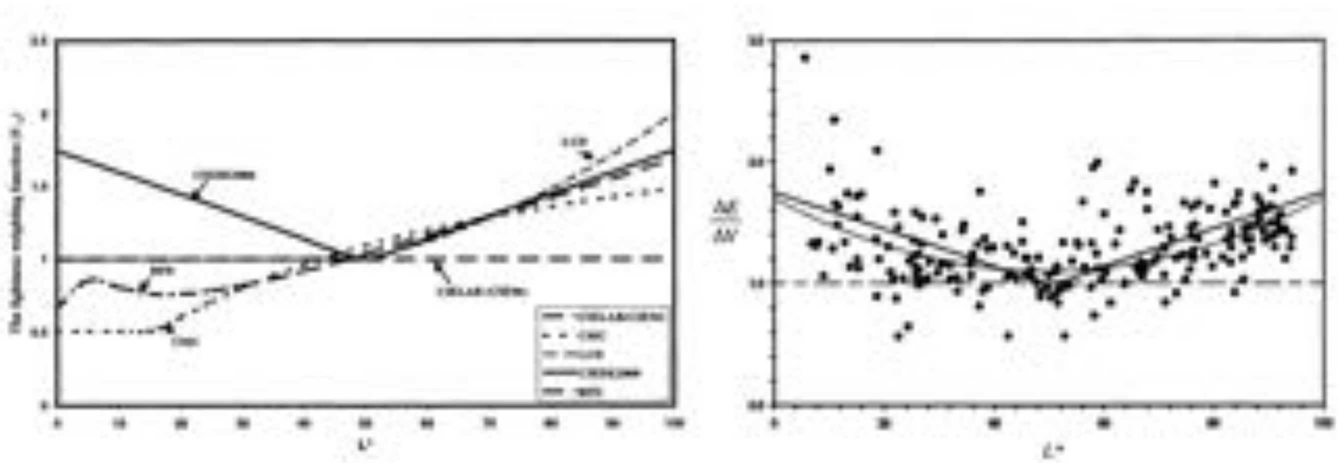
3. THE DEVELOPMENT OF THE LIGHTNESS WEIGHTING FUNCTION *(S_L)*

Figure *1(a)* shows five lightness weighting functions from *CMC, BFD, LCD* [5], *CIELAB* (or *CIE94*) and *CIEDE2000* plotted against L^*. It can be seen that all functions except *CIELAB* or (*CIE94*) indicate that the L^* scale over-predicts the lightness differences for the lighter samples. For predicting lightness differences for the darker samples, there are large differences between these functions. The *CMC* and *BFD* S_L functions indicate an under-prediction but the *LCD* function suggests that no correction to L^* scale is needed. Furthermore, the *CIEDE2000* function gave a diametrically opposite prediction.

Nobbs [10] at Leeds University investigated the lightness weighting functions (S_L). He selected the mainly lightness-difference pairs from the four datasets and plotted $\Delta E^*_{ab}/\Delta V$ value of each pair against L^* scale. He found that all datasets except BFD-Perceptibility show a distinct trend having a minimum value of $\Delta E^*_{ab}/\Delta V$ at about L^* =50 and the values rise to a maximum for both the very dark and very light regions. For the BFD-Perceptibility data, all functions fit reasonably well to the data due to a large spread of data.

At a later stage, the results from a research project supported by the Colour Measurement Committee of the Society of the Dyers and Colourists were reported by Chou *et al* [11]. Two hundred eighty pairs of near neutral matt and glossy paint samples exhibiting mainly lightness differences were assessed. The results showed that the lightness weighting function based upon Equation (3) gave an accurate prediction to the visual results. Figure *1(b)* shows the fit between the experimental data in terms of $\Delta E^*_{ab}/\Delta V$ and 3 functions: a best fit quadratic equation, Equation (3) and the CIE94 (or CIELAB) function plotted in dotted, solid and double-dashed lines respectively. The figure clearly shows a V or U shape function is required to fit the data. Equation (3) was finally chosen due to the fact that the best fit quadratic equation could under-estimate the lightness differences comparing with Equation (3) by 40% for a pair of samples around L* of 150, which may well occur for metallic coatings.

$$S_L = 1 + \frac{0.015\left(L^* - 50\right)^2}{\sqrt{20 + \left(L^* - 50\right)^2}} \qquad (3)$$



(a) (b)

Figure 1. (a) Various lightness weighting functions plotted against L^* scale. (b) The $\Delta E(CIELAB)/\Delta V$ values plotted against L^* scale for SDC/CMC dataset.

4. THE DEVELOPMENT OF THE CHROMATIC ROTATION FUNCTION (R_T)

Luo and Rigg [8] found that from their experimental ellipses plotted on *CIELAB* a^*b^* diagram (see Figure 2), all ellipses around blue region all do not follow the pattern of the others as pointing toward the origin. This resulted in the development of *BFD* formula including a hue and chroma interactive term (see Equation (1)). This concept was also employed by Kim and Nobbs [3] to develop their *LCD* formula by including an equation simpler than the *BFD* fifth-order cosine equation. Kuehni [12] was also investigated this by replacing the X tristimulus value by $X' = c_0X-(c_0-1)Z$.

All three types of equations were optimised to fit the COM dataset. Furthermore, a sub-dataset (Blue) selected from the COM including all pairs with hue angles between 230° and 320° was also used to test the performance of each optimised equation. Finally, a modified LCD hue and chroma interactive term as shown in Equation (4) was adopted due to its testing performance and robustness.

$$R_T = -\sin(2\Delta\theta)R_C$$

where

$$\Delta\theta = 30\exp\left\{-\left[\left(\overline{h'} - 275^\circ\right)/25\right]^2\right\} \qquad (4)$$

$$R_C = 0.5\sqrt{\frac{\overline{C'}^4}{\overline{C'}^4 + 10^4}}$$

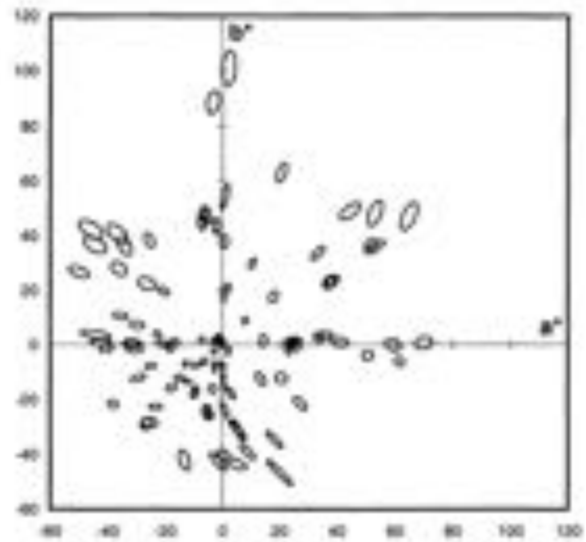


Figure 2. Luo and Rigg experimental colour discrimination ellipses plotted in a^*b^* diagram

5. THE DEVELOPMENT OF THE NEW REDNESS-GREENNESS SCALE (a')

It is also known that all CIELAB modified formulae give a poor fit to the chromatic differences close to neutral, because they all assume that the ellipses in a^*b^* diagram are circles. As shown in Figure 2, all experimental chromatic ellipses close to neutral are ellipses with an orientation around 90°. Attempts were also made to improve this shortcoming. The obvious approach is to re-scale the a^* axis. This would stretch the a^* scale to make these neutral ellipses become circles. A scaling factor of 1.4 was obtained by minimising the PF/3 measure to fit the COM data set. Another method was derived to allow for scaling the a^* axis but with a large effect for colours close to the neutral region and a smaller or no effect for higher chroma colours. This leads to Equation (5) which was later included in the *CIEDE2000* equation.

$$a' = a^*(1+G) \qquad (5)$$

where

$$G = 0.5\left(1-\sqrt{\frac{\overline{C^*}^7}{\overline{C^*}^7 + 25^7}}\right)$$

6. THE DEVELOPMENT OF THE HUE WEIGHTING FUNCTION (S_H)

A new hue S_H function developed by Berns [12] is given in Equation (6). Equation (6) was derived to fit 5 datasets exhibiting mainly hue differences. These include Luo-PhD (already included in the BFD-P data set), Qiao *et al* data [13], Luo-Rigg ellipses and RIT-DuPont and Witt. Figure 3 shows the data from each set plotted against *CIELAB* hue angle. The data were normalised so that each dataset has a normalised average of unity. It can be seen that there is good agreement between data in different datasets and Equation (6) fits well to most of the data points.

$$S_H = 1 + 0.015\bar{C}'T \qquad (6)$$

where

$$T = 1 - 0.17\cos(\bar{h}' - 30^\circ) + 0.24\cos(2\bar{h}') + 0.32\cos(3\bar{h}' + 6^\circ) - 0.20\cos(4\bar{h}' - 63^\circ)$$

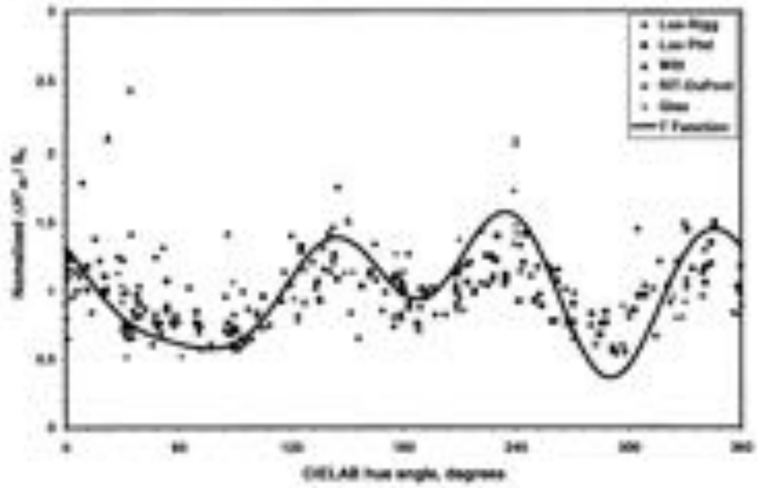


Figure 3. The normalised hue data plotted against CIELAB hue angle for the five datasets studied. The T function of Equation (6) is also plotted.

7. THE PERFORMANCE OF CIEDE2000

Although the *PF/3* measure (Equation (2)) was used in the development of the *CIEDE2000*, it does not indicate whether or not there is any statistically significant difference between the two formulae compared in predicting a particular dataset. Alman [16] proposed a method with the following testing hypothesis:

H_0: $V_{e,A} = V_{e,B}$

H_A: $V_{e,A}$ not equal $V_{e,B}$

$F_{test} = V_{e,A} / V_{e,B}$

$F_{crit} = F(df_A, df_B, 0.95)$ (critical F value)

Reject H_0 if $F_{test} > F_{crit}$ OR if $F_{test} < 1/F_{crit}$

where
$$V_{e,A} = \left(\sum_i \left(\Delta V_i - (a_o + a_1 \Delta E_i) \right)^2 \right) \Big/ (N-2)$$
$$V_{e,B} = \left(\sum_i \left(\Delta V_i - (a_2 + a_3 \Delta E'_i) \right)^2 \right) \Big/ (N-2)$$

where F_{crit} value can be calculated or found from statistics textbooks; $V_{e,A}$ and $V_{e,B}$ represent the residual error variances after scaling correction for the full and reduced *CIEDE2000* formulae with df_A and df_B error degrees of freedom respectively. The a_o and a_1 coefficients are obtained from the least-square fit between the ΔE from the full *CIEDE2000* formula (the combination of the Equations (1) to (6) except Equation (2)); the a_2 and a_3 coefficients are obtained from the least-square fit between the $\Delta E'$ from the reduced *CIEDE2000* formula. Finally, N is the number of pairs in the dataset.

The first test was made to compare the full *CIEDE2000* formula against each reduced version. For example, considering whether S_L should be calculated from Equation (3), the reduced version assumed that $k_L S_L = 1$. For testing each version against the full formula, two types of datasets were used. One was the combined data set, COM, and the other was a subset from the COM dataset. The subsets can be divided into two groups: individual component differences and selected colour regions. The former includes subsets consisting of essentially lightness differences, essentially chroma differences, and essentially hue differences. For example the lightness differences were selected from the COM dataset by only including those pairs where the value of $100|\Delta L^*|/\Delta E^*_{ab}$ was larger than 90%. Similarly $100|\Delta C^*|/\Delta E^*_{ab}$ was larger than 90% for chroma differences. The latter group includes all pairs located in the 230°< h< 320° sector for the 'blue' differences, and C*<10 for the grey regions respectively. The testing results are summarised in Table 3 in terms of F_{wa} values. The underlined bold values indicate a significantly better performance of *CIEDE2000* compared to the reduced version at the 99% confidence level, and at the 95% level for those in bold. The other values show that there is no significant difference between the performance of the two formulae tested.

Table 1 The F_{wa} values for comparing *CIEDE2000* with its reduced versions

Dataset	No. of Pairs	Degree of Freedom	$k_LS_L=1$	$k_CS_C=1$	$k_HS_H=1$	$T=1$	$R_T=0$	a'
COM	11273	3655	**0.889**	**0.472**	**0.770**	1.001	**0.872**	**0.916**
Lightness	1730	348	0.879	1.012	0.989	1.002	1.001	0.993
Chroma	2476	801	1.043	**0.521**	0.922	0.982	**0.795**	0.927
Hue	1438	486	1.007	0.931	**0.739**	**0.858**	0.985	0.942
Blue	2523	773	0.966	**0.573**	**0.707**	1.019	**0.678**	**0.821**
Grey	2436	637	**0.743**	1.023	0.997	1.003	1.000	**0.854**

The results show that (except for the T function) inclusion of each term in the formula gives a highly significant (99% level) improvement in the performance of formula. They are arranged as S_C, S_H, S_L, R_T and a' according to the degree of improvement. Although the T function is judged to be an insignificant improvement using the COM dataset, it is still a significant improvement at the 95% level using the Hue subset. The similar confidence level of improvement can also be found for the a' component using the Grey subset.

Table 2 The F_{wa} values for comparing *CIEDE2000* with the other colour difference formulae

Data set	No. of Pairs	Degree of Freedom	CIELAB	CMC	CIE94	BFD	LCD
COM	11273	3655	**0.488**	**0.838**	**0.763**	1.027	**0.891**
Lightness	1730	348	0.878	**0.837**	0.877	0.947	1.011
Chroma	2476	801	**0.471**	**0.819**	**0.818**	0.928	0.894
Hue	1438	486	**0.544**	**0.757**	**0.839**	0.943	**0.841**
Blue	2523	773	**0.417**	**0.715**	**0.629**	1.082	**0.817**
Grey	2436	637	**0.638**	**0.863**	**0.614**	0.960	**0.813**

The same testing method was applied to compare *CIEDE2000* with *CIELAB*, *CIE94*, *CMC*, *BFD* and *LCD* formulae. The results are given in Table 2 in terms of F_{wa} values for each comparison. Again, for the underlined bold values, there is a significant superiority of *CIEDE2000* at the 99% confidence level, and at the 95% level for those in bold.

For the COM dataset, *CIEDE2000* outperformed the other formulae except for *BFD* the improvement always being significant at the 99% level. For the Chroma subset, it is surprising that *CIEDE2000* performed significantly better than *CIE94* (they have the same S_C function) For the Blue subset, the formula again performed significantly better than the other formulae except for *BFD*. For the Grey subset, it still predicted more accurately than *CIE94*. The present results clearly showed that the *CIEDE2000* formula performed much better than the current standards: *CIE94* and *CMC* formulae.

8. CONCLUSIONS

This paper summarises the work involved in the development of CIE 2000 colour difference formula: *CIEDE2000*. Its performance was thoroughly evaluated by comparing with its reduced versions and the other formulae. The results show that all the components developed showed a significant enhancement to the CIELAB formula. In addition, this formula should be confidently used for industrial applications because it outperformed the current standards: *CMC* and *CIE94* by a considerable margin.

ACKNOWLEDGEMENTS

The author would like to thank D. Alman for his outstanding leadership of CIE TC1-47, J. Nobbs and R. Berns for contributing their work, B. Rigg for providing advice, W. Chou for conducting experiment and the other TC members for their strong encouragement. Also, the author would like to thank the support from the Society of Dyers and Colourists

(SDC), UK, for sponsoring colour-difference research, and finally, G. Cui for his involvement at every stage of the development work.

REFERENCES

1. CIE. Technical report: Industrial colour-difference evaluation. CIE Pub. No. 116. Vienna, Austria: Central Bureau of the CIE; 1995.
2. F. J. J. Clarke, R. McDonald, and B. Rigg. Modification to the JPC79 colour-difference formula. *J Soc Dyers Col* 1984;100:128-132 and 281-282.
3. R. S. Berns, D. H. Alman, L. Reniff, G. D. Snyder, and M. R. Balonon-Rosen, Visual Determination of Suprathreshold Color-Difference Tolerances Using Probit Analysis. *Col Res Appl* 1991;16:297-316.
4. K. Witt, Geometric Relations between Scales of Small Colour Differences. *Col Res Appl* 1999;24:78-92.
5. D. H. Kim, and J. H. Nobbs, New weighting functions for the weighted CIELAB colour difference formula. Proc Colour 97 Kyoto 1997;1:446-449.
6. M. R. Luo, and B. Rigg, BFD(l:c) colour-difference formula. Part I — Development of the formula. *J Soc Dyers Col* 1987;103:86-94. M. R. Luo, and B. Rigg, BFD(*l:c*) Colour-difference formula, Part II—Performance of the formula. *J Soc Dyers Col* 1987;103:126-132.
7. S. S. Guan, and M. R. Luo, Investigation of parametric effects using small colour differences. *Col Res Appl* 1999;24:331-343.
8. C. Alder, K. P. Chaing, T. F. Chong, E. Coates, A. A. Khalili and B. Rigg, Uniform chromaticity scales - new experimental data., *J. Soc. Dyers Col.*, 98, 14-20 (1982).
9. W. Schultz, The Usefulness of Colour-Differences Formulae for Fixing Colour Tolerances, Color Metrics, Soesterberg, AIC/Holland, 245-265 (1972).
10. J. H. Nobbs, Lightness difference weighting term S_L, unpublished CIE TC 1-47 report (1999).
11. R. G. Kuehni, Towards an improved uniform color space, *Col. Res. Appl.* 24, 253-265 (1999).
12. R. S. Berns, Derivation of hue-angle dependent, hue difference weighting function for CIEDE2000, ibid.
13. Y. Qiao, R. S. Berns, L. Reniff, and E. Montag, Visual Determination of Hue Suprathreshold Color-Difference Tolerances. *Col Res Appl* 1998;23:302-313.
14. D. H. Alman, Performance comparison for full and reduced color-difference models, unpublished CIE TC 1-47 report (2000).

Making Color Work in CIE Division 8

Todd Newman*
Canon R&D Center Americas, Inc.

ABSTRACT

There are two primary reasons that color imaging does not "work" today. The first is that there are no broad standards that can be applied across technologies and between applications. The second is that many standards groups do not consider what is known of color and vision science as they make standards. CIE Division 8 was created to address both these problems. The plan of work and progress to date of each of the technical committees (TCs) within Division 8 are described, along with a brief description how of the TC's work will help "make color work."

1.Introduction

Why doesn't color "work" today? Well, consider the cathode ray tube video display (CRT). There are many uses for a CRT: watching television, retouching photographs, viewing 3D simulations of architecture, and using an office workstation, to name just a few. The same physical device can be used for all these purposes. Yet if you were to look at the standards controlling these different uses, you would be struck by the widely different parameters for reproduction used. In an earlier paper, Michael Stokes and I enumerated 37 different standards for this one display technology[1]. This is why color is broken. Developers have to guess which standard to follow. In our paper, we showed that the different standards are determined by different assumptions about viewing conditions, display calibration, and upstream adjustments to the image. Each industry makes its own assumption and designs an image-processing pipeline based on those needs. But users today keep crossing industry boundaries. They want to use the same office workstation to view television clips, photographs, and architectural models. The users cross boundaries; their software and the standards it is based on do not. Thus imaging today is broken largely because of standards that take a narrow view and standards that ignore color and vision science.

CIE Division 8 was created to address both issues. Technical committees in ISO and IEC have relatively narrow terms of reference such as "photography" or "television." In contrast, Division 8 was deliberately charged with looking at "the big picture." Its terms of reference are: "To study procedures and prepare guides and standards for the optical, visual and metrological aspects of the communication, processing, and reproduction of images, using all types of analogue and digital imaging devices, storage media and imaging media." And of course, we created the division within the CIE so that we could draw upon the expertise in vision science found within CIE Division 1 and the expertise in optical metrology found within Division 2. This report summarizes the progress of the technical committees within CIE Division 8 to date, their plans for the future, and how each TC trying to bring the CIE's expertise to bear on problems in image technology.

2.Color Appearance Modeling for Color Management Applications (TC8-01)

The CIECAM97s color appearance model (CAM) represented a consensus opinion among a set of acknowledged experts, CIE TC1-34. However, as we applied this model in the imaging industry, we found problems. The goal of TC8-01 is to find ways to improve the model, based both upon the earlier consensus and upon more recent experience.

Currently, the working group is evaluating three linear chromatic adaptation transforms (CATs) for use as a simplified chromatic adaptation model. Drs. Hunt et al.[2], Fairchild[3], and Finlayson and Susstrunk[4] have each shown that it is possible to match or even exceed the performance of the nonlinear Bradford CAT currently in CIECAM97s with a linear CAT. A linear CAT would be invert more accurately, which is necessary when CATs are used in color management systems. The current issue is deciding which of the three proposals to incorporate. The working group is also reviewing Dr. Fairchild's revised chroma scale and Dr. Luo's revised saturation scale. The various proposed revisions and simplifications will be incorporated into a single revised color appearance model. The working group plans to present

* Canon R&D Center Americas, 3300 North First Street, San Jose, CA 95134; todd@cra.canon.com

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

a candidate revised color appearance model at a TC meeting immediately following the AIC conference. TC members will test out the new model in order to gain confidence that it works as advertised. Then, the TC can vote whether to accept the changes to the CAM at its next meeting in November 2001. A technical report would then follow from that.

3.Color Difference Evaluation in Images (TC 8-02)

The goal of TC8-02 is to derive an industrial color-difference evaluation method that is appropriate for images. Current color difference formulas (CIELAB, CMC, etc.) are designed for color patches that subtend 2 degrees or more of the field of vision. Color patches in images tend to be much smaller. The method must be based on a quantitative model of color-differences under conditions typical of commercial imaging applications.

There is no common practice in industry upon which to base a standard. So the TC will have to first develop a consensus among experts by created some coordinated research reports. From these, we can develop a common practice and then develop a standard. The TC will provide the following items in its final report:

- a color difference equation with an option to add three spatial filters
- a method for evaluating color reproduction fidelity including test images
- a TC Technical Report on Methods to derive color differences for images.
- experimental data sets available on the web
- a summary report on a collaborative research programmed for investigating the perceptibility and acceptability thresholds using a set of color difference images based upon SCID/XYZ images across different test sites.

The TC has made substantial progress, through both independent work and effective liaison with other standards bodies. An experiment was completed by GATF and SWOP on proof verification. The data analysis is in progress and will inform the TC's work. A color difference equation has been developed in CIE Division 1; this will probably be the basic equation to be used. The three spatial filters will be developed at RIT and tested independently at the University of Derby. A set of test images will be produced, based upon the Japanese standard XYZ/sRGB SCID images. These images will be distributed between different sites for assessing their perceptibility and acceptability thresholds. The TC plans to review these test images at their next meeting, in June. The TC has produced three drafts of their technical report and will be reviewing the latest draft at their meeting, as well.

4.Gamut Mapping (TC 8-03)

The goal of TC8-03 is to study, develop and recommend a baseline solution for cross-device and cross-media image reproduction. Figure 1 illustrates the difference between the gamut of a monitor and an inkjet printer. This solution will provide a standard procedure to calculate the color gamut of an image, an imaging system, or its components, and either one algorithm, or a set of algorithms and rules for use in specific applications.

The TC faces a challenge greater than the usual lack of consensus about best practices. Many industry experts believe that selecting an acceptable gamut mapping algorithm is always image-dependent, and so we cannot select a fixed set of rules that will always yield an acceptable reproduction. Some companies believe that they have a proprietary advantage to their gamut mapping algorithm, and so they do not want a standard to be created. Both sets of beliefs make it hard to come to a consensus. However, standardized baseline behavior is vitally important for reliable and unambiguous communication of color information across networks. So the goal for the TC is to try to forge agreement, again by using the technique of coordinated research.

The TC has decided to proceed by first developing a standard experimental design for gamut mapping research. The design requires standard experimental conditions, some standard algorithms to be tested in each experiment, and some standard images to be used in each experiment. If researchers use this design, it will be possible compare results between experiments. This has not generally been possible in the past. Intercomparison of results should allow the research community to converge upon a baseline more rapidly.

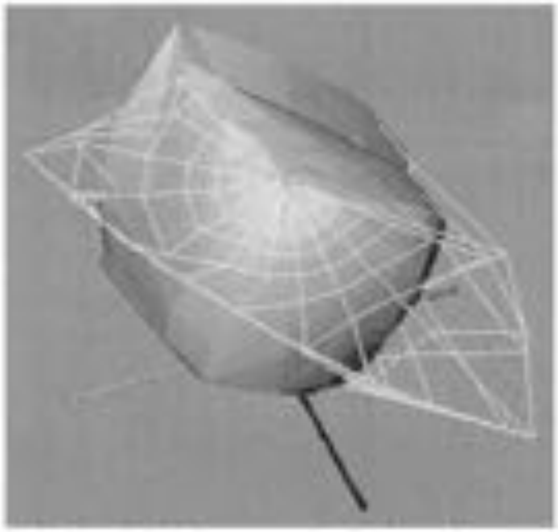


Figure 1. Comparison of printer gamut (solid) and monitor gamut (mesh)

Most of the experimental methodology is in place. At this point, we are only waiting for some test images. Then we can begin a coordinated research program. We expect to complete a first phase of research in October 2001 and discuss the results at a TC meeting held in conjunction with the Color Imaging Conference in 2001.

5.Adaptation Under Mixed Illumination Conditions (TC 8-04)

This is another area where Division 8 intends to extend the work done by another division in order to make it more useful to industry. CIE Technical Committee 1-27 has done fine work on appearance matching between video displays (soft copy) and paper (hard copy). However, their work requires that people completely adapt to each viewing condition. Both consumers and professional graphic artists want to compare an electronic original side by side with its hard-copy reproduction. (See Figure 2.) This causes some problems for color scientists. The primary one is figuring out what stimulus will appear white to people in this situation. As most color appearance models do, CIECAM97s requires us to specify a white point. We know that people find neither paper white nor the monitor white to be a "true white" in this situation. As yet, there is no consensus among experts for a standard mathematical formula to determine the adapted white point.

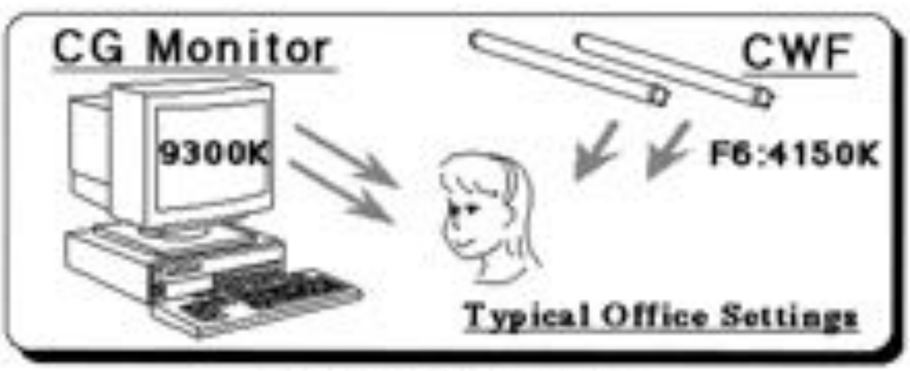


Figure 2. Typical office viewing conditions

Again, the technical committee chose to begin by defining a common experimental technique and then perform coordinated research. The committee has defined an experimental methodology, details of which are available on the TC's web site. The chairman provided the agreed upon model in the form of a spreadsheet. Sony has provided three standard images that might be used for the cross-examinations, and one member, Dr. Wenzel of Coloryte, provided a color-blind test. The TC is looking for researchers to perform the experiments. The TC hopes to have the research completed by the end of 2001. Then they plan to produce a technical report by the end of 2002.

6.Communication of Color Information (TC 8-05)

Unambiguous color communication of images, the goal toward which TC8-05 is aiming, can be achieved in one of two ways. Either a mapping must be supplied with each image or colors in the image must be translated into a standard color space. The International Color Consortium (ICC) device profile format supports the first approach; the CIE sees no reason to develop a competing solution. Our efforts have focused on the development of standard color spaces.

The challenge here is that there are so many proposed standards that there is no common practice. There are standards for video, standards for video games, standards for cameras, and standards for printing. All of these standards are currently incompatible. Several TCs within ISO and IEC are working on revisions of, and replacements for, these standards. Unfortunately, the next generation of standards will not be more compatible, because the TCs are not working together.

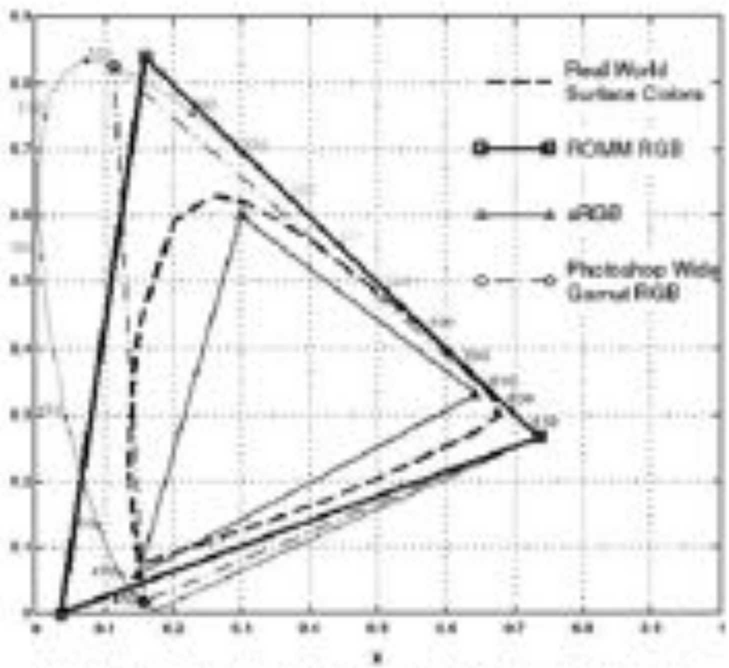


Figure 3. Locus of primaries for proposed extended gamut RGB spaces

TC8-05 is hoping that it can help the other standards bodies by providing a methodology that can help them select new color spaces in a more methodical manner. The plan is to develop appropriate criteria and metrics to serve as a guideline. The TC is also working with other standards bodies to develop application profiles that may be used to weight the relative importance of the metrics.

The idea is to develop a series of criteria by which to measure spaces (such as the size of the gamut, locus of primaries, or hue uniformity) and metrics to measure these criteria (quantifying gamut volume, the effects of different primaries, or assessing hue uniformity). A standards body could then decide which criteria were important to its clientele, and use the CIE's method for quantifying the degree to which a proposed standard met those criteria. The TC has prepared one sample metric: the size of the gamut boundary. They plan to have a preliminary set of evaluations available by November of this year. They will produce a draft technical report in April 2002.

7.Vocabulary (TC8-06)

You might think that vocabulary was not a technical issue, but it is. Often, our most heated arguments actually spring from inconsistent use of terminology. Terms such as "contrast" and "flare" can have very different uses in different technical fields. As these fields are brought together through the use of computer systems, we find that inconsistent use of terminology can lead to inconsistent use of technology. The work of this technical committee will be to create a master vocabulary of technical terms relating to image technology. This may either supplement the International Lighting Vocabulary or be published as a separate document. Of course, this is another area in which it is important to form and maintain active liaison with other standards bodies.

The Chairman has submitted parts of several terminology documents to members to consider what should be included in a technical report. At the TC meeting in November 2000, it was decided that the TC should collect a terms and definitions and place them in a database. Members and liaisons (from ISO and IEC TCs) will send recommendations for definitions by mid-December of this year. The chairman will consolidate the material as a database by the end of January 2002.

8.Summary

I have shown how the TCs within CIE Division 8 are trying to help make imaging work better. Each is trying to apply expertise in color and vision science to imaging applications. Each is trying to be cognizant of all the different imaging applications. The CIE, like all standards bodies, depends on the voluntary efforts of technical experts. Since our goal is to find solutions that work for a broad range of activities, we need a broad range of expertise in order to succeed. Thus, the work of the Technical Committees is open to all, and experts are always welcome. The more experts we have, and the more time they can donate, the faster we can move. The faster we can move, the sooner we can help make color work better. To find out more about what's going on, please visit our web site, www.colour.org. Be sure to follow the links to the web pages for each technical committee. The Technical Committee chairs would also be interested in hearing from you:

TC8-01	Nathan Moroney	Nathan_Moroney@hpl.hp.com
TC8-02	M. Ronnier Luo	m.r.luo@derby.ac.uk
TC8-03	Jan Morovic	j.morovic@derby.ac.uk
TC8-04	Naoya Katoh	naoya@dewd.crl.sony.co.jp
TC8-05	Rob Buckley	RBuckley@crt.xerox.com
TC8-06	Janos Schanda	schanda@ella.hu

REFERENCES

[1] 1 M. Stokes and T. Newman., "RGB Colour Standards: A Case Study," Proc. CIE Expert Symposium '97 on Standards for Colour Imaging, 1997.
[2] R.W.G Hunt, C.J. Li, L.G. Juan, and M.R. Luo, "Further Improvements to CIECAM97s," submitted for publication in *Color Res. Appl.*, 2001.
[3] Mark D. Fairchild, "A Revision of CIECAM97s for Practical Applications", submitted for publication in *Color Res. Appl.* 2000.
[4] Graham D. Finlayson and Sabine Susstrunk, "Performance of a Chromatic Adaptation Transform based on Spectral Sharpening," Proc. 8th Color Imaging Conference, 2000, p. 49.

Invited Paper

Report on a fundamental chromaticity diagram with physiologically significant axes

Françoise Viénot, chair of CIE TC 1-36

ABSTRACT

The scope of TC 1-36 is to supplement the CIE colorimetric observers with color matching data that make a clear connection between the color specification and the underlying physiology. After careful examination of color matching data, TC 1-36 has agreed on proposing a continuous fundamental observer with data from 10° to 1°. The 10° color matching measurements of Stiles and Burch (1959) will provide the basic data for this continuous fundamental observer. Fundamental response curves will be derived as a function of field size, taking into account the macular pigment, the ocular media and the photopigment optical densities.

1. INTRODUCTION

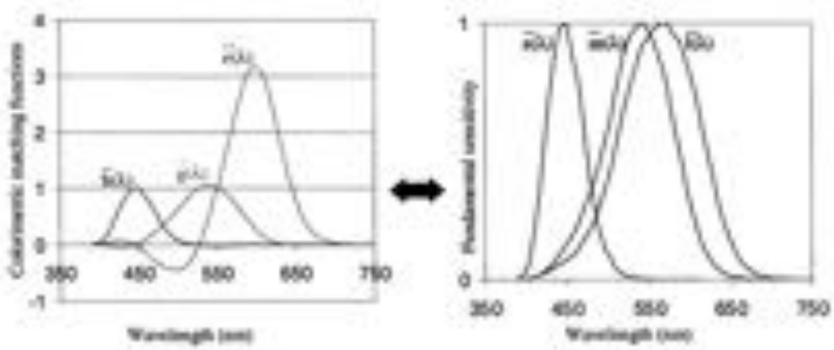
1. Background

The scope of TC 1-36 is to supplement the CIE colorimetric observers with color matching data that make a clear connection between the color specification and the underlying physiology. Over more than 70 years, the CIE has provided users with data and methods that accomplish color specification and which are widely used in industry. Colorimetry is based on visual experiments. Actually, color vision begins with the absorption of photons of light by the photopigments contained in cones. Therefore, as a visual stimulus, light is specified in terms of 3 numbers that are related to the responses elicited in the cones.

2. Fundamentals. Definition and properties

We call "fundamentals" the spectral response functions of the long-wave sensitive (L-), medium-wave sensitive (M-) and short-wave sensitive (S-) cone receptor mechanisms, measured in the corneal plane. For many years, the cone responses had not been accessible by objective experimental methods. Surely, the fundamentals must be linear transformation of the color-matching functions (CMF's) of the observer, since a color match is only obtained when 2 stimuli produce equal quantum catches in the 3 kinds of cone. From all possible sets of 3 primaries obtained from a linear combination of color-matching functions, there is only one set that specifies the spectral responses of the actual cone pigments (Figure 1). Recent estimates have been constructed from CIE 1931, CIE 1964, or the Judd-Vos 2 deg color matching functions. Every attempt[1-3] has contributed to an improved prediction of the fundamentals.

Figure 1. A linear relationship links L-, M- and S- fundamentals to the set of color-matching functions.



3. Agreed principles

The first work of the Committee consisted of choosing the best set of cone fundamentals. Although the color-matching functions of the CIE 1931 Standard Colorimetric Observer, of the Judd revised colorimetric observer and of the Stiles & Burch pilot study fall within normal physiological variability, they fail to be perfect. Another possibility is to derive the 2° color-matching functions from the 10° color-matching functions[4,5]. Because the color-matching functions $\bar{r}_{10}(\lambda)$, $\bar{g}_{10}(\lambda)$ and $\bar{b}_{10}(\lambda)$ of Stiles and Burch (1959)[6] which form the main basis of the CIE 1964 10° functions were directly measured rather than being reconstructed from chromaticity data and luminous efficiency data, they offer a purely colorimetric data base. TC 1-36 proposes that the 10° color matching measurements of Stiles and Burch (1959) constitute the starting point of the derivation.

Finally, TC 1-36 has agreed on proposing a continuous fundamental observer with data from 10° to 1°. Therefore, fundamental response curves will be derived as a function of field size, taking into account the macular pigment, the ocular media and the photopigment optical densities. The 10° color-matching functions from Stiles & Burch (1959)[8] will provide the basis data for this continuous fundamental observer. Consequently, neither the CIE 1931 nor the CIE 1964 color-matching functions will be used.

4. Hypotheses

4.1. The first theoretical basis for deriving fundamentals is the König hypothesis. König (1886) has postulated that dichromatic vision is a reduced form of trichromatic vision where one cone response is missing and the two others are left unchanged in spectral sensitivity. It has been agreed in the committee to propose cone fundamentals that satisfy the König hypothesis. Therefore, the proposed fundamentals should reflect:

- the ability of true congenital dichromats to match color.
- the spectral sensitivity of dichromats when one of the functioning cone mechanism is not active, for one or another reason. For instance S-cones are insensitive to rapid flicker, then in this condition, protanope and deuteranope vision reduces to M-cone or L-cone vision respectively.
- visual responses similar to those of dichromatic vision in the cases where normal vision naturally reduces to dichromacy as in foveal tritanopia.
- the spectral response of normal trichromatic vision if a correct and total cone isolation has been achieved by some specially designed experimental protocol.

4.2. Since the fundamental spectral sensitivities are measured outside the eye, in the corneal plane, and since the actual absorption of photons initiating the electrical signal for vision takes place in the outer segment of the photoreceptors, there are several factors that explain the deviation between the fundamentals and the cone action spectra (Figure 2):

- selective absorption by the lens and other pre-retinal media,
- selective absorption by the macular pigment,
- self-screening in the outer segments of the photoreceptors,
- other effects such as waveguide effects.

It might be possible to establish the link between the fundamentals and the underlying photopigment spectral absorptivity

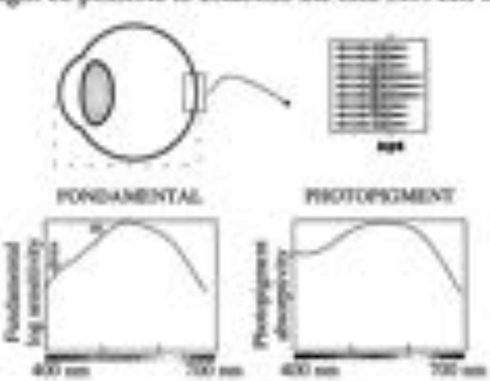


Figure 2. Deviations between the fundamental and the photopigment absorptivity

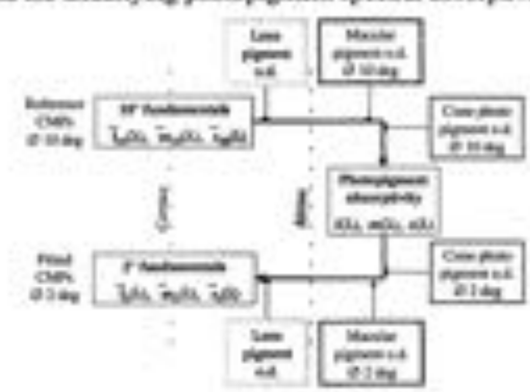


Figure 3. Reconstruction scheme for deriving fundamentals at any field size

5. From the cone fundamentals to the photopigment absorptivities

The procedure for deriving fundamental curves as a function of field size is the following (Figure 3):

(1) start with the 10° color matching functions from Stiles & Burch (1959)[8]

(2) derive 10° fundamental curves at the corneal level

(3) transform fundamentals into the spectral absorptivity curves of the photopigments

- correcting for ocular media spectral absorption
- correcting for macular pigment spectral absorption on 10° field

- correcting for the effect of cone photopigment optical density on the spectral absorptivity of the photopigment for 10° field

(4) do the reverse computation to find fundamental curves at the corneal level for another field diameter introducing appropriate corrections for this field size

2. RECOMMENDATIONS

1. Choice of the color-matching functions (CMFs) data basis

After a careful examination of color-matching data, TC 1-36 has approved the choice of Stockman & Sharpe[5] to base the future recommendation on the 'large field' 10° CMFs of Stiles and Burch (1959). It constitutes the most comprehensive set of CMF data, which were measured directly, in a large number of subjects (49 subjects from 392.2 to 714.3 nm, and in 9 subjects from 392.2 to 824.2 nm), were not contaminated by photometric adjustment and have not been modified by other CIE committees. TC 1-36 recommends to base the cone fundamentals on the 10° Stiles and Burch CMFs.

2. Color matching transformations

While measured at the corneal level, color matches are determined by the absorption of photons at the cone level.

$$\begin{pmatrix} L_R & L_G & L_B \\ M_R & M_G & M_B \\ S_R & S_G & S_B \end{pmatrix} \begin{pmatrix} \bar{r}(\lambda) \\ \bar{g}(\lambda) \\ \bar{b}(\lambda) \end{pmatrix} = \begin{pmatrix} \bar{l}(\lambda) \\ \bar{m}(\lambda) \\ \bar{s}(\lambda) \end{pmatrix}$$

3. Deriving 10° and 2° S-fundamental from 10° CMFs

- S-fundamental from 390 to 505 nm

We assume that the S-cones are insensitive to the red primary so S_R is zero.

If we are concerned only about the relative cone spectral sensitivity, the transformation for $\bar{s}(\lambda)$ simplifies to

$(S_G / S_B)\ \bar{g}(\lambda) + \bar{b}(\lambda) = k_s\ \bar{s}(\lambda)$

where k_s is a scaling constant. In a first step, the ratio (S_G/S_B) is obtained from the matches of test lights longer than ~ 560 nm where it equals minus ($\bar{b}(\lambda) / \bar{g}(\lambda)$). From 390 to 505 nm, the proposal is to obtain the 10 deg S-cone fundamental from the linear transformation of 10° CMFs.

In a second step, a photopigment optical density (o.d.) increase from 0.3 to 0.4 and a macular pigment o.d. increase from 0.095 to 0.35 are assumed. This allows to proceed back to the 2° S-cone fundamental. The proposal is to adopt this reconstructed function as the 2° S-cone fundamental from 390 to 505 nm.

- S-cone fundamental from 510 to 615 nm

In a first step, to produce the 2° S-cone fundamental from 510 to 615 nm, Stockman and colleagues[7] fitted a Gaussian function simultaneously to their psychophysics experimental data (see section 6) along with the 2° CMFs data of Stiles (1955). Beneath 615 nm, the S-cone fundamental is so small that it can be set to zero. From 510 to 615 nm, the proposal for the 10 deg S-cone fundamental would be the Gaussian expansion.

In a second step, the 2 deg function is readjusted back to 10 deg, using exactly the same parameters as from 390 to 505 nm. From 510 to 615 nm, the proposal would be to produce the 2 deg S-cone fundamental by readjusting from 2° to 10° the Gaussian expansion readjusted from 2° to 10°.

4. Deriving L- and M- fundamentals from CMFs. SB10 based fundamentals adjusted to 2°

If we are concerned only about the relative cone spectral sensitivity, the transformations for $\bar{l}(\lambda)$ and $\bar{m}(\lambda)$ simplifies to

$(L_R / L_B)\ \bar{r}(\lambda) + (L_G / L_B)\ \bar{g}(\lambda) + \bar{b}(\lambda) = k_l\ \bar{l}(\lambda)$

$(M_R / M_B)\ \bar{r}(\lambda) + (M_G / M_B)\ \bar{g}(\lambda) + \bar{b}(\lambda) = k_m\ \bar{m}(\lambda)$

where k_l and k_m are scaling constants

As a starting element, Stockman & Sharpe[5] defined the 2° cone fundamentals from the 2° CMFs of Stiles (1955) and used it as an intermediate step in the derivation of the 2° fundamentals based on the 10° CMFs from Stiles & Burch (1959)[6]. They optimized adjustments in macular, lens and photopigment densities in order to reconstruct the 2° L- and M-cone fundamentals that fit to the 2° L- and M-cone fundamentals previously defined from the 2° CMFs of Stiles (1955). The assumed peak photopigment optical density is 0.50 for $\bar{l}_2(\lambda)$ and $\bar{m}_2(\lambda)$ and 0.38 for $\bar{l}_{10}(\lambda)$ and $\bar{m}_{10}(\lambda)$. The macular pigment o.d. increases from 0.095 for 10° field to 0.35 for 2° field. (Figure 4). The proposal is to derive the 10° L- and M-fundamentals from the 10° CMFs of Stiles and Burch (1959)[8] and to adopt reconstructed functions as the 2° L- and M-fundamentals.

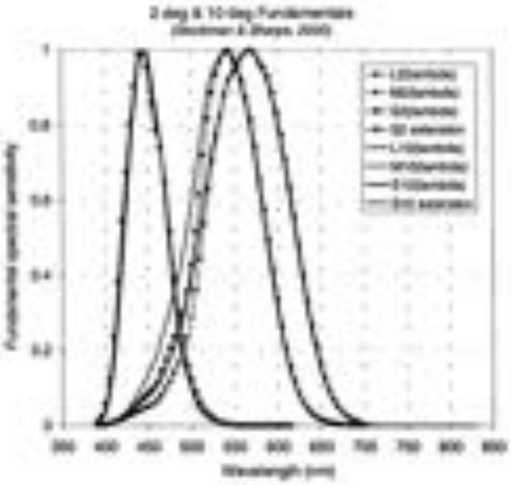


Figure 4. L-, M- and S-cone fundamental sensitivities

3. RECOMMENDED PARAMETERS

1. Pre-retinal pigments

The lens optical density increases at very short wavelengths. Stockman & Sharpe[1] have proposed slight modifications of van Norren and Vos' lens pigment density spectrum[8]. Although certainly dominated by lens pigment, this density spectrum is likely to reflect filtering by the lens and some absorbing media of unknown origin.

2. Macular pigment

The macular pigment density is maximum around 460 nm but varies considerably among observers. A maximum density of 0.35 at 460 nm is a representative average. The macular pigment spectrum adopted by Stockman & Sharpe[1] is the spectrum of lutein and zeaxanthin mixed in the same ratio as found in the foveal region[9].

Large field parameters			Small field pagameters		
Lens 1.7649			Lens 1.76		
MacPig10° / L 0.095	MacPig10° / M 0.095	MacPig10° / S 0.095	MacPig2° / L 0.35	MacPig2° / M 0.35	MacPig2° / S 0.35
L cone max o.d. 10° 0.38	M cone max o.d. 10° 0.38	S cone max o.d. 10° 0.3	Lcone max o.d. 2° 0.50	M cone max o.d. 2° 0.50	S cone max o.d. 2° 0.40

4. A CONTINUOUS AND AGE-DEPENDENT OBSERVER

1. Field size dependency

Given the macular pigment density spectrum, the lens pigment density spectrum, and the change of densities with eccentricity, it is possible to establish the link between the cone fundamental and the photopigment spectral absorptivity and to extend the derivation of cone fundamental at any field size. (In general, when considering the relationship of CMFs to cone spectral sensitivity energy units are used, and when considering raw spectral sensitivity data of photopigment spectra, quantal units are used.)

1.1 Macular pigment. The macular pigment distribution over the retina as assessed by color matching on circular fields can be described by the exponential relationship[10]

$$D_{mac\ pig} = a * 10^{(-Field\ diameter\ /\ b)}$$

2.2. Cone length. The length of the cones increases in the fovea. Beer-Lambert law states that as the thickness of a solution increases, its optical density proportionaly increases. Applied to the cones, this results in a broadening of the fractional absorption spectrum as the length of the photoreceptors increases. This is a source of variation of the color matching functions. The exponential decay of the optical density of the photoreceptors with field diameter has been formulated by Smith and Pokorny[11] as

$$D_{cone} = a + b * 10^{(-Field\ diameter\ /\ c)}$$

2. Age dependency

The lens optical density increases dramatically with age. Lens transmission has been characterized as having two components with one varying with age[12]. Therefore, it is possible to take into consideration age dependence. The optical density of the lens of an average observer may be estimated by a formula with one or another set of *a, b, c* and *d* values depending whether the age is between 20 and 60 or over 60 years old.

$$D_{lens} = a + b\,[c + d\,(Age - 60)]$$

5. THE CHROMATICITY DIAGRAM

1. Tristimulus values

Once the essential step of proposing fundamentals is made, it will be possible to specify colors in a 3-dimensional LMS space. Given a stimulus ***Q*** with its spectral distribution of light $P_\lambda(\lambda)$, its tristimulus values *L, M* and *S* are obtained

$$L_Q = k_l\, \Sigma\, P_\lambda(\lambda)\, L(\lambda)\, \Delta\lambda$$
$$M_Q = k_m\, \Sigma\, P_\lambda(\lambda)\, M(\lambda)\, \Delta\lambda$$
$$S_Q = k_s\, \Sigma\, P_\lambda(\lambda)\, S(\lambda)\, \Delta\lambda$$

2. Luminous efficiency function, luminance and units

TC 1-36 agrees that the S-cones do not contribute to luminance. Then normalization of M- and L- fundamental sensitivities could be made so that the weighted sum of $\bar{l}(\lambda)$ and $\bar{m}(\lambda)$ represents spectral luminous efficiency function.

$$V(\lambda) = w_L\, \bar{l}(\lambda) + w_M\, \bar{m}(\lambda)$$

After Stockman & Sharpe[3], the best fitting value of w_L/w_M is 1.76 for $\bar{y}_{10}(\lambda)$

This leaves the scale for S value arbitrary.

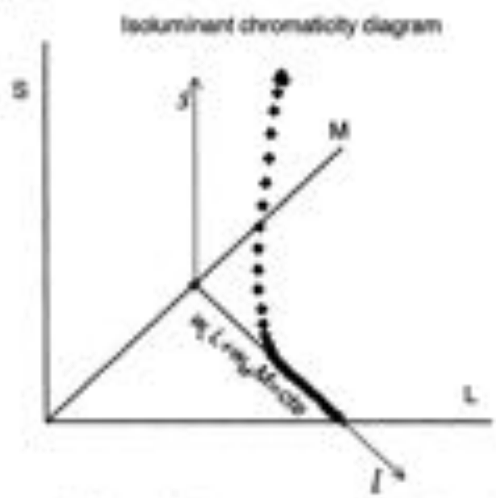


Figure 5. Fundamental chromaticity diagram in an isoluminant plane

3. Fundamental chromaticity diagram

The great advantage of assuming that luminance depends only upon the sum of L- and M- cone responses, which certainly is traceable to a color vision property, is to offer the possibility of plotting chromaticity in a unit-luminance plane[13] (Figure 5). In line with the accepted null luminosity from the S-system, an isoluminant chromaticity diagram is constructed. On the abscissa the fractional amount of L- cone fundamental response is reported. The ordinate scaling proceeds from the choice of units for the S-fundamental response. A possible disadvantage is that the white point appears almost to fall on the abscissa axis. TC 1-36 has agreed upon linear scaling.

$$l = w_L L\, /\, (w_L L + w_M M)$$
$$s = S\, /\, (w_L L + w_M M)$$

6. CONFORMITY TO INDEPENDENT PSYCHOPHYSICAL EXPERIMENTS ON 2° FIELD

The spectral sensitivities of the 3 cone types overlap extensively throughout the spectrum. Consequently, the measurement of the spectral sensitivity of a single cone type in the normal trichromatic observer requires special procedures to isolate its response from the responses of the other two unwanted cone types. Cone isolation can be simplified by the use of special observers, who lack one or more of the three cone types. Protanopes are missing L-cone function. Deuteranopes are missing M-cone function. The cone fundamentals derived from CMFs and proposed by TC 1-36 are close to the fundamental sensitivities directly measured in dichromatic observers.

7. CONCLUSION

After careful examination of color matching data, TC 1-36 has agreed on proposing a continuous fundamental observer with data from 10° to 1°. Fundamental response curves will be derived as a function of field size, taking into account the macular pigment, the ocular media and the photopigment optical densities. The 10° color matching measurements of Stiles and Burch(1959) will provide the basis data for this continuous fundamental observer. Consequently, neither the CIE 1931 nor the CIE 1964 color matching functions will be used. By making a clear connection between color specification and the underlying physiology, the fundamental chromaticity diagram proposes a unified framework for various scientific communities. Indeed, the cone responses are the signals entering the visual system and should be known in order to fully analyse a color situation. TC 1-36 is very much concerned that the color community should use the fundamental chromaticity diagram with physiological significant axes, not only for scientific and pedagogic purposes but also for specification and as a basis for future developments.

ACKNOWLEDGMENTS

I would like to express my thanks to all members and to the secretary P.L.Walraven of the committee for their contribution.

REFERENCES

1. Vos J J: "Colorimetric and photometric properties of a 2° fundamental observer", *Color Res. and App.* **3**, pp. 125-128, 1978.
2. Smith V C & Pokorny J: "Spectral sensitivity of the foveal cone pigments between 400 and 500nm", *Vision Res.* **15**, pp. 161-171, 1975
3. Vos J J, Estévez O & Walraven P L: "Improved colour fundamentals offer a new view on photometric additivity", *Vision Res.* **30**, pp. 937-943, 1990
4. Stockman A, MacLeod D I A & Johnson N E: "The spectral sensitivities of the human cones", *J. Opt. Soc. Am.* A **10**, pp. 2491-2521, 1993
5. Stockman, A & Sharpe, L T: "The spectral sensitivities of the middle- and long-wavelength-sensitive cones derived from measurements in observers of known genotype". *Vision Research*, 40, 1711-1737, 2000. http://www-cvrl.ucsd.edu/
6. Stiles, W.S. & Burch, J.M.: "NPL colour-matching investigation: Final report (1958)". Optica Acta, 6, 1-26, 1959.
7. Stockman, A., Sharpe, L.T., & Fach, C.C.: "The spectral sensitivity of the human short-wavelength sensitive cones derived from thresholds and color matches". *Vision Research*, 39, 2901-2927, 1999.
8. van Norren, D. & Vos, J.J.: "Spectral transmission of the human ocular media". Vision Research, 14, 1237-1244, 1974.
9. Bone, R.A., Landrum, J.T., & Cains, A.: "Optical density spectra of the macular pigment in vivo and in vitro". *Vision Research*, **32**, 105-110, 1992.
10. Pokorny J, Smith V C & Lutze M: "Aging of the human lens", *Appl. Opt.* **26**, pp. 1437-1440, 1987
11. Moreland J D & Bhatt P: "Retinal distribution of macular pigment", in: *Colour vision deficiencies VII*, ed.: Verriest G, Junk, The Hague, pp. 127-132, 1984
12. Pokorny, J., Smith, V.C., 1976, "Effect of field size on red-green colour mixture equations". *J. Opt. Soc. Am.*, 66, 705-708.
13. MacLeod D I A & Boynton R M: "Chromaticity diagram showing cone excitation by stimuli of equal luminance", *J. Opt. Soc. Am.* **69**, pp. 1183-1186, 1979

Background and the Perception of Lightness

Nathan Moroney
Hewlett-Packard Laboratories

ABSTRACT

A simultaneous equisection experiment using a CRT in a dark surround was performed to investigate the relationship between a uniform background and the perception of lightness. The resulting curves for different backgrounds show both exponential properties, for black and white backgrounds, and sigmoidal characteristics, for intermediate grays. The sigmoidal properties are due to crispening and roughly intersect the diagonal or identity at the lightness of the background. The simultaneous contrast is greatest for the middle gray and decreases as the device white and black points are approached. An example equation is provided to fit the observations. This equation has as its input the L* of the stimuli and the background and has two fitting parameters. The issue of lightness scaling for backgrounds is also considered and finally extensions to this research are briefly mentioned.

Keywords: Lightness, background, appearance modeling, simultaneous equisection, crispening, simultaneous contrast, tone reproduction

1. INTRODUCTION

Lightness has been defined as the perceptual attribute that corresponds to how bright a color is relative to a white or highly transmitting reference.[1] The lightness attribute has also been described as "a significant aspect of the mental picture of our surroundings".[2] The background is the area immediately surrounding the stimulus and subtends roughly ten degrees.[3] There are numerous references to how background influences the lightness of a given stimulus but these results have been difficult to compare directly or only implicitly model this phenomena. This paper begins with a brief review of earlier and current research[4-17] in the area of background and the perception of lightness.

Godlove[4] proposed the square root of a polynomial to model the effect of background on lightness. The resulting curves are similar to CIECAM97s,[5] which uses an exponential function to model the effect of background. Takasaki[6] gathered data and derived a model for a visual phenomena he refered to as crispening or the increased sensitivity to lightness differences as the stimuli lightness approaches the lightness of the background. Semmelroth[7,8] modeled the crispening and simultaneous contrast effects using a two-piece function with exponential terms and also the absolute value of the difference between the background and the stimulus. This equation predicts equally large simultaneous contrast effects for light, medium and dark gray backgrounds. It also has a sudden transition for the crispening effect such that there is considerable overlap for the upper and lower envelope of the family of curves. Braun and Fairchild[9] and Holm[10] have looked at image based tone reproduction and have used variations on sigmoidal functions to account for differences in image key. While image key is not strictly speaking the same as background, they are similar concepts and therefore it is interesting to consider these results as well. Finally, vision models such as those proposed by Land and McCann[11,12] also implicitly model how various larger spatial configurations of lightnesses impact the stimuli lightness. Using the test backgrounds and stimuli described later in this paper with the Retinex formulations provided by Funt, Ciurea and McCann[13] suggest that a white background will not change stimuli lightness and for darker backgrounds stimuli are only made lighter. It is interesting to consider how all of these results exhibit exponential and sigmoidal characteristics and which combinations of background and stimuli yield identity values.

Whittle[14] also used a simultaneous equisection experiment to study brightness and crispening. The experimental method presented in this paper differ from those of Whittle in that fewer test patches were used, the viewing condition was a dark surround, lightness was adjusted using unreferenced buttons instead of a palette and a larger number of observers were tested. In addition, this paper specifically addresses the influence of background by testing five different background lightnesses. The relationship of the results to the effect of simultaneous contrast is also clearly stated and one of the functions fit to the data is relative to L* or CIE lightness. Munsell[15] also used a version of simultaneous equisection but for papers with differing reflectances on a single background. Godlove extended Munsell's results but focused on modeling of lightness perception on different backgrounds and did not provide specific data for the different backgrounds. Both Whittle and Munsell found consistency between J.N.D. experimental results and the results from simultaneous equisection. Results by Belaid and

Martens[16,17] have confirmed Whittles results and have further explored the psychophysical implications for modeling these effects. They also have discussed the relevance of these results to digital imaging.

2. EXPERIMENTAL

In order to better understand and compare the extensive prior research in this area, a specific simultaneous equisection experiment was conducted. Fifteen color normal observers participated in a uniform lightness partitioning experiment. This experiment required the observer to make multiple individual stimulus adjustments in order to uniformly partition the lightness scale. Munsell[15] referred to this technique as a value step method and Whittle[14] called it equal-interval scaling. Gescheider[18] describes this technique as simultaneous equisection although the author finds the term partitioning a useful description of the observer task. A SONY MultiScanTC CRT in a dark surround was used as the test device. The CRT was configured to approximate the sRGB[19] specification. The test stimulus consisted of eight squares of approximately 2 degree subtense on a uniform background. Two of the squares were anchors of device black furthest to the left and device white farthest to the right. The intermediate squares were randomly initialized to an intermediate lightness and were separated from each other by approximately 2 degrees, as can be seen in figure 1. The observer task was to uniformly partition the lightness from left to right. Each of the six intermediate squares had individual buttons to lighten or darken the squares as needed. The increment was 5 digital counts in the native 8-bit RGB color space and stepped through the achromatic patches. This increment was derived during preliminary experiments and provided a reasonable trade-off between precision and the time required to complete the experiment. The user interface and data collection was performed using a TCl/Tk program. Five background luminances were used in an observer specific random sequence. The five backgrounds consisted of device white, device black and three intermediate lightnesses. The luminances for the backgrounds were 0.05, 30.0, 13.3, 25.4 and 65.7 cd/m^2.

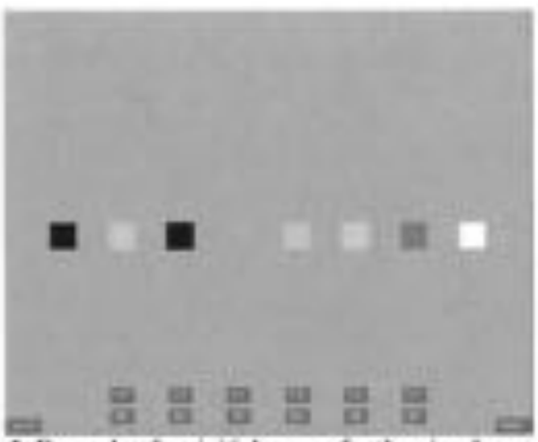


Figure 1. Example of an initial screen for the visual experiment.

3. RESULTS

The simultaneous equisection experiment provided a fast, simple and low noise method of determining the effect of background on the perception of lightness. There was a very low amount of inter- and intra-observer variability. Munsell noted that the value step method had twice the precision compared to the J.N.D. method for 3 observers and 4 replications. Whittle stated "seeing all the stimuli at once allows subjects to avoid some kinds of inconsistency, such as errors of order." The results were then plotted with the measured lightness on the x-axis and the lightness partition on the y-axis. Figure 2 shows the five different curves, one for each of the backgrounds. The white and black backgrounds were roughly exponential and consistent with the LUTCHI results. However, the backgrounds of intermediate lightnesses were sigmoidal and intercepted the 45-degree line at roughly the lightness of the background. The author lacks a satisfactory explanation for the small upward shift for the data for the background with an L* of 25. The observed data can be modeled using the equation:

$$L^* = 100\left(2I_S - I_S^{\left[c_2 - \left(c_1 + I_b/c_3\right)\right]}\right)_j \quad (1)$$

Where l_s and l_b are CIE L* normalized to the range 0 to 1 for the stimuli and background, respectively. The variables c_1 and c_2 are free parameters and can be used to fit the observations. L' is the background corrected lightness values for the stimulus. The results shown in Figure 2a and 2b were fit using values of 0.8 and 0.6 for c1 and c2. This equation is provided as an example only and while it fits the data with an r^2 of 0.95, it should be understood to be one of many functions that result in a similar family of curves. Specifically, equation one does not necessarily have a psychophysical or physiological basis. Such considerations are important but for the purposes of this paper the focus is the manifestation or characteristics of the visual phenomena and not the underlying mechanisms. An alternative approach is to fit the derivative of the results using a second order polynomial whose terms are also second order polynomials.

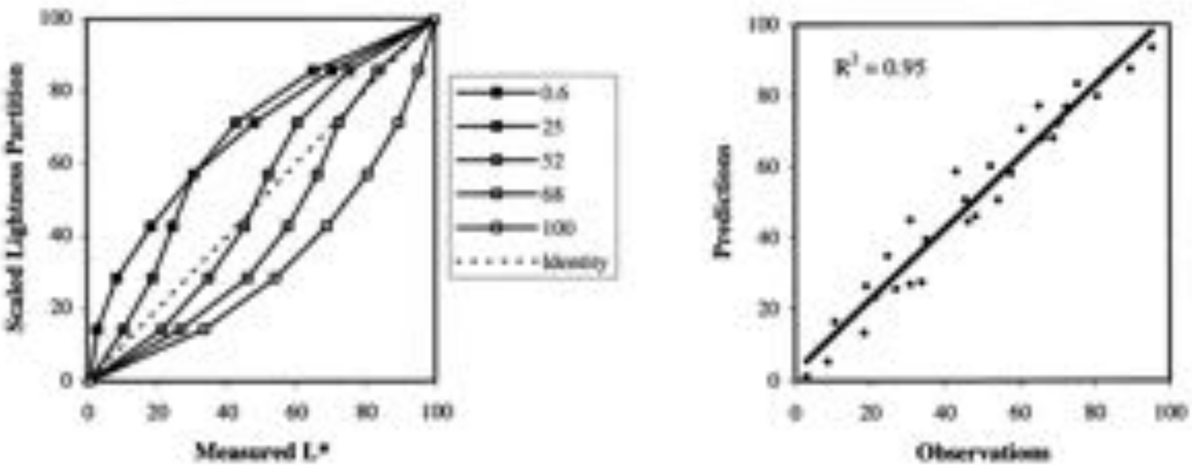


Figure 2a and 2b. Averaged results for the visual experiment, on left, and model fit for observed data, on right. The legend for the plot on the left lists the measured L* value for the uniform background.

4. DISCUSSION

The results shown in figure 2a clearly show both simultaneous contrast and crispening. The simultaneous contrast is evident in the range of stimulus lightnesses that result in a middle gray. Crispening is the inflection of the curve as the lightness of the stimulus approaches the lightness of the background. The curves have been extrapolated to connect the curves to the white and black points. This extrapolation follows the trends in the data well and fits practical imaging constraints in which white and black points cannot be adjusted. This family of curves also has interesting implications for lightness scaling of backgrounds. For example, the curves roughly intersect the diagonal identity at the lightness of the background.

The CIECAM97s color appearance model[5] was not designed to compute perceptual attributes for the background. However, as a thought experiment it is useful to consider how the model might be inverted given only the lightness or J value of the background and stimuli. Assuming the backgrounds are scaled to a luminance of 20 or a gray world assumption, then different luminance values could be computed given the same lightness for the background and stimuli. On the other hand if the lightness of the background is used to determine the corresponding Yb value, then this implies background lightness perception does not follow the gray world or Y_b of 20 stimuli lightness perception. The set of curves in Figure 2a show how the lightness scaling of backgrounds might be roughly equivalent to the gray world lightness scaling of stimuli. However, additional testing is required to verify this hypothesis, especially given the small deviation in the data for the background with an L* of 25.

Whittle[14] notes that crispening can be reduced or eliminated by including a border around the stimuli. The author has also repeated the previously described experiment using non-uniform black and white noise backgrounds and with the stimulus patches side by side. Both of these arrangements also reduce the effect of crispening. Whittle debates the importance of crispening relative to other visual phenomena. Belaid, Van Overveld, and Martens[17] investigate this question using digital images and conclude that the results are relevant for imaging. The author also finds that while crispening can be reduced in certain spatial configurations of stimuli, it should not be ignored with respect to digital imaging. A simple example might be the perceived tonal detail in bright clouds. According to a fixed global lightness scaling, such as modified cube-root function used in L*, these lightness differences should not be perceptible. However, relative to the overall high luminance of the cloud smaller luminance differences result in larger lightness differences than they would otherwise.

Finally, the author finds the simultaneous equisection technique to be a simple, efficient and low noise method to quantify a perceptual attribute. Additional testing is underway using this technique to investigate how the uniformity of the background, the lightness of the white and black anchors, ambient illumination and viewing distance impact the results. The author is also gathering data for a modified version of the experiment using reflection prints. Finally, there is ongoing work to apply the technique to other perceptual attributes, such as chroma.

5. CONCLUSIONS

The results of a simultaneous equisection experiment provided experimental data indicating how lightness perception for a CRT in a dark surround is influenced by the lightness of a uniform background. Crispening is evident as a sigmoidal inflection as the stimulus lightness approaches the lightness of the background. Simultaneous contrast is also present and diminishes as the stimuli approaches the device white or black points. These results could provide a more complete model of lightness perception for use in color appearance modeling. Lastly, in spite of giving the observers more control, the experimental technique of simultaneous equisection appears to be an efficient and low in noise method for deriving a scale for a single perceptual attribute.

REFERENCES

1. R.W.G. Hunt, *Measuring Colour*, 3rd Edition, Ellis Horwood, New York, 1998.
2. R. G. Kuehni, *Color: Essence and Logic*, Van Nostrand Reinhold Co., New York, 1983.
3. Mark D. Fairchild, *Color Appearance Models*, Addison-Wesley, Reading, Massachusetts, 1998.
4. I. H. Godlove, "Neutral value scales. II. a comparison of results and equations describing value scales", *J. Opt. Soc. Am.* **23**, pp. 419-425, 1933.
5. 5M.R. Luo and R.W.G. Hunt, "The structure of the CIE 1997 colour appearance model (CIECAM97s)", *Color Res. App.* **23**, pp. 138-146, 1998.
6. H. Takasaki, "Lightness change of grays induced by change in reflectance of gray background", J. Opt. Soc. Am., 56, pp. 504-509, 1966.
7. C. C. Semmelroth, "Prediction of lightness and brightness on different backgrounds", *J. Opt. Soc. Amer.* **60**, pp. 1685-1689, 1970.
8. C. C. Semmelroth, "Adjustment of the Munsell-Value and W* scales to uniform lightness steps for various background reflectances", *Applied Optics*, **10**, pp. 14-18, 1971.
9. Gustav J. Braun and Mark D. Fairchild, "Image lightness rescaling using sigmoidal contrast enhancement function", *J. Elect. Imaging*, **8**, pp. 380-393, 1999.
10. Jack Holm, "Photographic tone and colour reproduction goals", *CIE Expert Symposium '96 on Colour Standards for Image Technology*, pp. 51-56, 1996.
11. Edwin H. Land and John J. McCann, "Lightness and the retinex theory", *J. Opt. Soc. Amer.* **61**, pp. 1-11, 1971.
12. John McCann, "Calculating the lightness of areas in a single plane" *in Human Vision and Electronic Imaging V*, Bernice E. Rogowitz, Thrasyvoulos N. Pappas, Editors, Proceedings SPIE Vol. **3959**, pp. 243-253, 2000.
13. B. Funt, F. Ciurea, J. McCann, "Retinex in Matlab", *Proc. 8th IS&T/SID Color Imaging Conference*, pp. 112-121, 2001.
14. Paul Whittle, "Brightness, discriminability and the 'crispening effect'", *Vision Res.* **32**, 8, pp. 1493-1507, 1992.
15. A.E.O. Munsell, L.L. Sloan, and I.H. Godlove, "Neutral value scales. I. Munsell neutral value scale". ", *J. Opt. Soc. Amer.* **23**, pp. 394-411, 1933.
16. N. Belaid and J.B. Martens, "Grey scale, the "crispening effect", and perceptual linearization", *Signal Processing*, **70**, pp. 231-245, 1998.
17. N. Belaid, I. Van Overveld, and J.B. Martens, "Display fidelity: link between psychophysics and contrast discrimination models", *Spatial Vision*, **11**, pp. 205-223, 1997.
18. George A. Gescheider, *Psychophysics: Method, Theory, and Application*, Lawrence Erlbaum Associates, Pub., Hillsdale, NJ, 1985.
19. International Electrotechnical Commission, "Part 2-1: colour management - default RGB color space- sRGB",*First edition, IEC 61966-2-1*, 1999.

Magnitude estimation for scaling saturation

L. G. Juan and M. R. Luo[*],
Graduate School of Applied Arts & Design, Shu-Te University, Kaohsiung County, Taiwan, ROC.
[*]Colour & Imaging Institute, University of Derby, Derby, UK

ABSTRACT

Psychophysical experiments were carried out for describing colour appearance under 12 different sets of viewing conditions including variations of neutral backgrounds, sample sizes, textures, sample types and colour attributes. The results on saturation based upon 132 coloured cube samples are discussed here. It was found that observers can be trained to scale saturation with a great accuracy. There is little difference in the results for the white, grey and black backgrounds studied. Saturation is dependent upon lightness and colourfulness, i.e. an increase in saturation will increase colourfulness but with a reduction of lightness. It was also found that the saturation scale of CIECAM97s did not fit well to the visual results. An improved scale was developed.

Keywords: saturation, lightness, colourfulness, hue, magnitude estimation, CIECAM97s.

1. INTRODUCTION

Saturation is a difficult attribute to estimate using the magnitude estimation method. A monochromatic light appears fully saturated. The colour appears less saturated when it is mixed with different wavelengths. According to the CIE definition [1], saturation is the *colourfulness* of an area judged in proportion to its *brightness*, while brightness is the attribute of a visual sensation according to which an area appears to exhibit more or less light and colourfulness is the attribute of a visual sensation according to which an area appears to exhibit more or less of its hue. The saturation can be expressed by a formula, colourfulness/brightness. The brightness in the formula sometimes can be substituted by lightness. For neutral colours, saturation is zero because colourfulness is zero. The main problem for scaling saturation is illustrated in Figure 1. For a dark sample close to the black point (ideal black), there is only a short distance between the neutral and a maximally chromatic sample at that lightness level. Therefore, it is extremely to estimate saturation accurately.

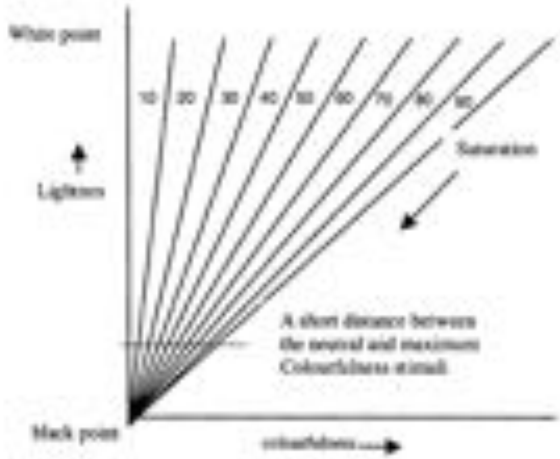


Figure 1. Difficulty of scaling saturation for dark stimuli

Cube shaped samples were used instead of using plane samples for scaling saturation because saturation is closely associated with viewing three-dimensional materials. Although each cube was covered by a single colour, large variations in colour appearance on different sides were seen. This is caused by the differences in the direction of illumination and viewing for each side of the cube. In the training session, observers were instructed that the colour appearance in each side of cube has the same saturation, but different lightness and colourfulness. The concept of colourfulness divided by lightness was then introduced to explain this phenomenon. An interesting point is that most observers described a colourful sample as having a high saturation, while a colour appearing close to 'white' was judged to have low saturation. They all agreed that saturation is not the same attribute as lightness and colourfulness because a darker colourful sample could be highly saturated. In the case of scaling saturation for neutral colours, half of them thought that black should be the most saturated colour rather than zero due to the definition of the CIE. Therefore they were excluded in the experiment.

2. EXPERIMENT

A psychophysical experiment was carried out for describing colour appearance under different viewing conditions [2]. The results from 6 out of 12 phases are associated with saturation. Their conditions are summarised in Table 1. There were 132 semi-matte samples used in each phase. These were chosen from a commercial version of the NCS Colour Order System [3].

Table 1 The experimental phases used in this study

Phase	Size	Texture	Background	Luminance in cd/m^2	No of samples	Attribute *
lpw	Large	Paint	White	687	132	L, C, H
lpgy	Large	Paint	Grey	400	132	L, C, H
lpk	Large	Paint	Black	366	132	L, C, H
cpw	Large	Paint	White	687	132	S
cpgy	Large	Paint	Grey	400	132	S
cpk	Large	Paint	Black	366	132	S

Note *: L, C, S and H represent lightness, colourfulness, saturation and hue attributes.

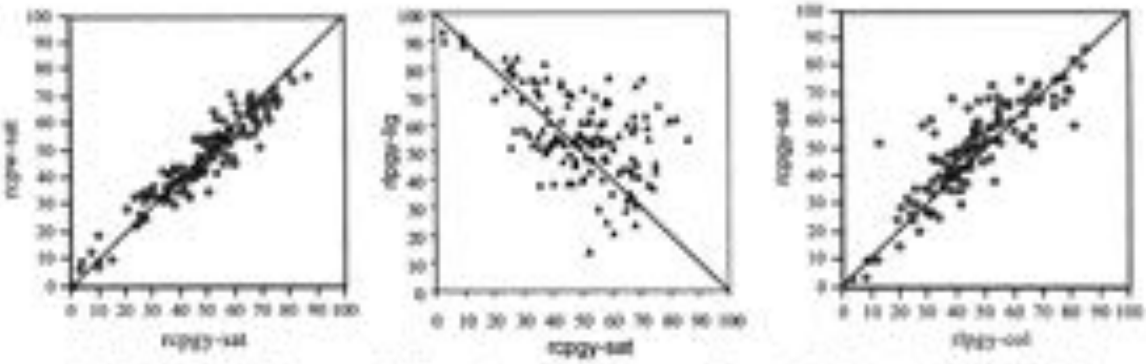
The experiment was carried out in a VeriVide viewing cabinet under a D65 simulator against white, grey and black backgrounds. Each sample was displayed together with a reference white sample for scaling lightness, or a highly chromatic reference for scaling colourfulness. The cube samples were only used to scale saturation and the same colours on plain paper were used to scale the other attributes. Seven to 9 observers participated in each phase. The magnitude estimation method used by Luo *et al* [4,5] was employed to estimate the colour attributes. A Minolta CS1000 tele-spectroradiometer with a 5nm bandwidth was used for measuring all samples under different phases of viewing conditions.

The data analysis was carried out the same as that used by Luo *et al* [4,5]. All observers used the same numerical scale with two fixed end points for estimating lightness and hue. Thus the arithmetic mean was used to represent the panel results. An open-ended scale was used for colourfulness and saturation estimations therefore the geometric mean was used. The coefficient of variation (CV) was used to investigate the agreement between each individual observer and the mean visual results, or between mean visual results and a colour model's predictions. CV corresponds to the percentage error. For a perfect agreement, the CV should equal zero. This means a 0% error. A CV of 30 means a 30% disagreement.

3. RESULTS

The observer accuracy in terms of CV values for saturation, lightness and colourfulness attributes was calculated for each phase. The mean CV values from all phases were averaged. These were 16, 13 and 19 for saturation, lightness and colourfulness respectively. It is encouraging that observers gave a more accurate estimation in scaling saturation than colourfulness.

The saturation results obtained in the white, grey and black backgrounds were also compared. It was found that the saturation results are not affected by the different backgrounds. Figure 2(a) illustrates this by plotting the visual results of grey background against those of white background. As it can be seen that all data points are close to the 45° line.



(a) Background effect (b) Saturation vs. Lightness results (c) Saturation vs. Colourfulness results

Figure 2. (a) The saturation results of a grey plotted against a white background, (b) The saturation plotted against lightness results and (c) The saturation plotted against colourfulness results

The comparisons between saturation and lightness results, and between saturation and colourfulness results were also made as shown in Figures 2(a) and 2(c), respectively. The former plot shows that saturation increases in company with a lightness reduction. The latter plot indicates that saturation is proportional to colourfulness except for some dark and saturated samples. Overall, saturation is closely associated with lightness and colourfulness.

4. TESTING COLOUR APPEARANCE MODELS USING SATURATION DATA

The experimental results were used to test the performance of 8 existing colour appearance models and colour spaces: CIELAB[6], CIELUV[6], Nayatani97[7], RLAB96[8], Hunt96[9], LLAB96[10], CIECAM97s[11] and CAM97s2[12]. The CIELAB and RLAB96 do not include a saturation scale. Hence, the equation of chroma divided by lightness was used to approximate saturation for these two models. Again, the CV measure was used to indicate the models' performance in predicting visual results. The LLAB96 model outperformed the other models with a CV value of 21, followed by RLAB96 (27), CIELAB (28), Nayatani97 (29) and CIELUV (34). The Hunt96, CIECAM97s and CAM97s2 gave the worst performance (45 CV units). It is disappointing that the CIE 1997 colour appearance model, CIECAM97s, performed badly. Hence, attempts were made to improve its performance.

A new saturation scale based upon CAM97s2 was derived in parallel with the other modifications to the CIECAM97s at the University of Derby. The new saturation scale, named (s_D), is given in Equation (1) together with the other latest correlates associated with the calculation of this new scale.

$$s_D(saturation) = M_D / Q_D \qquad (1)$$

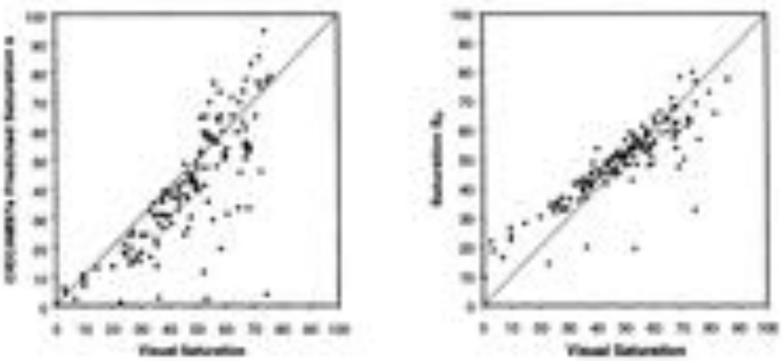
where

$$M_D(colourfulness) = C_D F_L^{0.15} \quad and \quad Q_D(brightness) = (1.24/c)(J_D/100)^{0.67}(A_w+3)^{0.9}$$

$$C_D(chroma) = 2.44 s^{0.69}(J_D/100)^{0.67n}(1.64-0.29^n)$$

$$J_D(lightness) = 100(A/A_w)^{cz'}, \quad with \quad z' = 0.85 + \sqrt{Y_b/Y_w}$$

Equation (1) shows that lightness, chroma, brightness and colourfulness correlates are required in order to calculate saturation. These are the latest modifications [13] to the CIECAM97s proposed by the authors to the CIE TC8-01 responsible for standardising e a colour appearance model for image applications. The new scale predicted the visual results quite well with a CV value of 23. Figure 3(a) and 3(b) show the degree of improvement from the original to the new scale respectively.



(a) (b)

Figure 3. The saturation predictions from (a) the original and (b) new CIECAM97s scales.

5. CONCLUSIONS

It is concluded that the observers can be trained to scale saturation with a great accuracy and the saturation is closely associated with lightness and colourfulness attributes. A new scale s_D was derived to improve the original scale in CIECAM97s.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. C. Li for providing technical assistance and Professor R. W. G. Hunt for advice, and many observers who took part in many sessions of experiments.

REFERENCES

1. CIE Publ. No. 17.4, International Lighting Vocabulary, 4th ed., Central Bureau of CIE, Vienna, see 845-02-34. (1987).
2. L. G. Juan & M. R. Luo, "New Magnitude Estimation Data for Evaluating Colour Appearance Models", Proceedings of Colour and Visual Scales 2000, 3–5 April 2000, Egham, UK.
3. F Śrginstitutet, Natural Color System A4 binders. Scandinavian Colour Institute AB, 8 volumes (1990).
4. M. R. Luo, A. A. Clarke, P. A. Rhodes, A. Schappo, S. A. R. Scrivener, C. J. Tait, Quantifying Colour Appearance Part I. LUTCH Colour Appearance Data, *Color Res. Appl.*, **16**:3, 166-180 (1991).
5. M. R. Luo, A. A. Clarke, P. A. Rhodes, A. Schappo, S. A. R. Scrivener, C. J. Tait, Quantifying Colour Appearance Part II. Testing Colour Models Performance Using LUTCH Colour Appearance Data, *Color Res. Appl.*, **16**:3, 181-183, 197 (1991).
6. CIE., Colorimetry, 2nd Ed. CIE Pub. No. 15.2. Vienna, Austria: Central Bureau of the CIE; 1986.
7. Y. Nayatani, A simple estimation method for effective adaptation coefficient, *Color Res. Appl.*, **22**:4, pp.259-268 (1997).
8. M. D. Fairchild, Refinement of the RLAB color space, *Color Res. Appl.* **21**:5, 338-346 (1996).
9. M. R. Luo and J. Morovic, Two Unsolved Issues in Colour Management - Colour Appearance and Gamut Mapping, 5th International Conference on Hight Technology, World Techno Fair in Chiba '96, 136-146 (1996).
10. M. R. Luo M. C. Lo and W. G. Kuo, The *LLAB (l:c)* colour model ,*Color Res. Appl.*, **21**:6, pp.412-429 (1996).
11. M. R. Luo and R. W. G. Hunt, The Structure of the CIE 1997 Colour Appearance Model (CIECAM97s), *Color Res. Appl.*, **23**:3, 138-146 (1998).
12. C. J. Li, M. R. Luo and R. W. G. Hunt, A Revision of the CIECAM97s Model, *Color Res. Appl.*, **25**:4, 260-266 (2000).
13. R. W. G. Hunt, C. J. Li, L. G. Juan and M. R. Luo, Further improvements to CIECAM97s, *Color Res. Appl.*, in print.

A uniform colour space based upon CIECAM97s

C. Li and M. R. Luo, Colour & Imaging Institute, University of Derby, Derby, UK

ABSTRACT

This paper describes a new uniform colour space which was derived by modifying CIECAM97s [1] to fit available large colour difference datasets including CII-Zhu [2], OSA [3], Guan [4], BFDB-Textile [5], BFDB-Paint [5] and Munsell. [6] Testing results show that the new colour space fit the above experimental datasets better than the current best CIELAB [7] and IPT [8] spaces.

Keywords: Uniform colour space, large colour difference data, small colour difference data, Munsell, CIECAM97s, IPT.

1. INTRODUCTION

A true uniform colour space (UCS) provides equal distances corresponding to equal perceived colour differences. It would be very useful for image applications such as gamut mapping, image compression, and evaluation of colour management and colour reproduction systems. The CIELAB [7] space was developed to fit the Munsell [6] colour spacing. Although it is by no means perfect, it has been the most widely used and provides a satisfactory tool for representing perceptual difference between large size colour patches.

In 1998, Ebner and Fairchild [8] derived a colour space, IPT. It transforms a stimulus defined by the tristimulus values to the I, P and T coordinates which represent lightness intensity, red-green channel and yellow-blue channel.

In 1997, CIE recommended a colour appearance model, CIECAM97s [1] for image applications. The model is capable of accurately predicting colour appearance under a wide range of viewing conditions. The CIECAM97s model transforms the tristimulus values of a stimulus under a particular set of viewing conditions to visual percepts: brightness (Q), lightness (J), chroma (C), colourfulness (M), saturation (s), hue composition (H) and hue angle (h). By combining different percepts and hue angle, different colour spaces can be formed. It was found that to use J C h attributes to produce the Cartesian coordinates J, a_c and b_c performed the best in predicting various experimental datasets. Here a_c and b_c are defined by $C\cos(h)$ and $C\sin(h)$, respectively.

The CIECAM97s model was originally derived to fit a large set of colour appearance data [9]. Recently, modifications to enhance the model for industrial applications have been suggested [10-13]. The uniform colour space developed here is actually based upon one of the revised models, CAM97s2 [10]. There is a large advantage to derive a uniform colour space based upon a colour appearance model because the current colour spaces or colour difference formulae can only be applied under a fixed set of viewing conditions. In typical image applications, there are large variations in illuminants, luminance levels, media/surrounds, backgrounds, etc. To have a colour appearance model based colour space would report accurate colour difference by automatically accounted for various viewing parameters.

The colour difference related to any of the above mentioned three colour spaces is a three-dimensional Euclidean distance (say with three coordinates be V_1, V_2, V_3). The colour difference can be calculated by Equation (1).

$$\Delta E = \sqrt{\Delta V_1^{\,2} + \Delta V_2^{\,2} + \Delta V_3^{\,2}} \quad (1)$$

Luo et al [14] accumulated eight colour discrimination datasets. These were then used to test 13 colour spaces or colour difference formulae. Their results showed that the colour spaces and colour difference formulae can be divided into two types: those which fit well datasets where the colour difference are small ($\Delta E^*_{ab} < 5$), and those which fit well datasets where the colour differences are large ($\Delta E^*_{ab} > 5$). All colour difference formulae modified from CIELAB fit well to the small colour difference datasets but not the large colour difference datasets. However, the CAM97s2, one of the CIECAM97s versions was also tested and gave a reasonable performance in fitting large colour difference datasets.

In this study, six datasets used in the earlier study were used to test the CIELAB, IPT and CAM97s2. Table 1 summarises the average ΔE^*_{ab} , the number of pairs and reference number for each data set. The CII-ZHU data [2] were accumulated based upon CRT colours by investigating 24 directions in CIELAB colour space. The 844 pairs of samples used in the original study of the Munsell spacing by the OSA committee [6] are also investigated. The OSA data [2] were used to derive the OSA colour space. The BFDB-P [3] and BFDB-T [3] are those studied by Dr. Badu at the University of Bradford using paint and textile samples respectively. The Guan data [4] was generated using wool textile samples.

Table 1 The average CIELAB ΔE^*_{ab} for each experimental data set

Data Set (No. of pairs)	No. of Pairs	Average ΔE^*_{ab}	Reference No.
CII-ZHU	144	9.9	4
OSA	128	14.3	5
Guan	292	11.4	6
BFDB-P	170	15.2	7
BFDB-T	238	11.7	7
Munsell	844	10.2	8

The PF/3 [11] measure was used to indicate the prediction of a colour space to a particular data set. For a PF/3 value of 20, it means that the disagreement between the colour space predictions and the visual results is 20%. The comparison results in PF/3 values are listed in Table 2. It can be seen that the overall uniformity performance of the IPT space performs the best, the CAM97s2 is the worst, and the CIELAB space is in between. However, it can be found that there are differences between datasets. For example, the CIELAB space fits the Munsell data well as expected, but gives poor fit to the other datasets. Conversely, the IPT space fits well to the Guan data set but does not fit well to the Munsell data. The BFDB-Paint can not be well fitted by the CIELAB and IPT spaces. The poor performance of the CAM97s2 in fitting the six large colour difference datasets stimulated the authors to try to develop a better uniform colour space based upon modifications of CAM97s2.

Table 2. Testing CAM97s2, IPT and CIELAB colour spaces using the large colour difference datasets

Data set \ Space	CIELAB	IPT	CAM97s2
CII-Zhu	29.48	27.27	36.75
OSA	26.68	23.67	26.29
Guan	27.11	18.83	37.24
BFDB-Textile	33.87	31.88	34.99
BFDB-Paint	47.86	41.08	34.93
Munsell	17.61	25.10	28.48
Mean	30.44	27.97	33.11

2. NEW *J' a' b'* COLOUR SPACE

The starting point was actually CAM97s2 [10] rather than the CIECAM97s [1]. Efforts were made to refine CAM97s2 to fit better to the available six datasets. The mean PF/3 for the six datasets accumulated was used to indicate the degree of improvement. The new colour space is different from the CAM97s2 in the following aspects:

1. The CMCCAT97 is replaced by the CMCCAT2000 [11].

2. The nine coefficients of the original Hunt-Pointer-Estevez matrix for calculating red, green and blue cone responses (R' G' B') were replaced by the following

$$\begin{pmatrix} 0.3376 & 0.6808 & -0.0184 \\ -0.3212 & 1.2443 & 0.0769 \\ -0.0428 & -0.0025 & 1.0453 \end{pmatrix} \tag{2}$$

3. The power factor of 0.73 included in the hyperbolic function, which is used to transform R' G' B' to the adapted red, green and blue cone responses (R'_a G'_a B'_a) is replaced by 0.63.

4. The lightness formula for J is replaced by

$$J' = 100(A/A_w)^z, \quad where\ z = 0.85+n^{0.5} \tag{3}$$

The other parts of CAM97s2 are unchanged. The new coordinates for the new space are denoted as J', a', and b'. Thus the new space is denoted by $J'a'b'$.

In addition, a lightness-weighting factor K_L was introduced into the colour difference (Equation (1)) for the first coordinate for any colour space. Thus the new colour difference formula becomes:

$$\Delta E = \sqrt{(\frac{\Delta V_1}{K_L})^2 + \Delta V_2{}^2 + \Delta V_3{}^2} \tag{4}$$

The matrix given by Equation (2), the power factor 0.63, and the lightness-weighting factor K_L were obtained by minimizing the mean PF/3 value to fit the six datasets. While the change for the lightness in Equation (3) is the same as the authors' latest proposal [11] on further improving CIECAM97s.

3. PERFORMANCE OF THE NEW COLOUR SPACE

The uniformity performances of the $J'a'b'$ space together with those of CAM97s2, IPT and CIELAB spaces were tested based on the generalized colour difference formula as Equation (4). Table 3 summarises the testing results again in PF/3 units. The optimum lightness weighting factors (K_L) for CIELAB, CAM97s2, IPT and $J'a'b'$ spaces are 0.72, 0.56, 1.0 and 0.5 respectively. The results show that the $J'a'b'$ space performs the best, and the CAM97s2 is the second best. The IPT space ranks third and CIELAB space is the worst. Comparing results in Tables 1 and 2, there is generally an improvement by introducing the lightness weighting factors into the colour-difference formula. By introducing the weighting factor for CIELAB, the PF/3 value decreases by 2 PF/3 units, while for CAM97s2, the PF/3 value decreases from 33.11 to 26.16 by 7 units. However, the performance of IPT was not affected.

Table 3. Testing colour models' performance using the large colour difference datasets

Space (K_L)	No. of Pairs	CIELAB (0.72)	CAM97s2 (0.56)	IPT (1.0)	$J'a'b'$ (0.5)
CII-Zhu	144	28.29	29.24	27.27	29.03
OSA	128	24.54	22.55	23.67	20.25
Guan	292	19.03	21.92	18.83	16.77
BFDB-Textile	238	30.24	26.50	31.88	21.20
BFDB-Paint	170	41.88	24.27	41.08	23.04
Munsell	844	24.02	32.49	25.10	33.60
Mean		28.00	26.16	27.97	23.98

4. CONCLUSIONS

This paper demonstrates that it is possible to develop a uniform colour space based upon a colour appearance model. The new colour space named *J'a'b'* was developed to fit the six large colour difference datasets. Further work is on the way to fulfill the authors' ambition to develop a colorimetric model for colour specification, colour difference evaluation and colour appearance prediction. It should provide a comprehensive solution for industry rather than using different tools for different applications.

REFERENCES

1. M. R. Luo and R. W. G. Hunt, The Structure of the CIE 1997 Colour Appearance Model (CIECAM97s), *Col. Res. & Appl.* 23, pp138-146(1998).
2. S. Y. Zhu, M. R. Luo and G. H. Cui, New experimental data for investigating uniform colour spaces, *ibid.*
3. D. L. MacAdam, Uniform colour scales, *J. Opt. Soc. Am.* 64, pp1691-1702 (1974).
4. S. S. Guan and M R Luo, A colour-difference formula for assessing large colour differences, *Col. Res. & Appl.* 24, pp344-355(1999).
5. S. A. Badu, Large colour differences between surfaces colours, Ph.D thesis, University of Bradford, UK, 1986.
6. S. M. Newhall, Preliminary report of the O.S.A. subcommittee on the spacing of the Munsell colors *J. Opt. Soc. Am.* 30, pp617-644 (1940).
7. CIE, Colorimetry, 2nd Ed., CIE Publ. No. 15.2, Recommendation on Uniform Color Space, Colour Difference Equations, Psychometric Color Terms, Central Bureau of the CIE, Vienna, 1986.
8. F. Ebner and M. Fairchild, Development and Testing of a Colour Space (IPT) with Improved Hue Uniformity, in the proceedings of the Sixth Color Imaging Conference: color Science, Systems, and Applications, pp8-13, 1998
9. M. R. Luo and R. W. G. Hunt, Testing colour appearance models using corresponding-colour and magnitude-estimation datasets, *Color Res.& Appl.*, **23** pp147-153 (1998).
10. C. J. Li, M. R. Luo and R. G. W Hunt, A revision of the CIECAM97s model, *Col. Res. & Appl.* 25, pp260-266 (2000).
11. C. J. Li, M. R. Luo, B. Rigg, and R W G Hunt, CMC 2000 Chromatic Adaptation Transform: CMCCAT2000, *Col. Res. & Appl.*, in print, 2001.
12. M. Fairchild, A revision of CIECAM97s for practical applications, *Col. Res. & Appl.*, in print, 2001.
13. R. G. W. Hunt, C J Li, L. Y. Juan and M R Luo, Further improvements to CIECAM97s, *Col. Res. Appl.*, in print, 2001.
14. M. R. Luo, S. Y. Zhu and G. H. Cui, Testing the uniformity of colour spaces, The Proc. of the CIE Expert Symposium, Scottsdale, Arizona, 7-10 November, in print.
15. S. S. Guan and M R Luo, Investigation of parametric effects using small colour-differences, *Col. Res. Appl.* 24, pp331-343 (1999).

Degree of color constancy in a photograph perceived as 3D space

Yoko Mizokami*, Hiroyuki Shinoda and Mitsuo Ikeda
Dept. of Photonics, Fac. of Science and Engineering, Ritsumeikan Univ.

ABSTRACT

We recognize the outside world as a 3-D space in spite of its two-dimensional retinal image. We demonstrated a two-dimensional photograph could be perceived as a 3-D scene in a special 'dimension-up' viewing condition that a subject observed only the photograph. The color constancy was then realized in part even in the photograph and its degree increases depending on the degree of 3-D recognition. A jumbled photograph was made from an original photograph taken for a room under incandescent lamps. Either was on a wall of an experimental booth illuminated by white light. In the normal viewing condition, the subjects perceived neutral white for almost the same test stimulus whether in the original or the jumbled. In the dimension-up viewing condition, the shift of the neutral perception for the original photograph was larger than for the jumbled. This should indicate that the recognized visual space of illumination (RVSI) for the scene illuminated by incandescent lamps was constructed for the original photograph and the test stimulus was perceived as an object in the scene. The degree of the color constancy was larger in the photograph perceived as a 3-D scene than in that perceived as a mere two-dimensional scene.

Keywords: Color, color constancy, recognized visual space of illumination, 3-D perception, photograph.

1. INTRODUCTION

Imagine we take a photograph in a room illuminated by an incandescent lamp and observe the picture in a room illuminated by a daylight type lamp. It is our experience that we see a very reddish scene in the picture contrary to our experience when we stayed in the incandescent room to take it. In the incandescent room the color constancy takes place and the room did not appear so reddish. This phenomenon can be explained by the concept of the recognized visual space of illumination (RVSI) proposed by us. The RVSI is the recognition of a 3-D space about illumination and is constructed in our brain. We have shown that the color appearance of objects in a space is determined in relation to the RVSI constructed for the room[1,2].

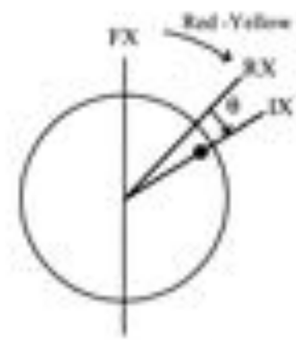


Fig. 1 Model of RVSI for a space illuminated by incandescent light. FX, fundamental recognition axis; RX, recognition axis; IX, illumination axis. Filled circle shows the color of a neutral white object under the illumination and θ indicates the apparent color of the white object.

A RVSI is schematically illustrated by a circle with a certain radius as shown in Fig.1. It has a so-to-speak inherent fundamental color recognition axis FX and a recognition axis RX which is determined by the color of illumination. When a room is illuminated by an incandescent light, the illumination axis IX is drawn at the corresponding color position and in the case of the red illumination it is shown at the angle rotated toward red side or clockwise as shown in Fig. 1. The visual system adapts to the illumination and the recognition axis RX also rotates toward the axis IX and comes very close to it. The color of a white object in the room should locate on the axis IX as shown by the filled circle and its apparent color is determined by the angle θ, namely the angle from RX to IX. The angle θ is very small and the white object does not appear so reddish but appears almost white in accordance with the phenomenon of the color constancy. If the RX coincides with the IX, the color constancy is said to hold 100 %. A white object taken in the incandescent room is indicated on the illumination axis IX if the color reproduction of the photograph is perfect. When we see the photograph in a whitely illuminated room, we are seeing it with the recognition axis RX which coincides with the fundamental axis FX. The angle from the RX to the IX is much larger compared to θ and the color of the white object in the photograph should appear very reddish. This phenomenon is said that the color constancy does not hold in the photograph. Can't we indeed experience the color constancy in the photograph? According to the concept of the RVSI there is a method that we do experience the color constancy in the photograph. This paper will present the method.

When we see the outside world we recognize it as a 3-D space in spite of the fact that we have only two-dimensional retinal image of the outside. In other words our brain changes the two-dimensional information to the 3-D recognition. Therefore it should be possible that a two-dimensional photograph can be perceived as a 3-D scene by an appropriate viewing condition. If that occurs the color constancy also should take place. In the previous experiment[2] we demonstrated a photograph could be perceived as a 3-D scene if only the photograph was given to the retina as incoming outside information. A RVSI was constructed for a photograph and the RX shifted toward red side. Consequently the color constancy took place at least in part in the photograph. In this paper we investigate whether the degree of the color constancy increases depending on the degree of 3-D recognition in the photograph. The present paper is composed of Experiment 1 to investigate the color constancy in the photograph and Experiment 2 to investigate the degree of the color constancy for an incomplete 3-D recognition by employing a jumbled photograph.

2. EXPERIMENT 1

2.1 Apparatus

We constructed an experimental apparatus composing of a subject's booth and a color scale booth as shown in Fig. 2a. The subject's booth simulated a real room arranged on a shelf and walls with various objects covering hues as seen in its front view shown in Fig. 2b. The subject's booth was illuminated by daylight type fluorescent lamps FL_1 of correlated color temperature 6000K and the illuminance was kept at 700 lx on the shelf in front of a subject S. A photograph P of the size 55 cm × 41 cm was hung on the front wall and observed at a distance 110 cm. A hole of the size 1.5 cm ×2.3 cm denoted by T was opened in the photograph and a color scale C was placed behind the hole. The color scale booth was illuminated by another daylight type lamp FL_2. When the subject viewed the photograph he/she saw the color scale pasted on the hole. The subject could change the color scale by rotating the color scale wheel with a handle H. A dimension-up viewing box VB was used to present only the photograph to the subject by removing other information than the photograph so that the brain automatically transfers the two-dimensional photograph to a 3-D scene. It was a black box with a rectangular aperture facing the photograph. When the subject inserted his/her head to the box he/she could see only the photograph monocularly without seeing any other parts of the subject's booth. The monocular vision was to eliminate the information that the photograph was a flat paper as much as possible.

Two photographs were prepared as taken at a living room illuminated by either incandescent type fluorescent lamps, Photo I, or daylight type fluorescent lamps, Photo D. The color reproduction was carefully controlled so that the photographs had as close colors as possible to the real object in the living room. The reproduction was limited and it was generally worse in objects with high and low lightness. The reproduced chromaticities are plotted for the different 25 positions of the white wall by open squares for Photo I and by open triangles for Photo D in Fig. 3. They scatter in a rather large area although the wall in the real living room had only one chromaticity. This makes it difficult to determine a real white in the photograph, but we took their average shown by a large filled circle in Photo I and a large open circle in Photo D. These could be used as a white point in these photographs. The chromaticity of a white paper placed in the subject's booth was measured and shown by a cross. In the experiment we asked subjects to select the color scale which

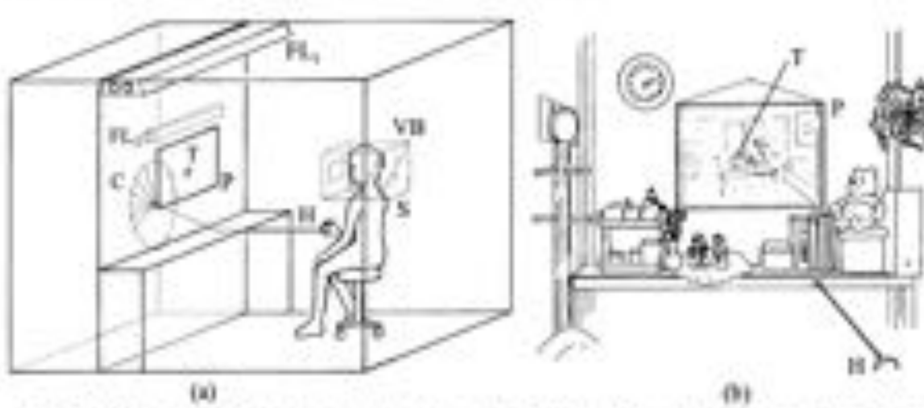


Fig. 2(a) Scheme of the experimental apparatus. P, photograph; T, test stimulus; S, subject; H, handle; C, color scale; FL1 and FL2, daylight type fluorescent lamps; VB, dimension-up viewing box. (b) View from a subject. P, photograph; T, test stimulus; H, handle.

appeared a neutral color by rotating the color scale wheel. Twenty-three patches were prepared for the color scale to have the chromaticity coordinates along the blackbody locus as shown by small dots in the same figure. Their luminance was kept equivalent to a paper of L*=70 on the photograph by adjusting the intensity of FL_T.

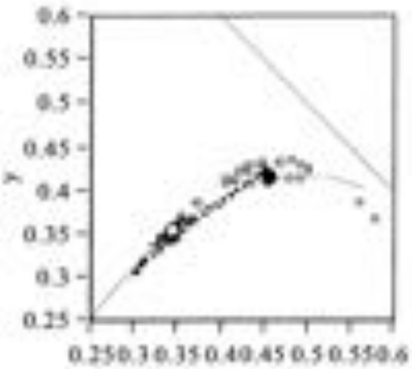


Fig.3 Xy chromaticity coordinates of white point of each environment; filled circle, photo I (average of small squares); open circle, Photo D (average of small triangles); cross, subject's booth. Small dots indicate color scale.

2.2 Procedure

The neutral color perception for the test stimulus T was obtained for Photo D and I, with and without the dimension-up viewing box VB. Without the VB the subject saw the photograph with two eyes as in a normal viewing situation. The subject was instructed not to gaze at the test stimulus but look around over the entire area of the environment. The photographs and viewing conditions were changed in a random order and the judgements were done for four combinations in each session. A subject set neutral color three times at a time in each condition. Five sessions were conducted to obtain fifteen data for each experimental condition. Ten subjects, MI, HS, YM, RY, HY, NO, KT, KK, YS and SHK participated in the experiment. All had normal color vision. The subjects NO, KT, YS and SHK did not know the purpose of the experiment at all.

2.3 Results and discussion

The most subjects expressed that with the dimension-up viewing box they felt as if they were looking at a real living room. A 3-D scene was perceived from the two-dimensional photograph with a help of the dimension-up viewing box VB. Further, they noticed that Photo I appeared very reddish when they saw it without the VB, but the redness decreased when they observed the photograph with the VB. When an experimenter inserted his/her hand into subject's visual field, the hand appeared very pale to indicate the rotating the recognition axis RX toward red direction. These phenomena all indicate that the subjects recognized a 3-D space in the photograph and a new RVSI was constructed with a new recognition axis oriented toward red direction.

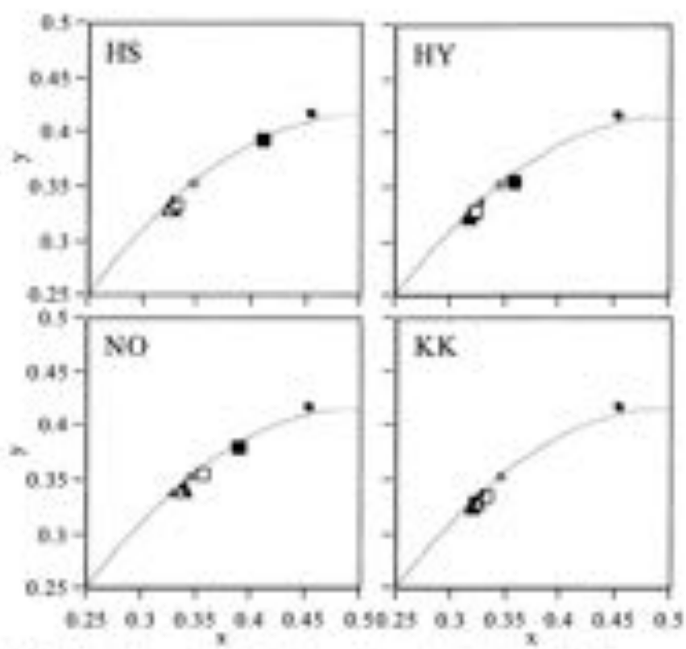


Fig.4 Neutral perception for four subjects in Experiment 1. Squares, Photo I; triangles, Photo D; open symbols, normal viewing condition; filled symbols, dimension-up viewing condition. Small filled circle, open circle and cross indicate white points in Photo I, Photo D and subject's booth respectively.

The chromaticities of the test stimulus for the neutral perception are plotted on the xy chromaticity diagram for four subjects in Fig. 4, by large triangles for Photo D and large squares for Photo I. Open symbols indicate the normal viewing condition and filled the dimension-up viewing condition, respectively. The cross indicates a white point under daylight illumination of the subject's booth. The data show that the neutral perception of the test stimulus in Photo D and I shown by the open triangle and open square come very close to the white point of the subject's booth. This indicates that the subject's perception for the white color was not influenced by the photographs when they observed the test stimulus under the normal viewing condition. It is clearly shown in the subject HS, HY and NO that the filled square sifted toward red direction by a large amount to indicate that reddish test stimulus is now perceived white. Then recognition axis RX moved toward red direction. The viewing box indeed worked to create the 3-D scene in the photograph and the color constancy took place in the photographs. In the case of subject KK there was not found the shift of filled square toward the red direction even with the dimension-up viewing box. This suggests that the degree of dimension–up effect in photograph differed depending on individuals. Among ten subjects six showed the large shift of the filled circle toward red. The rest four showed as similar result to the subject KK. The reason of the difference is not clear at this moment, but the four subjects might have been too conscious about the scene that was made by photograph. To conclude, present experiment demonstrated the color constancy for a photograph by raising that of the two-dimensions to the 3-D with a help of the dimension-up viewing box.

3. EXPERIMENT 2

3.1 Apparatus and procedure

In Experiment 2 we investigated whether the recognition of the 3-D space is important for the color constancy. We made a jumbled photograph by dividing Photo I to segments of 5 cm by 5 cm squares and by rearranging them in a random order to make the photograph of the same size as Photo I. It was expected that subjects can not perceive a 3-D scene for the jumbled photograph even with the dimension-up viewing box. It was further expected that the color constancy does not hold on the jumbled photograph. The same position was employed for the test stimulus as in Experiment 1 and it was centered at one segment so that the immediate surrounding of the test stimulus was retained as Experiment 1. Photo I and the jumbled photograph were employed as the photograph for viewing with and without the dimension-up viewing box. The illuminance condition was same as Experiment 1. The procedure of the experiment was also same. Subjects HY, YM and NO participated in Experiment 2.

3.2 Results and discussion

Subjects reported that they did not perceive the 3-D scene in the jumbled photograph and it appeared as a two-dimensional scene as expected. The results are shown in Fig. 5. Diamonds denote the results from the jumbled photograph and large squares for Photo I. Open and filled symbols indicate the normal viewing and the dimension-up viewing condition, respectively. The present subjects also showed a similar result as Experiment 1 for Photo I. When the subject observed Photo I with the dimension-up viewing box the neutral perception obtained from the test stimulus shifted toward red direction as shown by the filled square. It is quite clear, however, that the neutral perception did not shift in the same amount as these when the subjects viewed the jumbled photograph made by Photo I as shown by the filled diamond. This indicates the degree of color constancy decreased in the jumbled photograph. In the normal viewing condition the subjects perceived neutral white for almost the same test stimulus whether for Photo I or the jumbled photograph as shown by the open square and the open diamonds. It is concluded that the degree of the color constancy was larger in the photograph perceived as a 3-D scene than in the photograph perceived as a mere two-dimensional scene even when the color composition is the same.

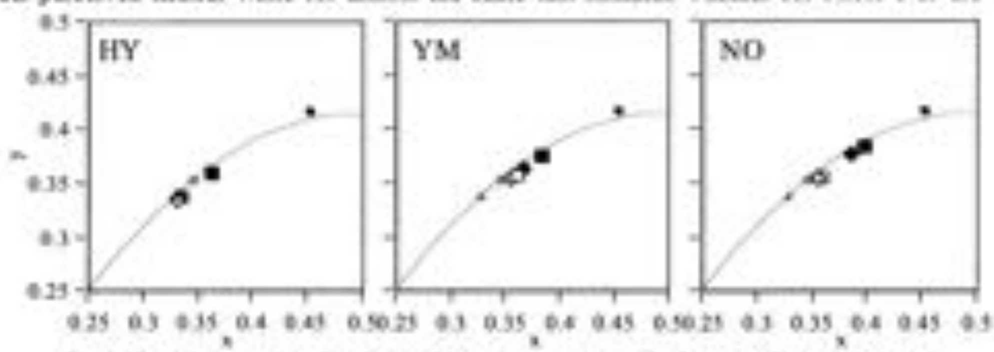


Fig.5 Neutral perception for three subjects in experiment 2. Squares, Photo I (original photograph); diamonds, Jumbled photograph; open symbols, normal viewing condition; filled symbols, dimension-up viewing condition.

This study was partially supported by a Grant-in-Aid for JSPS Fellows from Japan Society for the Promotion of Science

REFERENCES

1. Y. Mizokami, M. Ikeda and H. Shinoda, "Color Property of the Recognized Visual Space of Illumination Controlled by Interior Color as the Initial Visual Information", *Optical Review* **7-4**, pp.358-363, 2000
2. Y. Mizokami, Mitsuo Ikeda and H. Shinoda, "Dimension-Up from 2 to 3 in a Photograph to Yield Color Constancy for the Environment", *Proc. of AIC Meeting Seoul*, pp.80-83, 2000

*Correspondance: sce30136@se.ritsumei.ac.jp; phone +81-77-566-1111 (ex.8552); fax +81-77-561-2663; c/o Prof. M. Ikeda, Dept. of Photonics, Ritsumeikan Univ., Nojihigashi, Kusatsu, Shiga, 525-8577 JAPAN

Demonstration of the light source color on a photograph

Rumi Yamauchi, Mitsuo Ikeda and Hiroyuki Shinoda
Dept. of Photonics, Ritsumeikan Univ.

ABSTRACT

We don't normally perceive the light source color in a night scene photograph even at the spot of a shining lamp, although of course we do perceive the color if we are in the corresponding real world. This different experience can be nicely explained by the concept of the recognized visual space of illumination, RVSI. We see the light source color for a shining lamp in a real world because its luminance is too high to be included within the RVSI constructed for the world. On the contrary, the luminance of the shining lamp in the photograph never goes beyond that of N10 in Munsell Value and it is easily included within the RVSI constructed for the space where the photograph is observed. The spot should appear a mere white, not a light source color. We proposed in the present paper a new method to perceive the light source color in a printed photograph. A subject used a dimension-up goggle to input only the photograph into his/her monocular eye so that he/she can perceive a 3D scene in it. The RVSI of a small brightness size was made for the scene by employing a night scene photograph and a spot in the scene was perceived as the light source color when the area had lightness 8.1 or larger in Munsell Value.

Keywords: color appearance mode, object color, light source color, recognized visual space of illumination, dimension-up

1.INTRODUCTION

We can see the light source color in the real world, particularly at night, but not in a photograph even though it is a night scene. This paper presents a method to demonstrate the light source color in a photograph. We explain the reason for these different color appearance modes in the two situations by the concept of the recognized visual space of illumination, RVSI[1, 2, 3]. When we enter a space we can immediately understand how the space is illuminated such as brightly or dimly. This is expressed as that we constructed a RVSI in our brain for the space. We illustrate the RVSI by a circle with a certain radius as shown in Fig. 1(a) and any objects in the space are supposed to locate inside the circle. The brightness size of the RVSI is said small when we felt the space dimly illuminated such as a night scene and the RVSI is shown by a small circle. Lightness of any object in the space is determined in relation to the brightness size of the RVSI and it becomes large when its position comes closer to the border of the circle because of high luminance as indicated by O[4, 5]. The light source in the space, however, has luminance much higher than the brightest object in the space such as a white paper of N9.5 and its location in the illustration goes beyond the circle as shown by L. It cannot be recognized as an object in the space but an area radiating light, eventually causing the light source color appearance.

If we take a photograph of the space mentioned above, all the portions in the scene are reproduced as lightness between, say 0.5 and 9.5 in Munsell Value. When we see the photograph in a room, all of them should appear mere object color because they are indeed objects placed in the room. They all locate inside the RVSI, R1 constructed for the room even if it is an image of a light source, though its location should be very close to the border of the RVSI as indicated by O in Fig. 1(b). The spot O can only be recognized as a light source color when its location comes outside the RVSI. How could this happen?

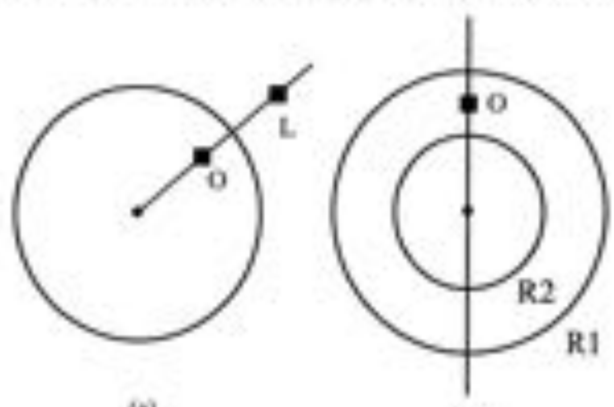


Fig.1 The scheme of the RVSI. (a) The appearance color mode, (b)The perception of the light source color and object color mode from a same photograph.

We notice that the photograph is a reproduction of the night scene although it is a two dimensional picture. When we see the night scene we get a retinal image of the scene, which is a 2D picture, same as the photograph. So if we input the only photographic image onto our retina our brain should not be able to distinguish whether the retinal image is made by the real outside scene or by the photograph. As the result the retinal image should be transferred to a 3D scene by the brain. If this happens, a RVSI for the night scene will be constructed with a very small brightness size as indicated by R2 in Fig.1 (b). Consequently the position of O effectively goes out the RVSI and that portion should appear as the light source color.

2. PRINCIPLE

It is essential to achieve two things in the present experiment. One is to show a 2D photograph to a subject in a way that he/she can perceive in it the corresponding 3D scene, and the other is to produce a small size of RVSI in the subject's brain so that a portion of even N8 or 9 can go outside the RVSI. For the former we used a dimension-up goggle by which only the image of a photograph can fall on the retina. For the latter we employed a photograph of a night scene.

3.EXPERIMENT

The photograph was a night scene with a dark atmosphere taken from a calendar, of which line drawing is shown in Fig.2. The photograph was composed of many houses built along a hill and a subject could experience a great depth perception if he/she perceived a 3D scene. Windows of the most houses exhibited the lighting. There were many street lamps and some of the buildings were lighted up. A rectangular hole of 0.3 x 0.5 cm was opened in the photograph as shown by "Target" so that the subject can observe a gray scale placed behind it.

The photograph was hung in a test room of the experimental booth as indicated by P in Fig. 3. It was uniformly illuminated at 40 lx by two daylight type of fluorescent lamps, FL placed at an upper and a lower position in the test room. The size of the photograph was 84 cm wide and 54 cm high. The subject observed the photograph from the subject room at a distance 115 cm with a help of the dimension-up goggle, or D-up goggle, which allowed the subject to use only one eye and limited his/her visual field to the photograph only. The monocular viewing condition was employed so that the subject could get the information about the photograph as an object, namely as a flat paper placed at 115 cm as less as possible. The subject had to recognize the scene exhibited by the photograph based on only his/her retinal image and he/she indeed could see the real 3D perspective night scene in front of him/her. Instantly the subject perceived the lit windows and street lights as shining as real to confirm our prediction for the light source color.

In this experiment we measured the lightness of the target to give the perception of the light source color. A rectangular hole was opened to coincide one of the windows of a house at around the center of the photograph to serve as the target as mentioned before. It was indicated by T in Fig.3 and had the visual angle, 0.25 high and 0.15 wide in degrees. Fig. 4 shows the front view of the test room, where the photograph is shown by a shadowed rectangle. Behind the rectangular hole T a gray scale wheel was placed against the photograph as shown by dotted drawing. Sixteen achromatic gray scales were attached on the wheel, which covered the range from 5.75 to 9.41 with interval 0.25 in the

Fig.2 The photograph and its subject's view through the D-up goggle. The window target is indicated by an arrow.

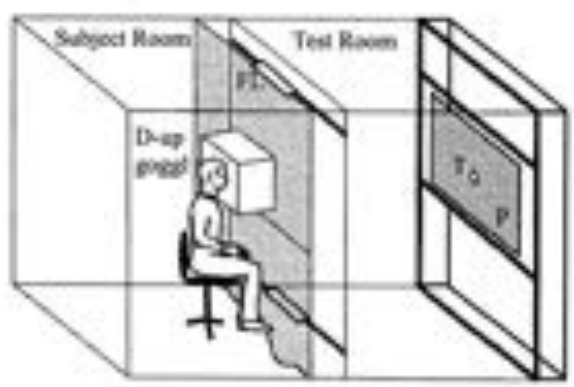


Fig.3 The scheme of the experimental booth.

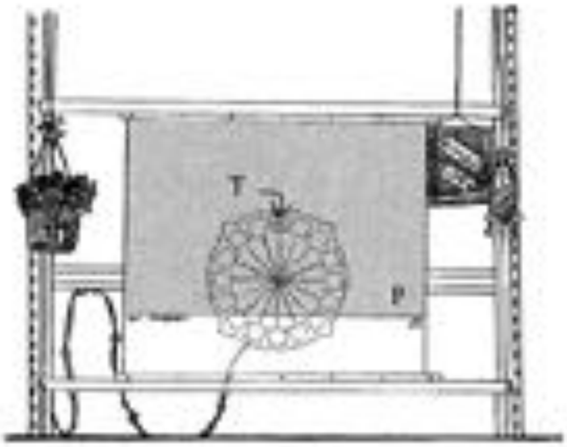


Fig.4 The view from the subject in the normal condition. T,the target; P, the photograph.

Munsell Value except the last patch of 9.41. The wheel was rotated in steps by a stepping motor as the subject pressed either button of two for clockwise or anticlockwise direction to increase or decrease the Value of the gray scale.

The photograph was surrounded by various objects such as potted flowers, a doll and a folk craft. Their colors were chosen to cover various hues. When the subject viewed the photograph binocularly without the D-up goggle, he/she could see these objects and also letters printed on the photograph and perceived the photograph as a mere object in the test room.

The experiment was carried out for two viewing conditions, with and without D-up goggle. The subject was asked to rotate the gray scale wheel back and forth and set it at the position where the target window just appeared to shine. The Munsell Value of the gray scale was read out as the lightness of the window target to produce the light source color. The subject was instructed not to fixate his/her eyes on the target but observe the entire scene from time to time so that he/she could recognize the perspective 3D scene. Within one session the subject repeated the determination for three or four times successively for one viewing condition. Three such sessions were done for one subject so that ten determinations of the threshold were obtained altogether. Five subjects YM, RY, ST, KK and TK participated in the experiment.

4.RESULTS AND DISCUSSION

To all the subjects it was quite evident that they could perceive a 3D and real scene with the D-up goggle. To mention a few of their impressions to show the evidence, the scenery expanded over the entire visual field, a space appeared above buildings although there were nothing, and the slope of the paths at the far left and far right became realistically steep. An area with a lightness gradation changed to a ground illuminated by a street lighting, the wall color of the building at the bottom right changed to a mere white from green as the green color shifted to that of the street lighting, all the street lights started to shine and the bright windows of houses changed to lit windows from inside.

The subjects determined the threshold for perceiving the light source color at the window target. The criterion for the threshold was that the window began to shine, but the subjects used other additional criterions such as the appearance changed from a paper to the light coming out, the blackness extinguished from the window and began to shine, the edge of the window disappeared, and so on.

The results are shown in Fig.5 for all the five subjects and for their mean. Along the ordinate the thresholds for the light source color are plotted in Munsell Value, by open circles for the D-up viewing condition and by filled circles for the normal viewing condition without the D-up goggle. Each subject could obtain the threshold for ten times in the D-up condition and their means are shown by an open square. In the normal condition, however, the threshold was not obtainable in some cases because the subjects felt to need a gray scale of a larger lightness than that available shown by the horizontal dotted line to reach the threshold. The numbers attached at the filled circles indicate the number of such cases. The subject TK never experienced the light source color at the window target even with the lightness, 9.41, and he saw a mere white paper there. The subject RY set the gray scale at the largest lightness for five times and responded unable for another five times, while she showed some variance in the thresholds for the D-up condition. This should imply that she was biased in the responses in the normal condition by the limit of available gray scale in the higher range. Other subjects also indicated their wish to have gray scales of larger lightness. Although it is safe at this moment not to draw an immediate conclusion that the threshold was obtained for the normal condition, the data suggest that the subjects could construct a 3-D scene in the photograph even when they observed it under the normal viewing condition. The present photograph had a very large size to cover a large visual field, which might have helped the subjects to construct a RVSI for the scene.

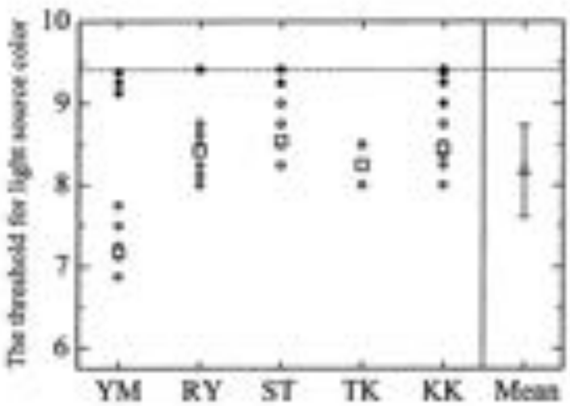


Fig. 5 Threshold for light source color for two different viewing conditions, with (○) and without (●) goggle from five subjects. The extreme right point is the average of the five and the vertical bar shows the standard deviation of the individual data. The dotted line indicates the maximum Gray scale of 9.41.

On the contrary, the threshold was easily obtainable by any subject in the D-up condition and their mean was 8.1 in Munsell Value as seen at the extremely right in the figure. We can conclude then that the light source color was demonstrated in a photograph by the presently proposed method of D-up method.

We employed only one kind of photograph and only one illumiance level of 40 lx in the present experiment. The threshold lightness 8.1 obtained presently may change for other photographs depending on the brightness size of the RVSI constructed for the pictures.

ACKNOWLEDMENT

This research was partially supported by the Grant-in-Aid for Scientific Research No.12650045, The Ministry of Education, Science, Sports and Culture.

REFERENCE

1. Mitsuo Ikeda, Appearance of colors in environment and their use in life. Abstract of the 7th Congress of AIC, Budapest, pp. 257-258 (1993).
2. Mitsuo Ikeda, Hiroyuki Shinoda and Yoko Mizokami, Phenomena of apparent lightness interpreted by the recofnized visual space of illumination, Optical Review, Vol.6, pp.380-386 (1998).
3. Rumi Yamauchi, Mitsuo Ikeda and Hiroyuki Shinoda, Color Change in the Construction Process of the Recognized Visual Space of Illumination for a New Environment, AIC Midterm Meeting, pp.89-93 (2000).
4. Rumi Yamauchi, Mitsuo Ikeda and Hiroyuki Shinoda, Apparent Lightness of an Object Determined by the Immediately Surrounding Recognized Visual Space of Illumination, AIC Midterm Meeting, pp.75-80 (1999).
5. Rumi Yamauchi, Mitsuo Ikeda and Hiroyuki Shinoda, Construction of the Recognized Visual Space of Illumination by Increasing the Initial Visual Information, KOGAKU, Vol.30, pp.41-48 (2001). (in Japanese)

Correspondence: re141952@se.ritsumei.ac.jp ; Phone +81-77-566-1111(ex.8552); Fax +81-77-561-2663; Department of Photonics, Faculty of Science and Engineering, Ritsumeikan University, 1-1-1 Nojihigashi, Kusatsu, Shiga 525-8577, JAPAN

Quantitative evaluation of color appearance between different media and appearance modes

Miyoshi Ayama, Noriyuki Suda, Takeshi Kumagai,
Dept. of Information Science, Utsunomiya University, Japan

ABSTRACT

In this study, we examined the influences of color media and mode of appearance on color appearance by evaluating four attributes of color such as saturation, hue, blackness, and categorical color. CRT display and color charts were used as color stimuli both were presented in the surface-color mode as well as in the aperture-color mode. Results indicated that saturation, blackness, and categorical color names strongly depend on the mode of appearance, while the results of hue does not clearly show such a tendency.

Keywords: Color media, mode of appearance, surface-color mode, aperture-color mode, opponent-type color evaluation, blackness, categorical color naming

1. INTRODUCTION

Color reproduction, not based on colorimetry but based on color appearance perceived by human observers is vitally important for multimedia color processing in various fields. Although a number of color gamut mapping studies have been reported, a generally applicable solution has not been obtained yet. Previous studies showed that mode of appearance, surface-color mode or aperture-color mode, affects on color appearance more significantly than the presentation media of color stimulus [1,2]. In this study, we investigated the color appearance of the stimuli presented in the above two modes produced by the color charts and the CRT display using psychophysical techniques to compare the effects of the mode of appearance and the color media quantitatively.

2. EXPRIMENT

In the experiment, 90 Munsell chips and 65 CRT color stimuli were used. Chromaticity coordinates of the test points plotted on the CIE1931 (x, y) chromaticity diagram are indicated in Figure 1. The test stimulus was 2° ×2° square and presented at the center of either a gray surround of 64.3 cd/m^2 (surface-color mode) or a dark surround (aperture-color mode). Luminance of the test stimuli was set at 32 to 35.7 cd/m^2 for all the conditions.

Following four different conditions were employed; the surface-color mode produced using the color chart or CRT display with the same gray surround, and the aperture-color mode produced using the color chart or the CRT display with the same elaborated dark surround. One session was carried out under one of the four different conditions. Each session was preceded by 5 min. of dark adaptation. Then observer began to judge color appearance of the test stimulus in the following way. First, hue and saturation were evaluated using the opponent-type color evaluation[2] which is based on the same concept as Boynton et al.'s color naming using four unique hue names. Instead of oral response, we employed a pointing technique in which the observer indicates perceived hue and saturation of the test color by pointing the corresponding positions respectively on the opponent-type hue circle and the saturation evaluation line attached on the digitizer. Secondly, perceived blackness is evaluated using a magnitude estimation where 0 corresponds to no blackness, i.e. white, while 4 corresponds to more than 75% of subjective blackness, i.e. mostly black. Thirdly, categorical color naming was done using eleven basic color terms. Eight color normals participated in the experiment as observers.

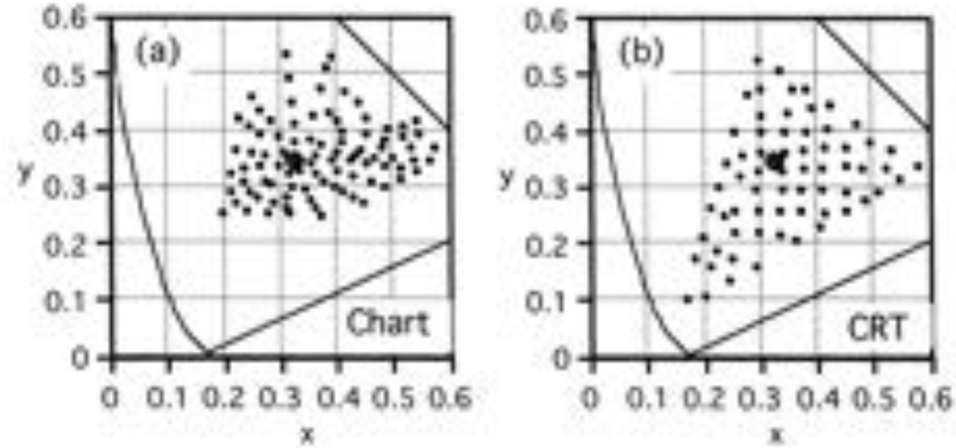


Figure 1. Test points of the color chart (a) and CRT (b) plotted on the CIE1931(x, y) chromaticity diagram. Circle with cross at the center denotes the chromaticity of the gray surround.

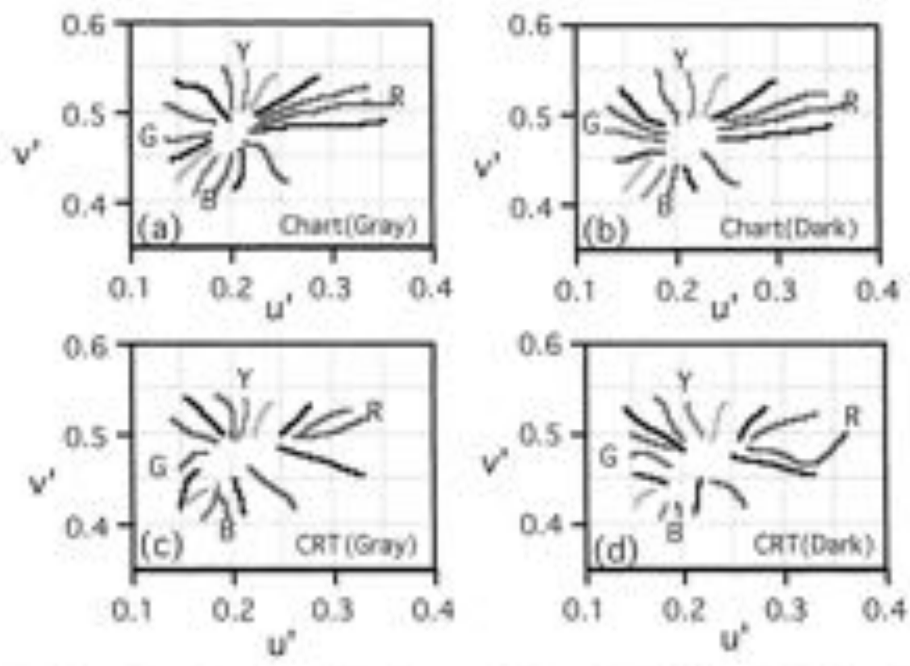


Figure 2. Constant hue loci drawn from the results of hue judgement plotted on the CIE1976 (u', v') chromaticity diagram. (a) Chart (Gray), (b) Chart (Dark), (c) CRT (Gray), and (d) CRT (Dark) denote the four conditions such as the color chart in the surface-color mode, the color chart in the aperture-color mode, CRT in the surface-color mode, and CRT in the aperture-color mode, respectively. R, Y, G, and B denote unique red, unique yellow, unique green and unique blue loci, respectively. Observer HT.

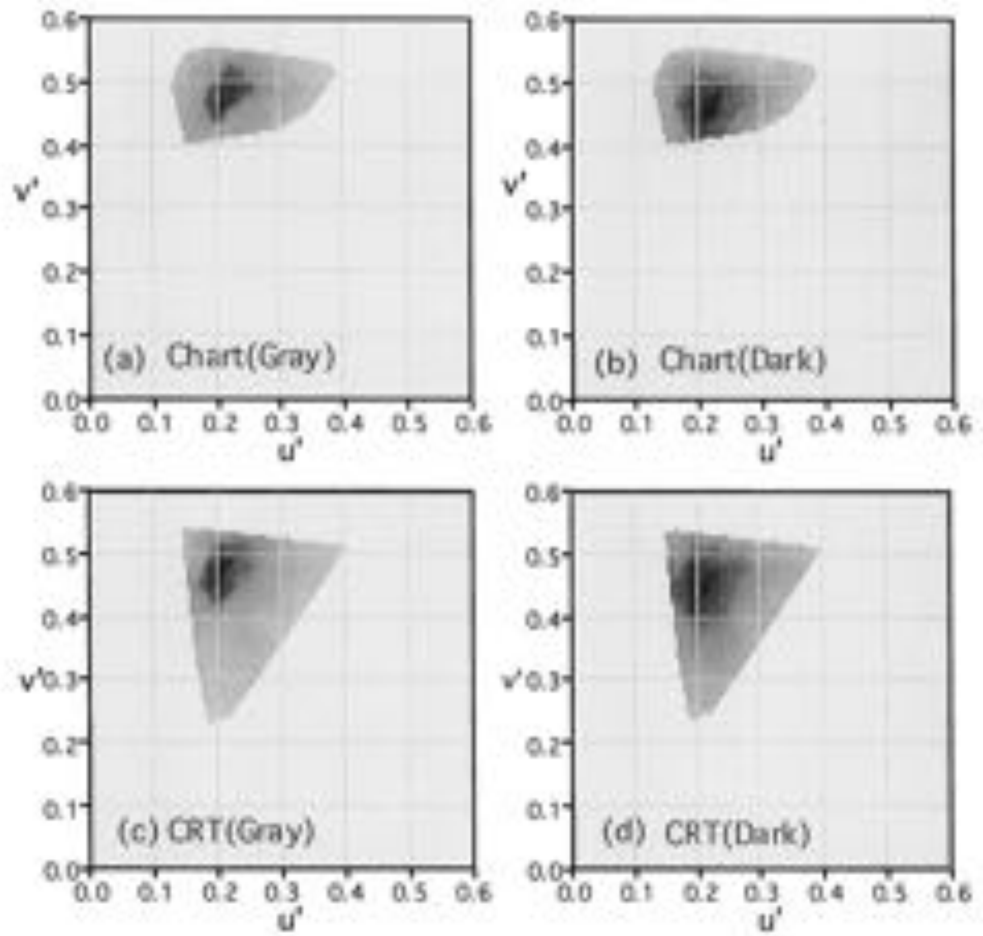


Figure 3. Results of saturation evaluation presented in a gray scale image plotted on the CIE 1976 (u', v') chromaticity diagram. Notations for (a), (b), (c), and (d) are the same as Fig.2. Observer HT.

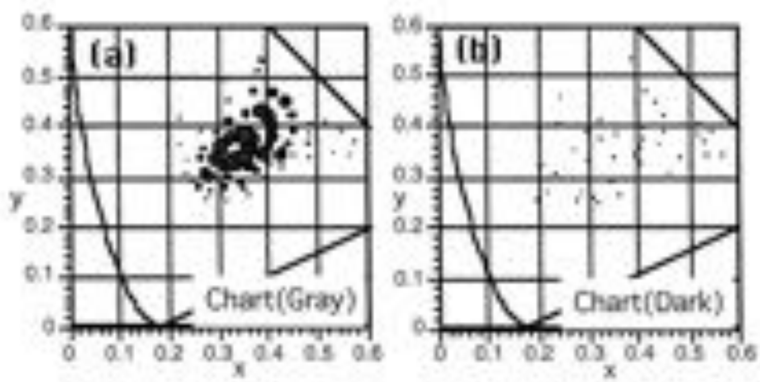


Figure 4. Results of blackness judgement plotted on the CIE1931xy-chromaticity diagram in the surface-color mode (a) and self-luminous color mode (b) conditions using Munsell chart. Dotted points in (a) and (b) denote the test points. Filled circles in (a) are plotted in the size according to the average value of blackness evaluation. Observer HT.

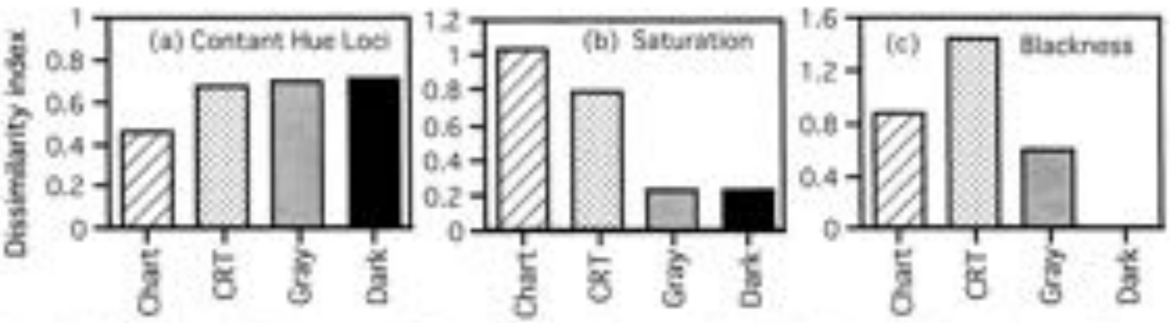


Figure 5. Dissimilarity indices between different conditions. Chart and CRT indicate the comparison between different modes but the same media, whereas Gray and Dark indicate the comparison between different media but the same mode. Ordinate represents dissimilarity index defined separately in each attribute. Observer HT.

3. RESULTS AND DISCUSSION

Figure 2 indicates constant hue loci drawn from the results of hue judgement of observer HT by connecting the points of the same ratio of unique hue components. Results of the four conditions, the color chart in the surface-color mode, the color chart in the aperture-color mode, CRT in the surface-color mode, and CRT in the aperture-color mode are respectively shown in Figure 2 (a), (b), (c), and (d). Figure 3 indicates the results of saturation evaluation in the four conditions represented in gray scale images drawn from the data of observer HT. The lower the saturation value, darker the image pixel of the corresponding chromaticity. As shown in the figure, dark area, i.e. desaturated area, is smaller in the results of the surface-color mode ((a) and (c)) than that in the aperture-color mode ((b) and (d)). Figure 4 shows the results of blackness judgement plotted on the CIE1931 (x, y) chromaticity diagram in the surface-color mode (a) and the aperture-color mode (b) conditions using the color chart. Similar results were obtained in the results using CRT display. Blackness appeared only in the surface-color mode as has been known in the literature.

To examine the effects of mode and media quantitatively, the results between different modes but the same medium and between different media but the same mode were compared with each other and dissimilarity index was defined for each attribute. For the results of unique hue loci, dissimilarity of the curve shape between the corresponding loci in different conditions was calculated being applied a modified Levenshtein distance which is used in assessing dissimilarity between two strings of character in information science. Dissimilarity indices against the four comparisons are plotted in Figure 5 (a). In this case, the effect of media seems to be stronger than that of mode. For the results of saturation, dissimilarity between different conditions was assessed by the sum of bit difference of the gray scale images shown in Figure 3. For the results of blackness, the absolute difference of the evaluated values in the blackness judgement at the test points that have nearly the same chromaticities were summed up to be defined as dissimilarity index. Dissimilarity indices for saturation and blackness are respectively indicated in Figure 5 (b) and (c), clearly showing stronger effect of the mode than the media.

The results in this study confirmed that not the media but mode of appearance more strongly affect on color appearance. Quantitative comparison showed that saturation and blackness distinctively depends on the mode of appearance while hue seems to depend on the color media.

REFERENCES

1. H.Uchikawa, K.Uchikawa, and R.M.Boynton, "Influence of achromatic surrounds on categorical perception of surface colors," Vision Res., **29**, pp.881-890,1989.
2. H. Otsuki, H. Toyama, N. Sakakibara and M. Ayama, "Constant hue loci for colors in surface and self-luminous modes," Proceedings of AIC Color 97, Vol. I, pp.310-313, 1997.

Color Constancy and Color Appearance Mode in Relation to the Visual Field Size

Azusa Kusumi, Mitsuo Ikeda and Hiroyuki Shinoda

Department of Photonics, Faculty of Science and Engineering, Ritsumeikan University
Nojihigashi, Kusatsu-shi, Shiga 525-8577, Japan

ABSTRACT

Based on the concept of the recognized visual space of illumination an experiment was conducted to measure the color appearance of a white test patch under the conditions where it was perceived as the object color and the light source color. The apparent color was measured by the elementary color naming method when it was viewed through a green color filter at its various positions between the patch and the eye in a room illuminated by a daylight type of lamps at the illuminance 20, 100, 500 or 1,600 lx. When the filter was placed close to the patch so that only the patch was seen through the filter, it appeared very green, but the amount of the chromaticity gradually decreased as the filter was moved to closer to the eye. The color finally returned to the original white when the filter was placed directly on the eye so that the entire visual field was covered by the green filter. A bright light was added on the test patch so that the appearance may become the light source color. The prediction for the apparent color based on the RVSI was that the color does not change in spite of the change in the visual field size through the green filter because the appearance cannot be controlled by the RVSI. The prediction was confirmed.

Keywords: Color Appearance, Color Appearance Mode, Color Constancy, Color Filter, RVSI

1. INTRODUCTION

The concept of the recognized visual space of illumination, RVSI was proposed at the 7th Congress of AIC, Budapest (1) and it showed to explain various phenomena of the color perception (2-6). When one comes to a space he/she immediately understands how the space is illuminated. The state is expressed as that the person constructed the RVSI in his/her brain for the space. The RVSI is schematically expressed by a sphere, or a circle for simplicity, of a certain radius with the fundamental recognition axis FX and the color recognition axis, RX as shown in Fig. 1. The FX is the color recognition axis possessed by a subject inherently and the RX is the color recognition axis determined by the illumination. An object in the space can be placed at a proper position within the circle and its apparent color is determined in relation to the RVSI. Let us suppose that we look at a white patch through a small green filter by holding the filter with a hand of a stretched arm in a room illuminated by a daylight type of illumination. We naturally see the patch greenish. This simple phenomenon can be explained by the concept of the RVSI. The patch is positioned on an axis tilted toward a green direction or counterclockwise as T_O in Fig. 1a. It has its own color through the green filter without being influenced by the illumination and the color is determined by the angle from the fundamental recognition axis FX. When seen in a room illuminated the apparent color is now determined in relation to the axis RX, which is drawn vertically to represent a white illumination and coincides with the axis FX. The angle from the axis RX to the object is large in this case and the color should appear very greenish.

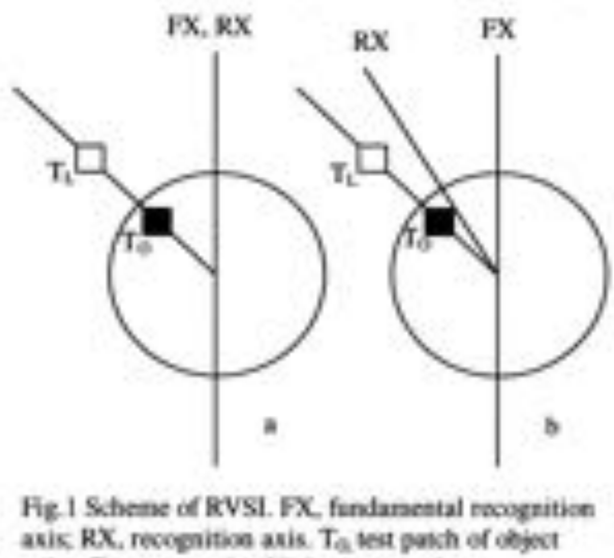


Fig.1 Scheme of RVSI. FX, fundamental recognition axis; RX, recognition axis. T_O, test patch of object color. T_L , test patch of light source color.

Now let us bring the green filter close to the eyes to see the entire space through the green filter. The situation is equivalent to the case when the entire room is illuminated by a green light and we will perceive the patch as whi te as we can expect from the color constancy phenomenon. We explain the situation by rotating the axis RX toward the green color as indicated in Fig. 1b. The physical situation of light coming from the patch toward the subject does not change and the patch remains at the same position in the RVSI as in the case of Fig. 1a. The angle from the RX became very small and the apparent color of the patch should almost return to its own color, a white. If the axis RX comes to the green position exactly the perfect color constancy takes place. In the present experiment we will firstly measure the change of the apparent color of the patch as a function of the distance between the green filter and the eyes, when the size of the visual field through the filter gradually changes.

Fig2. Over view of the apparatus.
T, test patch. ; F, filter ; P, projector.

Now, let us increase the luminance of the patch by illuminating it locally and additionally with a help of a slide projector. The position of the patch in the RVSI moves toward outside along the same axis of the green if the light coming from the projector is white. It will eventually go out of the RVSI as shown by T_L in Fig. 1. The appearance of the patch should vanish as that of an object in the space and only the bright light remains there. The color appearance is no longer of an object color but have a light source color. What is more the color is not controlled by the RVSI any more. In the case of the present experiment, this means that the color of the patch should not change in spite of the change of the visual field size through the green filter, when the recognition axis rotates according to the filter position. As the second part of the present experiment the prediction will be confirmed.

2. APPARATUS AND PROCEDURE

We constructed an experimental room shown in Fig.2. The room was illuminated by ceiling fluorescent ramps of the daylight type with the correlated color temperature 6500K. A white test patch T of N8.0 was placed under the illumination for the color appearance judgment. It was of 9 cm x 9 cm size and surrounded by black margins of 5 mm wide. A subject viewed the patch monocularly through a green color filter F of x=0.305 and y=0.417 at a distance 150 cm away. The filter was movable on an optical bench so that the subject's visual field through the filter can be changed in size. The filter had a size 4 cm x 4 cm with a 5 mm width frame. The subject used a biting board to fixate his/her eyes although not shown here. Artificial flowers, books, dolls, and other objects were placed on shelves and a mask, a fan, a calendar and a small vase were hung on the walls. Their colors were chosen to cover hues. In order to illuminate the test patch locally a slide projector P of 150 W was used with an appropriate mask placed at the film position. Its

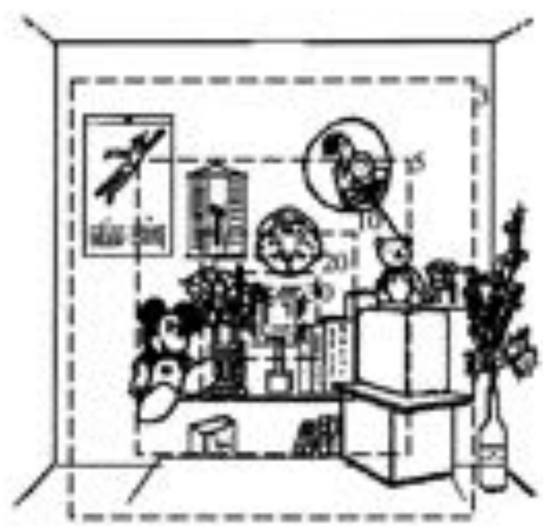


Fig3. Subject's view. The field size through the color filter is shown by dotted squares. Numbers indicate the positions of the filter in cm.

chromaticity coordinates were x=0.419 and y=0.424 and the color was a little bit orange. The luminance of the patch when illuminated only by the projector was 174 cd/m^2. Four illuminance levels of 20, 100, 500 and 1,600 lx were employed for the room illumination when measured on a table in front of the test patch. The color specifications of the test patch through the green filter are summarized for various conditions in Table 1.

Eleven positions of the green filter were employed and they were 0, 3, 5, 10, 15, 20, 25, 30, 50, 70, and 90 cm from the subject's eye. The fields seen through the filter at these distances were shown by dotted squares in Fig. 3 which shows the front wall. The distances are attached at the squares in cm. The bold square at the center indicates the test patch. The dotted square inside the patch is for the distance 90cm. The dotted square for the distance 70cm just coincided with the test patch. To provide the 0 cm condition the filter was placed against the subject's face, when his/her visual field was completely covered by the green filter.

Room Ill.	Projector	x	y	Y (cd/m^2)
20 lx	off	0.309	0.435	3
	on	0.380	0.482	118
100 lx	off	0.305	0.418	13
	on	0.373	0.476	128
500 lx	off	0.304	0.415	66
	on	0.351	0.456	180
1600 lx	off	0.305	0.416	214
	on	0.330	0.438	328

Table1. Color specifications of the test patch seen through the green filter with and without the projector.

Subjects judged the apparent color of the test patch and reported the amounts of chromaticness and the hue by the method of the elementary color naming by using four unique hues R, Y, G and B. Two subjects participated in the experiment, AK (female, 24) and MI (male, 68).

3. RESULTS AND DISCUSSION

Before carrying out the main experiment to determine the apparent color at various filter positions we conducted a supplemental experiment where we determined the patch's own color with and without the green filter without being influenced by the illumination in the room, namely the apparent color based on the axis FX rather than RX. The test patch was observed through a tube with a mask at the tip so that only the test patch could be seen and its apparent color was determined for two cases, with and without the green filter.

Fig.4 shows the results for two illuminance conditions, 20 lx and 1,600 lx. The left two figures are from the subject AK and the right from MI. The amount of chromaticness is taken along the radius and the outmost circle represents 40%. The hue is shown along the arc. The color appearance of the test patch itself through the green filter is denoted by the filled signs and that without the filter by the open signs. Those color were obtained with the viewing tube mentioned above. Let us look at the results of AK at 20 lx in the case of no additional light on the test patch from the projector shown by triangles. A large filled triangle indicates the patch's own color through the green filter, which was determined with the tube. A large amount of chromaticness of yellowish green was perceived. A similar color was perceived when the patch was observed with the green filter in the illuminated room placed close to the test patch, or 90 cm apart from the subject as

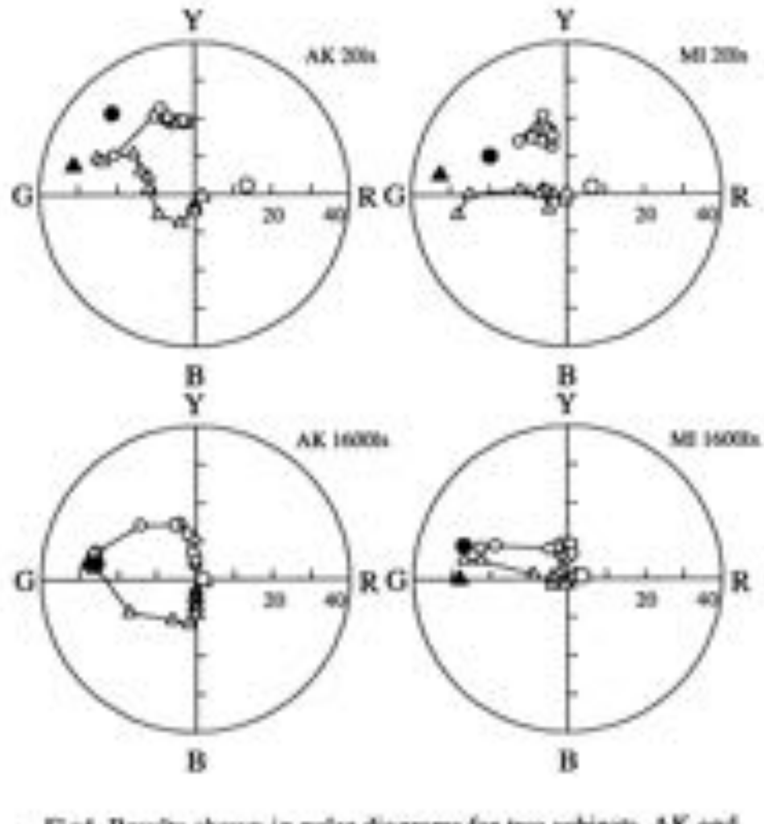


Fig4. Results shown in polar diagrams for two subjects, AK and MI. Small open triangles, apparent color without the projector; small open circles, with projector; large filled signs, the original color through the filter; large open sighs, without the filter.

shown by the most left open triangle. The chromaticness gradually decreased as the filter was moved toward the subject's eye and it finally became almost zero when the filter was attached to the eye. The color is very close to the large open triangle, which shows the color of the patch itself without the green filter. The apparent color of the test patch returned to its own color confirming the color constancy. The hue change took place rather complicatedly in this subject. The hue change was simple in another subject MI, keeping the green hue constant. Only the amount of chromaticness decreased returning to a white patch. The test patch was perceived as the object color and the color changed from green to white. When the test patch was additionally and locally illuminated by the projector the color on the test patch became the light source color regardless the position of the green filter. The results show only a small amount of change in color appearance for different filter positions as shown by open circles except the most left open circle of the subject AK. The point was obtained at the filter position, 90 cm, when the test patch was larger than the filter. The filter was effectively surrounded by a very bright orange color coming from the projector. The subject might have been influenced by the bright orange in judging the color of the test patch and perceived green color emphasized by the simultaneous color contrast. The subject MI tried not to gaze at the test patch to avoid the contrast. It is quite clear that the color of the test patch did not change much and it remained closer to the filled circle and did not come close to the open circle. This implies that the color remained as its own color and was not influenced by the RVSI for the room.

When the room illuminance was increased to 1,600 lx the color of the test patch changed from the starting point of large filled signs to the returning point of large open sign even when the patch was additionally illuminated by the projector. In other words the shift of the apparent color was that of the object color. The luminance of the test patch was 328 cd/m2 when seen through the green filter with the projector on. The luminance of the wall immediately surrounding the test patch was 343 lx when seen outside the green filter to represent the situation of the filter position at 90 cm. When it was seen through the green filter to represent the situation of the filter at 10 cm or less the luminance was 214 cd/m2. In any cases the luminance difference between the test patch and the surrounding bright wall was small. The position of the test patch T_L in Fig. 1 was near to the boundary of the RVSI if it were outside the RVSI and the color appearance of the test patch must be still influenced by the RVSI.

In both subjects the results for 100 lx condition were very similar to those for 20 lx and the results for 500 lx were to those for 1,600 lx.

To conclude the present experiment, the color of the test patch was determined in relation to the RVSI when it was seen as the object color. It was not determined in relation to the RVSI when the surface was perceived as the light source color. The color almost remained as the color of the test patch itself as predicted from the concept of the RVSI.

The present research was partially supported by the Grant-in-Aid for Scientific Research No. 10650047, The Ministry of Education, Science, Sports and Culture.

REFERENCES

1. M. Ikeda: Appearance of colours in environment and their use in life. Abstract Volume, AIC 7th Congress, Budapest (1993) 257.
2. Yoko Mizokami , Mitsuo Ikeda and Hiroyuki Shinoda : Lightness judgment in relation to the size of the recognized visual space of illumination controlled by lightness and color saturation of objects. Proc. AIC 8th Congress, Kyoto 1 (1997) 167.
3. Mitsuo Ikeda, Hiroyuki Shinoda, Yoko Mizokami : Three dimensionality of the recognized visual space of illumination proved by hidden illumination. Opt. Rev. 5 (1998) 200
4. Mitsuo Ikeda, Hiroyuki Shinoda, Yoko Mizokami : Phenomena of apparent lightness interpreted by the recognized visual space of illumination, RVSI. Opt. Rev. 5 (1998) 380.
5. Y. Hattori, M. Ikeda and H. Shinoda: Method of displaying exact colored scenes perceived by the aged. Proc. AIC Midterm Meeting, Warsaw (1999) 109.
6. R. Yamauchi, M. Ikeda and H. Shinoda: Color change in the construction process of the recognized visual space of illumination for a new environment. Proc. AIC Interim Meeting, Seoul (2000) 89.

Colour Appearance Comparison between LCD Projector and LCD Monitor Colours

Youngshin Kwak*, Lindsay W. MacDonald, M. Ronnier Luo
Colour & Imaging Institute, University of Derby, Derby, UK

ABSTRACT

Two sets of colour appearance data were accumulated for investigating the difference between LCD projector and LCD self-luminous colours. Psychophysical experiments were conducted using magnitude estimation methods. These colours were viewed against different neutral backgrounds. These data sets were used to test the performance of five colour appearance models (CIECAM97s, Hunt94, LLAB, RLAB and CIELAB together with two most recently proposed revisions of CIECAM97s: Fairchild and FC).

Keywords: Colour appearance model, magnitude estimation, dark surround, projected colour, self-luminous colour

1. INTRODUCTION

For achieving cross-media colour reproduction, surround is one of the most important viewing parameters to be considered by a colour appearance model. The CIECAM97s specifies four different surround conditions: average, dim, dark and cut-sheet. The dark surround in CIECAM97s corresponds to the experimental results obtained using a 35-mm slide projector in a dark room[1] and the dim surround is based upon the experimental results using self-luminous colours generated by a CRT monitor[2]. Although the self-luminous colours were also viewed in a dark room, their results were significantly different from those of projected colours. Hence, the self-luminous colours were categorised as dim surround viewing because the visibility of surround was clearer than under projection conditions. In this study, colour appearance difference caused by media difference was examined using an LCD projector for projected colours and an LCD monitor for self-luminous colours. Also the effect of background luminance level was investigated.

The whole experiment was divided into five phases – 2 for LCD projector with a mid-grey and a black background and 3 for LCD monitor with a white, a mid-grey and a black background. Luminance values of reference white were 154 cd/m^2 for LCD projector and 90 cd/m^2 for LCD monitor.

Colour appearance of the projected colours generated by an LCD projector and self-luminous colours produced by an LCD monitor was compared to reveal the difference of colour appearance between two media together with luminance levels. Finally the performance of 7 colour appearance models (CIECAM97s, Hunt94, LLAB, RLAB and CIELAB and two modified CIECAM97s; Fairchild and FC) was tested.

2. EXPERIMENT

For projected colours, a Sanyo PLC-5605B LCD projector driven by a Samsung Sense 820 laptop computer was used to project the image onto a white matte screen, which was a veneer painted with Dulux White paint. The projected image size was 117x88 cm. The LCD monitor of a Samsung Sense 820 laptop computer was used to present self-luminous colours. The image size was about 28x21 cm. To avoid the angular dependency of the output colours of the LCD monitor, observer's eye position was fixed to the normal direction of the monitor. The distance between screen/monitor and observer (or telespectroradiometer) was adjusted to be within the recommended distance (3±1 picture heights from the screen) for normal cinema by ANSI[3]. Figure 1 shows the viewing pattern, which was used for both experiments. Each patch had a size of 5.5x5.5 cm for projected images and 1.3x1.3 cm for monitor images subtending a visual angle of about 1°. Twenty-five decorating colours were used to form a complex viewing field. Three patterns including different decorating colours were displayed in sequence during the psychophysical experiment to avoid adaptation to particular image.

---

*Correspondence: Y.Kwak@derby.ac.uk, phone 44 1332-622217; fax 44 1332-622218; http://colour.derby.ac.uk; Colour & Imaging Institute, University of Derby, Kingsway House East, Kingsway, Derby DE22 3HL United Kingdom

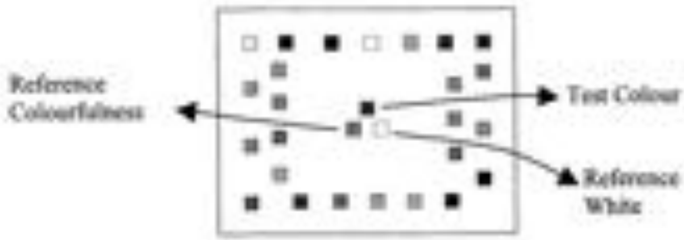


Figure 1. Viewing pattern

The chromaticity of the reference white for LCD monitor was adjusted to match with that of LCD projector. For LCD projector, 32 test colours were chosen to cover a large range of the colour gamut of the projector and 10 colours were repeated per session to investigate the observer repeatability. For LCD monitor phases, 40 colours were used and 10 colours were again repeated. Because of the colour gamut difference between the two devices used, only 10 colours were close to each other in terms of chromaticities, which were used directly to compare the colour appearance between two devices. Figure 2 shows the test colour distributions for each device.

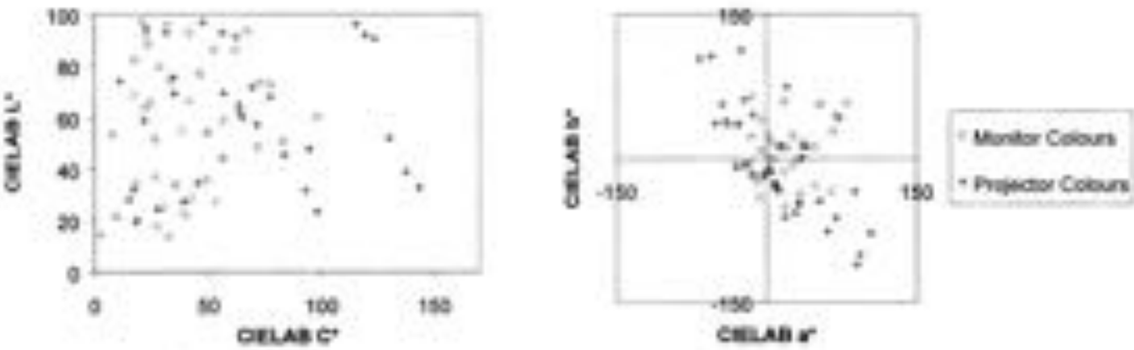


Figure 2. Colour distribution in CIELAB space

Twenty-one observers with normal colour vision participated in the projector experiments. The results[4] showed that a subgroup of 10 observers performed not significantly differently from the whole panel of 21 observers. Hence, only 11 or 12 observers were used in LCD monitor experiments. Table 1 summarises the experimental phases.

Phase	Device	Y% of background	Tristimulus values of the reference white			No. of colours	No. of observers
			Y_L (cd/m²)	X	y		
1	LCD projector	18.3	154.0	0.294	0.353	42	21
2	LCD projector	0.4	152.7	0.294	0.353	42	21
3	LCD monitor	20.7	90.3	0.294	0.353	50	12
4	LCD monitor	0.4	89.8	0.295	0.354	50	11
5	LCD monitor	100	90.2	0.294	0.353	50	12

Surround Condition : Dark room

Table 1 Summary of the experimental phases

Magnitude estimation method was used to assess the colour appearance of each test colour. Experimental procedures and data analysis were carried out using the same method used by Luo et al[3]. To quantify the performances of the observers and colour appearance models, the coefficient of variation (CV) was used as a statistical measure to investigate the agreement between any two sets of data, say x and y.

$$CV = 100\frac{\sqrt{\sum(x_i - y_i)^2 / n}}{\bar{y}},$$

n : number of samples in x and y sets
$\bar{y}$: the mean value of the y set

For a qualitative comparison between phases, scatter diagrams were plotted against two data sets.

The repeatability of each observer was examined using the repeated ten colours in each session. The CV value between two sets of estimation results was calculated as the repeatability of each observer. Also the CV between the individual's and the mean visual results was computed, which represents accuracy for each observer. The mean and standard deviation of overall repeatability and accuracy of each phase are given in Table 2.

CV	Repeatability			Accuracy		
	Lightness	Colourfulness	Hue	Lightness	Colourfulness	Hue
LCD Projector	18.2	28.0	9.6	17.3	24.3	7.7
LCD Monitor	15.7	26.6	9.0	17.4	23.6	10.4

Table 2 Observer performances

3. PARAMETRIC EFFECT

3.1 Device dependency of colour appearances (LCD projector vs. LCD monitor)

Psychophysical experiment results were directly compared using scatter diagrams for 10 common colours between two devices, LCD projector and LCD monitor. Figure 3 shows the result. CIELAB L* and C* values from measured XYZ are used as the measurement values corresponding to psychophysical lightness and colourfulness. L* and Lightness did not show any significant difference between devices but projector colours showed higher colourfulness than monitor colour unlikely CIELAB C* showing no difference between them. However note that C* corresponds to chroma rather than colourfulness and projector colours had higher luminance of reference white inducing higher colourfulness.

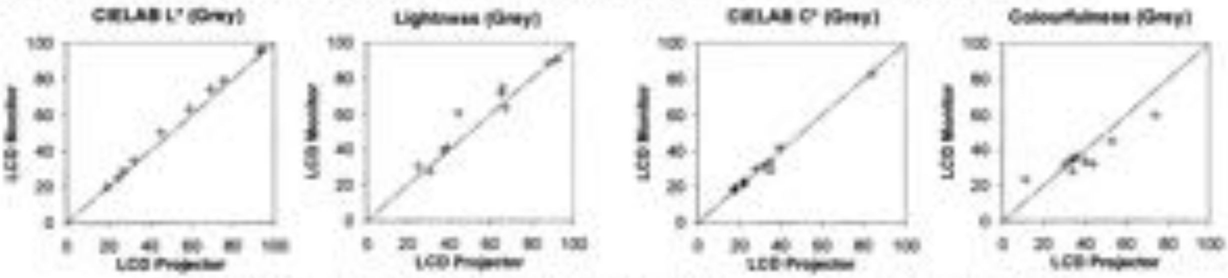


Figure 3. Measurement and psychophysical data comparison between LCD projector and monitor

As an indirect test method, colour appearances for monitor colours were calculated using dark and dim surround and the results showed that dark surround fits psychophysical experiment results better than dim surround. Note that all experiments were done in a dark room.

3.2 Effect of background luminance level

As found in the earlier studies, when the background becomes darker, colours appear lighter[3] and dark colours do become more colourful, light colours have a tendency to become less colourful[3]. These characteristics clearly showed for monitor colours but in the case of projected colours, lightness showed no difference and colourfulness appeared generally higher for grey than black background.

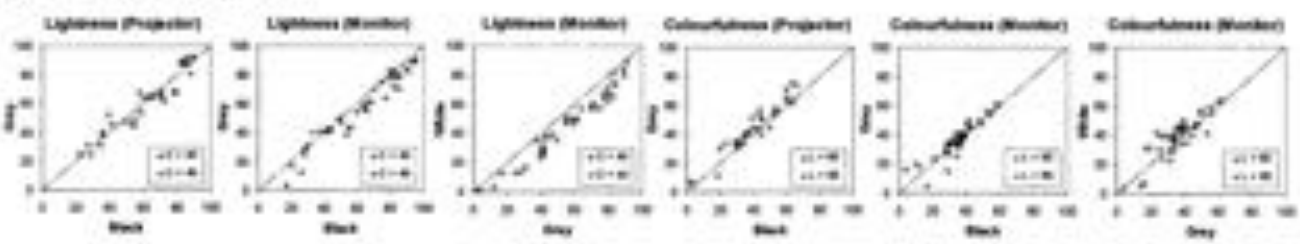


Figure 4. Effect of background luminance levels

In the case of lightness, the background effect might be less clear for projector because background luminance difference between grey and black background for projector was slightly smaller than for monitor. The reason for overall colourfulness increment on lighter background in the case of projector is not clear. One of the possible explanations might be the effect of absolute screen size. That means that a large screen could induce the surround effect more than small one. In other words, if screen colours are changed from white to black, surround might be perceived as darker for a large screen than a small screen. To test this effect more experiments using a cinema screen will be needed.

4. PERFORMANCE OF THE COLOUR APPEARANCE MODELS

The new colour appearance data sets were used to test the performance of five widely used colour appearance models: CIECAM97s, Hunt94, LLAB, RLAB and CIELAB. Table 3 shows the results. Generally speaking CIECAM97s showed better performance than the others.

	Y	Mean Visual Data						
	X	CIECAM97s	Hunt94	LLAB	RLAB	CIELAB	FC	Fairchild
Average CV for 5 phases	Lightness	14.2	16.1	15.8	22.6	18.5	14.0	15.3
	Chroma	22.6	23.0	17.6	29.2	30.3	22.6	31.3
	Colourfulness	24.5	23.7	21.9	N/A	N/A	24.4	35.1
	Hue	8.8	9.1	10.0	11.0	N/A	8.9	8.8

Table 3 Colour appearance model performance test results for LCD projector and LCD monitor

Also the experimental data were used to test the latest colour appearance models[6]: FC and Fairchild. These two models are the modifications to CIECAM97s having simplified chromatic adaptation transforms and modified colour appearance predictors. FC showed similar performance with CIECAM97s but Fairchild had poorer performance. Both FC and Fairchild, used modified achromatic response A' to improve the lightness prediction of dark colours, but it was proved in this experiment that this modification induced general over-prediction for lighter colours. For FC, this effect was compensated by modifying the z function in lightness J, but the result was poorer performance than CIECAM97s for Fairchild model, which used original CIECAM97s equation. In the case of colourfulness/chroma, the Fairchild model was derived to fit Munsell chroma scales, which do not seem to fit with the results from magnitude estimation method. The performances of lightness J and brightness Q are directly affected by surround parameter c, and lightness J is used to determine chroma C and colourfulness M. Therefore using proper value for surround parameter c is very important to improve the model performance. Optimised surround parameter c was calculated for CIECAM97s, FC and Fairchild. Original value for CIECAM97s is 0.525 for dark surround. Results are summarised in Table 4. CIECAM97s and FC did not show much improvement by c values but the Fairchild model showed similar performance with others after using optimised c value.

CIECAM97s			FC			Fairchild		
Optimised c	Original CV	New CV	Optimised c	Original CV	New CV	Optimised c	Original CV	New CV
0.517	14.3	14.2	0.517	14.4	14.0	0.459	15.2	13.9

$$J = 100\left(\frac{A}{A_w}\right)^{cz}$$

Table 4 Optimised c and CV values between lightness J and visual data for CIECAM97s, FC and Fairchild models

5. CONCLUSION

New colour appearance data sets for projected and self-luminous colours were accumulated. From this study, we could not find any strong evidence that colour appearances depend on the colour display method – projected or self-luminous. For monitor colours, the well-known background effects are confirmed that all colours tend to look lighter as the background becomes darker and as the background becomes darker, dark colours do become more colourful, light colours have a tendency to become less colourful. However projected colours showed some inconsistency with previous studies for colourfulness, indicating another effect to be considered. Using these new data sets five colour appearance models (CIECAM97s, Hunt94, LLAB, RLAB and CIELAB) were tested and CIECAM97s showed best results. Also the latest colour appearance models (FC and Fairchild) were tested and a new value of parameter c for Fairchild is suggested to improve the performance of lightness J.

REFERENCES

1. M. Ronnier Luo and X. Wang Gao, Peter A. Rhodes, H. John Xin, Anthony A. Clarke, Stephen A. R. Scrivener, Quantifying colour appearance. Part IV. Transmissive Media, *Color Res. Appl.* **18**, 191-209 (1993)
2. M. Ronnier Luo and Anthony A. Clarke, Peter A. Rhodes, Andre Schappo, Stephen A. R. Scrivener, Chris J. Tait, Quantifying colour appearance. Part I. LUTCHI colour appearance data, *Color Res. Appl.* **16**, 166-180 (1991)
3. ANSI/SMPTE 196M-1986, Screen Luminance and Viewing Conditions – Indoor Theater Projection
4. Y.Kwak, L.W.MacDonald, M.R.Luo, Quantifying Colour Appearance for Projected Images, *Proc. 2000 AIC Meeting Seoul*, Seoul, Korea, (2000)
5. R.W.G. Hunt, An Improved Predictor of Colourfulness in a Model of Colour Vision, *Color Res. Appl.* **19**, 23-26 (1994)
6. R.W.G. Hunt, C.J. Li, L.Y. Juan and M.R.Luo, Further Improvements to CIECAM97s, , *Color Res. Appl.* in print (2001)

An objective method for quantifying whiteness perception by applying CIECAM97s

Kenji Mukai*, Tetsuji Takeuchi*, Miyoshi Ayama**, Sueko Kanaya***
* Lighting Company, Matsushita Electric Industrial, Japan
** Dept. of Information Science, Utsunomiya University, Japan
*** Dept. of Human Information Science, Kanazawa Institute of Technology, Japan

ABSTRACT

There are many white objects around us. For example, there are white papers, white clothes, white ceramics etc. Therefore the whiteness perception of white objects plays an important role in the impression of lighting as well as perceived color of colored objects. Whiteness perception of white objects is influenced by color temperature or chromaticity of the light sources more than the colored objects. Ayama et al. has been investigating the relationship between color temperature or chromaticity of the light sources and the whiteness perception of white objects. In this paper an objective method for quantifying whiteness perception is studied. We attempt to investigate the relationship between chroma derived from some recent color appearance models and whiteness perception. Mainly the relationship between chroma derived from CIECAM97s and whiteness perception is discussed. As a result of the investigation, it was made clear that as the chroma becomes lower the whiteness perception becomes higher and that the whiteness perception is equal if chroma is equal even if the hue varies.

Keywords: whiteness perception, color temperature, light source, CIECAM97s, chroma, color appearance models

1. INTRODUCTION

There are many white objects such as white papers, white clothes, etc. in our living environments. Therefore, the whiteness perception of white objects plays an important role in the impression of lighting. Especially in Japan, most people prefer illuminants that make white objects whiter. Some studies on estimating whiteness perception of white papers and cloths have been done [1,2]. From results of these studies, we see that spectral reflectance of papers or cloths that make higher whiteness perception under a certain illuminant have been made clear. However, there are few studies on spectral distributions of illuminants that make white objects whiter. To clarify the requirements of illuminants which provide higher whiteness perception of white objects, the relationship between the spectral distributions of illuminants and the whiteness perception of white objects must be studied. Ayama et al. conducted a series of experiments to make clear the appropriate spectral distribution of illuminants in order to provide higher whiteness perception [3,4]. In this study we attempted to establish an objective method to quantify whiteness perception. We investigated the relationship between the whiteness perception of white objects examined in a series of experiment conducted by Ayama et al. and the chroma derived from some recent color appearance models especially CIECAM97s.

2. EXPERIMENT

The series of experiments was conducted by Ayama et al. An outline of the experiment is mentioned below.

2.1 Test stimuli and Illuminants

Two achromatic Munsell charts and five nearly white charts were selected. The Munsell notations of them are N9.5, N9.25, 4YR9.25/0.5, 3G9.25/0.5, 5B9.25/0.5, 3PB9.25/1.0 and 10PB9.25/0.5. The charts were put on rectangular gray cards of 90mm x 50mm. The size of the each chart is 35mm x 35mm and the viewing distance was 500mm, so the visual angle of the each chart was about 4 degrees x 4 degrees. Eight different Illumination conditions were adopted. The combination of correlated color temperature and duv are 6700K +1, 5000K +1, 3500K –3, 3200K 0, 3200K –3, 3200K –4.5, 3000K –1 and 2800K –3. Duv is an index to indicate the 1000 times of distance from the Planckian locus in the CIE 1960 UCS diagram.

The positive and the negative signs denote the upper and the lower part of the Planckian locus, respectively.

2.2 Apparatus

Cubic viewing rooms (2100mm x 2100mm x 2100mm) were prepared. The insides of the rooms were finished in a neutral gray color. Fluorescent lamps of various colors were attached on the ceilings. Each lamp can be dimmed independently. The arrangement of the viewing room, fluorescent lamps, test charts and observer are shown in Fig.1.

Fig.1 Arrangement of the apparatus

2.3 Procedure

The observer sat in the viewing room alone. After five minutes of adaptation to the given illumination condition, he or she looked at the test charts illuminated at 500[lx] one by one. He or she was requested to mark the whiteness of each chart, 0-100, very white is 100 and not white at all is 0. The experimenter recorded the oral responses of the observers from outside.

2.4 Observers

Eleven observers, nine males and two females participated in the experiment. One was in her forties and the others were in their twenties. All tested for normal color vision on the Farnsworth-Munsell 100 hue test.

2.5 Results

The relationship between the hue of the test chart and the average of the whiteness perceived by observers is shown in Fig.2. Each symbol indicates the color of the illuminants. This figure shows the perceived whiteness varies according to not only the hue of the charts but also the correlate color temperature and duv of the light sources. Charts said to be whiter changed from the bluish charts to the purplish charts as the correlated color temperature becomes less. The perceived whiteness of the achromatic charts is less, as the correlated color temperature is lower. And the test charts can be grouped into three types. One is the group whose perceived whiteness becomes lower as the correlated color temperature becomes less. Next is the group whose perceived whiteness becomes higher, and the other one is the group whose perceived whiteness is constantly high. In order to quantify the whiteness perception, it is necessary to consider both the hue of the objects and the color of illuminants.

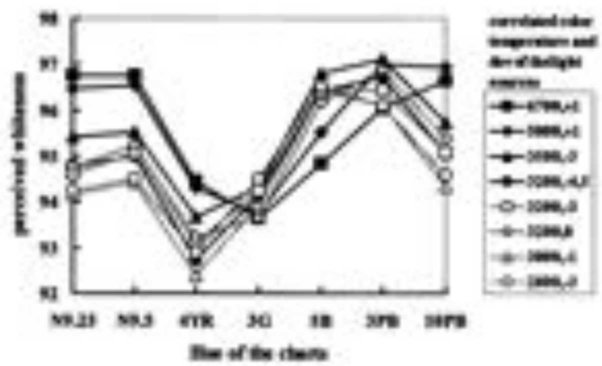


Fig.2 Relationship between hue and perceived whiteness

3. DATA ANALYSIS

To quantify the whiteness perception from the results of the experiments above, the relationship between the chroma and the perceived whiteness was investigated based on a hypothesis that the whiteness perception is higher, as the chroma lessens. The CIELAB is one of the most basic color spaces for calculating a metric chroma. So, first, the relationship between the metric chroma in the CIELAB and the perceived whiteness was investigated. Secondly, the relationship between chroma derived from CIECAM97s and the perceived whiteness was investigated. This is because CIECAM97s is one of the best-known color appearance models for predicting the color appearance of a given stimulus under a variety of static adapting conditions. Thirdly, the relationship between the metric chroma in CIELAB with a prediction method for corresponding colors and the perceived whiteness was investigated. As a prediction method for corresponding color, the method reported by CIE in 1994 was adopted, this is because CIECAM97s and the method reported by CIE in 1994 have different chromatic adaptation models and it was necessary to check which adaptation model fits the experimental results.

The colors of the presented charts illuminated by three illuminants in the CIELAB are shown in Fig.3. The symbols indicate the light color which illuminated each chart and numerals beside the symbols indicate the average of the perceived whiteness estimated by the observers. This figure shows that the same charts are calculated as having almost equal color in the CIELAB even if the illuminants are different. But the perceived whiteness varies even if calculated a^* and b^* are almost the same. Next, the metric chroma C^* of all charts under all illuminants are calculated by the equation (1).

$$C^* = (a^{*2}+b^{*2})^{1/2} \qquad (1)$$

The relationship between the metric chroma and the average of the perceived whiteness estimated by all observers is shown in Fig.4. This figure indicates a tendency for the perceived whiteness to be higher, as the metric chroma is less. But the

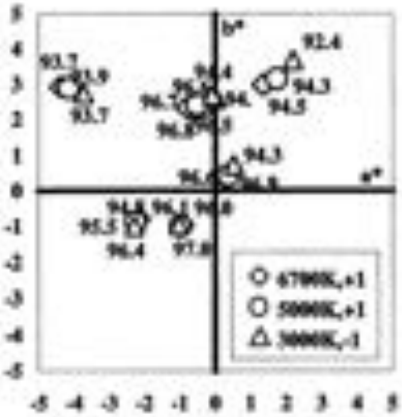


Fig.3 Color points of the charts illuminated by three lights and perceived whiteness

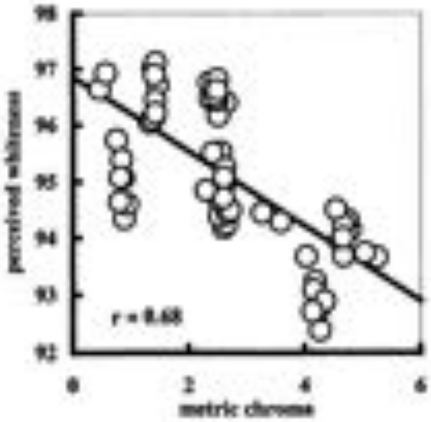


Fig.4 The relationship between metric chroma and the perceived whiteness

correlation coefficient between them is -0.68, so it can not be said that whiteness perception is correlated closely with metric chroma in the CIELAB. The reason may be that CIELAB does not investigate chromatic adaptation completely enough. Therefore, again the relationship between the chroma derived from CIECAM97s and the perceived whiteness was investigated. The calculated colors of the charts in the red-green and yellow-blue opponent dimensions, represented by a and b, respectively, under three illuminants are shown in Fig.5. The symbols and the numerals beside the symbols have the same meanings as with Fig.3. This figure indicates that neither the hue of the charts nor the colors of the illuminants can group the charts. This may be an indication that CIECAM97s only partly takes account of chromatic adaptation. The relationship between the chroma derived from CIECAM97s and the perceived whiteness is shown in Fig.6. This figure indicates that whiteness perception is closely correlated with the chroma derived from CIECAM97s. The correlation coefficient is -0.93. The hypothesis that "the whiteness perception is higher, as the chroma is less" was demonstrated by using chroma derived from CIECAM97s.

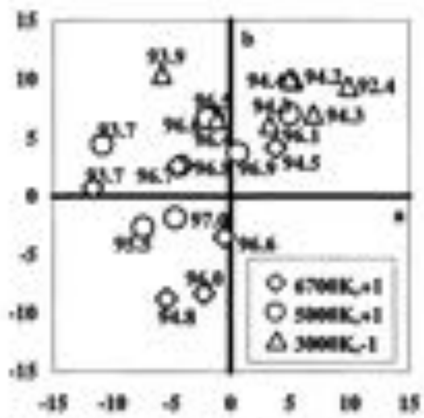


Fig5 Post adaptation signals in R-G and Y-B of the charts illuminated by three illuminants

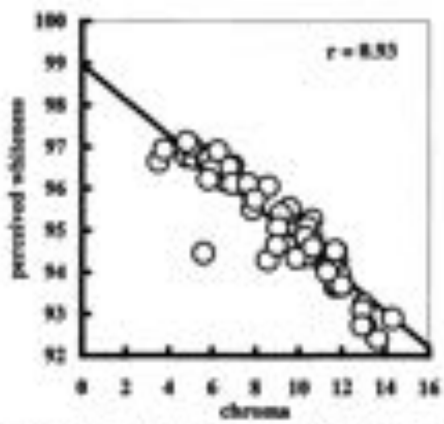


Fig6 The relationship between chroma derived from CIECAM97s and the perceived whiteness

Then, the relationship between the metric chroma in CIELAB calculated from the predicted corresponding colors and the perceived whiteness was investigated. Corresponding colors of all the charts under all the illuminants to a standard light source D65 were predicted, and L*, a*, b*, C* were calculated. The corresponding colors of the charts under three illuminants in CIELAB are shown in Fig.7. The symbols have the same meaning as with Fig.3. This figure shows that a* and b* in all charts are close to each other under the same illuminants, while a* and b* of same charts are apart under different illuminants. The reason for this may be that the prediction method takes almost complete account of the chromatic adaptation. The relationship between the metric chroma C* calculated from the corresponding colors and the perceived whiteness is shown in Fig.8. This figure indicates that whiteness perception is scarcely correlated with metric chroma calculated from the corresponding colors. The results of these investigations suggest that it is difficult to quantify the whiteness perception by CIELAB and the predicting method of corresponding colors.

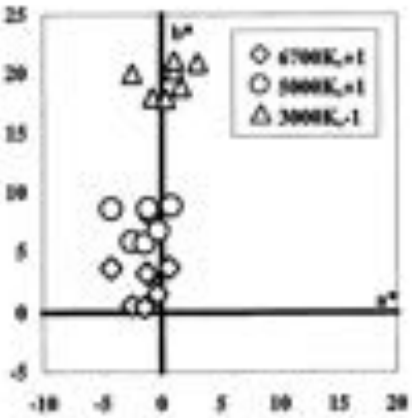


Fig.7 Color points of the charts illuminated by three lights

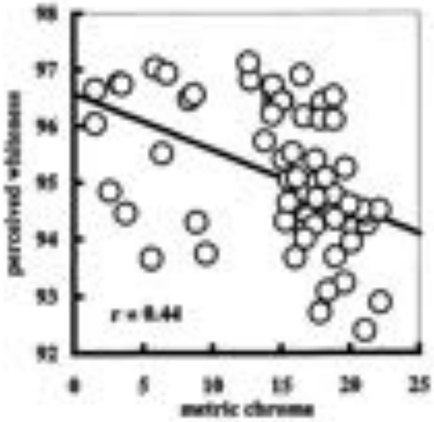


Fig.8 The relationship between metric chroma and the perceived whiteness

5. CONCLUSION

The relationship between whiteness perception and chroma derived from the CIELAB, CIECAM97s and the CIELAB with the prediction method for corresponding colors were investigated by using the results of a series of experiments to estimate the whiteness of white and nearly white papers conducted by Ayama et al. It was made clear that the whiteness perception is closely correlated with the chroma derived from CIECAM97s. From the investigations it was suggested that by using the chroma derived from CIECAM97s it is possible to quantify the whiteness perception. That is, whiteness perception is higher as the chroma derived from CIECAM97s is less.

However there remains some problems. One of them is that though observers should estimate the whiteness as 100 when the chroma is 0, this investigation does not reach the conclusion. In order to solve the problem, it is necessary to examine the whiteness perception of charts with less chroma. One other problem is that the relationship between the chroma and the perceived whiteness of one chart is detached from the other charts. The hue of the chart is 4YR9.25/0.5 and the illuminant is 6700K, +1. In order to solve the problem, it is necessary to examine the whiteness perception of more charts around YR under illuminants with a high correlated color temperature.

The whiteness perception is scarcely correlated with the metric chroma in CIELAB concerning a prediction method for corresponding colors. The chromatic adaptation in the experimental condition mentioned in this paper may fit the adaptation model of CIECAM97s but not the prediction method reported by CIE in 1994.

REFERENES

1. T.Suzuki: Whiteness Formula Based on Acceptability of Perceptual Whiteness (Application for Photographic Color Paper), JOURNAL OF THE COLOR SCIENCE ASSOCIATION OF JAPAN, Vol.14, No.2, pp.114-121 (1990)
2. Y.Uchida and T.Hukuda: Estimation of Whiteness of Fluorescent Whited Cloths, JOURNAL OF THE COLOR SCIENCE ASSOCIATION OF JAPAN, Vol.11, No.2, pp.15-22 (1987)
3. T.Akatsu, E.Toriumi, T.Takagi, M.Ayama, K.Mukai and S.Kanaya: Whiteness perception in achromatic and chromatic visual environments, Proceedings of 1999 Annual Conference of The Illuminating Engineering Institute of Japan, p.194 (1999)
4. T.Akatsu, E.Toriumi, M.Ayama, K.Mukai and S.Kanaya: Effects of color temperature of fluorescent lamp on the whiteness perception, CIE Proceedings 24th Session Warsaw, pp.48-50 (1999)
5. CIE TC1-34: The CIE 1997 colour appearance model (simple version), CIECAM97s, CIE Publ. No.131 (1998)
6. CIE TC1-32: A Method of Predicting Corresponding Colours under Different Chromatic and Illuminance Adaptations, CIE Technical Report No.109 (1994)

Quantification of the Helmholtz-Kohlrausch Effect for CRT Color Monitors.

J. Michael Sanchez and Mark D. Fairchild
(Xerox Corporation and Rochester Institute of Technology)

ABSTRACT

The perceptual amplification of color, otherwise known as the Helmholtz-Kohlrausch effect, has been experimentally characterized for a common CRT computer monitor and the highly saturated, and pure, colors Red (255,0,0), Green (0,255,0), Blue(0,0,255), Cyan(0,255,255), Magenta(255,0,0) and Yellow(255,255,0). Twenty-four human observers conducted direct brightness adjustment, on a CRT monitor, of the original colors to match the brightness perception of corresponding equal luminance gray images. Experiments were conducted in complete darkness to eliminate the de-saturating effect of flare light. Results are presented in both the monitor R, G, B color space and the 1976 CIELAB color space.

Keywords: Helmholtz-Kohlrausch Effect, Color Amplification Relative to Gray, Computer Monitor.

1. INTRODUCTION

The Helmholtz-Kohlrausch (H-K) effect, for object colors, is well characterized and succinctly summarized in the following excerpt from Wyzecki and Stiles(1982):

> *"When a test stimulus of complex spectral radiant power distribution has been matched in brightness against a fixed "white" reference stimulus, it is generally found that the luminance of the chromatic test stimulus is lower than the luminance of the reference stimulus. Or, stating it another way, for a chromatic stimulus, of the same luminance as the "white" reference stimulus will, in general, appear brighter than the reference stimulus. To many observers, the chromatic stimulus appears to "glow" (or appears to exhibit "Farbenglut"). The effect is sometimes referred to as the Helmholtz-Kohlrausch effect (see, for example, Kohlrausch, 1935; H. Konig, 1947;, Judd, 1948)."*

Many other investigators have carefully delineated the H-K effect, for object colors, in many color spaces (Wyzecki, 1964; Guth, 1969; Fairchild & Pirrotta, 1991; Nayatani, et. al. 1987-1998; Stalmeier & de Weert, 1994). The H-K effect has its roots in the methods of brightness matching that result in the $V(\lambda)$ curve for the achromatic channel response of the eye and the CIE has issued two recent reports delineating the effect as a function of wavelength (CIE No. 75, 1988; CIE No. 88,1990). Fundamental to all brightness matching is the failure of the $V(\lambda)$ function, as derived by flicker photometry (i.e. the achromatic response of the 1931 Standard Observer), to accurately represent brightness matching for different colors of equal luminance or for colors matched to equal luminance grays.

2. COMPUTER MONITOR CHARACTERIZATION

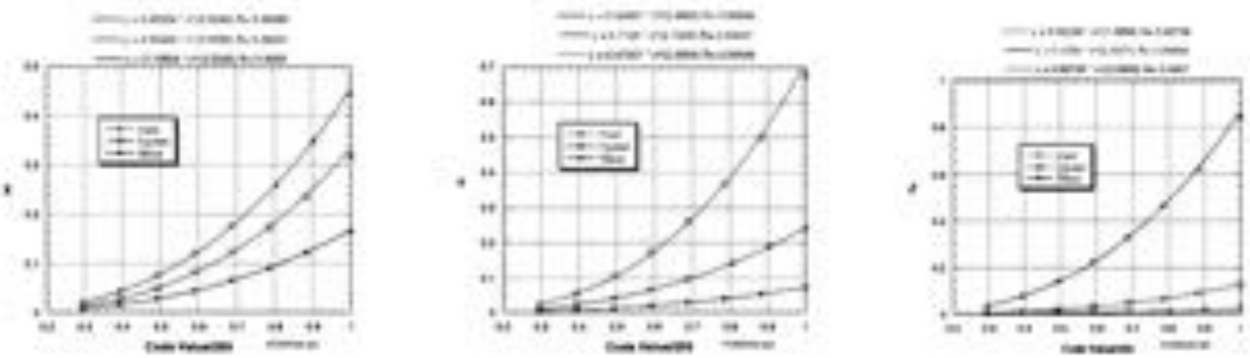
A common monitor that ships with Compaq business computers was utilized for all experiments. Primaries were similar to those for Rec. 709 HDTV standard. The monitor was fully characterized for each Red, Green and Blue channel utilizing a Graseby SLS9400 colorimeter. Colorimetric functions X, Y and Z, as computed utilizing the 1931 Standard Observer functions, were built as a function of Red, Green and Blue Code values for code values > 75. Values below this were never utilized in the experiment and small code values simplified the monitor modeling.

The experimentally characterized, and invertible, monitor model is shown below:

$$\begin{vmatrix} X \\ Y \\ Z \end{vmatrix} = \begin{vmatrix} 0.45224 & 0.33449 & 0.16834 \\ 0.24391 & 0.71230 & 0.07307 \\ 0.02236 & 0.12660 & 0.86735 \end{vmatrix} \begin{vmatrix} R^{2.5044} \\ G^{2.4774} \\ B^{2.5044} \end{vmatrix} \quad (1)$$

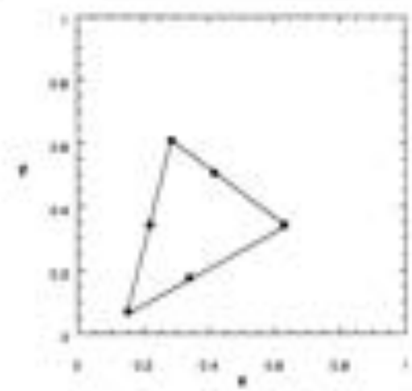
Equation (1) is derived from the measurements of X, Y, and Z as a function of code value >75, shown below for reference.

Figure 1: Computer Monitor Colorimetric Characterization for each X, Y and Z as f(code value).



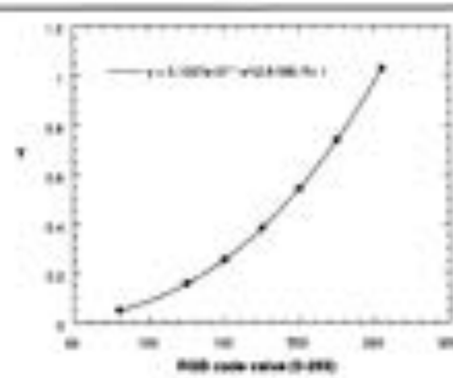
Monitor chromaticity coordinates for each of the colors measured is shown below:

Figure 2: Monitor Chromaticity Coordinates



Luminance for "gray" images of R=G=B is shown below and this function was utilized to construct equal luminance grays.

Figure 3: Luminance as a function of R=G=B gray code value.
Utilized to construct equal luminance grays.

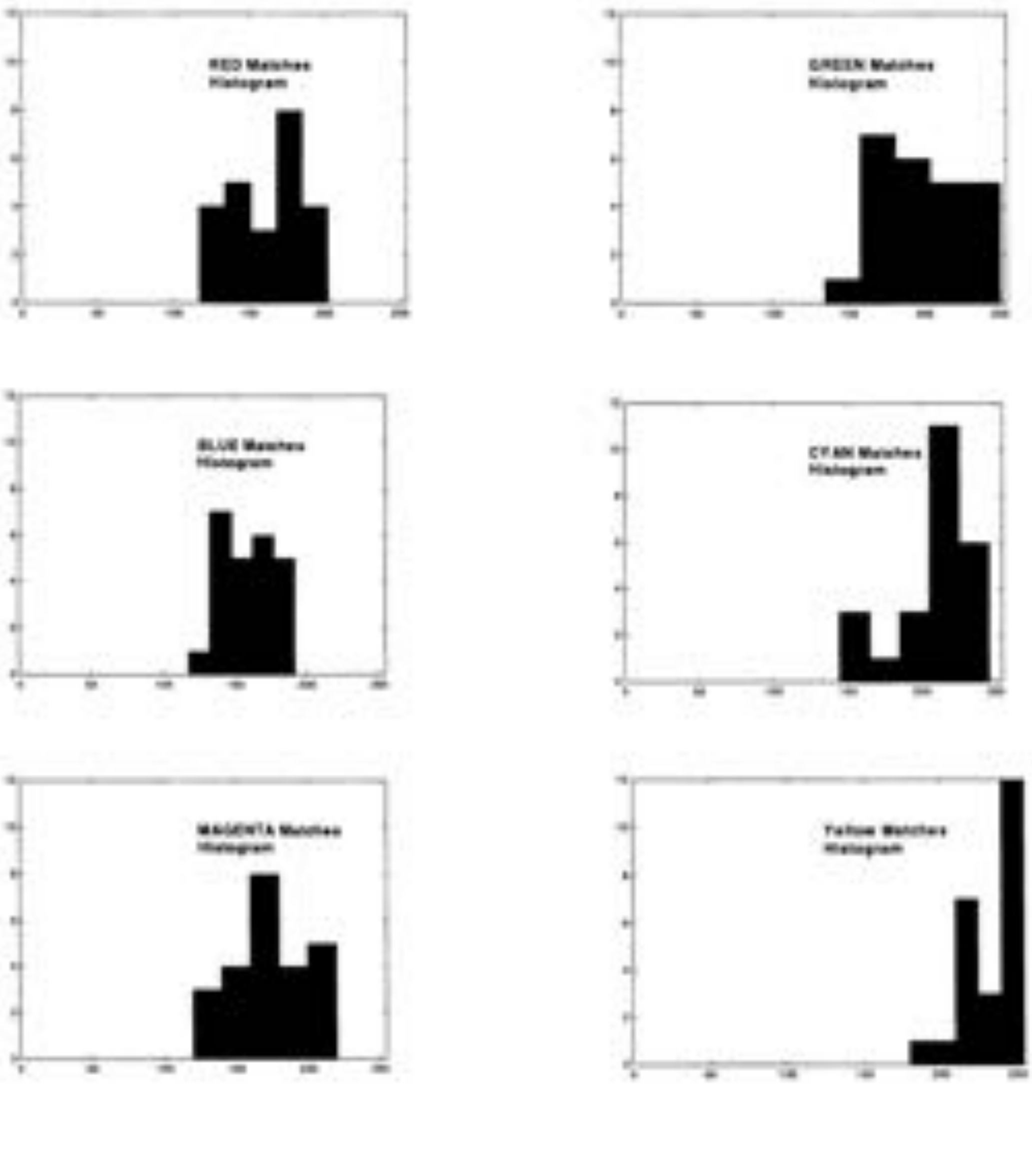


3. Observer Brightness Matching

The colors R, G, B, C, M, and Y (each at maximum intensity of 255) were presented to 24 observers in complete darkness. Observers were dark adapted for 5 minutes prior to initiating the experiment. The original color was horizontally opposed to the original color's equal luminance gray. A large slider on a MATLAB designed Graphical User Interface enabled each observer to adjust the brightness, along lines of constant chromaticity, for each color. The brightness of the original color was adjusted downward, by each observer, for each color, to match the gray brightness appearance. A total of 24 observers for six colors provided 144 matched RGB sets of input/output colors.

4. RGB Brightness Matches to Equal Luminance Grays.

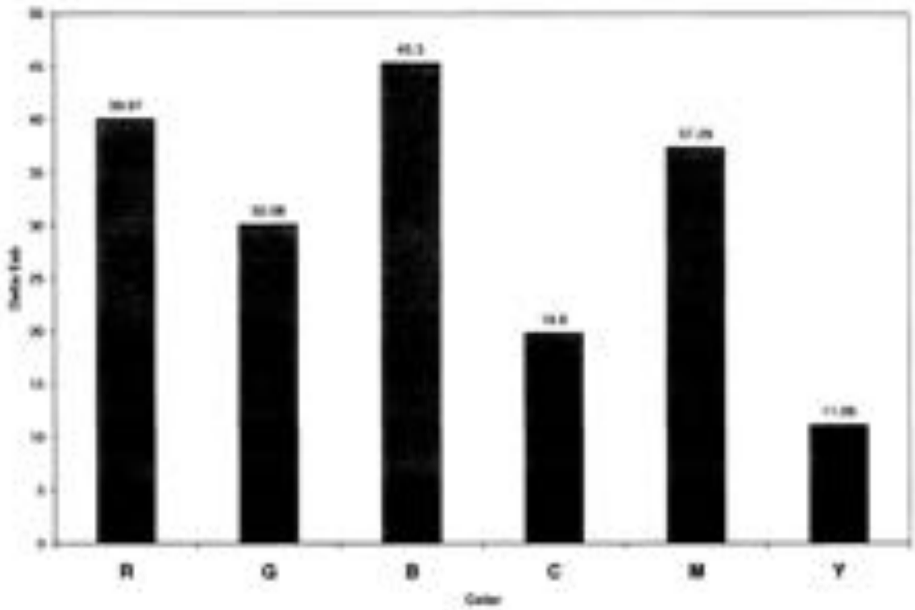
Figure 4: Binned Observer Data Matching R, G, B, C, M, Y Brightness Appearance to Corresponding Equal Luminance Grays. Intensity on x-axis represents final matched intensity (eg., Magenta, at matched intensity = 170, 0 ,170 or just 170 on x-axis).



5. Color Compression in CIELAB to Match Equal Luminance Gray

Transporting RGB values through the monitor model and then to L*a*b* enabled computation of the effective color compression of the original color, to match its corresponding equal luminance gray. Mean values for each color (matched) were utilized and then ΔE_{ab} of the original color relative to the matched color was computed and is shown below. Clearly, the H-K effect is most pronounced for blue, and least pronounced for Yellow. Models in progress building on the concepts presented in Nayatani, 1998, and Fairchild and Pirrotta, 1991, will be published.

Figure 4: Color Compression of Original Color Necessary to Match Brightness Appearance of E. L. Gray. Compression space is ΔE_{ab}.



ACKNOWLEDGEMENTS

The author's wish to thank Xerox Corporation for funding this work. We thank the human observers who were Xerox employees who kindly took time to make observer matches either at lunch or on their own time. None were trained in color.

REFERENCES

Fairchild, Mark, D.; Pirotta, Elizabeth: *Predicting the Lightness of Chromatic Object Colors Using CIELAB*", Color Research and Application, Volume 16, (1991), pp. 385-392.

Guth, S. L.; Donley, N.V., and Marrocco, R. T.: "*On Luminance Additivity and Related Topics*", Vis. Res., Vol. 9, pp. 537-575 (1969).

Publication CIE No. 86 , CIE 1988, *CIE 1988 2° Spectral Luminous Efficiency Function for Photopic Vision*, Central Bureau of Vienna, (1990).

Publication CIE No. 75, Spectral Luminous Efficiency Functions Based on Brightness Matching for Monochromatic Sources, Central Bureau of CIE, Vienna, (1988).

Nayatani, Yoshinobu: "*A Colorimetric Explanation of the Helmholtz-Kohlrausch Effect*", Color Research and Application, Volume 23, Number 6, December (1998), pp. 375-378.

Stalmeier, Peep F. M.; de Weert, Charles M. M.: "*On the Conditions Affecting the Contribution of Color to Brightness Perception*", Color Research and Application, Vol. 19, Number 3, June (1994), pp. 192-201.

Wyszecki, Gunther & Stiles, W.S.: Color Science: Concepts and Methods, Quantitative Data and Formulae, Second Edition, John Wiley and Sons, 1982.

Modelling incomplete adaptation under mixed illuminants

S. Sueeprasan and M. R. Luo
Colour & Imaging Institute, University of Derby, United Kingdom

ABSTRACT

Three chromatic adaptation transforms; CMCCAT97, CMCCAT2000 and CIECAT94, and the S-LMS mixed adaptation model were tested for cross-media colour reproduction under mixed illuminants. For each model, the adaptation ratio was varied to represent the state of adaptation. Printed complex images were used as originals. A series of softcopy reproduction pairs was displayed on a CRT with a D93 white point. Observers compared the hardcopy with a given pair of softcopies simultaneously and decided which reproduction was the closer colour match. The experiments were divided into three phases according to the ambient lights in the experimental room. They varied from D50 simulators, Illuminant A and Cool-white Fluorescence at similar luminance level to that of the CRT. The results clearly showed that in most cases, the adaptation ratio of 0.4 was best for all models. It was also found that the adaptation ratio was not dependent on the colour temperature of the ambient light and image content. The CMCCAT2000 performed relatively well in all cases.

Keywords: Mixed adaptation, chromatic adaptation transform, incomplete adaptation

1. INTRODUCTION

In 1997, CIE recommended the CIECAM97s model[1] as a colour appearance model (CAM) mainly for image applications. The earlier experimental results from the authors [2] verified its superior performance to the other models in cross-media colour reproduction under single-state adaptation. However, little is known about how to apply the model for mixed adaptation. Recent work by Henley and Fairchild[3] showed promising results for the use of CIECAM97s in predicting colour matches across media under mixed illuminants. Their results showed that to choose an appropriate incomplete adaptation factor (D) is crucial for achieving optimal matches. This study aimed to evaluate the performance of some promising chromatic adaptation transforms (CATs) in comparison with a mixed adaptation model developed by Katoh[4] for hardcopy/softcopy image comparisons under mixed illuminants. For each model the best incomplete adaptation factor was determined.

EXPERIMENTAL SET-UP

1.1 Image preparations

Four images were used: party, picnic, pier and bottle. Party was a picture of a lady shot indoors while picnic was an outdoor scene containing three ladies of different races. Pier consisted of buildings and a blue sky. Bottle was a picture including some metallic objects. They were printed on glossy paper using a Kodak Color Proofer 9000A printer at 200 dpi.

The process of image transformation is illustrated in Figure 1. Each image was captured by an Agfa StudioCam digital camera at a 300-dpi resolution. The camera was characterised using a polynomial regression technique[5] with a precision of 2.82 ± 1.59 (mean ± standard deviation) ΔE_{ab} units, allowing RGB data to be transformed to CIE XYZ tristimulus values. Softcopy matching images were generated on a pixel-by-pixel basis. Each CAT was then used to transform the XYZ data under the room ambient illuminant to the corresponding XYZ data under monitor white point (D93) with different adaptation ratios. Four CATs were investigated: CMCCAT97[6] (the CAT used in CIECAM97s), CMCCAT2000[7] (a simplified version of CMCCAT97), CIECAT94[8] and the S-LMS mixed adaptation model.[4] In the case of the S-LMS model, the adaptation ratio, R_{adp}, was varied whilst the incomplete adaptation factor was automatically determined by the model. The adaptation ratios for the other CATs varied from 0.2 to 0.8 at a 0.2 interval. The GOG model[9] was used to characterise the CRT monitor for converting the reproduction XYZ data to digital counts. Its precision was 0.23±0.13 ΔE_{ab} units.

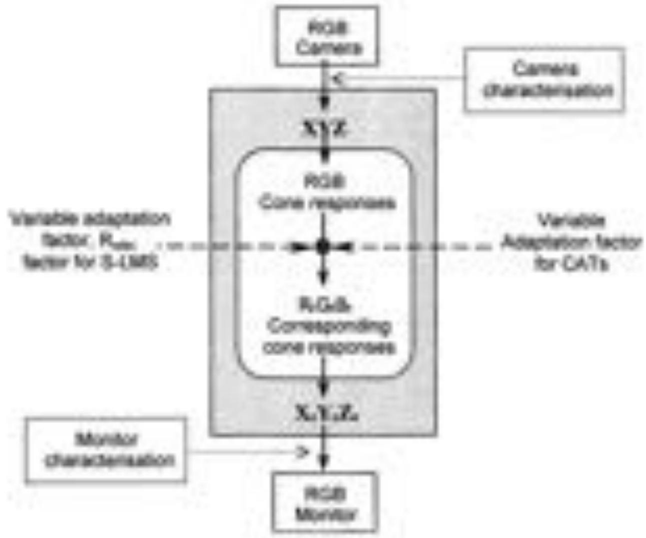


Figure1. A flow chart of image transformation.

1.2 Viewing conditions

Softcopy reproductions were displayed on a Barco monitor at a 72-dpi resolution with the same physical size as those of the hardcopy originals. The white point of the monitor was set to 9300K (referred to as D93 throughout the paper). A pair of softcopy reproductions was displayed on a uniform grey background with 20% of luminance factor against the monitor white point which was presented by surrounding each image with a 5-mm width. The hardcopy having a 5-mm white border was presented against a uniform grey cardboard again with 20% of luminance factor against the white paper. The cardboard had the same physical size as the display area of the CRT and was placed next to the monitor in which the hardcopy and softcopies were co-planar. The experimental room was illuminated by a D50 simulators (4964K), an illuminant A simulator (2478K), or a typical office lighting (Cool-white Fluorescence with 3867K). These are referred to as D50, A and CW, respectively. The luminance levels of the paper white and monitor's white point (in a darkened room) were approximately equal. The experiment was divided into three phases according to the simulators used. Table 1 summarises each experimental phase.

Table 1. Experimental phases

Phase	Print environment				CRT's white point			
	Illuminant	x	Y	L (cd/m²)	Illuminant	x	y	L (cd/m²)
1	D50	0.3478	0.3582	60.10	D93	0.2824	0.2954	60.21
2	CW	0.3943	0.4033	60.08	D93	0.2824	0.2954	60.21
3	A	0.4520	0.4181	40.82	D93	0.2824	0.2954	40.52

1.3 Psychophysics

The experiment was conducted using a paired comparison technique. Observers were well instructed to compare a given pair of softcopy reproductions with a hardcopy original and judged which of the two reproductions gave a closer match. The simultaneous binocular matching method was employed (side-by-side matching). Fifteen normal colour-vision observers participated in each experimental phase. The observers sat at the midpoint between the monitor and the hardcopy image with a distance of approximately 50-60 cm. Before the experiments, they were given approximately a minute to adapt to the environment of the experimental room. Note that the hardcopy was placed in the middle of the cardboard so that each observer had to move their eyes some distances for image comparisons. No time constraint was posed to the observers. The order in which the pairs were presented was randomised and different for each observing session.

2. DATA ANALYSIS

By applying the Thurstone's Law of Comparative Judgement, [10] the experimental raw data were converted to an interval scale of colour reproduction quality for the investigated models. The results were presented in terms of z-scores (unit normal deviate), indicating the models' performance in producing visual colour matches. Since the unit normal deviate is undefined for a proportion of zero or one, where either no or all observer(s) selected a given reproduction over another, the logistic function was applied. Bartleson [11] describes this technique in great detail.

A 95% confidence interval was calculated to indicate significant differences in performance between the models and is defined as $\mu \pm 1.96\sigma/\sqrt{N}$ where μ is the mean value and N is the number of observations for each pair. Since one unit on the interval scale equals $\sqrt{2}\sigma$, the standard deviation, σ, of a given value is $1/\sqrt{2}$ units. Thus the 95% confidence scale can be calculated by $\mu \pm 1.39/\sqrt{N}$.

A measure of wrong decision (WD) [12] was used to indicate the agreement between each individual observer's and the mean results. The wrong decision is defined as one where an individual judgement disagrees with the overall panel decision. The results were presented as WD%, the percentage of times that an observer made the wrong decision.

3. RESULTS AND DISCUSSION

As can be seen in Table 2, the largest WD% occurs in Phase 1. This indicates that difference between images was small and it was difficult for observers to select the better matches. The smallest WD% was found in Phase 3. This shows that the difference between matching images was large. Hence, the observer agreements were largely improved. However, different images gave quite similar results, i.e. observer variation is not much affected by image contents.

Table 2. Observer errors (WD%)

Phase	Print	CRT	Party	Picnic	Pier	Bottle	Mean
1	D50	D93	26	24	27	24	25
2	CW	D93	19	25	18	16	20
3	A	D93	15	8	17	19	15
Mean			20	19	21	20	20

The experimental data from all phases were combined to indicate overall models' performance. The results are summarised in Figure 2. The same trend was found for all models, i.e. the human visual system is 40 to 60% adapted to the white point of monitor under mixed-illuminant condition. This trend is again shown in Figure 3 for different pairs of adapting illuminants and different images. This indicates that the adaptation ratio is independent of the illuminants of the ambient lights and the contents of the images.

From the overall results, considering the best ratio for each model, CMCCAT2000 performed the best. However, different trends were found for different illuminants. When the room was illuminated by D50, all models gave a similar performance. In the case of illuminant A, CIECAT94 and the S-LMS model performed very much worse than the other two models whilst in the CW condition S-LMS performed as well as the best model, CMCCAT2000. This shows that the performance of each model is illuminant-dependent. When changes in colour temperature between two fields are relatively small, say from D50 to D93, all models performed well. But when the difference is increased, say from A to D93, some models fail badly. Additionally, it is encouraging that the CMCCAT2000 performed slightly better than CMCCAT97.

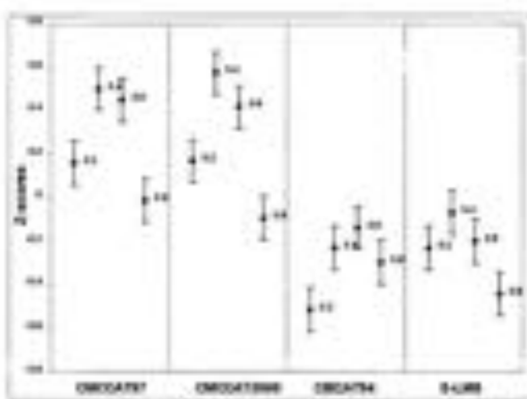


Figure 2. Models' performance averaged from Phase 1, 2 and 3.

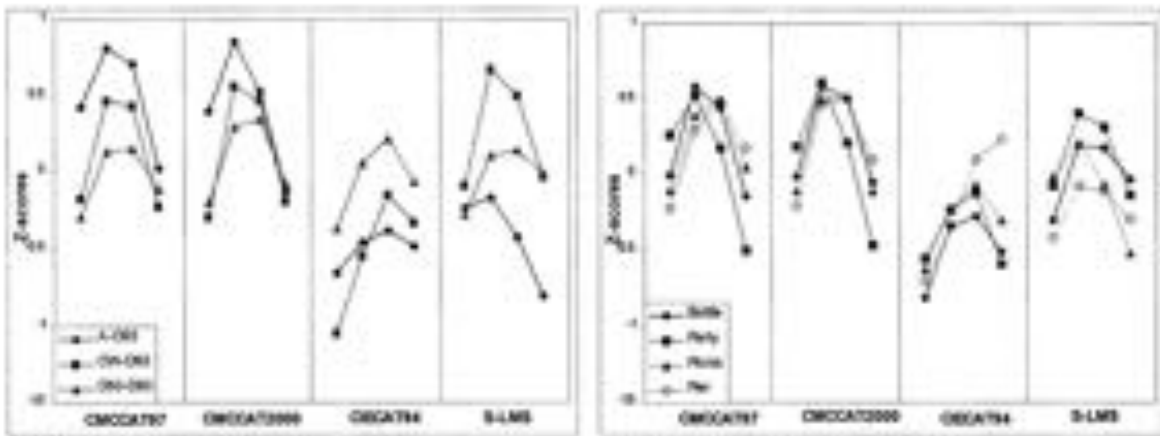


Figure 3. (a) Illuminant dependency and (b) image dependency of the models.

4. CONCLUSIONS

The experiment was performed to evaluate the state of incomplete adaptation for hardcopy/softcopy image comparisons under mixed-illuminant condition at the same luminance level. The results showed that the best adaptation ratio was around 40% to 60% and this was independent of the illuminants and the image contents used. However, models' performance depends upon the colour temperature differences between two adapting fields. The performance of CMCCAT97 and CMCCAT2000 with proper incomplete adaptation factors outperformed the Katoh's mixed adaptation model. This strongly indicates that a reliable chromatic adaptation model is sufficient for the mixed-illuminant applications.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Peter Rhodes for his technical assistance, and many thanks to the observers who participated in the experiment. Their time and patience is highly appreciated.

REFERENCES

1. M.R. Luo and R.W.G. Hunt, The structures of CIE1997 colour appearance model (CIECAM97s), *Color Res. Appl.* **23**, 138-146 (1998).
2. S. Sueeprasan and M.R. Luo, Testing colour appearance models for use in cross-media colour reproduction, *Proc. Colour and Visual Scales 2000*, Nation Physical Laboratory, London, UK.
3. S. A. Henley and M.D. Fairchild, Quantifying mixed adaptation in cross-media color reproduction, *Proc. IS&T/SID Color Imaging Conf.* **8**, 305-310 (2000).
4. N. Katoh, K. Nakabayashi, and M. Ito, Effect of ambient light on the color appearance of softcopy images: Mixed chromatic adaptation for self-luminous displays, *J. Elec. Imaging* **7**, 794-806 (1998).
5. G. Hong, M.R. Luo, and P.A. Rhodes, Colorimetric characterisation for digital cameras, *Proc. ICPS'98 International Congress on Imaging Science* **2**, 354-357 (1998).
6. M.R. Luo and R.W.G. Hunt, A chromatic adaptation transform and a colour inconstancy index, *Color Res. Appl.* **23**, 154-158 (1998).
7. C. Li, M.R. Luo, and B. Rigg, Simplification of the CMCCAT97, *Proc. IS&T/SID Color Imaging Conf.* **8**, 56-60 (2000).
8. Y. Nayatani, T. Yano, K. Hashimoto, and H. Sobagaki, Proposal of an abridged color appearance model CIECAT94LAB and its field trials, *Color Res. Appl.* **24**, 422-438 (1999).
9. R.S. Berns, Methods for characterizing CRT displays, *Display* **6**, 173-182 (1996).
10. L.L. Thurstone, A law of comparative judgement, *Psycholog. Rev.* **34**, 273-286 (1927).
11. C.J. Bartleson and F. Grum, Optical radiation measurements, Vol.5: Visual measurement, Academic Press, 472-476 (1984).
12. R. McDonald, Industrial pass/fail colour matching part I- Preparation of visual colour-matching data, *J. Soc. Dyers Col.* **96**, 372-376 (1980).

The Measurement of Appearance

Dr Helen White & Dr Michael R Pointer*

ABSTRACT

The visual appearance can be one of the most critical parameters affecting customer choice and, therefore, it needs to be quantifiable to ensure uniformity and reproducibility. A starting point in assessing the appearance of a consumer product might be the measurement of its colour. The description of its total appearance, however, cannot be achieved by the definition of colour alone; other attributes of the material from which it is fabricated contribute to the overall appearance. The texture of a surface, for example, will cause changes in colour depending on the lighting direction; the freshness of food is judged by its overall appearance, but in a way that is much more subtle than by just its colour; and novel effects such as pearlescence are added to products to enhance their attractiveness. For some products, such as cosmetics, it is not only their own appearance characteristics that are important, but also the visual effect after they have been applied to the skin, nails, hair, etc. It is clear, therefore, that the interest of industry in the measurement of appearance goes beyond simply surface colour.

Keywords: Colour, appearance, complex visual surfaces, gonio-apparent, translucency, digital imaging, gloss

1. INTRODUCTION

We use our visual sense all of the time to process the complex patterns of light around us into objects, space, location and movement, and from that information we make judgements leading to a particular course of action. For example, how we perceive the visual "appearance" of a product may cause us to buy it, reject it or even write in and complain about it! We may choose to buy a particular food because its appearance suggests freshness. Our choice of car may have been influenced because its glossy/sleek appearance made us think of quality and prestige. Alternatively, we may reject a particular surface finish because its appearance suggested poor quality and the presence of defects[1]. All of these examples are judgements made on appearance. Is this food safe/desirable to eat? Will this car improve my image? Will this surface finish do the job? If it were possible to measure "appearance", and make the links between those measurements, consumer perception and product characteristics, then the possibility would then exist to ensure an affirmative answer to all the above questions before the products left the factory. It is hardly surprising to learn, therefore, that there is considerable interest within industry in making quantitative measurements of "appearance", in order to improve efficiency in such areas as product development and production/quality control. The sophistication of our visual sense works against us when it comes to considering the measurement of "appearance", since we perceive "appearance" so easily that it is often difficult for us to analyse what actual physical attributes contribute to our observations[2]. The overall appearance of an object is a combination of different attributes, which are produced via the interaction of the object with the light falling upon it[3]. Spectral absorption and diffuse reflection of the light by the pigments within the object gives them the attribute of colour. Some objects reflect the light from their surface, which we then perceive as gloss. The amount of scattering of the light as it is transmitted through parts of an object, prompts a judgement on transparency. Although at the moment it is not possible to make a single measurement called "appearance", it is possible to design instruments to measure the various components of appearance and to make some kind of correlation back to visual perception. Over the past few years the National Physical Laboratory (NPL) has been investigating some of the issues surrounding the Measurement of Appearance. As a result of discussions with a range of UK companies, three areas of appearance measurement were highlighted as being of particular concern: complex visual surfaces, translucency and imaging systems. The project was co-funded by industrial partners and the National Measurement System Policy Unit of the Department of Trade and Industry. This paper presents an overview of the areas of research included within that programme of work.

2. COMPLEX VISUAL SURFACES

The addition of metallic, pearlescent or interference pigments can produce variable colour and accentuation of gloss with viewing angle – such complex surfaces are termed as being "gonio-apparent". Metallic effects are produced via the incorporation of thin Aluminium flakes into a surface finish, which are oriented parallel to the object's surface[4]. The flakes produce an increase in brightness near the specular angle of reflection, which decreases as the angle of view moves away from the specular[5]. Interference/pearlescent pigments create a lustrous, brilliant finish, plus colour variation with viewing angle, through the interaction of light with thin flakes of metal oxide coated mica[3,6,7]. The colours occur through the interference of the light reflected from the flakes, rather than by absorption of light at different wavelengths[3,6,7]. Special effect finishes such as these have increased in popularity over the years; a good example of this is the automotive industry, where by the 1990s almost 80% of vehicle finishes produced in the USA, and 54% of vehicle finishes produced in Europe, contained either metallic flakes or mica pigments[3]. However, metallic and interference/pearlescent effects are used for a wide variety of applications outside the automobile industry and are also seen in such products as jewellery[8], shampoo[9] and inks for use on paper and textiles[10]. Traditional solid colours are relatively easy to colour match using established spectrophotometric techniques and the CIE system of colour measurement[11]. Such measurements are internationally accepted and are traceable back to national standards, allowing for absolute as well as relative measurement. The viewing/illumination geometries specified by the CIE for current standard colour measurements are limited[11], and do not allow for the range of viewing/illumination angles needed to characterise a complex gonio-apparent surface[12]. Several suggestions have been put forward for suitable illumination/viewing angle combinations[12] but so far there has been no international standardisation and while the debate continues, multi-angle instruments are being offered commercially which differ in the geometries and angular combinations utilised. Since there are no national standards laboratories currently providing a calibration service to cover the full range of angles used by multi-angle spectrophotometers, these instruments currently lack traceability and the capacity to make absolute colour measurements. As part of the Measurement of Appearance project at NPL, an in depth comparison is being made of the various multi-angle instruments available commercially and inhouse. The study will form the basis of a best practice guide, and could be used to give a solid foundation for the future establishment of a traceable measurement system.

3. TRANSLUCENCY

Many industries quote translucency, transparency, opacity, haze etc. as factors influencing the perception of their products. For example, translucency is a consideration for objects made of porcelain[14]. The uniformity of colour, gloss and translucency are suggested as being the extremely important properties influencing the perception of food and drink[13,15]. Many foods/drinks have been described as being translucent; fruit juice, milk, fish and meat are just a few examples[13,15]. Personal care products such as shampoo, deodorant and cleaning creams could also be thought of as being translucent, along with some of the packaging in which they are presented. But, what exactly is translucency? Although several definitions could be put forward (such as "the ability of a material to transmit light diffusely without permitting a clear view of objects behind it") no standard definition exists, leading to confusion over what type of measurements are appropriate and how those measurements should be made. As part of the Measurement of Appearance project, a preliminary definition of the attribute "translucency" is to be proposed and investigations made into possible measurement techniques. A potential area for the expansion of this part of the project could be to investigate the links between visual perception and physical measurement of translucency.

4. IMAGING SYSTEMS

The development of digital imaging techniques has heralded a move towards the use of digital camera systems both in industry and in science. These systems are being used increasingly for the assessment of various appearance attributes, but in particular, they are now being used in industry to measure colour for the purposes of quality control. Colorimeters and spectrophotometers have traditionally been used for colour measurement - such instruments obtain the most accurate results from flat samples placed in contact with the instrument aperture, and give an average colour reading from the sample area at the aperture[16-17]. Such experimental procedures place restraints on the use of these standard techniques that can become a problem where a continuous production process is being monitored, a texture surface is being examined or an intricately patterned sample is being looked at[16,17,18]. Digital camera systems have the advantage over traditional colour measuring techniques in that they are non-contact, allowing for on-line colour control and the observation of heavily textured samples, and can give pixel-by-pixel analysis of colour, allowing patterned objects to be analysed[16,17,18]. However, in order to produce accurate colour data careful consideration must be given to the characterisation of such systems as the red, green, blue signals obtained are device-dependant, and the transform to device-independent CIE tristimulus values is not a trivial issue[18,19]. Currently, there is no systematic technique for the characterisation of digital imaging systems, and the colour results obtained have no traceability back to the National Measurement System. Yet these systems clearly have great potential for capturing not only colour information, but also a wide variety of appearance attributes. This coupled with the move towards colour appearance modelling and digitally defined colour specification, will cause an increase in the call for absolute, traceable, measurements. At the National Physical Laboratory, work is in progress for the production of a best practice guide to highlight the issues surrounding the use of digital imaging systems for the assessment of colour and appearance. A possibility for the future direction of this project would be the installation of a National Reference Camera, the development of metrics for characterisation and the derivation of uncertainties.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contributions made to the project by the industrial partners. They also thank Dr Julie Taylor, of the National Physical Laboratory, for her groundwork in establishing the project, and for constructive discussion during the last two years.

REFERENCES

1. Smith, K.B., A Sharper Look At Gloss, Surface Coatings International, 80, 573-576, 1997.
2. Hunter, R.S., Harold, R.W., The Measurement Of Appearance, John Wiley & Sons, 2nd Edition, 1987.
3. Nicholls, C.A., Visual and Instrumental Characterisation of Special Effect Colours, Thesis for the Degree of PhD, University of Leeds, April 2000
4. Knowles, R., Aluminium Pigments in Vehicle finishing and Refinishing Paints, Automotive Coatings, 181, 713, 1991.
5. Rodrigues, A.B.J., Measurement of Metallic and Pearlescent Colors, Die Farbe, 37, 65, 1990.
6. Carroll, J., Measuring Pearlescent Color, Modern Paint & Coatings, 87, 30, 1997.
7. Armanini, L., Producing Three-Color Effects from Interference Pigments, Plastics Engineering, 50, 31, 1994.
8. Weatherall, I.L., Interference Colors of Oxidised Titanium Metal Surfaces, Color Res. Appl., 17, 352, 1992.
9. Miller, D.J., Reng, A.K., Skrypzak, W., Optical Methods for Measuring the Pearlescent Effect in Toiletries, International Journal of Cosmetic Science, 10, 161, 1988.
10. Houseman, G., Coloration and Colour Enhancement of Inks by Nacreous Pigments, J. Oil Col. Chem. Assoc., 70, 329, 1987.
11. CIE Document 15.2, Colorimetry, 1986, Reprinted 1996.
12. McCamy, C.S., Observation and Measurement of the Appearance of Metallic Materials. Part I, Macro Appearance, Color Res. Appl., 21, 292, 1996.
13. Hutchings, J.B., Food Colour And Appearance, Blackie Academic & Professional (Chapman & Hall), 1994.
14. Sugiyama, T., Horiuchi, T., & Osaki, T., Measurement Of Translucency Of Porcelain Bodies, Journal of The Ceramic Society Of Japan, 104 (9), 877-881, 1996.
15. Hutchings, J.B., The Importance Of Visual Appearance Of Foods To The Food Processor And The Consumer, Journal Of Food Quality, 1, 267-278, 1977.
16. Connolly, C., Leung, T.W.W. & Nobbs, J.H., Colour Measurement By Video Camera, JSCD, 111, 373-375, 1995.
17. Connolly, C., Leung, T.W.W. & Nobbs, J.H., The Use Of Video Cameras For Remote Colour Measurement, JSDC, 112, 1-4, 1996.
18. Hong, G., Luo, M.R., Rhodes, P.A., A Study Of Digital Camera Colorimetric Charaterisation Based On Polynomial Modelling, Color Res. Appl., In Press, 1999.
19. Pointer, M.R., Digital Cameras For Colour Measurement, Conference Proceedings, Colour Image Science 2000, Colour and Imaging Institute (University of Derby), April 2000.

---

* Correspondence: mike.pointer@npl.co.uk, National Physical Laboratory, Centre for Optical and Environmental Metrology, Queens Road, Teddington, Middlesex, TW11 0LW (UK). Phone: (+44) 020 8943 6716

Perceptually based colour difference for complex images

Guowei Hong and M. Ronnier Luo
Colour & Imaging Institute, University of Derby, Derby, UK

ABSTRACT

Faithful colour reproduction of digital images requires a reliable measure to compare such images in order to evaluate the reproduction performance. The conventional methods attempt to apply the CIE Colorimetry based colour difference equations, such as CIELAB, CMC, CIE94 and CIEDE2000, to complex images on a pixel-by-pixel basis, and calculates the overall colour difference as the averaged difference of each pixel in the image. This method is simple and straightforward but often does not represent the colour difference perceived by human visual system. This paper proposes a new algorithm for calculating the overall colour difference between complex images. The results show that this new metric corresponds more closely to the colour difference perceived by human visual system.

Keywords: colour imaging, colour difference, complex image, colour reproduction, colour appearance

1. INTRODUCTION

With the rapid growth of digital colour imaging, faithful colour reproduction of digital images is becoming a major challenge today. The ultimate goal is to allow the end user to control all imaging devices and to move digital colour images from one media to another without changing the appearance of the original image. After a digital image is reproduced, a measure of the colour difference between the new and the original images is required to evaluate the reproduction performance. This ability to quantitatively measure the colour difference between two digital colour images is necessary to allow for an automatic evaluation of the performance of the reproduction system and subsequently an optimised reproduction. Obviously this measurement should correspond to the subjective assessment of human visual system. The need for this kind of image-based colour difference algorithm has been widely recognised[1, 2] and has been brought to the forefront with the formation of the CIE Technical Committee 8-2.[3] Current colour difference formulae such as CIELAB, CMC, CIE94, and CIEDE2000 are all based on the CIE Colorimetry. They were derived from psychophysical experiments on assessing small colour difference using large size uniform surface patches under uniform grey backgrounds. Because of their successful application to specify small colour difference for large size uniform surface patches and the lack of image-based colour difference formula, these equations were often adopted for calculating colour difference for complex images.

The current typical method attempts to apply these colour difference equations to images on a pixel-by-pixel basis, and calculates the overall colour difference as the averaged difference of each pixel in the image. Song and Luo[4] have recently adopted this approach and compared the performances of all above mentioned colour difference formulae on a set of complex images. Interestingly, they found that the lightness, chroma and hue weighting factors, which were derived for small colour difference using uniform colour patches under grey backgrounds, needed to be set to different values for complex images. This indicates that CIE Colorimetry based colour difference formulae cannot be directly used for complex images. Further, other researches[5,6] actually demonstrated that the conventional approach by averaging each pixel's colour difference often provided an inaccurate representation of the perceived colour difference. Zhang and Wandell[5] considered the situation where a pixel-by-pixel averaging of the CIELAB colour differences would certainly fail for half-tone images. Instead they proposed the use of S-CIELAB, a spatial extension of CIELAB that incorporates spatial filtering in an opponent colours representation prior to the CIELAB calculation. McCann[6] studied another well known case, i.e. when all the pixels in an image have a reproduction error in the same direction (lightness, chroma, hue), the colour constancy mechanism would make large errors appear small; when all the errors for each pixel are randomly distributed, small errors appear large. He found that the human eyes care more about the relationships of the parts of the image than they do about the absolute value of the match and he proposed the use of edge ratios

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

to solve this problem. This paper describes the study of another more practical phenomenon where reproduction errors of each colour presented in the image are not the same, i.e. some colours or areas are less accurately reproduced than others. This phenomenon is often occurred in cross-media image reproduction where colorimetric characterisation usually does not produce the same prediction errors for all the colours. This phenomenon becomes even more significant when there is a large colour gamut difference between the original media and the reproduction media and certain kind of gamut mapping algorithm is applied. Examples of such a case are shown in Figures 1 and 2. The original images ("Woman with glass" and "Threads") are shown in Figures 1(b) and 2(b), which are two standard images adopted from ISO/DIS 12640-2[7]. Figure 1(a) is a simulated reproduction in which the same colour difference (a combination of lightness, chroma, and hue shifts) is applied to every pixel in the image. Figure 1(c) is another simulated reproduction in which only the colours of the human skin and the blue dress and decorations are altered (a combination of lightness, chroma, and hue shifts), with the rest of the image unchanged. Likewise, in Figure 2(a) every pixel in the image is shifted by the same colour difference. In Figure 2(c), the colour changes are made only to the red and pink bows, the red ribbon, and the red and pink ball of threads. Calculated by averaging each pixel's difference using CIELAB, colour difference between 1(b) and 1(a) ($\Delta E_{ab} = 3.75$) is the same as the colour difference between 1(b) and 1(c) ($\Delta E_{ab} = 3.72$). In the same way averaging colour difference produces the same colour difference between 2(b) and 2(a) ($\Delta E_{ab} = 3.81$) and between 2(b) and 2(c) ($\Delta E_{ab} = 3.78$). However, their perceived colour differences are very significant when the images were compared on a calibrated CRT monitor in a dark surround. It was unanimously judged by all observers that Figures 1(c) and 2(c) were having a much larger colour difference than Figures 1(a) and 2(a) respectively. This demonstration shows that spatial colour difference is important for evaluating colour difference for images. This paper proposes a new algorithm to solve this problem.

2. THE PROPOSED ALGORITHM

As mentioned earlier, current colour difference formulae are based on colour patches that subtend 4 degrees or more of the viewing field. However, colour patches in images tend to be much smaller. It is well known that our eyes tend to be more tolerable towards colour errors of such smaller patches; however, systematic errors over the entire image would be quite noticeable and unacceptable. Hence, to find an image-specific colour difference algorithm, some image analysis is necessary. Therefore, it is not surprising that a simple extension of CIE Colorimetry based colour difference formulae to complex images does not work well. Nonetheless, these formulae have been extensively tested on solid colour patches and we believe they should not be abandoned completely. The question is how these formulae should be applied to images. The proposed new algorithm for calculating colour difference between images is based on the following conjectures:

- The overall colour difference between the images can be calculated as a weighted sum of colour difference between pixels. One obvious problem with the conventional method is that every pixel difference is weighted equally. However, not all pixels are equally important when viewing an image. It is possible that pixels or areas of high significance can be identified and a suitable weights allocation scheme can be found.
- Larger areas of the same colour should be weighted higher. This is rather intuitive but is likely to be true in most cases. Previous psychophysical experiments on comparing image difference showed that observers tended to focus on certain areas of an image, and gave their judgements mainly based on the colour difference of those areas. Therefore, it is reasonable to assign higher weights to those areas of larger size.
- Larger colour difference between the pixels should be weighted higher. One shortfall of the current CIE Colorimetry based colour difference formulae is that they are meant for small colour difference only. Thus, they are not capable of giving accurate perceived colour difference for large colour difference. But for an image, it is possible that the reproduced colour of certain pixels or area is quite different from the original, especially when gamut mapping algorithm is applied. The appearance of the whole image usually becomes unacceptable when there are areas with quite large colour difference. In the proposed new algorithm, a power function of 2 is adopted.
- Hue is an important colour percept for discriminating colours within image context. The hue of an object is normally dictated by the light-absorbing or reflecting properties of the material of which the object is made. The lightness and chroma of the object, however, is seriously affected by illumination and viewing angle. For example, a shadow falling across an object will usually have more effect on the lightness and chroma of the pixels therein than on the hue. Thus, it is reasonable to segment the image in the hue plane rather than in three-dimensional colour space.

The following is the proposed new algorithm for image-based colour difference:

Step 1: To transfer each pixel's L^*, a^*, b^* values into L^*, C^*_{ab}, h_{ab}.

Step 2: Calculate the histogram, i.e. the probability of each pixel's occurrences, of the h_{ab} image plane and store the histogram information in an array *hist*[hue].

Step 3: The array *hist*[hue] is sorted in an ascending order. Then this array is divided into 4 sections: i) For the first *n* hue angles, while $\sum_{i=0}^{n} hist[i] < 25\%$, $hist[i] = hist[i]/4$; ii) For the next *m* hue angles, while $\sum_{n}^{n+m} hist[i] < 25\%$, $hist[i] = hist[i]/2$; iii) For the next *l* hue angles, while $\sum_{n+m}^{n+m+l} hist[i] < 25\%$, $hist[i] = hist[i]$; iv) For the rest of hue angles, $hist[i] = hist[i] * 2.25$.

Step 4: For each pixel having the same hue angle in the image, their average is calculated and stored in *CD*[hue].

Step 5: The overall colour difference for the whole image is calculated by $CD_{image} = \sum hist[hue] * CD[hue]^2 / 4$.

3. RESULTS AND CONCLUSION

The following Table summarises the results obtained by the conventional average method and the proposed new algorithm. This paper has shown that the conventional average method does not accurately reflect the perceived colour difference of images in many cases. Our proposed algorithm gives higher weights to errors in areas of the image that are perceptually important than errors in other locations in the image. This weighting provides a quantitative method for comparing images that more closely matches a subjective comparison. Further experiments will be carried out to verify and optimise the parameters used in the algorithm.

Colour difference formula for images	Woman with glass		Threads	
	(b) and (a)	(b) and (c)	(b) and (a)	(b) and (c)
Conventional average	3.75	3.72	3.81	3.78
Proposed new algorithm	3.60	8.98	3.92	9.95

REFERENCES

1. S.N. Pattanaik, M.D. Fairchild, J.A. Ferwerda, and D.P. Greenberg, "Multiscale model of adaptation, spatial vision and colour appearance," *Proceedings of IS&T/SID 6th Color Imaging Conference*, pp.2-7, Scottsdale, 1998.
2. J. Morovic, "Review of cross-media colour reproduction," *Course notes of Colour & Imaging 2001*, pp.132-138, Derby, 2001.
3. T. Newman, "CIE Division 8: New Directions and Dimensions to Colour Standards," *Proceedings of International Colour Management Forum*, pp.7-14, Derby, 1999.
4. T. Song, and M.R. Luo, "Testing color-difference formulae on complex images using a CRT monitor," *Proceedings of IS&T/SID 8th Color Imaging Conference*, pp.44-48, Scottsdale, 2000.
5. X. Zhang, and B.A. Wandell, "A spatail extension of CIELAB for digital color image reproduction," *SID Symposium Technical Digest* **27**, pp.731-734, 1996.
6. J.J. McCann, "Color imaging systems: past, present and future," *Proceedings of 5th International Conference on high technology: imaging science and technology*, pp.2-12, Chiba, 1996.
7. "Graphic technology – Prepress digital data exchange – XYZ/sRGB standard colour image data (XYZ/SCID)," *ISO working draft 12640-2*, 2000.

PRINT IN COLOR

(a) (b) (c)

Figure 1. (a) Modified image with every pixel shifted with the same colour difference; (b) Original image; (c) Modified image with changes made only to skin tones and blue dresses

(a) (b) (c)

Figure 2. (a) Modified image with every pixel shifted with the same colour difference; (b) Original image; (c) Modified image with changes made only to the red and pink bows, red ribbon, and the red and pink ball of threads

Colour Difference Metrics and Surround Effects: Preliminary Results

R. Victor Klassen[1], Xerox Corporation

ABSTRACT

Whereas both the CMC colour difference metric[1] and CIE94[2] show a considerable dependence on chroma, our measurements of contrast sensitivity show little or no such dependence. That is, the sensitivity to spatial variations in lightness, chroma and hue do not appear to depend on chroma, at least not to an extent greater than inter-observer variability. A key difference between a contrast sensitivity experiment and a colour matching experiment is that the background colour in the former is of necessity the mean colour of the grating, whereas the background in the latter is typically a neutral gray of specified reflectivity or luminance. Goodman hypothesized that the chroma dependence in CMC and CIE94 may result from distance from background, rather than distance from neutral; the experiments reported here test that hypothesis. Results are only preliminary: a single combination of hue and lightness was used throughout the experiments, however they indicated at least partial agreement with Goodman's hypothesis.

1 INTRODUCTION

Previously reported experiments[3] found no measurable chroma dependence in the visibility of various coloured sinusoidal gratings. The gratings varied L*, a*, b*, C*, or H_{ab} against a background whose colour varied from condition to condition over a large range of colour space. At none of the spatial frequencies tested did we find a measurable dependence on chroma of the mean colour. In contrast, both the CMC colour difference metric and CIE94 include a significant dependence on C*, substantially greater than could be hidden in the noise of our measurements. Goodman hypothesized that a possible explanation was that the colour difference metrics involved colour patches on a neutral grey background, whereas in our measurements, the colours being compared are the peaks and troughs of a sinusoid, displayed against a background of the mean colour. Furthermore, Goodman hypothesized that the threshold difference is a function not of the chroma of the standard colour, but the difference in chroma between the standard and the surround. In the grey-surround paradigm, these are the same.

This paper reports on experiments designed to test Goodman's hypothesis. Two experiments were conducted: one with prints and the other with CRT-based stimuli. In the print experiment, observers viewed carefully prepared samples containing four equal sized patches of either a near-neutral grey, or a high-chroma red. One of these four patches differed from the other three, and the observer's task was to identify which one. In the CRT-based experiment, observers indicated which of two patches was more chromatic, the more chromatic patch being randomly presented on the left or right side of the monitor. The L*a*b* values of the background and non-varying patches were essentially the same across experiments. The background on which the patches were presented was either neutral grey, or a red of similar chroma and identical hue to those of the patches. All hues and lightnesses of the patches and backgrounds were specified to be identical, as chroma was the only intended independent variable. All patches and backgrounds were measured after printing, for the print experiment; representative values of the colours presented on the CRT were measured after calibration. The backgrounds differed sufficiently in chroma from the chromas of the patches as to guarantee that the observers could not use a disappearing border as a criterion.

2 PRINT STUDY

In a preliminary study, chroma values were found that bracket threshold, for each of the four cases (high/low chroma patches; high/low chroma background). Nine values of chroma were used within the four ranges thus found, to provide a total of thirty-six samples. In principle, these provide a precision of from 0.25 (ΔE_{ab}) to about 1.6, depending on the case. Samples were prepared using 16 bit precision to specify the L*C*H_{ab} values, and then converted to 8 bits using error diffusion[4] before converting to CMYK using traditional interpolated lookup table techniques. The samples were printed and measured and then corrected values of L*C*H_{ab} were computed to improve the precision of the specification. Corrected samples were then printed on a Xerox/Tektronix Phaser 850 printer, which provided very smooth rendition of the patches and backgrounds.

[1] RVKlassen@crt.xerox.com; 0128-27E 800 Phillips Rd., Webster NY 14580 USA.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

A given page contained a uniform background square 19cm on a side, and four 6.8 cm squares (foreground patches), all distinct from the background. Of the four foreground patches, three were approximately identical, while the fourth differed from the other three only in its value of C*. The foreground and backgrounds shared common values of L* and H_{ab}. Eight observers selected the "most different" patch on each page; responses were pooled across observers. For as few as six observers, a unanimous response to a four-alternative forced choice query has only a one in 1024 probability of occurring by chance.

The resulting thresholds ranged from approximately 1.2 for the matching chroma background and foreground to approximately 3.5 for the high chroma foreground on a low chroma base, with a value 3.8 for a low foreground on a high chroma base. The best predictor of threshold (for these four cases) appears to be the difference (ΔE_{ab}) between the foreground colour and the surround. There may be a component of chroma dependence when the foreground colour and the surround differ, however for the print experiment this difference is lost in the noise. Goodman's hypothesis appears to be at least partially correct. The table below summarizes the results of the print experiment.

	Background L* a* b*	Foreground Patch C*	Threshold ΔC_{ab}
Grey on Grey	47 3 3	6.8	1.22±0.3
Red on Red	47 40 40	46	1.16±0.13
Red on Grey	47 3 3	46	3.5±1.3
Grey on Red	47 40 40	6.8	3.8±0.36

Table 1. Results of print experiment

2.1 Sources of error

Besides the normal inter-observer variability, there were two main reasons for the large error bars, esp. on the non-matching cases. First, typical printer calibrations have errors of ΔE ~2-5 or greater[3]. By repeating the calibration in the region of colour space of interest, we achieved errors of roughly ±1.5, but these errors were randomly distributed in direction. By hand-selecting the prints with the smallest ΔL and ΔH (i.e. the purest C* variation), from a run that bracketed the desired values, we achieved errors of only ±0.7, which is quite remarkable for print. All of the prints were measured, and their measured, rather than calculated values were used in the analysis to estimate the threshold. Two samples exhibiting anomalous behaviour were discarded when it was discovered that their "different" patch failed to be significantly more different than the others, when L* and hue variation were considered.

The second source of error resulted from uneven quantization. As a result of the pilot, the initial estimate of threshold in the red-on-grey case was around 4. As a result, nine prints were prepared with their intended ΔC ranging from 0 to 8 in equal steps. However, an error of ±2 in the initial prints (from which the prints with purest C* variation were chosen) resulted in steps of ΔE_{ab} of from 0.1 to 3.4. Thus the primary source of error in the estimate of threshold for the red-on-grey case is that there were no prints between 2.2 (clearly below threshold) and 4.8 (clearly above). Similarly there were no prints between 3.43 and 4.14 for the grey-on-red case.

One could iterate the experiment, with a larger selection of prints taken closer to the refined threshold. However printer stability is such that the only way one can guarantee ΔE_{ab}<0.1, is to carefully calibrate and then print a very large number of prints closely bracketing the intended colours, and then measure them all and hand-pick those (if any) that meet the criterion. Such an effort was beyond the scope of this work.

3 CRT BASED EXPERIMENT

The CRT based experiment used the same equipment and similar calibration to that of our previously reported experiment[1]. To increase the chroma resolution, error diffusion[8] was introduced. A line of constant L* and H_{ab} was constructed from the colour of greatest chroma in a condition to the colour of least chroma for the same condition. For example, for the case of a red foreground patch, on a grey surround, the line ranged from L*a*b = (47, 28.25, 28.25) to (47, 36.75, 36.75). Triangles of achievable (i.e. 8 bit) RGB colours were computed along the line. Vertices of these triangles were within 1 RGB unit of the line, and the planes of the triangles were as close to perpendicular to the line as possible. Dithering among the vertices of two neighbouring triangles produced a given colour on the display. For speed, colours were specified as 16 bit integers before error diffusing to the 8-bit vertices.

The calibration using the method described by Berns et al[9] gave an excellent fit, with root-mean-square error of less than 1% for seven points on each of the gamma curves. With only 3 digits of precision from the Minolta Photometer, we were not able to measure the accuracy of the colours displayed in the experiment with sufficient precision. The colours displayed were accurate to within the precision of the measuring device.

The CRT based experiment followed a two spatial alternative forced choice paradigm. For each of the four conditions (as in the print experiment) observers viewed 50 presentations of varying C* difference between the patch on the left and the patch on the right. Observers were required to indicate the side on which the patch further from grey appeared. One patch was a reference patch, always presented at the same C* value, the other a test patch, with a ΔC^* from the reference of between ±2 times the (previously) estimated threshold t, randomly above or below the reference patch. The reference was on the left or right at random. Values of ΔC^* were presented in strict succession from 0 to $\pm 2t$ in two sequences, one increasing and the other decreasing. The two sequences were randomly interleaved. The observers were not indicating which patch was the reference, only which had greater chroma, and indirectly (through their probability of a correct response) their threshold values of ΔC^*, for both positive and negative values of ΔC^*, independently.

Five colour-normal observers (Ishihara plates) provided data for the CRT based experiment; one (the experimenter) did five runs; the others did one or two. Table 2 (below) gives the results. The five runs were averaged and counted as two, so as to not overly weight the results in favour of one observer.

3.1 Results

Because the test patch chroma could be greater than or less than that of the reference patch, these were measured separately. Especially near grey, standard colour difference metrics would predict a lower threshold when the test patch is less chromatic than the reference patch. The observers did not know which was the test and which the reference, hence the value of C* used in the colour difference formulae would be the mean of the two chromas, and therefore a smaller value when the test patch is less chromatic. Contrariwise, if it is not distance from neutral (*i.e.* chroma) that is the key determinant of threshold, but rather distance from background, one would expect a similar, but opposite effect when the background is more chromatic than the foreground patches.

Table 2 (below) gives the results. The thresholds reported are the means of the thresholds estimated independently from eight runs with five observers (three observers contributing two runs each). The error estimates are twice the standard error of the means (i.e. with 95% confidence another experiment with a similar population would be expected to give the same average threshold to within that error).

	Background L* a* b*	Foreground Patch C*	Threshold $-\Delta C_{ab}$	Threshold ΔC_{ab}
Grey on Grey	48 1 1	11.3	-.77±0.15	0.82±0.25
Red on Red	48 46 46	57	-.65±0.20	0.42±0.19
Red on Grey	48 1 1	57	-1.23±0.50	1.46±0.34
Grey on Red	48 49 49	6.8	-1.39±0.35	1.29±0.37

Table 2. Results of CRT experiment. The two thresholds correspond to variation above and below the test condition.

The like-chroma cases are all within measurement error of each other, and significantly lower than the different-chroma cases, which are themselves well within measurement error of each other. While standard colour difference metrics would predict that the red-on-red case should have a significantly higher threshold than the grey-on-grey case, it has, if anything, a lower threshold (although this is likely an artifact as the difference is small). The red- or grey- on grey cases have threshold ΔE94 averaging .45 with a standard deviation 0.075.

Oddly, the thresholds in the CRT experiment are all roughly a factor or two less than those of the print-based experiment, although the trend is the same. This can not be explained by measurement error or inter-observer variability (the five observers in the CRT based experiment all did the print-based experiment). The CRT based experiment was a two alternative forced choice staircase, while the print-based experiment was four-alternative forced choice on a fixed collection of prints. It may be that the CRT-based experimental paradigm is more sensitive. Lighting conditions (normal office lighting) were similar in the two experiments, although one was reflective and the other emissive.

3.2 Discussion

While the CRT based experiment has lower measurement error than the print based experiment, there did remain quantization issues in the neighbourhood of 0.2 ΔC_{ab}. This quantization error results from the attempt to make small changes to the red signal, and even smaller changes to the green and blue in order to hold H_{ab} and L* fixed. Thus, even in the absence of inter-observer noise, one can expect no better than an error of 10-20% for the like-chroma cases. With that in mind, they are indistinguishable.

4 Colour Appearance Models

Of the colour appearance models summarized in Fairchild's book[7], only Hunt's model addresses the effect of surround. Hunt's model appears to treat the proximal field as providing partial adaptation to its colour and luminance, as if it changes the illuminant[8]. That is, it is mathematically equivalent to a change in illuminant, in that it alters the white point. Suppose that the change in the proximal field is equivalent to a change in the white point, and total adaptation occurs (a rather extreme supposition). Then colour appearance models would predict that the colours of the reference and test patches would shift as far as the background has to be shifted to be treated as neutral. In the high chroma background case, the high chroma patches would have the equivalent effect of low chroma patches on a low chroma background, while the low chroma patches would have the equivalent effect of high chroma patches (of the complementary colour to the background) on a low chroma background. By this argument one would expect that the high/high and low/low cases would have the same threshold ΔC and the high/low and low/high would also have the same thresholds.

Total adaptation to a chroma of 40 is rather a stretch. A model such as Retinex bases more of its calculations on edge strengths and, given the right set of tuning parameters, would be likely to predict the responses we measured. The difficulty with Retinex is the number of free parameters[9].

While we were unable to distinguish between the two matching chroma cases or between the two distinct chroma cases, there may be a difference within our measurement error. Such a difference would be significantly less than that predicted by either of the commonly used colour difference metrics. Any difference would reduce the amount of adaptation predicted in a colour appearance model based explanation.

5 SUMMARY

Whereas both the CMC colour difference metric and CIE94 show a considerable dependence on chroma, our measurements of contrast sensitivity show little or no such dependence. Goodman hypothesized that the chroma dependence in CMC and CIE94 may result from distance from background, rather than distance from neutral; the experiments reported here are intended to test that hypothesis. Results are only preliminary: a single combination of hue and lightness was used throughout the experiments, however they show no conflict with Goodman's hypothesis. They do appear to match Goodman's hypothesis better than either the CMC or CIE94 colour difference metrics.

For isolated patches and comparing large uniform objects (such as a jacket and pants) with each other, the existing colour difference metrics are likely superior. However for measuring variations within a patch or a single object, ΔE_{ab} appears to be more appropriate.

These experiments were necessarily preliminary, however they have demonstrated an effect that would be worth further investigation, with attention being given to a larger range of hues, and more than two values of C*.

6 ACKNOWLEDGEMENTS

Alicia Wright (summer intern) prepared and measured the prints for the pilot experiment. Raja Balasubramanian assisted with printer calibration issues, and Dean Harrington prepared and measured the prints for the print experiment. Stephen Morgana modified the software from the previous experiment[3], to for this experiment, and calibrated the monitor. Nancy Goodman suggested the print experiment.

7 REFERENCES

[1] Clarke, F.J.J., R. McDonald and B. Rigg, "Modification to the JPC79 colour-difference formula", Journal of the Society of Dyeists and Colourists, **100**, p. 130, April 1984

[2] Berns, R.S., "The Mathematical development of CIE TC 1-29 proposed color difference equation: CIELCH", *Proceedings of AIC colour 93*, **B** (c19-1-4), 1993

[3] Klassen, R.V. and N.B. Goodman, "Human Chromatic Contrast Sensitivity: Exploration of Dependence on Mean Color", *Proc 8th Color Imaging Conference*, Scottsdale, AZ, November 2000

[4] Floyd, R. and L. Steinberg, "An adaptive algorithm for spatial grey scale", *Proc SID 17*, p. 75, 1976.

[5] Bohr, S.B., "A perspective on non-impact printing in color" *Proc SPIE 1670*, pp. 2-11 (1992)

[6] Berns, R., R. Motta, and M. Gorzynski, "CRT Colorimetry. Part 1: Theory and Practice", *Color Research and Applications* **18**, 299-314.

[7] Fairchild, M. *Color Appearance Models*,. Addison Wesley Longman, Reading Mass. 1997.

[8] Hunt, R.W.G. *Measuring Colour, 2nd ed.* Ellis Horwood, Chichester, England, 1991

[9] Funt, B., F. Ciurea and J. McCann, "Retinex in Matlab", *Proc. 8th Color Imaging Conference*, Scottsdale, AZ, November 2000, pp. 112-121

New experimental data for investigating uniform colour spaces

S. Y. Zhu, M. R. Luo and G. H. Cui, Colour & Imaging Institute, University of Derby, UK

ABSTRACT

An experiment was carried out using CRT colours. The stimuli were selected along 24 vectors in *CIELAB* colour space. The data was used to test various colour difference formulae and uniform colour spaces. The results show that there are some discrepancies between *CIELAB* space and experimental data. The results also suggest that there are three types of colour models according to the data used to develop these models: small colour-difference, large colour-difference and Munsell data.

Keywords: Colour difference formula, uniform colour space, CIELAB,IPT, GLAB.

1. INTRODUCTION

Much research work has been conducted to derive a universal uniform colour space where equal distances in that space correspond to equal perceived colour differences. In 1976, CIE recommended the CIELAB [1] space as a uniform colour space for industrial application. It has been widely used in many industries, such as textiles, paints etc. However, it was later found that it does not fit well to the experimental data with small to medium magnitudes of colour differences. It also has a shortcoming: colours along a constant hue angle in blue region appear to have a large hue shift. [2,3] Although CIE has just recommended a new colour difference formula, *CIEDE2000*, [4] nevertheless it is still a modification to the CIELAB and does not have an associated with a colour space. Hence, the search for a universal uniform colour space is still continuing.

In this study, five types of scales in CIELAB colour space were investigated: hue, lightness, chroma, a light series and a dark series. The names of the 'light' and 'dark' series are only used here, but are not defined by CIE. The latter four directions are illustrated in Figure 1(a) at a constant CIELAB hue angle. For the lightness scale, the colours were all neutral, ie C*=0, and L* ranged from 5 to 95. For the 'light series', L* decreased from 95 to 50 while C* increased from 0 to the maximum value. The hue was constant, but the experiment was repeated at five different hues. For the hue scales, the hue circle was divided into four quadrants which were investigated separately. For one series of experiments, L* and C* were fixed at 50 and 30 respectively, while for a second series, different values of L* and C* were chosen for each quadrant to maximise the chromas which could be studied. (see Figure 1(b)).

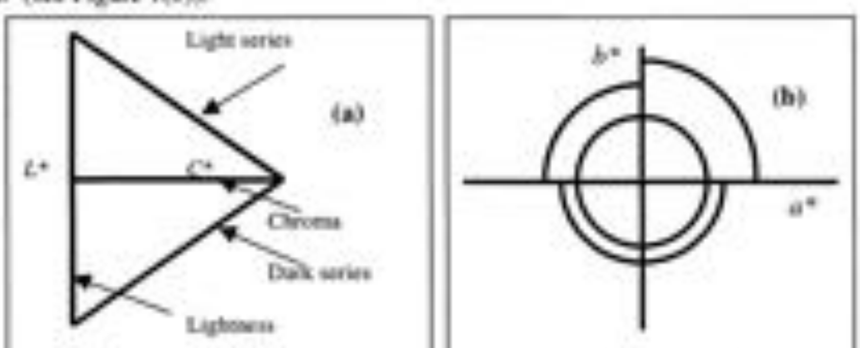


Figure 1. (a) The lightness scale, chroma scale, light series and dark series studied.
(b) The hue scales studied

Experimental software was developed to allow observers to adjust colours along each scale on a CRT display. The visual results were accumulated for discerning the non-uniformity of CIELAB space. The results were also used to test various colour spaces and colour difference formulae.

2. EXPERIMENT

The experiment was conducted using a Barco Reference Calibrator with a white point set to illuminant D65 and CIE 1931 standard colorimetric observer. The GOG [5,6] model was used to characterise the monitor. The experiment was conducted in a

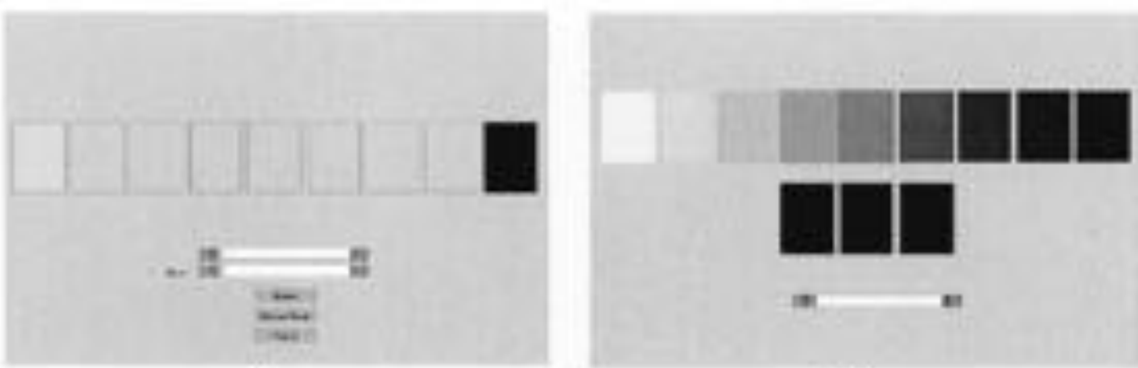
9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

darkened room. Ten normal colour vision observers aged between 25 and 35 years old took part in the experiment. Each observer repeated the experiment twice. Twenty-four vectors corresponding to the five CIELAB scales introduced earlier were studied. Figure 2(a) shows a scale including 9 colours against a grey background with L* of 50. The 24 vectors studied are described in Table 1 including one lightness, five chroma, eight hue-angle, five light series and five dark series. The two ends of each vector are also given in Table 1. There are five chroma vectors, light series and dark series at hue angles of 42°, 139°, 305°, 102° and 330° corresponding to the CRT's first and secondary primaries (red, green, blue, yellow and magenta). Each hue vector only covers 90° (a quadrant) as shown in Figure 1(b).

Scale	Parameter	No. of vectors	Repetition	No. of Observers	Total Judgements
Lightness	L* (5-95), C*=0	1	2	10	20
Chroma	L*=50, C*(0-max) 5 hues	5	2	10	100
Hue	L*=50, fixed C*=30	4	2	10	80
	Fixed L* and C* but different L* and C* for each quadrant	4	2	10	80
Light Series	L* (50-95), 5 hues	5	2	10	100
Dark Series	L* (5-50), 5 hues	5	2	10	100

Table 1 Experimental conditions

In Figure 2(a), each observer was asked to fill in the colours between the two fixed ends based upon their own visual judgement. The aim was to make the colour differences between each pair of neighbouring samples look the same. They used three control bars: L*, C*, hue and 'series' to adjust colours. For adjusting the lightness scale, the L* control bar was used. Observers used the C* and hue control bars for adjusting colours in chroma vectors. (The chroma bar was used to adjust the sizes of the steps, while the hue bar was used only to make the hues of all the samples look the same). For adjusting the hue vectors, observers only used the hue control bar. For vetors of light and dark series, observers used both the 'series' and hue control bars. The inclusion of hue adjustments to the chroma scale and dark and light series was to investigate the degree of hue changes in these vectors. After the experiment, the L*, C* and hue angle values were averaged for each colour patch to represent the mean visual results.



(a) (b)

Figure 2: (a) The experimental condition for adjusting each colour patch.
(b) The experimental condition for scaling colour differences.

A supplementary experiment (see Figure 2(b)) was later conducted to bring the colour differences of all vectors into one visual scale. Observers adjusted the colour differences of all the other vectors (3 colours in the bottom row) to agree with those of lightness vector (top row). Each vector was divided into three parts, i.e. patches 1-3, 4-6 and 7-9.

3. RESULTS

Finally, 144 colour differences calculated between two neighbouring colours in each vector were gathered with a mean of 10 ΔE^*_{ab}. These were used to examine the uniformity of CIELAB colour space. In Figure 3 the original lightness results (L*) are plotted against the measured results for the samples which the observers considered to be equally spaced (L^*_v). The L* results have an equal step, i.e. (95-5)/8=11.25. The same principle applies to chroma results as shown in Figure 4 for the blue hue. For a perfect agreement between the visual results and CIELAB scales, all data should fall on the 45° line. Obviously, this is not the case for both scales as most points are above the 45° line. Figure 3 shows that the experimental results agree with the

L* scale for L* <40, but not for the lighter colours . For the chroma results, the CIELAB C* values in Figure 4 run from 0 to 90. Thus a colour with C*=45 might be expected to fall in the middle of the set. However it can be seen that the midpoint actually occurs at L*=40. This implies that a chroma change of C*=0 to 45 looks larger than one corresponding to C*=45 to 90. This is consistent, at least qualitatively, with results for experiments involving small colour differences

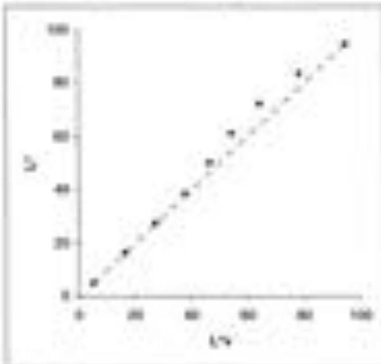


Figure 3. Original Lightness (L*) vs. Lightness results (L^*_v)

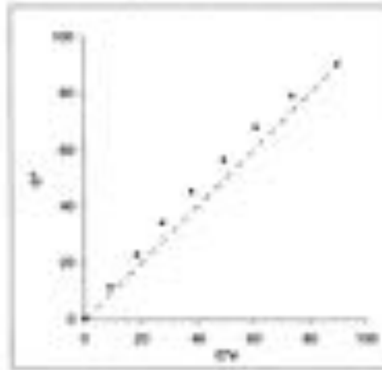


Figure 4. Original chroma (C*) vs. Chroma results (C^*_v) at blue hue.

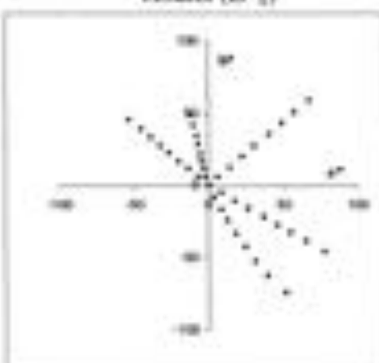


Figure 5. Chroma results plotted in a^*b^* diagram.

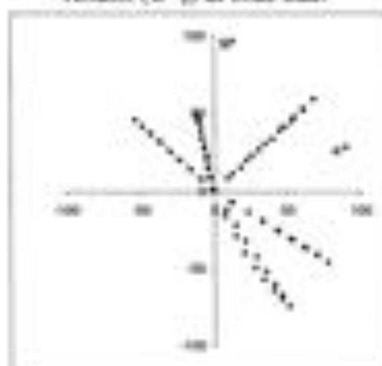


Figure 6. The results for Light and dark series plotted in a^*b^* diagram.

Figures 5 and 6 show the visual results for the chroma vector, and light and dark series for each of the 5 hues plotted in the CIELAB a^*b^* diagram For a perfect agreement between the visual results and CIELAB space, the experimental visual results for each hue should fall on a straight line. Both figures reveal that some curvature occurs for blue hues. This implies that constant hue angle in CIELAB space does not correspond to a constant hue as judged visually, at least for blue colours. A similar effect was found for the light and dark series, again for blue hues (see Figure 6). Overall, it can be concluded that there are systematic discrepancies between the experimental data and CIELAB colour space.

Finally, the experimental visual results were then used to test 11 colour difference formulae and colour spaces: 1) CMC,[7] 2) CIE94,[8] 3) CIEDE2000,[6] 4) GLAB,[9] 5) OSA,[10] 6) IPT,[2] 7) CAM97s2,[11] 8) CIELAB,[1] 9) Kuehni,[12] 10) SVF,[13] and 11) NC_IIIC,[14]. Models 1-3 were developed to fit small colour differences, and the other models to fit large colour differences. Also, Models 1 to 6 are colour difference formulae, and the other models are uniform colour spaces. The performance factor divided by three (PF/3) is used as measure of fit [9]. For a perfect agreement, PF/3 should equal to zero. A PF/3 of 30 means a 30% disagreement between the formula or space's predictions and the visual results. The results are summarised in Table 2. For each model, a lightness weighting factor was also optimised in order to improve each model's performance.

Table 2 shows that PF/3 values are more than 30 for Models 1-3 and 9-11 but less than 30 for Models 4-8. The GLAB and IPT models gave the most accurate prediction amongst all the models tested. The results also indicate that there are large differences amongst these three groups of models. The current results confirmed the authors' earlier study [15] using many other datasets that the colour models can be divided into three categories according to the data used to develop these models: small colour-difference (1-3), large colour-difference (4-8) and Munsell data (9-11).

	Model	PF/3 with $K_L=1$	PF/3 with optimized K_L	Optimized K_L
1	CMC	45	45	1.0
2	CIE94	34	34	1.0
3	CIEDE2000	31	30	0.8
4	GLAB	26	26	1.0
5	OSA	29	29	1.1
6	ITP	27	27	1.1
7	CAM97s2	37	29	0.5
8	CIELAB	29	28	0.8
9	KUEHUNI	39	35	0.6
10	SVF	34	33	0.8
11	NC_IIIC	38	36	0.6

Table 2 The performance of 11 colour models

4. CONCLUSIONS

An experiment was carried out using a CRT display. Observers were asked to adjust colours on 24 directions in CIELAB space to form equally spaced series. The results showed that there are systematic discrepancies between the visual results and CIELAB space. The data were also used to test 11 colour spaces and colour difference formulae. It was found that the models can be divided into three groups according to the data used to develop these models: small colour-difference, large colour-difference and Munsell data.

ACKNOWLEDGEMENTS

The authors would like to thank B. Rigg for advice and all the observers who participated in many experimental sessions.

REFERENCES

1. CIE Colorimetry, CIE Pub. no, 15.2, Centre. bureau CIE, Vienna. Austria. 1986.
2. F. Ebner and M. D. Fairchild, "Development and testing of a color space IPT with improved hue uniformity", Proc. of The Sixth Color Imaging Conf.: Color Science, System, and Applications, pp8-13, 1998.
3. P. Hung and R. S. Berns, "Determination of constant hue loci for a CRT gamut and their predictions using color appearance spaces", *Col. Res. Appl.* 20, pp285-295,1995.
4. M. R. Luo, G. Cui and B. Rigg, "The development of CIE 2000 colour-difference formula: CIEDE2000", *Col. Res. Appl.*, 26, in print, 2001
5. R. S. Berns, M. E. Gorzynski, and R. J. Motta., "CRT colorimetry. Part I: Theory and Practice", *Col. Res. Appl.*, 18 pp299-314, 1993.
6. R. S. Berns, M. E. Gorzynski, and R. J. Motta., "CRT colorimetry. Part II: Metrology", *Col. Res. Appl.*, 18 pp315-325, 1993.
7. F. J. J. Clarke, R. McDonald, and B. Rigg, "Modification to the JPC79 colour-difference formula.", *J Soc Dyers Col*, 100:128-132 and 281-282, 1984.
8. CIE, "Industrial colour-difference evaluation", CIE publ. No. 116, Central Bureau of the CIE, Vienna, Austria 1995.
9. S. S. Guan and M. R. Luo, "A colour difference formula for assessing large colour differences", *Color Res. Appl.*, 24 pp344-355, 1999.
10. D. L. McAdam, "Uniform color scales", *J. Opt. Soc. Am.*, 55, pp1619-1702, 1974.
11. C. J. Li, M. R. Luo and R. W. G. Hunt, "A revision of the CIECAM97s model", *Col. Res. Appl.*, 25, pp260-265, 2000.
12. R.G. Kuehni, "Towards an Improved uniform color spaces", *Col. Res. Appl.*, 24, pp253-265, 1999.
13. T. Seim and A. Valberg, "Towards a uniform color space: a better formula to describe the Munsell and OSA color spaces", *Col. Res. Appl.*, 11, pp11-24, 1986.
14. K. Ikeda and K. Obara, "Improvement of uniformity in colour space in terms of colour specification and colour difference Evaluation", CIE Proceedings 22nd Session, pp49-50, 1991.
15. M. R. Luo, S. Y. Zhu, and G. H. Cui, "Testing the uniformity of colour spaces", CIE Expert Symposium, Scottsdale, Arizona, 7-10 November. 2000, in print

Comparative Study of Visual Colour Differences Using Reflective and Self-luminous Colour Stimuli

John H. Xin*, C.C. Lam
Institute of Textiles & Clothing, The Hong Kong Polytechnic University, Hong Kong

ABSTRACT

In this study, visual colour difference assessments were conducted using both reflective colours which are dyed cotton fabrics with no obvious texture pattern and self-luminous colours displayed on a CRT monitor. All together, eighty-two pairs of colour samples belonging to five different colour centres were used. The average colour difference for all pairs is about 5.0 CIELAB units. The values of the colour difference for the self-luminous colour pairs ($\Delta E_{self\text{-}luminous}$) are very close to those of the corresponding reflective colour pairs ($\Delta E_{reflective}$), i.e., the reproduction of the reflective colour pairs onto the CRT monitor was very accurate. Grey scale method was used in the visual assessment of colour difference. The assessments were done using five different viewing conditions, i.e., reference viewing condition recommended by CIE (CIE Technical Report CIE 116-1995), and the other conditions which include a 3-inch gap between samples in a pair, small sized sample corresponding to 2° angle of subtend, and two different background colours. In comparison with the visual colour differences of the reflective pairs under the reference condition, the results obtained from the CRT colour pairs are 15% smaller. Under other viewing conditions, the visual colour differences of the CRT colour pairs are 13 to 18% smaller than those of the reflective colours pairs. Further comparison was made using chromatic colour discrimination ellipses for self-luminous and reflective colours.

Keywords: Self-luminous Colour, reflective Colour, parametric effect, colour discrimination ellipses

1. INTRODUCTION

CRT (Cathode Ray Tube) displayed colours have been widely used for product design, quality evaluation, and communication. The increasing activities in B-to-C and B-to-B Internet application also demand high fidelity colour display. In some of these applications colour-matching qualities such as colour differences, are directly assessed using CRT displayed colours. There are many advantages of using these virtual colours in colour information communication. The reduction in communication lead time in comparison with sending surface colour samples could provide much needed time for product design and developement, product colour quality, as well as colour product sourcing. Comparing with the physical samples, the use of CRT colours can also avoid colour fading and contamination. While many researches on visual colour difference evaluation have been conducted using reflective colours, it is of interest to know whether there exists any significant difference in visual colour discrimination between reflective colours and self-luminous colours, which is the main aim of this current study. In addition, the current practice of colour quality evaluation using CRT colours is solely dependent on visual assessment. The results of this comparative study might be useful for the objective colour difference evaluation of CRT colours. Since the viewing parameters could influence the colour difference assessment, we conducted the comparative study using several different parametric conditions. These conditions include sample separation, sample size and background colour. The size of the average colour difference of all colour pairs was around 5.0 CIELAB units, which belongs to medium colour difference domain. Five-colour centres were selected according to a previous study in which the highest disagreements of colour difference formulae were observerd[1].

2. COLOUR DISCRIMINATION ELLIPSE

The semi-major axis (A), ratio of the semi-major and semi-minor axes (A/B), orientation angle (θ) and the area ratio are parameters used to describe an ellipse[2]. The differences in these ellipse parameters can be used for investigating the parametric effects of colour difference evaluation. The advantages of using ellipses or ellipsoids to represent the colour difference results were given by Robertson[3]. Many studies use ellipsoids or ellipses in x, y, Y space. The ellipsoids or ellipeses are a sets of contours of equal perceived colour difference (ΔE) from a particular colour. To simplify the representation of these contours, ellipse formula is used when only chromatic difference is considered:

$$(\Delta E)^2 = b_{11}(\Delta a^*)^2 + 2b_{12}\Delta a^*\Delta b^* + b_{22}(\Delta b^*)^2 \qquad (1)$$

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

For most of the perceptibility data, the visual results are represented by visual difference ΔV values which are intended to be directly proportional to the differences assessed. To calculate the b_{ij} values in equation (1), the sum of square differences between the ΔV and ΔE values are minimised using equation (2).

$$S^2 = \sum^{N} (\Delta V_i - \Delta E_i)^2 \qquad (2)$$

3. EXPERIMENTAL DESIGN

Surface colour samples were prepared using reactive dyeing on a plain knitted cotton fabric. All the colorimetric data of samples were calculated based on measurements using CE-7000a spectrophotometer and Photo-research Research PR-704 spectroradiometer for reflective and monitor colours respectively. The colorimetric data of reflective samples were then converted into RGB values for screen display of the colours. GOG method was employed to characterise the monitor[8]. Further fine-tuning was required to make all of the displayed colour pairs having more or less the same colour difference values as the reflective colour pairs. The mean ratio of $\Delta E_{self\text{-}luminous} / \Delta E_{reflective}$ for all eighty-two pairs used was 1.03. The CIEL*a*b* values of five colour centres in both self-luminous colour and reflective colour are shown in table I. It is seen from the table that the differences in L*a*b* values between two set of data are quite small so that further comparison in terms of visual colour difference can proceed.

Table I: L*, a* and b* values of five colour centres for both self-luminous and reflective colours

Colour centre	Reflective colour			Self-luminous colour		
	L*	a*	b*	L*	a*	b*
Orange	49.25	11.15	17.42	49.13	11.64	17.7
Yellow	76.87	-0.55	18.81	77.96	-1.178	17.81
Grey	48.44	-0.88	-0.68	48.66	-0.806	-0.387
Green	28.84	-13.42	-1.27	28.67	-13.16	-1.53
Blue	25.45	9.02	-19.42	25.41	9.37	-21.34

Eighty-two reflective colour pairs and self-luminous colour pairs were assessed twice by a panel of 10 observers under five different viewing conditions. The details of experiment design are shown in table II.

Table II: Details of experiment phases.

Phase	Background	Sample Size	Gap
I. (reference)	Medium Grey	3 inches square	Hairline
II. (gap separation)	Medium Grey	3 inches square	3 inches
III. (2° viewing field)	Medium Grey	0.6 inches square	Hairline
IV. (green background)	Green	3 inches square	Hairline
V. (blue background)	Blue	3 inches square	Hairline

Grey scale method[3] was adopted in visual assessment under D65 light source for reflective colour pairs. The light source conforms to British standard BS-950. The monitor white point was also set to D65. The grey scale specification is according to ISO standard 105-A02, Grey Scale for Change of Colour. The grey scale rating (GS) was converted to visual colour difference (ΔV) by curve fitting method using a third polynomial.

4. RESULTS AND DATA ANALYSIS

4.1 Direct Comparison

Since the size of colour difference for the reflective and the self-luminous colour pairs are almost the same, the direct comparison between ΔV of self-luminous and reflective colour pairs can be used to indicate the difference of the medium types. The radio of the ΔV, K_v are calculated by equation (3):

$$K = \Sigma(\Delta V_{self\text{-}luminous} / \Delta V_{reflective}) / N \qquad (3)$$

K equalling to 1 indicates a perfect agreement between two visual difference evaluations. The K values for different phases are shown in table II.

Table II K values calculate for the visual difference between self-luminous and reflective colour pairs

Phase I	Phase II	Phase III	Phase IV	Phase V
0.85	0.82	0.84	0.87	0.83

It can be seen that the K values for all five phases are smaller than 1.0. The deviation ranges from 13% to 18%. The K values are similar for five phases, i.e., there is similar deviation between different medium types of colours in spite of the different viewing conditions. These results indicate that the visual difference perceived is smaller for the self-luminous colour pairs when comparing with the reflective colour pairs. In other words, the colour difference evaluation for the textile materials seems more sensitive than CRT displayed colours in grey scale assessment. As the current colour difference formulae used were developed using reflective colour pairs, it may not be directly applicable to the self-luminous colour. An adjusting factor may be needed for these colour difference formulae.

4.2 Chromatic Colour Discrimination Ellipse

In order to further evaluate the colour discrimination, the colour discrimination ellipses for the five colour centres of all phases were used. The size of ellipse indicates the sensitivity of colour difference evaluation. The smaller the size of the ellipse, the higher is the sensitivity. The results from Phase I, the reference phase, were plotted in Fig.1. Other data are listed in Table III. From Fig. 1, it is clear that the ellipses for the self-luminous colour pairs are larger than those of the reflective colour pairs of yellow and green centres which indicates the higher sensitivity for the reflective colour pairs in yellow and green region. For the grey colour centre however, the two ellipses have almost the same size, which means that they have almost the same sensitivity. There are thin ellipses of self-luminous colour when compared with the reflective colour in orange and blue region. For orange and blue centres, the ellipses are different in size and also shapes which indicates difference colour discrimination. This is to say that in orange and blue colour centres, the colour difference evaluation have some differences.

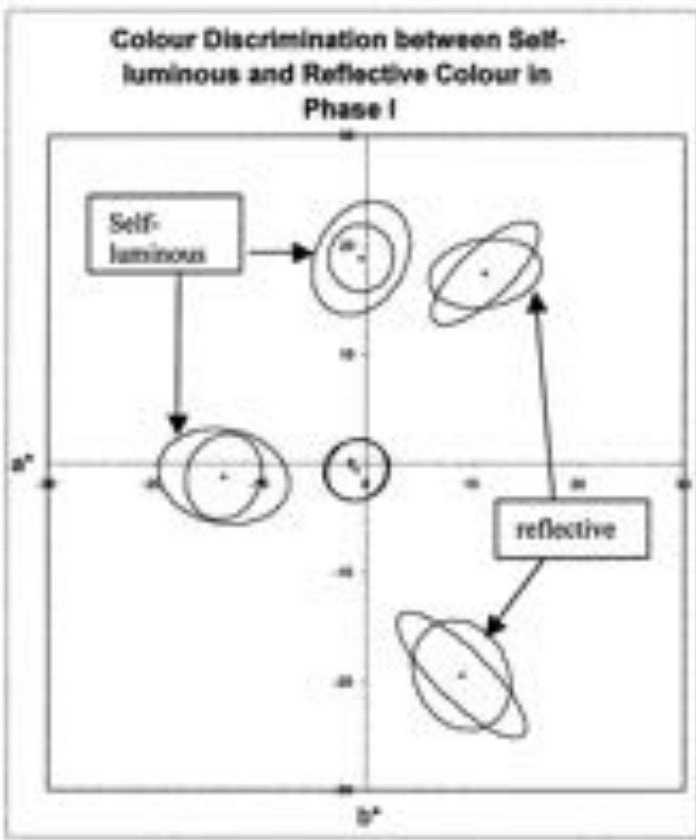


Fig.1. Colour discrimination ellipses of five colour centres for self-luminous and reflective colour pairs in phase I.

To indicate colour discrimination of the five colour centres of all the phases, the ratio of ellipse area is used for comparison. The results are given by Table III.

Table III: Ratio of ellipse area between self-luminous colour and reflective colour ($Area_{self-luminous}$ / $Area_{reflective}$).

Color	Phase I	Phase II	Phase III	Phase IV	Phase V
Orange	1.0	0.9	1.4	0.8	1.3
Yellow	1.3	1.0	1.2	1.5	1.4
Grey	1.0	1.1	1.2	1.1	1.0
Green	1.4	1.9	1.5	1.3	1.5
Blue	1.1	1.4	1.3	1.2	1.4
Average	1.2	1.2	1.3	1.2	1.3

The results show that most of ellipse area of the self-luminous colour pairs are larger than those of the reflective colour pairs, which indicate that the colour discrimination for the self-luminous colour pairs are less sensitive than that of the reflective colour pairs. There are only two exceptions, both belong to orange centres in Phase II and IV, especially for Phase IV, that the green background seems to enhance the visual difference of orange colour pairs on screen. The average ratio for all five phases ranges from 1.2 to 1.3. When the size has been reduced into 2° viewing field, the sensitivity for the colour discrimination is reduced more for the self-luminous colour pairs. A highest discrepancy of colour difference evaluation for all phases is obtained for green colours. The areas of the ellipses for green colours of the self-luminous medium are 30% to 90% larger than those of the green colours of the reflective medium. The visual colour difference evaluations for both media are very similar in grey region. The ratios of ellipse area for all of the phases are quite close to 1.0.

5. CONCLUSION

From this study, it can be seen that there is a difference for the visual colour difference evaluation between self-luminous and reflective colours. The direct comparison of the ΔV indicates that the average discrepancies are around 13% to 18% for the five colour centres studied under the five different viewing conditions. For the same size of colour difference, the self-luminous colours have the smaller visual colour difference. When further study these discrepancies using chromatic ellipses, the results also indicate the same trend. However, for difference colour centres, the differences between the visual assessment are not the same. Colours of the green centre exhibits largest difference while colours of the grey centres have were almost unaffected by the medium type. This kind of colour centre related phenomenon would make the quantification of the effect of the medium type more difficult and further study is suggested in order to clearly understand the difference of the colour assessment between those two media.

ACKNOWLEDGEMENT

The authors wish to acknowledge the Hong Kong Polytechnic University for providing funding for this study and the 10 observers took part in the visual assessment experiment.

REFERENCES

1. D. Hegie, R H Wardman and M. R. Luo, A Comparison of the Colour Differences Computed Using the CIE94, CMC(l:c) and BFD(l:c) Formulae, J. Soc. Dyers Col, 1996;112:264-269.
2. M. Melgosa, E. Hita, A. J. Poza, D. H. Alman and Roy S. Berns, Suprathreshold Colour-Difference Ellipsoids for Surface Colours, Col. Res. Appl., 22:3 148-155, (1997).
3. CIE, Guideline for Coordinated Reasearch on Colour Difference Evaluation.
4. Roy S Berns, Methods for characterizing CRT displays, Displays Magazine, Vol. 16 No. 4 1996.
5. M. R. Luo and B. Rigg, Chromaticity-discrimination Ellipses for Surface Colours, Col. Res. Appl., 11:1, 25-42, (1986).

*Correspondence: tcxinjh@inet.polyu.edu.hk; phone: 852-27666474; fax: 852-27731432; Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

Investigation of the 'crispening effect' on lightness differences

G. Cui, M. R. Luo and B. Rigg, Colour & Imaging Institute, University of Derby, UK

ABSTRACT

An experiment was carried out to investigate the crispening effect on lightness differences. Thirty-nine neutral lightness-difference pairs were generated using CRT colours. The experiment was divided into sixteen phases according to different physical arrangements for each sample pair such as different sample separations, sizes, and background colours. The results show that the crispening effect does exist but is highly dependent upon the particular viewing parameters.

Keywords: colour difference, lightness difference, crispening effect, parametric effect

1. INTRODUCTION

The crispening effect is the change of perception of colour differences caused by the change of background colours. Kaneko[1] investigated the achromatic lightness differences and found that a grey background enhances the sensitivity of the observer to lightness differences between grey samples of about the same luminance factors as that of background. This has also been found in other previous studies.[2,3]

Figure 1 shows the results reported by Chou *et al.*[4] Two hundred and eighty pairs of near neutral matt and glossy paint samples exhibiting mainly lightness differences were assessed by a panel of twenty observers using a grey scale method. The experimental data in terms of CIELAB ΔE/ΔV are plotted against L*, together with two functions: the weighting function of CIEDE2000[5] and the CIE94[6] (or CIELAB) function plotted in solid and dashed lines, respectively. The results showed that the CIEDE2000 lightness weighting function gave a more accurate prediction of the visual data than the CIELAB (see the horizontal dashed line). This function is a V-shape curve with the lowest point at the lightness of 50. This shape indicates that the largest lightness difference occurs for pairs close to L* values around 50 and the ΔL* values predict too high for very light and dark lightness differences. This shape agrees with the so-called "crispening effect" because all colour differences were assessed against a mid-grey background with a L* of 50. If there is a systematic crispening effect, it should be easy to fit a new lightness weighting function as a function of the lightness of the background, i.e. the lowest point of the function should correspond to the lightness of background.

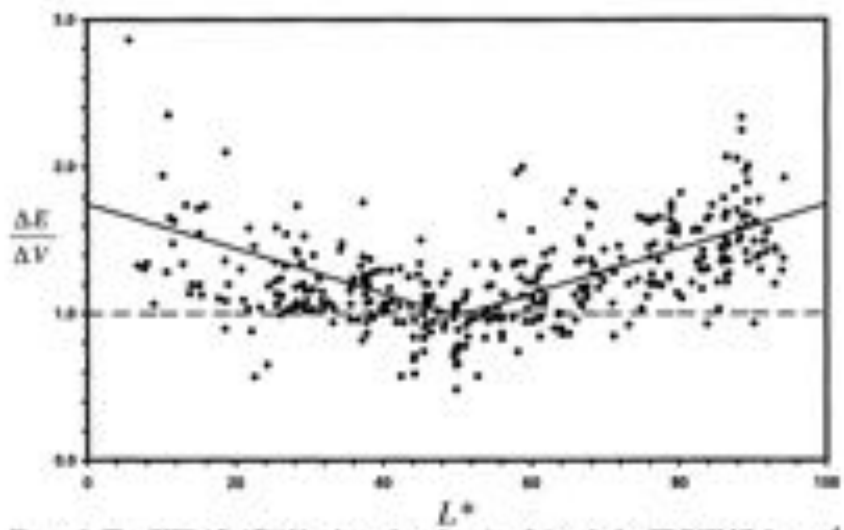


Figure 1: The CIELAB ΔE/ΔV values plotted against L* scale for SDC/CMC dataset.[4]

2. EXPERIMENTAL

In this study, an experiment was carried out to investigate this effect based upon CRT colours. The whole experiment was divided into 16 phases according to the different viewing parameters used: two sample sizes (2° and 10° fields of view), eight background colours (mid-grey, white, black, grey, red, yellow, green and blue), two frames (black frame and without frame) and different widths and colours of separations between pairs of samples. For each phase, thirty-nine neutral pairs showing lightness differences with an interval of approximately ΔL* = 2.5 from L* = 0 to 100 were displayed on a CRT. Each pair was assessed by a panel of 20 observers using the grey scale psychophysical method used by Luo and Rigg[7]. The experimental conditions for each phase are summarised in Table 1.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

Each phase is expressed by five characters: the first describes small (S) or large (L) sample size; the second character distinguishes between mid-grey (M), white (W), black (B), grey (g), red (r), yellow (y), green (g) or blue (b) background; the third character defines black frame (B) or without frame (G); the fourth character represents no (0), 1-pixel (1), 2-pixel (2) or large-gap (L) separation between a pair of samples; the last signifies grey (G), black (B) or no (N) separation colour. (The standard pair was always presented in large size, except for the SMB1B phase.)

Table 1 The experimental conditions for each phase.

Phase		Sample Size (pixel)		Background Colour	Frame	Width of separation (pixel)		Colour of separation	
No.	Name	Standard	Sample			Standard	Sample	Standard	Sample
1	LMG0N	140x140	140x140	Mid-grey	No	0	0	-	-
2	LMG1G	140x140	140x140	Mid-grey	No	1	1	Mid-grey	Mid-grey
3	LMG2G	140x140	140x140	Mid-grey	No	2	2	Mid-grey	Mid-grey
4	LMGLG	140x140	140x140	Mid-grey	No	1	140	Mid-grey	Mid-grey
5	LMG1B	140x140	140x140	Mid-grey	No	1	1	Black	Black
6	SMG1B	140x140	25x25	Mid-grey	No	1	1	Black	Black
7	SMBLG	140x140	25x25	Mid-grey	Black	1	25	Black	Mid-grey
8	SMB1B	25x25	25x25	Mid-grey	Black	1	1	Black	Black
9	LMBLG	140x140	140x140	Mid-grey	Black	1	140	Black	Mid-grey
10	LWB1B	140x140	140x140	White	Black	1	1	Black	Black
11	LBB1B	140x140	140x140	Black	Black	1	1	Black	Black
12	LGB1B	140x140	140x140	Grey	Black	1	1	Black	Black
13	LrB1B	140x140	140x140	Red	Black	1	1	Black	Black
14	LyB1B	140x140	140x140	Yellow	Black	1	1	Black	Black
15	LgB1B	140x140	140x140	Green	Black	1	1	Black	Black
16	LbB1B	140x140	140x140	Blue	Black	1	1	Black	Black

3. DATA ANALYSIS

The raw data in terms of grey-scale grades were first transformed into the visual difference (ΔV) for each pair. This can be done by fitting a polynomial equation between the ΔE (CIELAB) and grade values of the grey scale. These ΔV values can be used to test the performance of various colour-difference formulae.

In this study, the PF/3 value calculated by Equation (1) was used as the measure for testing the performance of the different colour-difference formulae.

$$PF/3=100(\gamma-1+V_{AB}+CV/100)/3 \qquad (1)$$

where CV and γ were proposed by Coates *et al*[8], and V_{AB} derived by Schultz[9].

Note that it is desirable to consider errors in percentage terms in this type of work. If one colour-difference formula is identical to a second, except that it gives ΔE values twice as big, the absolute error in ΔE doubles, but the percentage error remains the same, consistent with the fact that the formulae are of equal merit. The testing results for different colour-difference formulae are shown in Table 2 grouped according to the pattern of results as described below.

Table 2 The performance (PF/3) of CIELAB and CIEDE2000.

Pattern	Phase	CIELAB	CIEDE2000
One	LMG0N	16.4	11.3
	LMG1G	25.4	19.1
	LMG2G	25.7	19.3
	LMGLG	26.4	22.6
	LMG1B	22.3	20.9
	SMG1B	29.1	26.2
	Mean	24.2	19.9
Two	LWB1B	9.9	19.8
	LBB1B	11.7	17.1
	LGB1B	17.0	21.3
	LrB1B	9.4	13.8
	LyB1B	8.8	19.2
	LgB1B	10.3	15.8
	LbB1B	12.2	12.9
	Mean	11.3	17.1
Three	SMBLG	24.6	29.8
	SMB1B	23.6	26.4
	LMBLG	18.8	24.0
	Mean	22.3	26.8
Total	Mean	18.2	20.0

The parametric effect in the lightness direction was also investigated. Again, the CIELAB $\Delta E/\Delta V$ values for each phase were plotted against the L^* scale, as in Figure 1. Nine diagrams are given in Figure 2, each diagram corresponding to a representative phase. The S_L functions of the CIEDE2000 and CIELAB (or CIE94) are again plotted. The two original functions were plotted without scaling. Hence, their shapes can be compared with the data points but not their magnitudes. For perfect agreement between ΔE (CIELAB) and ΔV values, all data points should be located at the horizontal line. These plots showed three distinct patterns: a V-shape, a horizontal line and a decline line.

Pattern One shows a strong crispening effect similar to that in Figure 1. This pattern can be found in Figures 2(a) to 2(d) for Phases LMG0N, LMG1G, LMG2G, and LMGLG, respectively. Similar plots for Phases LMG1B, and SMG1B are not given here. The samples in these phases all had a mid-grey background (L^* = 53) and no black frame surrounding each sample. As expected, the CIEDE2000 formula performed much better than CIELAB in these phases as shown in Table 2. The results indicate that the ΔL^* values are predicted too high for both lighter and darker lightness differences. There is also a sharp dip at about L^* of 53. A systematic parametric effect can also be found in these figures. The slope of the V-shape increases when the distance of the separation between a sample pair increases, i.e. from no gap (LMG0N, Figure 2(a)), 1-pixel (LMG1G, Figure 2(b)), 2-pixel (LMG2G, Figure 2(c)) to large gap (LMGLG, Figure 2(d)). Comparing the grey (LMG1G, Figure 2(b)) and the black (LMG1B, not shown here) dividing line phases, the V-shape is much less marked for the latter phase.

Pattern Two shows that there is little or no variation of ΔE/ΔV values with L^* in each plot as illustrated in Figures 2(e) to 2(g) for Phases LWB1B, LGB1B and LBB1B, respectively. This group of phases also includes the other 4 coloured background phases. The common viewing parameters for these phases are the 'black frame' plus a 'black dividing line'. This indicates that L^* scale fits the data well when each pair is presented with a black frame and a black dividing line regardless of the colour of the background. For these phases, The CIELAB and CIE94 formulae performed better than CIEDE2000 (see Table 2). There is no sign of the 'crispening effect' for Pattern Two, otherwise Figure 2(e) to 2(g) should show the lowest point corresponding to L^* of 93 (white), 63 (grey) and 0 (black), respectively. However, the flat pattern shown here could be caused by the viewing parameters of the black frame and black dividing line used. It is worthwhile to obtain new experimental results using sample pairs with a grey dividing line and no black frame conditions against at least white, grey and black backgrounds. The crispening effect could occur in the proposed viewing conditions.

Pattern Three is given in Figures 2(h) and 2(i) for SMB1B and SMBLG respectively. The trend shows an over-prediction of lightness differences (compared to L^*) only for lighter, not for darker regions. This trend is completely different from the previous two patterns.

4. CONCLUSIONS

In conclusion, this study shows that there is a crispening effect for samples having no frame and a grey dividing line between a pair of samples against a grey background. However, the effect disappears when samples have a black frame and a black dividing line between a pair of samples regardless of background colours. Further experiment is required to investigate whether this effect occurs against the other coloured backgrounds using former viewing parameters. It would be particularly interesting to repeat the experiment for the LMG0N, LMG1G, and LMG2G phases with grey backgrounds of say L^* = 25 and L^* = 75 rather than the value of L^* = 53 used in this study.

REFERENCES

1. T. Kaneko, "A reconsideration of Cobb-Judd lightness function", *Acta Chromatica*, **1**, 103-110, 1964.
2. T. Takasaki, "Lightness change of greys induced by change in reflectance of grey background", *J. Opt. Soc. Am.*, **56**, 504-509, 1966.
3. C. C. Semmelroth, "Prediction of lightness and brightness on different backgrounds", *J. Opt. Soc. Am.*, **60**, 1685-1689, 1970.
4. W. Chou, H. Lin, M. R. Luo, S. Westland, B. Rigg, and J. Nobbs, "Performance of lightness difference formulae", *Color. Technol.*, **117**, 19-29, 2001.
5. M. R. Luo, G. Cui and B. Rigg, "The development of the CIE 2000 colour difference formula: CIEDE2000", *Col. Res. Appl.*, in print, 2001.
6. CIE, "Industrial colour-difference evaluation", *CIE Pub.*, No **116**, Vienna, Austria: Central Bureau of the CIE, 1995.
7. M. R. Luo, and B. Rigg, "Chromaticity-discrimination ellipses for surface colours", *Col. Res. Appl.*, **11**, 25-42, 1986.
8. E. Coates, K. Y. Fong, and B. Rigg, "Uniform lightness scales", *J. Soc. Dyers Col.*, **97**,179-183, 1981.
9. W. Schultz, "The usefulness of colour-differences formulae for fixing colour tolerances", *Color Metrics*, 245-265, Soesterberg: AIC/Holland, 1972.

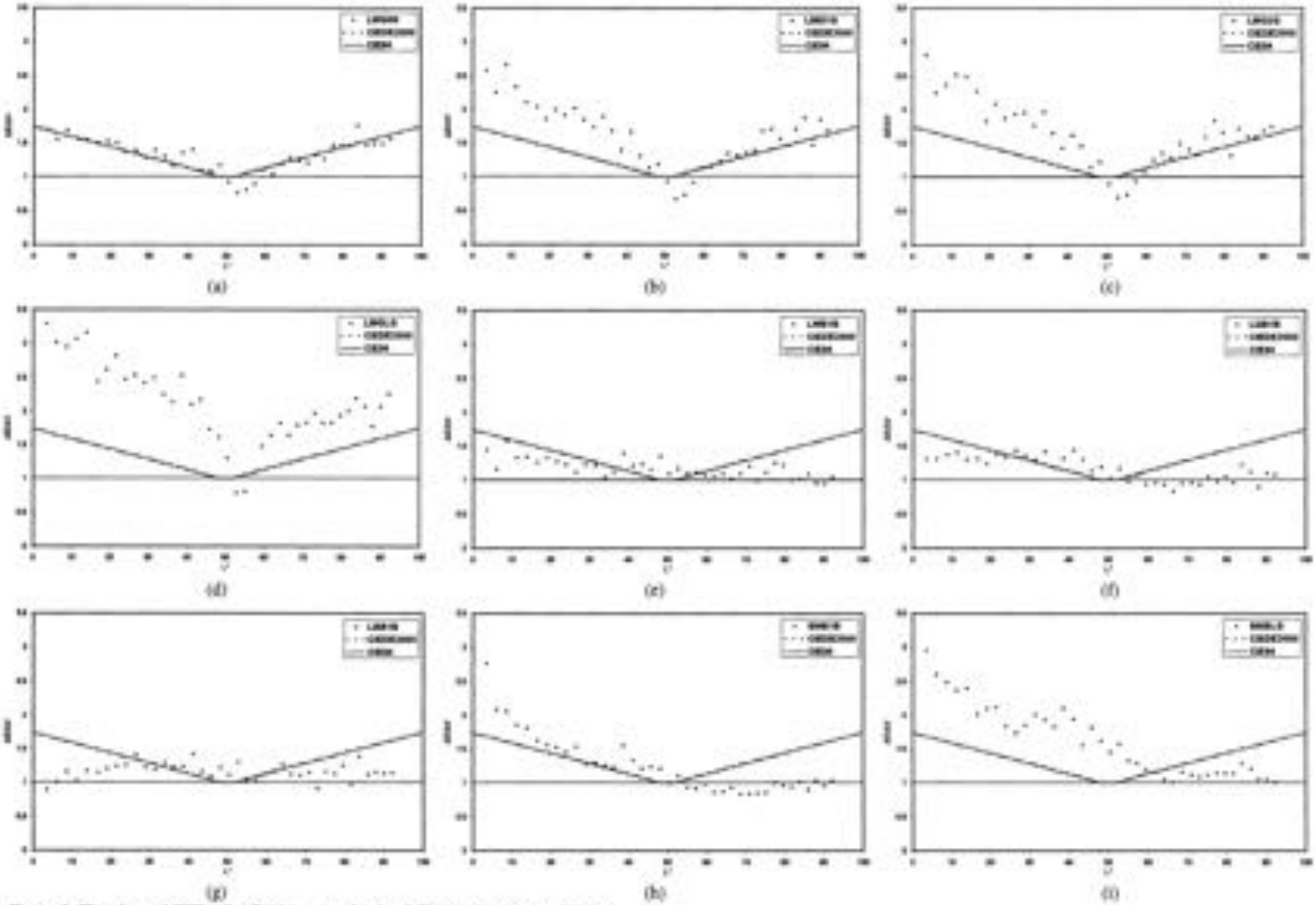


Figure 2: The plots of CIELAB ΔE/ΔV against L* for different viewing conditions.

Derivation of a hue-angle dependent, hue-difference weighting function for CIEDE2000

Roy S. Berns,* RIT Munsell Color Science Laboratory

ABSTRACT

CIE technical committee TC1-47 was established with a goal to improve the performance of the CIE94 color-difference equation. Recent visual experiments indicated that a hue-angle dependency might exist. Four datsets focused on hue differences were used to derive a new hue-angle function. The resulting function resulted in a statistically significant improvement compared with existing color-difference equations.

1. INTRODUCTION

During 1998, CIE technical committee TC1-47 was established, its goal to improve the performance of CIE94[1] in light of newly published visual data.[2] Four potential enhancements were identified: a new lightness-difference weighting function, a modification of the a* coordinate axis, a chromatic rotation function, and a hue-angle dependent, hue-difference weighting function. This paper describes the derivation of the last enhancement.

2. DATASETS

Four hue-difference datasets were developed. Each dataset consisted of CIELAB positions and ΔH^*_{ab} values, all corresponding to equal visual difference, i.e., $\Delta V = 1$. The Luo-Rigg dataset[3] was derived from historical datasets and suprathreshold visual decisions resulting in an extensive x,y,Y ellipsoidal dataset. From these ellipsoids, 132 ΔH^*_{ab} tolerances were derived by Maier.[4] The Luo-Hue dataset[5] consisted of 78 visual tolerances of dyed textiles predominantly varying in hue. These data were from the Luo-Rigg[3] visual experiments. The RIT-DuPont-Witt dataset was the third set and consisted of 19 hue tolerances. The RIT-DuPont data[6] were derived from suprathreshold visual judgements of automotive painted samples. The Witt data[7,8] were x,y,Y ellipsoids based on threshold judgments of painted samples. Hue tolerances for both sets of data also were derived by Maier.[4] The achromatic tolerances were discarded and the remaining tolerances were combined by normalizing each set to have the same average ΔH^*_{ab}. The Qiao, *et al.*[9] dataset consisted of 44 hue tolerances based on visual judgments of glossy photographic paper samples. Tolerances were derived using the same techniques used to develop the RIT-DuPont dataset, described in reference 6. The a*b* coordinates of each database are plotted in Figure 1. From a sampling perspective, the Luo-Hue and Qiao datasets were most appropriate for fitting a hue-dependent function because of their uniform sampling in h_{ab}. The majority of the Luo-Hue data were centered at L* equal to 50 while the Qiao data sampled at L* of 40 (two hue circles) and 60 (single hue circle). Thus, these data were not confounded by potential errors in any selected S_L function.

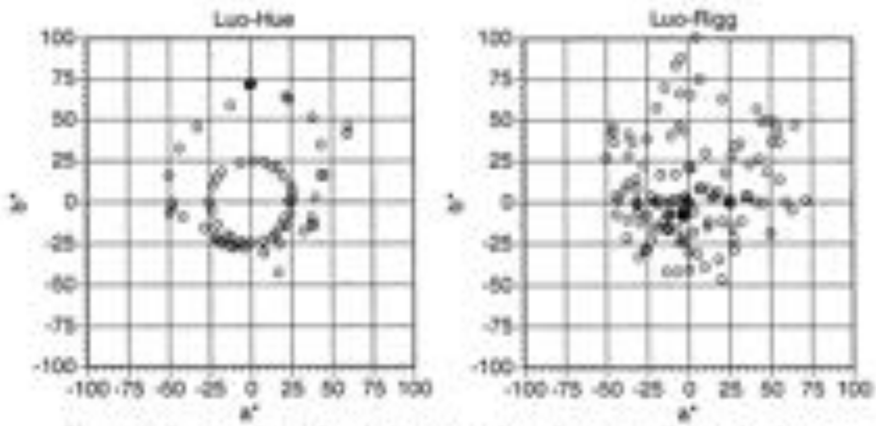


Figure 1. Scatter plots of each dataset projected on to a a*b* projection.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

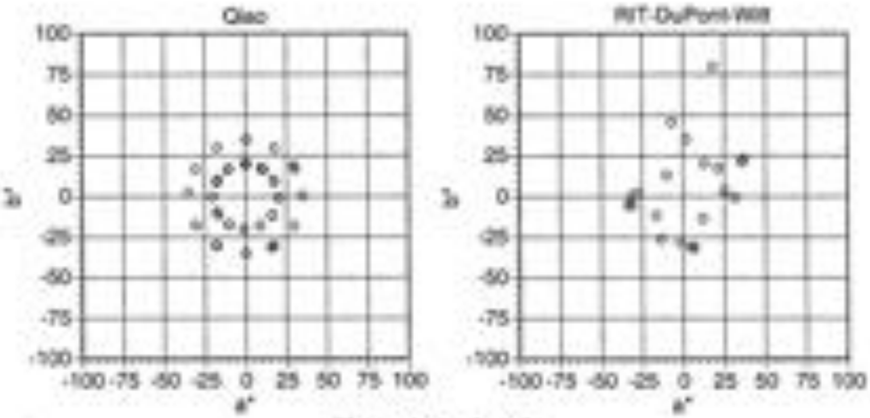


Figure 1 continued.

3. EQUATION OPTIMIZATION

Each dataset consisted of visual-difference data, ΔV, colorimetric coordinates for the 1964 standard observer and illuminant D65, and ΔH^*_{ab} difference data. Colorimetric and difference data were first corrected using the proposed modification of the a* coordinate axis, essentially a slight rotation in order to improve the circularity of neutral tolerance ellipsoids. The Luo-Hue data also had small differences in ΔL^* and ΔC^*_{ab}. Accordingly, for each dataset, the following equation was fit using nonlinear optimization:

$$\Delta V = k\left[\left(\frac{\Delta L^*}{S_L}\right)^2 + \left(\frac{\Delta C'}{S_C}\right)^2 + \left(\frac{\Delta H'}{1+\beta_0 C' T}\right)^2\right]^{0.5} \quad (1)$$

where

$$T = 1 + \beta_1 \cos(h' + \beta_2) + \beta_3 \cos(2h' + \beta_4) + \beta_5 \cos(3h' + \beta_6) + \beta_7 \cos(4h' + \beta_8)$$

and where $h' = h'_{ab}\,\pi/180$. The S_L and S_C functions were those used in the CIE94 equation.

The chroma- and hue-difference data are notated as $\Delta C'$ and $\Delta H'$ to indicate the incorporation of the modification to the a* axis. The T function of Equation (1) was based on the BFD equation[20] except a fourth-order cosine series was used rather than the BFD fifth-order cosine series. Coefficient k compensates for differences in the magnitude of each dataset's underlying anchor-pair stimulus. Coefficients β_0 – β_8 describe the hue-angle dependent function model parameters. The hue-angle function is commonly referred to by the variable T. The optimization minimized the RMS error between the estimated and visual color differences. The optimized T functions are plotted in Figure 2. The two Luo datasets are very similar, an expected result given their common origins. The Qiao and either the Luo-Hue or Luo-Rigg T functions are quite similar. The RIT-DuPont-Witt function is also similar to the other datasets except between 80° and 180°. Given the sparse sampling of this dataset in this region, evident in Figure 1, this is understandable. There is strong similarity between each dataset; this is a very significant result providing independent validation.

Each dataset has advantages and disadvantages: In general, experiments based on Probit analysis (i.e., RIT-DuPont and Qiao) tend to have twice the precision as those based on gray-scale methods (i.e., Luo-Rigg and Luo-Hue). The Luo datasets are the most comprehensive in their sampling of CIELAB. The Qiao database has the advantage of both high precision and uniform hue sampling, but does not span a large range of chroma. For this optimization, uniform sampling around the hue circle was considered the most important criterion. Thus, the Qiao and Luo-Hue datasets were given twice the weight as Luo-Rigg and RIT-DuPont-Witt. The weight-average β_0 was 0.05, more than a three-fold increase compared with CIE94's value of 0.015. A number of analyses by members of TC1-47 led to the opinion that the CIE94 value of 0.015 should be retained. The optimizations were repeated with β_0 replaced by 0.015. However, this second optimized T function had poorer performance than the initial weight-average with the substitution of 0.015 for β_0. Thus, this first weight-average T function was sent to the committee for consideration.

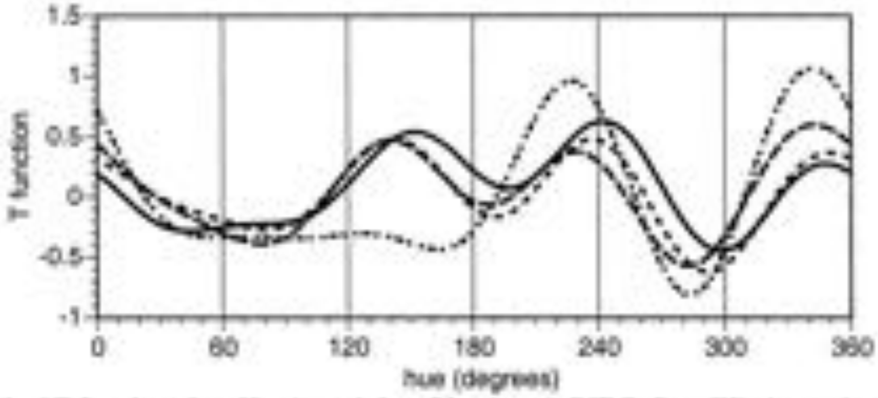


Figure 2. Optimized T functions: Luo-Hue (— —), Luo-Rigg (– – –), RIT-DuPont-Witt (- - - -), and Qiao (——).

4. FINAL EQUATION AND PRELIMINARY PERFORMANCE TESTING

The first-order performance of the candidate weighting function was determined by calculating the average and standard deviation of the calculated total color difference for each dataset. One hundred color-difference pairs, with $\Delta H^*_{ab}/\Delta E^*_{ab} > 0.75$, from the RIT-DuPont dataset were used rather than the 19 hue-difference pairs forming the RIT-DuPont-Witt dataset. The standard deviation divided by the average is a qualitative performance metric, listed in Table 1. The closer the number is to zero, the better the performance. Table 1 lists CIELAB, CIE94 and CIE94 with the derived S_H function. Except for the RIT-DuPont sorted dataset, adding the T function improved performance. The degree of improvement of each enhancement (i.e., CIELAB to CIE94 to CIE94 with the new S_H) reveals that the hue-angle effect is small.

Table I. Normalized standard deviation comparing CIELAB, CIE94, and CIE94 with the Equation 2 S_H function.

Dataset	CIELAB	CIE94	CIE94 and new S_H
Luo-Rigg	0.41	0.22	0.20
RIT-DuPont sorted	0.25	0.23	0.24
Luo Hue	0.28	0.27	0.23
Qiao	0.35	0.35	0.27

Other members of TC 1-47, M. R. Luo, B. Rigg, and committee advisor G. Cui, performed a rigorous statistical analysis of this weighting function.[11] They found statistically significant improvement compared with CIE94, CMC, and BFD equations in predicting a combined dataset of 486 color difference pairs, largely varying in hue and having the same visual differences.

Because of the statistical significance of the candidate weighting function, it has been adopted by TC 1-47. The resulting hue-angle hue-difference weighted function is shown below:

$$S_H = 1 + 0.015\bar{C}'\,T$$

where (2)

$$T = 1 - 0.17\cos(\bar{h}' - 30) + 0.24\cos(2\bar{h}') + 0.32\cos(3\bar{h}' + 6) - 0.20\cos(4\bar{h}' - 63)$$

The optimized cosine model parameters had units of radians. These were converted to degrees. A sensitivity analysis was performed to minimize the number of significant figures for each coefficient. For the multipliers, two significant figures beyond the decimal point defined the minimum precision without worsening estimation accuracy. For the cosine coefficients, values could be rounded to the nearest integer degree. This final equation is plotted in Figure 3.

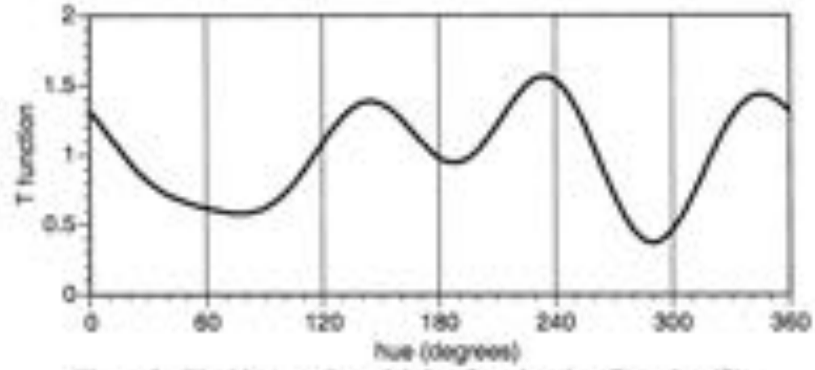


Figure 3. Final hue-angle weighting function, i.e., Equation (2).

5. CONCLUSIONS

When CIE94 was derived, a consistent hue-angle dependency could not be identified. The additional research by Qiao, *et al.* and isolating hue-difference data from the Luo-Rigg visual experiments enabled a hue-angle dependency to be identified and quantified. This reinforces the value of performing visual experiments optimized to answer a specific question, rather than relying on optimization to uncover any significant effects.

6. ACKNOWLEDGMENTS

This research would not have been possible without the enthusiasm of the chair of TC 1-47, D. Alman. R. Luo promptly provided data and statistical analyses. G. Cui created a productive spirit of competition by deriving independent weighting functions that were compared with those derived by the author. This research was supported by the R. S. Hunter Professorship in Color Science, Appearance, and Technology.

REFERENCES

1. CIE Pub. No. 116, "Industrial Colour-Difference Evaluation," Commission Internationale de l'Éclairage, Vienna, 1995.
2. P. Alessi, "Next step in industrial colour difference evaluations, Report on a colour-difference research meeting," CIE Pub. No. 124-1997, Collection in Colour and Vision, Commission Internationale de l'Éclairage, Vienna, 1997.
3. M. R. Luo and B. Rigg, "Chromaticity-discrimination ellipses for surface colors," *Color Res. Appl.* **11**, 25-42 (1986).
4. T. Maier, Written communication to CIE TC 1-29, 1992.
5. M. R. Luo, Personal communication, 1999.
6. R. S. Berns, D. H. Alman, L. Reniff, G. D. Snyder, and M. R. Balonon-Rosen, "Visual determination of supra-threshold color-difference tolerances using probit analysis," *Color Res. Appl.* **16**, 297-316 (1991).
7. K. Witt and G. Döring, "Parametric variations in threshold color-difference ellipsoid for green painted samples," *Color Res. Appl.* **8**, 153-163 (1983).
8. K. Witt, "Three-dimensional threshold color-difference perceptibility in painted samples: variability of observers in four CIE color regions," *Color Res. Appl.* **12**, 128-134 (1987).
9. Y. Qiao, R. S. Berns, L. Reniff, E. Montag, "Visual determination of hue suprathreshold color-difference tolerances," *Color Res. Appl.* **23**, 302-313 (1998).
10. M. R. Luo and B. Rigg, "BFD (l:c) colour-difference formula part 1 - development of the formula," *J. Soc. Dyers Colour.* **103**, 86-94 (1987); "BFD (l:c) colour-difference formula part 2 – performance of the formula," ibid, pp. 126-132.
11. M. R Luo, G. Cui, and B. Rigg, Written communication to CIE TC 1-47, 2000.

Correspondence: berns@cis.rit.edu; phone:716-475-2230; fax:716-475-5988;www.cis.rit.edu:80/people/faculty/berns/; RIT Center for Imaging Science, 54 Lomb Memorial Drive, Rochester, NY 14623-5604, USA.

Uniform Color Space is Not Homogeneous

Rolf G. Kuehni, North Carolina State University, Raleigh, NC

ABSTRACT

Historical data of chroma scaling and hue scaling are compared and evidence is shown that we do not have a reliable basis in either case. Several data sets indicate explicitly or implicitly that the number of constant sized hue differences between unique hues as well as in the quadrants of the a^*, b^* diagram differs making what is commonly regarded as uniform color space inhomogeneous. This problem is also shown to affect the OSA-UCS space. A Euclidean uniform psychological or psychophysical color space appears to be impossible.

Keywords: Uniform color space, hue scaling, chroma scaling.

1. INTRODUCTION

The general belief is that what we consider to be perceptually uniform space is homogeneous. Aside from general considerations, the Optical Society of America Uniform Color Scales (UCS) where color differences have been established in twelve directions from a central color leads one to assume that this is so. The assumption is also made in regard to the Munsell color space even though it is known that its hue, value and chroma scales are not perceptually equivalent. The colors representing unit divisions of a space uniform in terms of small color differences viewed against a defined achromatic background are different from those representing a space tiled in terms of Munsell or UCS sized differences. The reason is the apparent fading of the chroma crispening effect with increasing chroma difference magnitude. Another kind of color space is one based on infra threshold differences: color matching error data. Here, increments in Z or S are relatively significantly larger than differences in X or L and M, when compared to supra threshold small and large color differences. Increment ratios compare approximately as follows:[1]

Data set	**Relative size of increment in**	
	S	***L***
Color matching error data (MacAdam Ellipses)	9	1
Munsell, UCS data	6	1
Supra threshold small color differences	3	1

It appears that while the ratio for color matching error data is based on intrinsic sensitivity of the cone receptor system the ratios at larger distances are determined by other, as yet unclear, factors. We have the surprising situation of three different kinds of color spaces that, however, most likely continuously transition from one to the other as unit difference magnitude increases.

It is generally accepted that the two most important organizing principles of our object color experience are hue and lightness. As Munsell has shown first, this leaves room for a third principle that he called chroma. The idea of chroma is only 100 years old and it is for untrained observers not a readily intuitive magnitude, as Melgosa et al. recently have shown again.[2] Painters, with an otherwise keen sense for color relationships, have not created a term for chroma until Munsell. The neurophysiological basis for lightness perception must be quite complex and is not explained by the luminance signal alone, not even for achromatic colors, as Whittle, Gilchrist and others have shown.[3] For chromatic colors there is, in addition, the Helmholtz-Kohlrausch effect. As Helmholtz and others surmised chromaticness contributes to lightness perception. It can be modeled accurately using assumed opponent color signals.[4] The result is a system that is no longer contained within the colorimetric system of color matching. Comparably unknown is the neurophysiological basis for hue and hue difference perception. Color vision scientists currently offer two ideas: 1. there is a single hue detection mechanism that is based on a ratio of two opponent color signals. Two colors with different hues have two different ratios and the hue difference between them is related in some way to the two different ratios; 2. There are several (many) hue detection systems of as yet unknown constitution. Hue differences near the neurophysiologically supported axes L-$2M$ and L+M-S are different from those between the axes.[5] A further complication is that the so far identified neurophysiologically significant axes are not psychologically significant.[6] The accepted psychological axes are those of Hering, represented by the unique hues. They are located (on average) as shown in Fig. 1 in the chromatic diagram formed by the just mentioned axes. The unique hues are averages determined from 40 observers.[7] There clearly still is a disconnect between what we know about the neurophysiology of color vision and what we experience psychologically. There is, to my knowledge, no

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

neurophysiological model explaining the scaling of chroma perceptions. Chroma is connected to the process of hue cancellation. When, for example, increasing amounts of a hypothetical colorant resulting under standard conditions in the perception of the unique green hue are added to concentrations of a colorant resulting in the unique red hue perception and there are judicious additions of a "white" colorant to maintain constant luminous reflectance the resulting reflectance functions change from curves with peaks in the short and long wave ranges to a flat curve and then to one with a peak in the middle wave region. Chroma steps along this continuum involve certain absolute values of opponent color responses that at the same time may signal a particular hue.

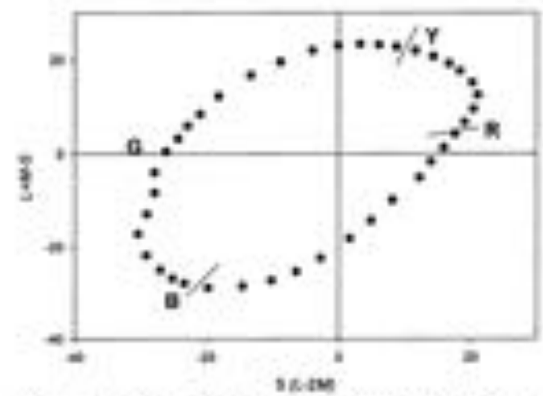


Fig. 1 Munsell V6/C8 hue circle and average unique hues in 5(L-2M) vs. L+M-S diagram, 10° observer.

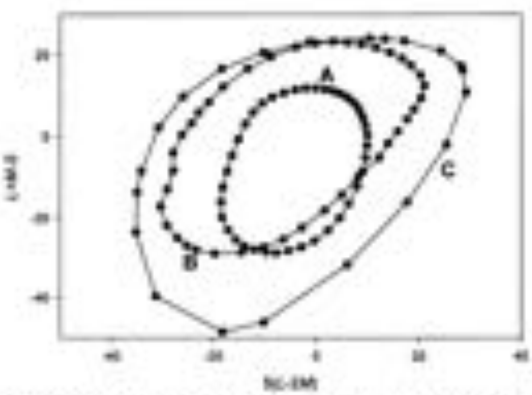


Fig. 2 Three constant chroma contours in the 5(L-2M) vs L+M-S diagram; A:Nickerson et al., B: Munsell Renot. V6/C8; C: OSA-UCS *g,j.*

The experimental record indicates that determination of object colors of constant chroma is difficult. Figure 2 compares in the 5 (*L-2M*) vs. *L+M-S* diagram two direct and one indirect assessements of colors of constant chroma. Contour B reflects the value 6 and chroma 8 hue circle of the Munsell Renotations, contour A the constant chroma colors at value 6 determined by Nickerson, Judd and Nimeroff in 1956 involving 23,040 observations,[8] contour C is calculated from the UCS formula assuming that constant chroma can be calculated as the Euclidean sum of the magnitudes of *g* and *j*. The basic experiment behind UCS did not involve chroma assessments but 76 observers assessed the relative magnitude of complex color differences. The formula fitted to the UCS experimental data contains biases in certain directions in regard to the implied hue and chroma differences. They vary significantly by quadrant. None of the three contours is matched well by CIELAB. It seems to be generally overlooked that constant luminous reflectance small color differences, threshold differences and color matching errors, like the UCS data, do not involve explicit hue and chroma difference assessments but only total color differences. In the case of supra threshold small color difference data hue and chroma differences are implied based on unverified assumptions about the nature of such differences and applicability of the Euclidean space model.

2. SCALING OF THE HUE CIRCLE

The Munsell hue circle has been scaled in terms of 40 perceptually equally different hue steps over a period of some 40 years. This scaling has received a good degree of support from multidimensional scaling data by Indow and his associates.[9] An extensive hue scaling experiment has been performed on the Nickerson-Judd-Nimeroff chroma circle by Newhall, involving 14,484 visual assessments of hue differences.[8] Figure 3 compares the hue angle differences of the Renotations and the Newhall experiment. They are clearly not in agreement. Neither of these experiments included consideration of unique hues. Another kind of scaling of a hue circle has been performed as part of the developement of the Swedish "Natural Color System." Here observers assessed the relative "content" of two unique hues in intermediate hues and in this way chips representing average 10% increments/decrements in unique hue content between two unique hues were selected.[10] That constant unique hue increments are not in agreement with constant perceived differences was commented on by Hesselgren in 1954.[11] The difference is most startlingly made clear by plotting the average experimental unique hues into the Munsell psychological hue diagram (Fig. 4). What startles is that the unique hues (perhaps coincidentally) fall on diametrical lines and that the segments between them vary by a ratio of approximately 1.4:1. A slightly larger ratio is obtained when plotting them into Indow and Aoki's reconstruction of the diagram from multidimensional scaling data.[9] Among the resulting conclusions are: 1. The number of constant sized hue differences between unique hues varies with more differences between yellow and green and blue and red than between blue and green and yellow and red, 2. Constant hue differences are not formed by constant relative increments in unique hue content.

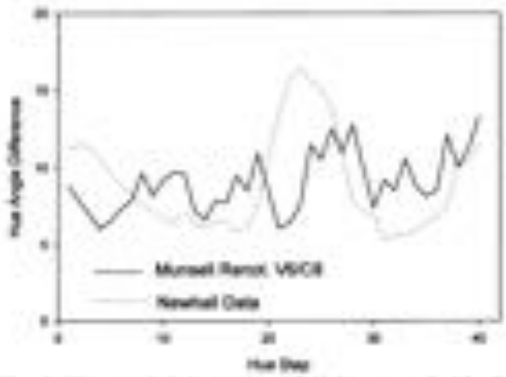


Fig. 3 Hue angle increments of 40 hue steps beginning at hue angle 0° in the linear a, b diagram.

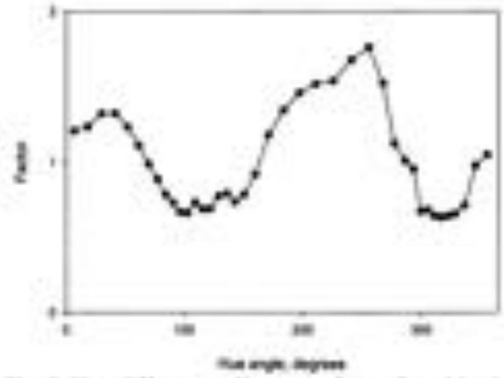


Fig. 5 Hue difference adjustment factor from Newhall experiment, CIELAB formula.

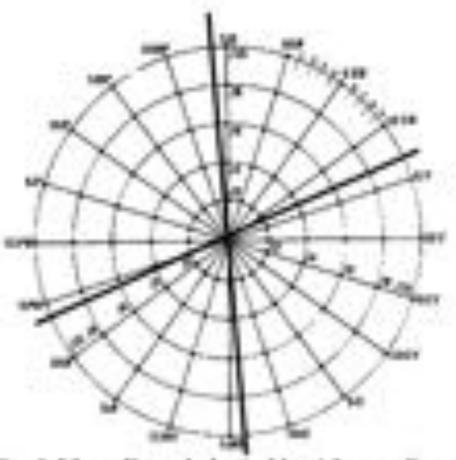


Fig. 4 Munsell psychological hue/chroma diagram with location of average unique hues.

TABLE I Hue angle ranges between unique hues, degrees

Data Set	R-B	B-G	G-Y	Y-R
Munsell Renotations	106	74	106	74
Munsell MDS/Indow	109	72	108	71
DIN	120	45	90	105
Newhall	126	63	108	84
Kuehni[12]	115	65	98	82
Qiao[13]	122	81	81	76
Berns function[14]	126	83	86	65
OSA-UCS	140	69	83	68
Mean	120.5	69	95	78.1
Coeff. of variation, %	8.4	16.2	11.3	15.1

What other support is there for this finding? Table I lists the direct and implied results of various pertinent experiments. The trend is everywhere the same except in the yellow segment of the DIN system. In addition, I fitted a linear model to the MacAdam color matching error data with a coefficient of variation for 100 color differences of 15% and used it to calculate the number of hue "threshold" steps between the average unique hues with the following results: R-B: 127, B-G: 55, G-Y: 94, Y-R: 52. [15] The trend is the same here also. It is evident that significantly different numbers of constant size hue differences between the unique hues is a fact. A careful experiment with the purpose of scaling hue in terms of constant differences of different sizes between unique hues is very desirable. When considering the issue in terms of colorimetry we can locate the unique hues for example in the CIELAB a^*, b^* diagram. Their location differs depending on the standard observer on which the colorimetric data are based. If they are based on the 2° observer the blue, green and yellow unique hues fall close to the a^*, b^* axes. If based on the 10° observer only the green unique hue falls near the a^*- axis. It means that in the 2° observer based diagram there are more constant sized hue differences in the second quadrant than in the third quadrant. In the first and fourth quadrant things are more complicated because the red unique hue always falls into the first quadrant. We do not know what increments/decrements in a^* and b^* are necessary to represent constant sized hue differences. In terms of hue angle differences in this diagram, the Qiao et al. results and the Berns function give some indication that the results are not uniform in terms of such changes. From the Newhall data, applicable to the 2° observer, we can also calculate an hue angle dependent S_H type adjustment function that indicates with what factor the average hue angle of 9° has to be multiplied to result in the hue angle occupied by a constant sized hue difference. This function is shown in Fig. 5, calculated from a^*, b^*. It bears only a vague resemblance to the Berns function (10° observer), that has minima at 75°, 190° and 290°. The biggest discrepancy is in quadrant 2. The Newhall data also allow us to calculate, using hue angle differences, the number of constant sized hue differences per quadrant of the a^*, b^* diagram: Q1: 9, Q2: 12.5, Q3: 6, Q4: 12.5. Given the extensive experimental data behind the Newhall function the discrepancy between that function and the Berns function needs to be investigated and resolved.

3. IS THE *g, j* DIAGRAM UNIFORM?

Using the location of average unique hues in the *g, j* diagram and the mean number of unit hue differences between them as derived from the data in Table I one can estimate the number of such differences (adding up to 40) in each quadrant of the *g, j* diagram. The result is as follows: Q1 and Q2: 11.5 each, Q3 and Q4: 8.5 each. These figures are considerably different from those of the a^*, b^* diagram mentioned above. They indicate that also this diagram is not uniform in terms of hue differences and its chroma scale is different from those of the Munsell system and the Nickerson et al. experiment.

4. DISCUSSION AND CONCLUSIONS

We have arrived at a point where the meaning of *uniform* needs to be defined. In the colorimetric community the term is understood to mean that in a uniform space equal geometrical differences mean equal perceptual differences. However, the Swedish "Natural Color System" color space can also be called uniform. Here, *uniform* has the meaning of equal relative increments in unique hue and in blackness/whiteness based on defined starting and end points. The two are clearly very different. It might be useful to call the latter a "constant relative increment space." To be meaningful, a psychological color space must be based on the psychologically unique hues. As we have seen, such a space cannot be uniform in terms of differences, i.e., equal geometrical distances do not conform to equal perceived differences in all directions. Thus, psychological color space (in form of an Euclidean space) is not homogeneous in terms of perceived differences. A space like the Munsell space may be more homogeneous but it is not a meaningful psychological space as its chromatic axes are not defined. A uniform psychophysical space should mirror a uniform psychological space as closely as possible. In an Euclidean based colorimetric system this is not possible. Opponent color spaces based on either standard observer are not homogeneous. A corollary is that a uniform color space cannot be Euclidean. Euclidean color geometry has been found to fail in other tests also.[16] It develops that our experimental basis for hue and chroma scales is quite tenuous. We do not have a reliable chroma scale despite extensive efforts, as Fig. 2 shows. Table I also indicates that there is considerable variability in hue difference scaling around the hue circle, perhaps in part as a result of the uncertainty in chroma scaling and the possible partial conflation of the two. We have as yet no clear understanding how hue and chroma perception functions and how the brain computes uniformity of differences. We can fairly state that both the Munsell and the UCS systems are only rough approximations of a uniform color space. It is not evident which one is more uniform. Finally, our efforts to fit perceptual color space into an Euclidean system is simplistic. Much fundamental work needs to be done.

References

1. R.G. Kuehni. From color matching error to large color difference. *Color Res. Appl.*, in publication.
2. M. Melgosa, M.J. Rivas, E. Hita and F. Viénot. Are we able to distinguish color attributes? *Color Res Appl* **25** (2000) 356-366.
3. A.L. Gilchrist (ed). *Lightness, brightness, and transparency*. Hillsdale: Lawrence Erlbaum Associates, 1994.
4. R.G. Kuehni. An opponent color model for the Sanders-Wyszecki Helmholtz-Kohlrausch effect data set. Color Res. Appl. *25* (2000) 292-293.
5. M.J. Sankeralli and K.T. Mullen. Ratio model for suprathreshold hue-increment detection. *J. Opt. Soc Am. A* **16** (1999) 2625-2637.
6. E.g. J. Krauskopf. Higher order color mechanisms. In K.R. Gegenfurtner, L.T. Sharpe eds. *Color vision*. Cambridge: Cambridge University Press, 1999.
7. R.G. Kuehni. Determination of unique hues using Munsell color chips. *Color Res. Appl*. **26** (2001 61-66.
8. D.B. Judd. Progress report of the OSA Committee on Uniform Color Scales. *Farbe* **14** (1965) 287-295.
9. T. Indow. Multidimensional studies of Munsell color solid. *Psychological Review* **95** (1988) 456-470.
10. A. Hård, L. Sivik and G. Tonnquist. NCS, Natural Color System – from concept to research and applications. Part I. *Color Res. Appl.* **21** (1996) 180-205.
11. G. Tonnquist. A comparison between symmetrical and equi-spaced hue circles. In *Proceedings of the International Colour Meeting "Color 69,"* Göttingen: Musterschmidt, 1966.
12. R.G. Kuehni. Towards an improved uniform color space. *Color Res. Appl*. **24** (1999) 253-265.
13. Y. Qiao, R.S. Berns, L. Reniff and E Montag. Visual determination of hue suprathreshold color difference tolerances. *Color Res. Appl.* **23** (1998) 302-313.
14. R.S. Berns. Private communication.
15. R.G. Kuehni. Color space and its divisions. *Color Res. Appl.*, in publication.
16. S.M. Wuerger, L.T. Maloney, J. Krauskopf. Proximity judgments in color space: tests of a Euclidean color geometry. *Vision Res.* **35** (1995) 827-835.

Author address: 4112 Blaydes Court, Charlotte, NC 28226, rkuehni@carolina.rr.com.

Determination of industrial colour tolerance limits, case studies in the textile industry

Jennifer Gay* and Robert Hirschler**, SENAI/CETIQT, Rio de Janeiro, Brazil

ABSTRACT

The approach and findings during the application of instrumental colour quality control in industry are described, where the best tolerance formulae and tolerance limits were determined by correlating visual and instrumental evaluations. A panel of previously tested observers evaluated a collection of samples taken from production and colour measurements are then compared to these assessments, according to different colour difference formulae. The formula and the limit giving the best agreement with visual evaluations were determined with two different methods. For a large variety of textile substrates, processes and market situations the CMC(2:1) formula was always the best or one of the bests, but the limits varied widely, according to the individual application. Additional shade sorting, based on the tolerance limit, was also applied in several companies. The ideal box size was also determined by comparing visual and instrumental evaluations. The application as logistical tools was established according to individual necessities.

Keywords: Instrumental colour control, tolerance limit, colour difference, shade sorting, industrial application

1. INTRODUCTION

Instrumental colour quality control is even today one of the most controversial issues of applied colour science. While a number of European countries have already standardized on the CMC tolerance formula, it is still being debated elsewhere. BFD does not seem to have caught on, and there are very few industrial experiments published with the CIE 94 formula.

For the past 6 years the authors have been involved in developing instrumental pass/fail methods for a number of large textile companies in Brazil as well as the Brazilian Navy. These companies work with varied textile products, such as dyed yarn, knitwear, 100% cotton heavyweight drill, 100% cotton lightweight fabric and fibre mixtures with acetate, silk, polyamide and polyester. They attend the fashion segment with short yardages, sportswear with larger productions and utility wear with strict requirements as to colour fidelity.

The basic approach of establishing an appropriate colour tolerance is that of

1. Selecting a panel of visual observers whose colour vision has been tested by three different tests according to ASTM *E 1499-97*[1], and who have day-to-day experience in visual pass/fail decisions in the company.
2. Selecting a number of different colour standards from the company's colour cards, some being considered representative and others known as "difficult", and collecting a large number of samples around these standards from the daily production.
3. Making visual pass/fail assessments with the members of the panel on the sample collection and their standards.
4. Calculating the number of wrong instrumental decisions (using the panel decision of visual assessment as a criterion for pass or fail) with the following formulae: CIELAB, CMC(2:1), CMC(1:1), BFD(2:1), BFD(1:1) and CIE94 and finding the tolerance limit itself (utilizing a proprietary software): the formula and tolerance limit giving the lowest number of wrong decisions being considered the best.

2. VISUAL TESTS

Several hundred observers have been tested in more than 12 textile and other industrial units using the Farnsworth-Munsell 100-Hue, the HVC Color Vision Skill and the Japanese Color Aptitude tests. Details of the results and some considerations on the tests themselves will be reported in another paper submitted to this Conference[2]. Only observers with better than medium classification in both the FM-100 and the HVC tests were selected for the panels. Apart from having the aptitude of distinguishing small colour differences the members of the panel also need to have working experience in the company's quality control or any other area that is in contact with the customer and they need to know, even if not being able to express or explain, what is considered a pass or a fail by the company.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

3. VISUAL PASS/FAIL ASSESSMENTS

Over the years approximately 50 000 visual assessments were collected and in each factory several hundred standard/sample pairs were evaluated by their visual panel of 6 to 14 professionals. The "right decision" of approving or rejecting a sample in comparison with its standard was taken as the judgement of the majority of the panel (at least 50%).

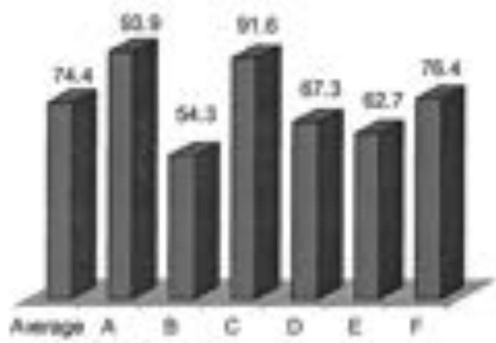


Figure 1: Right visual assessments (%) of six colourists (A to F) for passed samples

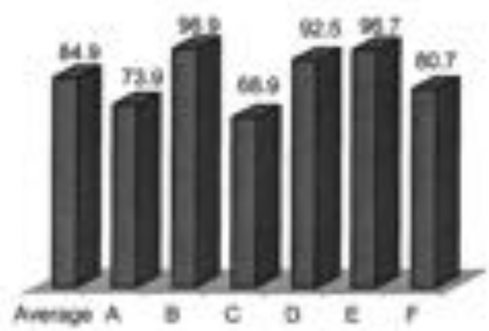


Figure 2: Right visual assessments (%) of six colourists (A to F) for failed samples

In the example taken from one company (Figures 1. and 2. above) six trained colourists evaluated 30 colour standards with approximately 40 samples each, a total of 1200 samples. Some of observers (A and C) evaluated passed samples correctly most of the time (93.9 resp. 91.6% right decisions) but in the case of samples rejected by the majority they did not agree in 26.1 resp. 31.1% of the cases. They are too lenient observers: when in doubt, they pass. Observers B, D and E are too severe, when in doubt, they reject. (In another company one of the observers rejected 55% of the samples passed by the majority of the panel!) Finally observer F is quite consistent, having 23.6 resp. 19.3% wrong decisions. The percentage of wrong decisions made by observer F and by the average of this company's panel can be considered representative, as these values of 15% to 25% of wrong visual decisions repeat themselves over the 50 000 visual assessments made in eight different companies (Figure 3.), confirming the findings in the classic studies of McLaren[3]. The surprisingly high fraction of ¼ of wrong decisions made on average by all visual observers, in this case excluding psychological factors such as fatigue or pressure from superiors or customers they additionally are exposed to in daily situations, is one of the main reasons and most convincing arguments to migrate from visual to instrumental colour quality control.

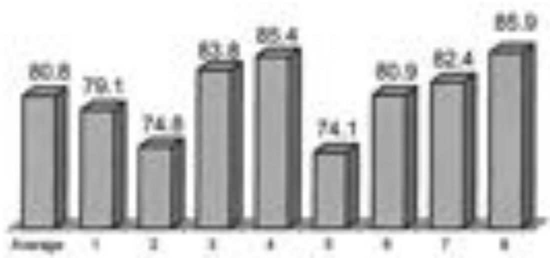


Figure 3: Right visual assessments (%) in eight different textile companies

4. INDUSTRIAL TOLERANCES BASED ON THE NUMBER OF WRONG INSTRUMENTAL DECISIONS

A simple software developed by the authors compared the instrumental and visual (panel) decisions and calculated the number of wrong instrumental decisions (i.e. those not agreeing with the panel) for different "commercial factors" between DE=0.0 and DE=3.0 at increments of 0.03 units. The DE value with the highest rate of right decisions was taken as the tolerance (pass/fail) limit. This differential approach can be compared with the cumulative approach[4] and the result, the tolerance limit with the highest number of right decisions, is very similar in both approaches, as Figure 4 and 5 show. The main difference being that the differential method gives additional information if this is the only possible limit and if it is clearly defined or if several limits are possible.

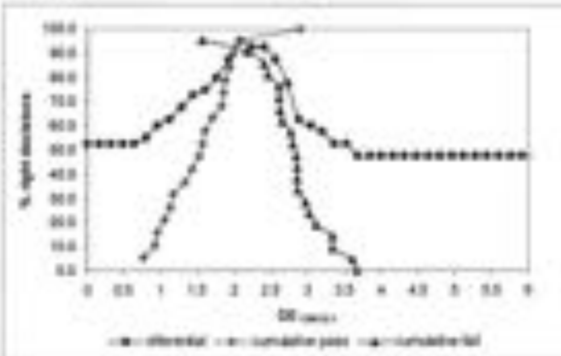


Figure 4: Comparison of evaluation methods
Sample set with a clearly defined limit

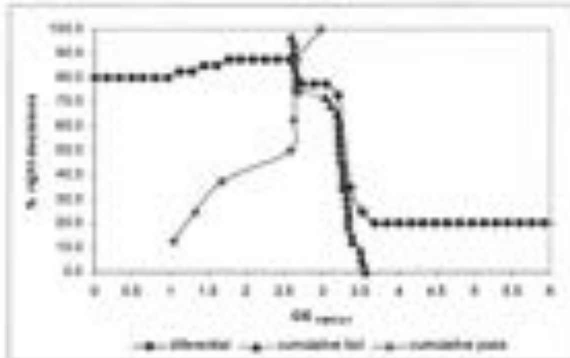


Figure 5: Comparison of evaluation methods
Sample set without a clearly defined limit

In all the cases evaluated with the differential method the CMC(2:1) formula gave the best result, sometimes CIE 94 and/or BFD being equally good (but in no case significantly better). Depending on the product mix and the marketing policy of the companies the tolerance values were found to be between 0.7 and 2.5 CMC(2:1) units. The ratio of wrong instrumental decisions was generally in the order of 15% but always better than the average of the wrong individual decisions of the panel as can be seen in Figure 6. It's interesting to note, that there is only a slight improvement in the ratio of right instrumental assessments since the days of the FMC-2, 3√ and ANLAB formulae, which gave about 80% RIA for the Davidson-Friede data set (McLaren[7]).

Company	CMC(2:1)		CMC(1:1)		CIE94:1		CIE94:2		CIELAB		BFD:1		BFD:2	
	Tolerance	RIA %	Tolerance	RIA %	Tolerance	RIA %	Tolerance	RIA %	Tolerance	RIA %	Tolerance	RIA %	Tolerance	RIA %
1	1.3	79.6	1.6	74.1	1.5	71.8	0.8	77.9	1.5	71.9	1.7	75.7	1.2	78.9
2	0.7	74.8	1.3	71.0	0.8	71.0	0.6	72.0	1.4	71.5	1.3	72.0	0.8	74.0
3	1.1	88.5	2.0	80.1	2.0	77.2	1.1	85.0	2.0	80.5	1.9	85.0	1.3	88.5
4	0.7	72.5	0.7	48.7	0.9	69.2	0.8	65.6	1.1	71.3	1.5	59.4	0.6	70.8
5	1.0	69.9	1.7	69.0	1.1	67.1	0.7	68.8	1.3	67.3	1.8	68.0	1.1	71.6
6	0.7	79.3	0.9	79.3	0.7	75.2	0.6	78.6	1.0	76.2	1.0	78.6	0.9	76.5
7	2.5	85.5	2.3	77.5	2.1	83.3	1.8	87.0	2.8	77.8	3.7	82.3	3.0	85.0
Average		78.6		74.2		73.8		76.4		73.7		74.1		77.4

Figure 6: Right instrumental assessment (RIA %) for different tolerance formulae and limits in six different textile companies

Although the aim was always to arrive at a single tolerance limit for the full production range within the company, in some cases different limits had to be applied for different products, or for some of the colours in the product range. The tolerance limit was established first for every single colour, then for every group of products and at last all the data were pooled and one universal tolerance limit for the company was calculated. If any of the individual tolerances differed strongly from the pooled value, both options were tested in practice in comparison with visual evaluations and the decision was then taken favouring the option that gave the best practical results. In one company the tolerance limit was established as 0.8 CMC(2:1) unit, but for the same range of cotton fabrics when suede finished the limit needed to be increased to 1.2. In another case a commission dyer (cotton yarns) had all the preparatory work done excellently, and arrived to the instrumental limit of 0.8 units. The factory, however, could not control the production well enough for this level, and doubled the tolerance limit to 1.5. Customer complaints have been pouring in ever since. A third company took a different approach and evaluated the performance of each colour and product very carefully at the end of every month. They found out where their weak points were, which colours and products they were doing worst in, and focused on improving recipes or process in order to have mores samples within the tolerance the following month. Their percentage of passed samples increased significantly, they were able to tighten their tolerance limit and enter into a different market segment.

It was also confirmed in practice that the tolerance limit really is a commercial factor and is not related to the colour or substrate. Two of the companies with which this work was done produce exactly the same type of product in very similar colours, one of them is working with a commercial factor of 2.4 $CMC_{2:1}$ units and the other with 0.7 $CMC_{2:1}$ unit. Both are working well with their limits and are keeping their customers satisfied.

5. SHADE SORTING

Some of the textile factories, when introducing instrumental pass/fail, opted to also implement 555 shade sorting[5]. Generally the reason for this decision was to provide their customers, the garment manufacturers, with auxiliary information on how to cut the fabric. Receiving this additional data has become a commercial argument to buy from one supplier or the other.

The previously established tolerance limits were taken into consideration when the size of the 555 "boxes" was determined. The sides of the boxes were found to be generally half of the tolerance limits, but in some cases they had to be reduced to one third. The ideal box size was determined once again by the panel. A selection of groups of colour samples was shade sorted according to different box sizes and the separations of the samples into different shades where presented to the members of the panel, starting with the biggest boxes and gradually reducing the size. The members of the panel gave their opinion if the separation was satisfactory or if there were still some samples in the group that should not be there because they could cause problems if cut and sewn together with the others. The box size that was accepted by the majority of the panel was the adopted as the one to be used by the company.

Depending on the market segment served by the company, the shade sorting limits could be very different even for the same product group. For example, Company A (supplying denim and drill for a demanding market) has been using DL=DC=DH= +/- 0.25 ($CMC_{2:1}$ units), while company B (supplying very similar articles for a less demanding market) is getting away with DL=DC=DH= +/- 1.0 ($CMC_{2:1}$ units).

As shade sorting is much more a logistical tool than quality control itself, one of the important aspects is how to attend a customer's order with the fabric the company has in stock or produced to order. A successful practical application goes beyond establishing the ideal box size. At this stage the fabric has already been dyed, finished and cut into small rolls ready to be shipped to the customer. Ideally each order should be attended with one single shade, one 555 code, but this is not always possible because the order is very large or the dyeing process not very uniform. The criteria which codes can be sent together with others need to be established very carefully to be able to attend the customer in a satisfactory manner. The best results were found by selecting directly adjacent shades, giving preference first to lightness, then to chroma and last to hue, following the increasing human sensitivity to different types of colour difference.

6. SUMMARY

The experience of several years of work in applying instrumental colour quality control in industry show that for textiles the CMC(2:1) formula provides the best correlation between visual and instrumental colour assessment. The tolerance limit, though, needs to be established individually and the approach described in this paper has lead to valid results proven by their day-to-day utilization in several major Brazilian textile companies. The application goes beyond the mere implementation of scientific findings, as the settings encountered in the industrial environment of each individual enterprise surely need to be taken into consideration to develop a system robust enough to survive in a real-life surrounding. The method of determining the tolerance limit applied by the authors has given the necessary robustness and awareness of possible weak points. Especially in shade sorting the most crucial part for a successful application of the methodology is the determination how to make best use of the results, how to put together a customer's order according to the different shades available.

REFERENCES

1. ASTM E 1499-97 *Standard Guide for Selection, Evaluation and Training of Observers.*
2. Hirschler, Gay and Oliveira: *Field Trials of Three Tests for Colour Vision and Colour Aptitude*, AIC 01, Rochester
3. K. McLaren, *Colour Passing – Visual or Instrumental?* J. Soc. Dyers & Col. **86** 389-393 (September 1970)
4. R. S. Berns, *Deriving Instrumental Tolerances from Pass-Fail and colorimetric Data*, Color R&A. **21** 459-472 (1996)
5. F. T. Simon: *Small color difference computation and contro.l* Farbe **10** 225-234 (1961)

Correspondence: SENAI/CETIQT Applied Colorimetry Laboratory, Rua Dr. Manuel Cotrim, 195, Riachuelo, Rio de Janeiro, 20961-040, Brazil, Fax: 55-21-2410495, *lgav@cetiqt.senai.br, phone: 55-21-582-1017; **rhirschler@unido.org, phone 55-21-582-1029

Lightness-difference data set for evaluation of CIELAB-based colour-difference formulae

Dong-Ho Kim*[a], Hee Kang Song[b], Jae Pil Kim[b],
[a]Ewha Color and Design Research Institute, Ewha Womans University, Korea
[b]School of Materials Science and Engineering, Seoul National University, Korea

ABSTRACT

A new colour-difference data set has been produced to evaluate the lightness difference weighting functions of eight CIELAB-based formulae: CIELAB, CMC, CIE94, DCI-95, LCD97, LCD99, BFD-II, and CIEDE2000. Glossy polyester fabric was dyed to prepare 220 colour-difference pairs, each having mainly lightness-difference. The grey-scale method was used to assess the colour-difference of each pair by an average of twenty-five colour normal observers. The test results of the visual data are presented.

Keywords: lightness weighting function, grey scale, CIELAB, CMC, CIE94, Leeds colour difference (LCD), CIEDE2000

1. INTRODUCTION

Numerical colour control by instrumental measurement has been widely accepted in the coloration industries as it provides an objective colour evaluation and improves the efficiency in pass/fail tests, hence reducing the time and cost in the coloration process. However, it is only useful when we have the reliable colour-difference equation that could well correlate between instrumental and visual measurement results. A great deal of efforts has been made to devise the advanced equation through carefully controlled visual experiments.

The first author, Dr. Kim, of this paper has carried out a colour-difference evaluation works since 1993. As part of the Ph.D. project[1] with his supervisor, Dr. Nobbs, in the Department of Colour Chemistry and Dyeing of the University of Leeds, England, during 1993 to 1997, Kim quantified the influence of parametric effects on the appearance of small colour differences as well as developed a colour-difference equation through the modification of the weights of the CIE94 equation. Kim and Nobbs named the new equation as the Leeds Colour Difference (LCD)[2]. In 1999, at the 24th session of the Commission International de l'Eclairage (CIE), Kim[3] reported the results of the evaluation of several CIELAB-based colour-difference equations with a data set prepared by a M.S. student, Ms. Cho[4], in the Department of Fiber and Polymer Science of the Seoul National University (SNU), Korea. The LCD equation has shown the best performance, even better than CMC[5] and CIE94[6] equations, to the Cho data obtained from the grey-scale (denoted GS hereafter) assessments of 570 textile colour-difference pairs evenly well distributed in the CIELAB space.

This paper is based on the new data set produced as part of the M.S. project[7] by Ms. Song in the School of Materials Science and Engineering of SNU. (The Fiber Science Department is combined to the Materials Science School in 2000.) It is the continuation of the above described colour-difference evaluation researches. In the Song data, a particular emphasis was laid on the test of the lightness-difference weighting functions of the currently available and reliable colour-difference equations.

2. EXPERIMENTAL

Two hundred twenty colour-differences ranging from 0.7 to 12.0 CIELAB units (ΔE^*) were selected from the pair combination of several hundred dyed glossy polyester fabric samples. Around 80 percent of colour-difference pairs satisfied the primary requirement of varying along the lightness (L^*) axis direction in the CIELAB space, i.e., $|\Delta L^*/\Delta E^*| > 0.85$. The mean L^* value of each pair varied from 24.6 to 90.8, and the mean colour-difference of all pairs was 4.2 ΔE^* units. Among 220 pairs sampled, there were 151 neutral grey and 69 chromatic pairs.

Each colour-difference pair was prepared from 5.0 x 6.5 cm^2 cut rectangle samples attached to hard cardboard side to side

 9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

with a hair-line gap (separation) between them. The sample pairs were measured with a Macbeth Color Eye 3000 spectrophotometer in specular component excluded (SPEX) and UV included modes. In each pair, CIELAB co-ordinates of samples and the colour-difference were calculated for the Illuminant D65 and the 10° Observer. Instrumental measurements were repeated 2 times: before and after the visual tests. The standard deviation (error) in measured colour-difference value was 0.1 ΔE^* unit.

Visual assessments were carried out in a GretagMacbeth The Judge-II Lighting Booth with approximate 0/45 illuminating/viewing geometry. The simulated fluorescent daylight had a correlated colour temperature of 6500°K, and the L^* value of the booth's bottom (background) was about 60. Twenty-five colour normal observers assessed each test colour-difference pair against a 9-step GS pairs of the same size as the test. The GS was produced following ISO 105-A02, fastness testing for assessing change in colour. The observers were asked first to pick the GS pair thought to be closest in magnitude to the test pair, then to answer a GS grade up to 1 decimal place, e.g., 3.2.

In the preliminary stage of experiments, two types of GS were produced by using two different substrates: textile and paint. The textile GS pairs were made by dyeing the same polyester fabric as those for the test. The paint GS pairs were made by coating matte pigment pastes on the flat and stiff paperboard. The values for textile GS grades and corresponding colour-differences ΔE^* were given in Figures 1 and 2. The 7th order polynomial equation relating GS grade and ΔE^* was found using a common computer curve-fitting software:

$$\Delta E^* = (73.418183) + (-165.76303)(GS) + (193.10693)(GS)^2 + (-123.85946)(GS)^3 \\ + (45.294242)(GS)^4 + (-9.4201664)(GS)^5 + (1.0374465)(GS)^6 + (-0.046984128)(GS)^7 \quad (1)$$

The coefficients of correlation and determination and the standard deviation of the fitting were 0.99997, 0.99994 and 0.09823, respectively. The colour difference, ΔE^*, calculated from Eq.1 can be regarded as the visual difference, ΔV. Thus, all ΔV values were estimated from Eq.1. A similar regression equation was sought for the paint GS, however, the equation had not good correlation as that for the textile. Moreover, the inherent difference in appearance of the paint GS produce a greater variability than that from the textile. Though, in the main experiment, the data were also gathered using the paint GS, they were excluded in the further analysis.

3. RESULTS AND DISCUSSION

The level of uncertainty of the visual data was quantified adopting the similar procedures used by Luo[8] and Kim[3]. The standard error was ±9.4% slightly larger than those of previous studies. For reference, the precisions of other representative colour-difference data sets were ±8.7% (Kim[1]), ±8.9% (Luo[8]), and ±5.7% (Berns[9]), respectively.

In Figure 3, for each colour-difference pair the normalised lightness difference ($\Delta E^*/\Delta V$) is plotted against the mean CIE lightness L^*. The pattern of the distribution of data points in the plot is rather similar to those in Figure 4 that was prepared by Kim[3]. Figure 4 is a plot of the selected lightness dependent data points from the Cho data[4]. It showed, however, the fan-shapes at the low and high extreme lightness levels, and the Song data showed slightly a V-shape through the all lightness levels. Moreover, the average normalised lightness difference values were quite different: 1.15 (Song[7]) and 2.15 (Cho[4]), respectively. It is not expected as the colour-difference pairs of both data sets were made from the same kind of substrate (polyester fabric) and they were assessed by the same visual method (GS).

Figure 5 shows the overall performance of eight CIELAB-based colour-difference formulae: CIELAB, CMC[5], CIE94[6], DCI-95[10], LCD97[3], LCD99[1], BFD-II[1], and CIEDE2000[11]. The performance test was carried out by setting the lightness relative tolerance (l or lightness parametric factor K_L) of all equations to 1. The increasing order of variation (disagreement) to the visual data for these 8 equations is as follows (the % PF/3 values are in the parentheses):

CIE94 or LCD99 (20) < CIELAB (23) < DCI-95 (25) < CIEDE2000 (26) < BFD-II (28) < LCD97 (29) < CMC (30)

It is interesting that CIEDE2000 showed the better performance to CMC but not to CIE94 for this data set. The validation of the V-shaped new lightness-difference weighting function of CIEDE2000 might need more well controlled visual data sets.

The supplementary test results of the CIEDE2000 for other data sets those not being necessarily lightness-dependent are given in Figure 6. CIEDE2000 showed the performance as good as LCD99 and BFD-II those showing the top class performances for these three data sets. CIEDE2000, however, failed to show the outstanding performance to these sets.

Though there might be a limitation of improving the performance of the CIELAB-based colour-difference equation, the complexity of any given equation is only justified when the performance of that equation certainly exceeds those existing similarly and theoretically based. It seems that, in the current status, the quantification of the mechanism of the lightness-difference perception would be more difficult than the chroma or hue difference evaluation.

4. CONCLUSIONS

A new lightness difference data set has been produced to test the performances of the major advanced CIELAB-based colour-difference formulae. The performance of the new CIE recommended equation, CIEDE2000, was not good as expected for the new data set. For more objective comparison and evaluation to be made, a great care must be taken in the visual tests and data gathering process. It seems that we still need more reliable lightness difference data sets for the elaborate lightness difference weighting calculation. In addition, though it was a long way leading to CIEDE2000, now would be the time for us to reserve for the new CIE colour-difference equation.

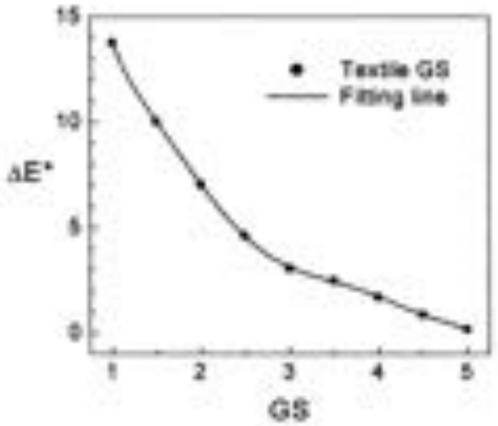


Figure 1. GS vs. ΔE^* for textile grey-scale pairs.

Grade	ΔE^*_{act}	ΔE^*_{cal}	Diff.
5	0.19	0.19	0.00
4-5	0.89	0.88	-0.01
4	1.72	1.74	0.02
3-4	2.51	2.46	-0.05
3	3.10	3.16	0.06
2-3	4.65	4.60	-0.05
2	7.07	7.09	0.02
1-2	10.03	10.02	-0.01
1	13.77	13.77	0.00

Figure 2. GS and ΔE^* values of textile grey-scale pairs. (The subscripts act. and cal. denote the values from the colour measurement and those calculated from the regression Eq.1.)

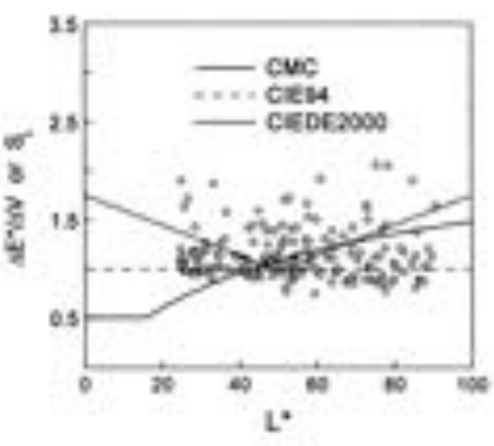


Figure 3. Normalised lightness difference vs. mean L^* for each pair of the Song data[7] with lightness difference weighting functions of CMC, CIE94, and CIEDE2000 equations.

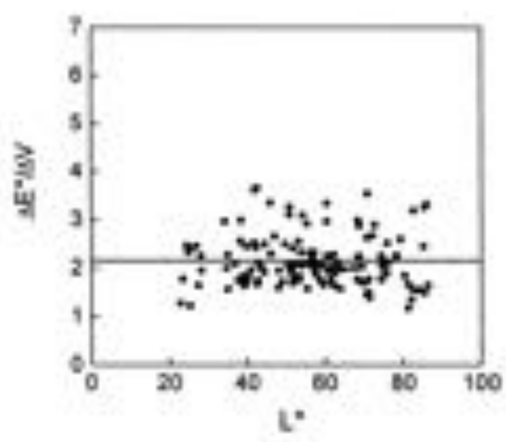


Figure 4. Normalised lightness differences vs. mean L^* values for selected pairs of the Cho data[8].

Formula	PF/3[a]	PF/4[a]
CIELAB	23	18
CMC	30	24
CIE94	**20**	**16**
DCI-95[b]	25	19
LCD97	29	23
LCD99	**20**	**16**
BFD-II	28	23
CIEDE2000	26	21

Figure 5. Performance of the lightness difference weighting functions of 8 colour difference equations to the Song data[7]. [(a) Performance factor (PF or PF') is an indicator of goodness of fit of a given equation, and (b) P_1 and P_2 parameters of DCI-95 are set to 0.001 and 0.050, respectively.]

Data Set	Luo	Berns	Cho	Overall
No. of pairs	533	163	570	-
Measure[a]	PF/4	TSD	PF/4	-
f (or K_L)[b]	1.5	1.0	2.0	-
CIELAB	47	36	37	40
CMC	29	28	25	27
CIE94	26	21	23	23
DC1-95[c]	28	23	24	25
LCD99	22	**19**	**21**	**20.7**
BFD-II	**21**	20	23	21.3
CIEDE2000	22	20	**21**	21.0

Figure 6. Performance of seven colour-difference equations to the Cho data[4]. [(a) Tolerance standard deviation (TSD) is also an indicator of goodness of fit of a given formula, (b) K_L values of DCI-95 are 0.75, 0.5, 1.0 for the Luo, Berns, Cho data sets, respectively, and (c) P_1 and P_2 are set to 0.001 and 0.050, respectively.]

ACKNOWLEDGMENTS

The authors wish to thank Prof. Keelhong Kim of the Ehwa Womans University, the Director of the Ewha Color and Design Research Institute, for allowing us to use the lighting booth and for providing financial support to take part in this AIC Color 01 Rochester congress.

REFERENCES

1. D. H. Kim, The influence of parametric effects on the appearance of small colour differences. Ph.D. Thesis, University of Leeds, England, 1997.
2. D. H. Kim and J. H. Nobbs, "New weighting functions for the weighted CIELAB colour-difference formulae," Proc. AIC 8th Congress - AIC Colour 97 Kyoto, **1**, pp. 446-449, 1997.
3. D. H. Kim, "New colour-difference data set for evaluation of CIELAB-based colour-difference formulae," Proc. CIE 24th Session - Warsaw '99, **1**, pp. 23-27, 1999.
4. E. K. Cho, The evaluation of CIELAB-based colour-difference formulae using a new colour-difference data set, M.S. Thesis, Seoul National University, Korea, 1999.
5. F. J. J. Clarke, R. McDonald, and B. Rigg, "Modification to the JPC79 colour difference formula," J. Soc. Dyers Col. **103**, pp. 128-132 (1984).
6. CIE Publ. No.116, Industrial colour-difference evaluation, CIE Central Bureau, Vienna, 1995.
7. H. K. Song, Lightness-difference data set for evaluation of CIELAB-based colour-difference formulae, M.S. Thesis, Seoul National University, Korea, 2001.
8. M. R. Luo, New colour-difference formulae for surface colours, Ph.D. Thesis, University of Bradford, England, 1986.
9. R. S. Berns, D. H. Alman, L. Reniff, G. D. Snyder, and M. R. Balonon-Rosen, "Visual determination of suprathreshold color-difference tolerances using probit analysis," Color Res. Appl. **16**, pp. 297-316, 1991.
10. E. Rohner and D. C. Rich, "Eine angenähert gleichförmige metrik für industrielle farbtoleranzen von körperfarben (An approximately uniform object color metric for industrial color tolerances)", Die Farbe **42**, pp. 207-220, 1996.
11. M. R. Luo, private communication.

----

* Correspondence: donghokim@korea.com; phone +82-(0)2-3277-4402; fax +82-(0)2-3277-3730; http://colordesign.ewha.ac.kr/; Ewha Color and Design Research Institute, 12-14 Fls. International Education Building, Ewha Womans University, 11-1 Daehyun-dong Seodaemun-gu, SEOUL 120-750, Korea.

Visually assessed colour description including the luminance of the background

Eva Lübbe

ABSTRACT

In many technical areas of the colouring industry, like printing, textile- and automotive industry, colouring is controlled by colour measurement and colour-difference evaluation. However, colour- difference formulae used in practice are not well adapted to human perception.

There are two formulas presented which calculate the colour differences better adapted to human perception. Both formulas correct the CIE-76 formula. One of this formulas has the advantage, that it is very simple. That's why measurement results can be corrected in a simple way after measurement.

There is another formula given which allows including the luminance of the background in the colour measurement. So far the luminance of the background was out of consideration by colour measurement, although the background is very important in colour vision.

Keywords: colour difference, colour difference formulas, luminance of the background

1. INTRODUCTION

Making colour measurement you see that the colour difference formulas in many cases are not adapted to human perception. Because of this I have tried to make the formulas better adapted to human perception.

There are many differences between a colour measurement and the human vision. Many effects of the human vision are without any consideration by colour measurement. So the measurement does not include the background of the measurement field. In the human vision we know the phenomenon's simultaneous contrast and successive contrast.

I have tried to get a formula, which includes the luminance of the background in the colour measurement.

2. CORRECTION OF THE COLOUR DIFFERENCE

The colour difference formula CIE 76 [1] is in many cases not good adapted to human perception.

The CIELAB formula calculates the colour differences ΔE^*_{ab} of colours with a big chroma to large. The colour difference should be corrected by means of the chroma. Because of this, corrections were investigated which correct ΔE^*_{ab} by means of the chroma. The following formula (2) corrects all three parts of the CIELAB-formula in a way similar to CIE94 and also similar to the formula (1) presented in 1993 from the author.

$$\Delta E^*_{93} = \frac{\Delta E^*_{ab}}{1+\frac{C^*_{ab}}{70}} = \left[\left(\frac{\Delta L^*}{1+0{,}014C^*_{ab}}\right)^2 + \left(\frac{\Delta C^*_{ab}}{1+0{,}014C^*_{ab}}\right)^2 + \left(\frac{\Delta H^*_{ab}}{1+0{,}014C^*_{ab}}\right)^2\right]^{1/2} \qquad (1)$$

Experiments was done with colour pairs only different in luminance or chroma. The experiments shows that the terms for the corrections should dependent on the ratio of luminance and chroma. In the new formula we have combined luminance and chroma terms for the correction of luminance and chroma differences as follows:

$$\Delta E^*_{ad} = \left[\left(\frac{\Delta L^*}{1+S_L\left(1-\frac{|\Delta C^*_{ab}|}{|\Delta L^*|+|\Delta C^*_{ab}|}\right)C^*_{ab}}\right)^2 + \left(\frac{\Delta C^*_{ab}}{1+S_C\left(1-\frac{|\Delta L^*_{ab}|}{|\Delta L^*|+|\Delta C^*_{ab}|}\right)C^*_{ab}}\right)^2 + \left(\frac{\Delta H^*_{ab}}{1+S_H C^*_{ab}}\right)^2\right]^{1/2} \qquad (2)$$

with $S_L = 0{,}022$ $S_C = 0{,}042$ $S_H = 0{,}014$.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

A test of these formulas (1) and (2) shows, that these formulas better correct the CIELAB-formula than before, especially realated to the CIE94-formula in the cases of large colour differences and colour pairs which are different mainly in luminance. [5]

In figure 1 we have a comparsion of four colour difference formulaes ΔE_{93}, ΔE_{94}, ΔE_{vu} and ΔE_{sd} with the visuell colour differences ΔE_{vis} and with the correlation coefficients.

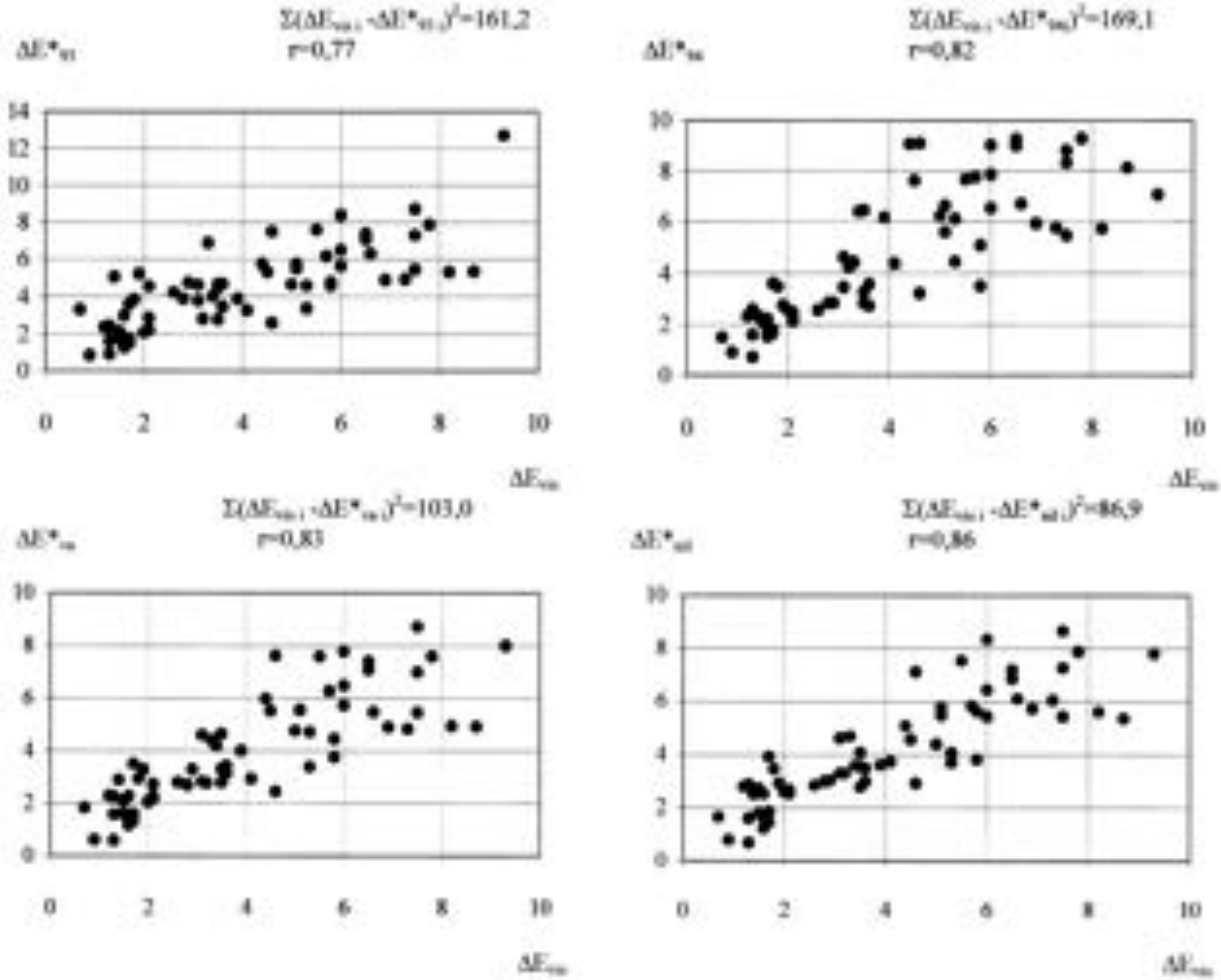


Fig.1 Comparison of ΔE* formulas

The function ΔE_{vu}^* has the following shape:

$$\Delta E_{vu}^* = \left[\left(\frac{\Delta L^*}{1+0{,}013C_{ab}^*}\right)^2 + \left(\frac{\Delta C_{ab}^*}{1+0{,}032C_{ab}^*}\right)^2 + \left(\frac{\Delta H_{ab}^*}{1+0{,}014C_{ab}^*}\right)^2\right]^{1/2} \qquad (3)$$

The investigations of visuell colour differences ΔE_{vis} were done with colour pairs on a white background [3,5].

The adaption of the eye to the background provokes that the largest colour differences are seen if the colour pair is presented on a background with the same lightness. This is the expression of the crispening effect described by Takasaki.[6]

3. INFIELD LUMINANCE AFFECTED BY LUMINANCE CONTRAST TO THE BACKGROUND

If we look at pictures in photo-albums or at pictures with passepartouts on a wall we often have a black or white background. If we want to print pictures displayed on a monitor we see it at a grey background on the monitor and at a white sheet as background after printing. We know of the serious effect of these variable backgrounds on colour precepts that are not described by simple colorimetry.

In reality, we have to distinguish between two effects in simultaneous contrast: the chromatic contrast and the luminance contrast. Chromatic contrast means the influence of the background chromaticness on the chromaticness of the infield and luminance contrast means the influence of the luminance of the background on the luminance of the infield. The chromaticness of the background causes a chromaticness in the infield that is nearly complementary to the chromaticness of the background.

There are many works about simultaneous contrast and luminance contrast, but we have no solution of this problem. The formulas given for the luminance contrast are very different and complicated. Some formulas use the distance between infield and background and some try to use only the luminance of the infield and of the background. But the human vision is more complicated and we have to look for a solution in practice.

Let L^* be the luminance of the infield and L_u^* the luminance of the background. Then the effective luminance of the infield $L^{*\prime}$ is written as follows:

$$L^{*\prime} = L^* - f(L_u^*, L^*) \cdot (L_u^* - L^*) \qquad (4)$$

To determine the quantity f some investigations were done. The method consisted in choosing pairs of colours so that the pairs look equal if they were put on different backgrounds.

For example grey scales on five different grey backgrounds were investigated. The following table 1 shows CIELAB L^*-values that appeared equally light on the five backgrounds .

Tab. 1 Luminance's looking equal on five different backgrounds

greyscale	background				
	black L^*_u=11	dark grey L^*_u=28	middle grey L^*_u= 48	light grey L^*_u= 67	white L^*_u=90
1	11	14	16	18,5	25
2	21	30	39	46,5	54
3	40	44,5	50	60,5	69
4	54	58	64	69,5	81
5	64	69,5	75,5	81,5	89
6	75,5	81,5	88	93	94

The function f depends on the luminance of the infield and also on the luminance of the background. A good description of the data is given by:

$$f = 0{,}53\frac{L^*}{L^*_u} + 0{,}06 \quad \text{for } 0{,}53L^*_u + 0{,}06 < \frac{-L^*}{125{,}8 - 0{,}629L^*_u} + 0{,}846 + 0{,}00588L^*_u \qquad \text{and}$$

$$f = \frac{-L^*}{125{,}8 - 0{,}629L^*_u} + 0{,}846 + 0{,}00588L^*_u \qquad \text{in the other cases.}$$

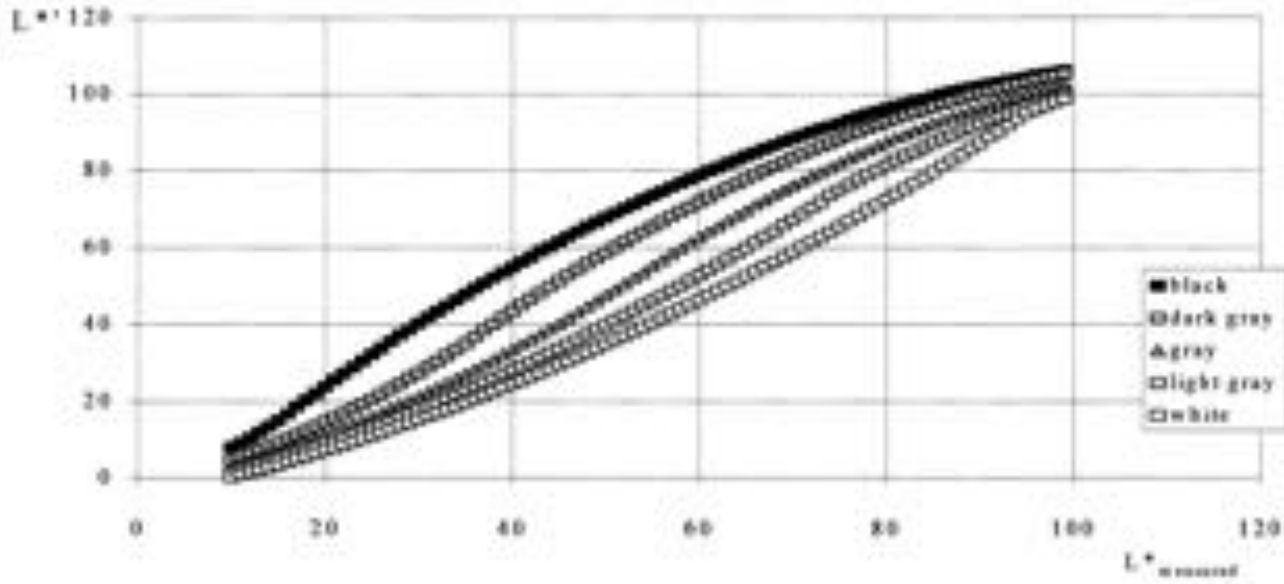


Fig.2 Influence of the luminance of the background on the luminance of the infield

The first investigations were done by using the daylight, the following by using the cabin Colour-Control-Professional (2500...3500 lux) and other investigations were done on a computer monitor. The formula (4) can be used in usual situations of view also at working on a computer.

The formula (4) can be used if the infield includes the infield completely. If the backgrounds includes a rectangle only on three sides the lightening is nearly complete.

The influence of the area of the background and of the area of the infield is small [5]. This is in agreement with the investigations of Heinrich [7]. Because of this the formula (4) can be used in many cases. It is possible to use these formulas in the fields of computergraphics, in advertising and also in architecture.

ACKNOWLEDGMENTS

This research has been done as a dissertation on the RWTH Aachen and was supported by Prof. Hill and Dr. Vorhagen from this institute.

REFERENCES

1. DIN 6174, Farbmetrische Bestimmung von Farbabständen nach der CIELAB-Formel, 1979
Fig.2 Influence of the luminance of the background on the luminance of the infield an, Magenta
3. Lübbe, E., "Verbesserung der Farbabstandsformel CIELAB für Druckfarben", *Die Farbe*, **41**, pp.25-29, 1995
4. CIE Technical Report: Industrial colour-difference evaluation CIE 116-1995
5. Lübbe, E. Empfindungsgemäße Farbbeschreibung unter Berücksichtigung des Umfeldes, Dissertation RWTH-Aachen, Shaker Verlag Aachen, 1999
6. Takasaki, H., "Lightness Change of Grays induced by Change in reflectance of gray Background", *J. Opt. Soc. Am.* Vol. **56**, No.4, pp. 504 –509, 1966
7. Heinrich, F., "Experimentelle Untersuchungen zum farbigen Simultankontrast", Dissertation, München, 1967

Eva Lübbe, Germany
04318 Leipzig
Mascowstr.1a
Tel./Fax: 0049 (0)341 6993729
e-mail: Eva.Luebbe@aol.com

Weighting Function for the Measurement of Lightness Differences in Gonioapparent and Dark Colors

Allan B. J. Rodrigues, John S. Locke
DuPont Performance Coatings

ABSTRACT

In gonioapparent colors, as Lightness increases, larger ΔL^*s as measured by CIE76 are visually acceptable. This study used Logit Analysis of visual observations of lightness difference to determine this dependency of ΔL^* on absolute L^*. A linear functionality was found. Non-linearity of this function for very dark colors observed at flop angles, where sparkle is not observed lead to a further study of dark solid colors.

Keywords: Color difference, lightness difference, colorimetry

1. INTRODUCTION

Most color difference equations today are based on enhancements to the CIE1976 equations. The general form is:

$$\Delta E = \left[\left(\frac{\Delta L^*}{K_L S_L}\right)^2 + \left(\frac{\Delta C^*_{ab}}{K_C S_C}\right)^2 + \left(\frac{\Delta H^*_{ab}}{K_H S_H}\right)^2\right]^{0.5} \qquad (1)$$

Where $\Delta L^*, \Delta C^*, \Delta H^*$ are the CIE76 lightness, chroma and hue differences
ΔE^* is the improved total color difference
S_L, S_C, S_H are weighting functions to correct for the non-linearities of CIE1976 color space
K_L, K_C, K_H are parametric factors adjusting for viewing conditions (e.g., sample separation)

The CIE94 color difference equations define the weighting functions for Lightness difference as:

$$S_L = 1.0 \qquad (2)$$

This constant lightness function has worked well for glossy solid colors. However, color shaders have long recognized that in gonioapparent colors, as Lightness increases, larger ΔL^*s are visually acceptable. This study used Logit Analysis to analyze visual observations on metallic lightness differences to determine S_L for gonioapparent colors. Logit analysis is very effective at estimating the slope of a sigmoid type of curve, essentially linearizing the central portions. It requires some confusion among observer decisions, because calculating the logit function, [log(f/(1-f))], where f is the observer response frequency, a unanimous decision between observers results in either a division by zero or an infinite value.

Completion of the gonioapparent color study showed that S_L values determined for the very darkest colors ($L^* < 20$) seemed to level off, inconsistent with the trend for lighter colors. These very dark color centers were from observations far from specular, where flake texture is barely apparent. These results led to a second similar study of visual tolerance versus absolute lightness for dark high gloss solid colors.

2. GONIOAPPARENT COLORS

2.1 Experimental Work

Three series of color difference pairs were prepared from glossy automotive paints using only an aluminum flake and black pigmentation. Varying the ratio of black to aluminum flake provided small lightness differences within each series. The three series were a light, a medium and a dark set. All samples were measured on an X-Rite MA68 spectrophotometer with an illumination angle of 45°, viewed at aspecular angles of 15°, 25°, 45°, 75°, and 110°, thus providing 15 lightness levels (3 series at each of 5 angles) with 5 -8 color difference pairs in each series. Thirty observers viewed these color difference pairs in a Macbeth Skylight Booth, which permitted observations at these same five aspecular angles. They were asked whether they would accept or reject the color match in each pair. All viewers were experienced colorists in an automotive finishes color laboratory. Color difference pairs were shown to each observer in a randomized order so that their judgements were not influenced by trends.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) · 0277-786X/02/$15.00

A Logit Analysis was done for all 30 observations at each of the fifteen lightness levels. The ΔL^* acceptability tolerance was taken as the lightness difference at which 50% of the observers rejected the observed difference, estimated from the Logit regression. Results of the Logit Analysis are summarized in Tables 1-3.

Table 1: L^* of each Color Center

SERIES	15°	25°	45°	75°	110°
Light	140.33	103.40	57.15	37.77	33.64
Medium	130.76	93.75	48.69	28.29	22.37
Dark	78.66	51.72	24.17	11.42	6.80

Table 2: Observed Tolerance (ΔL^* at 50% Rejection)

SERIES	15°	25°	45°	75°	110°
Light	4.98	3.29	1.53	1.67	0.57
Medium	4.25	2.71	1.20	0.92	0.52
Dark	3.36	1.81	0.88	0.59	0.52

Table 3: Goodness of linear fit (R^2)

SERIES	15°	25°	45°	75°	110°
Light	0.76	0.96	0.82	0.73	0.76
Medium	0.81	0.92	0.83	0.98	0.98
Dark	0.74	0.79	0.84	0.99	0.99

2.2 Results and Discussion

Tolerances from the Logit Analysis are plotted as a function of L^* in Figure 1. This tolerance is in fact the value of S_L which should be used in Equation (1). The data are fit linearly, giving S_L as a function of L^*.

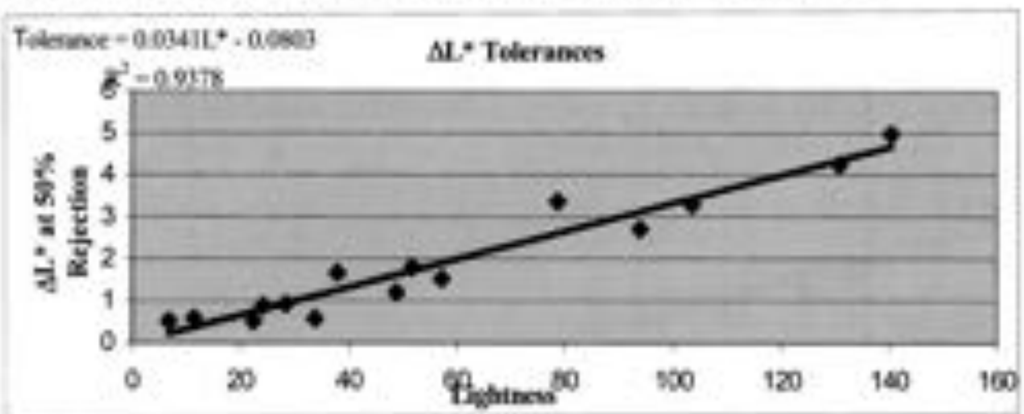


Figure 1: Tolerance as a Function of Lightness

The tolerance is observed to level off in the 0.5 - 0.6 range for the very darkest samples, suggesting that S_L be held to a constant at very low lightness. However, these data points are for the 110° aspecular angle and the dark color at the 75°. On these four observations, very little, if any of the flake texture is observable. This observation suggests that a similar study is necessary for very dark solid colors to properly define tolerancing in this region. A study of these dark colors is underway and initial results are reported below. Until this dark region study is completed, our recommendation is:

$$S_L = 0.034\, L^* \qquad L^* > 29.4 \qquad (3)$$
$$S_L = 1.00 \qquad L^* < 29.4$$

Flake in gonioapparent colors provides a visual texture. This texture seems to make visual judgements of lightness difference more forgiving as lightness increases. This result is similar to the S_L function in the CMC equations, even though the curvature in CMC is not observed here.

3. Dark Colors

3.1 Experimental Work

Panels representing total of nine lightness centers were prepared; using the same automotive paints in achromatic black. The lightness levels were adjusted using TiO_2 adds to the initial formulas. The mean lightness levels had the following values {2.1, 5.3, 9.9, 12.5, 15.9, 18.2, 19.9, 22.2, and 23.4}. At each of these centers, seven panels were prepared with very small differences in L*. We planned to utilize these seven panels in a Paired Comparison experiment yielding a total of 21 decisions per lightness center. One unique aspect of the design of these seven panels was to build the TiO_2 tinting base adds non-linearly. This resulted in a very flat sampling of the lightness differences at each lightness center over the 21 decision points. Linear adds would have resulted in a high population of similar ΔL^*'s within each center point. The study eventually was divided into three distinct phases; each succeeding phase addressed shortcomings or deficiencies identified during the visual testing portion of the study.

The visual experiments for Phases 1 and 2 were performed in a MacBeth® SpectraLight booth with standard medium gray surround under simulated D65 daylight illuminating conditions. The panels were placed on a fixture that maintained a viewing geometry nearly normal to the observers and diffusely illuminated at 45 degrees. Pairs of panels were placed with slight overlap on the fixture in a random (as far as ΔL^* values were concerned) fashion. Observers were forced to decide between two possible responses depending on the particular phase of the experiment. A maximum limit of approximately 100 decisions in a single observer-experiment frame was imposed.

3.2 Results and Discussion

Data analysis and evaluation was similar to that reported for the gonioapparent series; specifically we would also use a Logit analysis to evaluate the final tolerance specification for each Lightness level. During the Phase 1 of the study, we asked each observer a single question in a forced binary sense: "Can you see a difference between these two panels?" This question resulted in a very high number of unanimously positive responses that resulted in very poor logit evaluations. Based on these results, the conditions for the visual experiment were altered. This next part of the study will be referred to as Phase 2.

The single significant improvement in Phase 2 was to incorporate an anchor pair, which had a demonstrated lightness difference. The selection of the anchor pair was based on obtaining a demonstrated lightness difference and absolute Lightness level which was as close as possible to the mean ΔL^* and L* of all of the pairings available in the study. The actual pair selected was from the pairings with an absolute Lightness level of 12.5 and a ΔL^* of 0.6. The observers were now asked "Is the lightness difference between the test pair larger or smaller than that of the anchor pair?" The viewing conditions, etc. remained similar to those reported for Phase 1.

3.2 Results and Discussion

Seven observers viewed all pairings at the nine lightness levels. The raw observer data and logit results for the Lightness level = 5.3 are reproduced below as an example.

The resulting Logit plot along with the 'best fit' straight line is shown below:

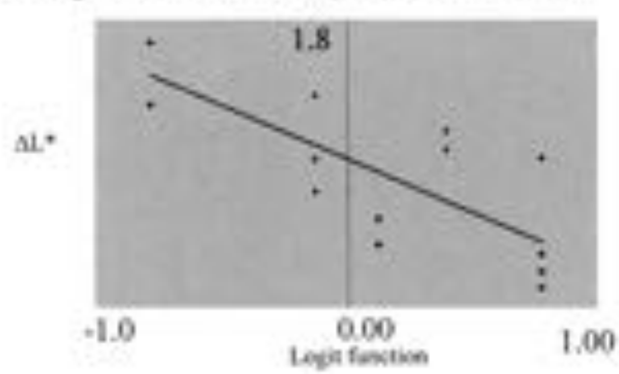


Figure 2: Logit analysis for data at L* = 5.3

In a similar fashion, the data for the remaining lightness centers were analyzed. The plot for the ΔL* vs L* data is given below:

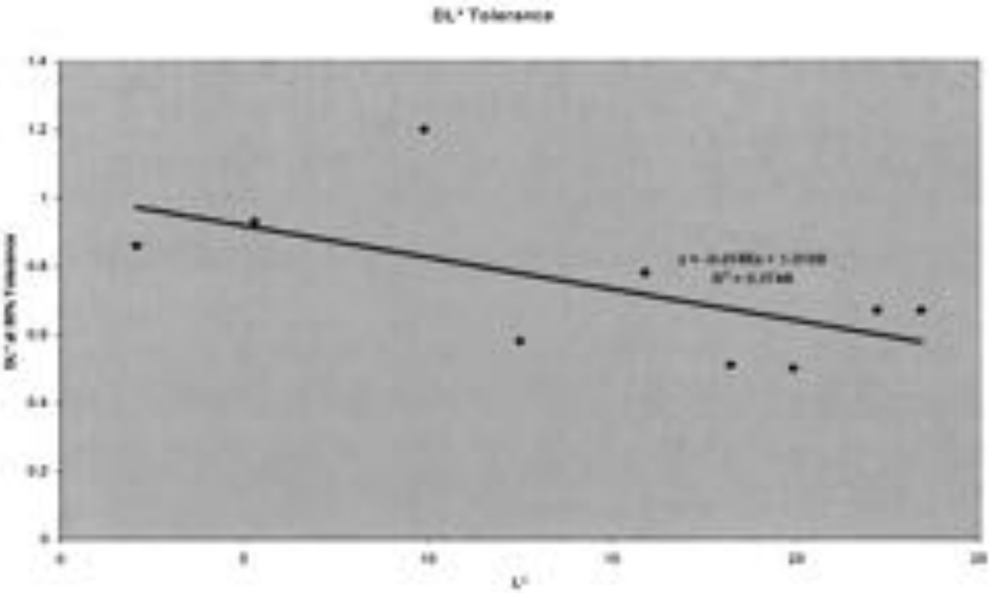


Figure 3: Tolerance as a Function of Lightness for Very Dark Colors

The wide scatter of data in both graphs is due to the use of only seven observers. Typically Logit analysis requires a minimum of 30 observers.

4. PATHFORWARD

The dark color study must be extended to Phase 3 to include more observers. Since the results must be compared to those for the dark colors in the gonioapparent study, for consistency we will redo the entire study in the Macbeth Skylight. The data in both experiments will also be analyzed for consistency of response by each observer using a low-pass-filter algorithm applied to non-monotonic response data described by Berns[1].

ACKNOWLEDGEMENTS

Our thanks to the members of ASTM Subcommittee E-12.12 for their inputs to this work and who participated in specifying the lightbooth needed for the visual observations. Our thanks to Gretag-Macbeth, for implementing that specification in their Skylight viewing booth and loaning us the prototype for these experiments.

REFERENCES

1. R. S. Berns et al., "Visual Determination of Suprathreshold Color-Difference Tolerances using Probit Analysis", *Color Research and Application*, **16**, 297-316 (1991)

Relationship between color discrimination threshold and suprathreshold color-difference perception

Haisong Xu*[a,b], Hirohisa Yaguchi**[a], Satoshi Shioiri[a]
[a]Department of Information and Image Sciences, Chiba University, Japan
[b]State Key Laboratory of Modern Optical Instrumentation, Zhejiang University, China

ABSTRACT

Based on the psychophysical method of constant stimuli, an experiment was carried out, using CRT-generated stimuli and in CIELAB color space, to test the visual color differences in relation to colorimetric scales. The CIE Gray and Blue color centers, the most basic color and, perceptually, the most different color, respectively, were chosen, and the maximum average size of test color difference was 12 CIELAB ΔE units. The resultant visual data, processed via probit analysis, were used to analyze the relationship between color discrimination threshold and suprathreshold color-difference perception. The equal color-difference contours, corresponding to all the visual scales, 4.0, 8.0, and 12.0 CIELAB ΔE units, were well fitted into ellipses while maintaining the orientation of the threshold one, but the shapes were not completely same, especially, at Blue center. The comparisons between visual color differences and their colorimetric counterparts, in CIELAB ΔE units or threshold units, show linear relations at both color centers, but the slopes were, in general, not equal to 45° and differed for all directions. Thus the suprathreshold color differences can be derived by enlarging the thresholds linearly but not uniformly, i.e. with different ratios for individual directions.

Keywords: color-difference perception, color discrimination threshold, suprathreshold color difference, CRT-display, method of constant stimuli, probit analysis

1. INTRODUCTION

Numerous studies on color-difference evaluation have been performed and color-difference formulae are being modified again and again towards practical applications. However, till now the final goal, to develop an international standard on color-difference evaluation for most industrial applications, has not yet been achieved. The basic issue is how to make the colorimetric magnitude represent the visual one. One of the most important aspects is the relationship between measured color-differences and perceived scales, which is usually assumed linear for a practical use in industry. However, the direct researches about the geometrical relation of visual and colorimetric scales of color difference are few and mainly concerned a limited range of color difference, such as the typical studies by Witt[1,2] for small color difference. It has not been investigated thoroughly for the range from threshold (very small) through moderate to large suprathreshold level of color difference. The aim of this study was to analyze the relationship between color discrimination threshold and suprathreshold color difference using a new data set from a specially designed experiment described below.

2. METHODOLOGY

2.1 Stimuli

The experiment was carried out using the color stimuli on a CRT display of Sony Multiscan G500, driven by a visual stimulus generator system of Cambridge Research Systems VSG 2/4 with 15-bit resolution. The test color stimuli were selected, in CIELAB color space,[3] around the CIE Gray and Blue color centers,[4,5] the most basic color and the most different color for perceptual characterization, respectively, of which the CIELAB chromaticity parameters are listed in Table 1.

Table 1. The CIELAB chromaticity parameters of the color centers studied.

Color center	L^*	a^*	b^*	C^*	h°
Gray	61.65	0.11	0.04	0.12	20
Blue	35.60	4.83	-30.18	30.56	279

The stimulus pattern, viewed at a distance of 500 mm, consisted of a reference color-difference pair, also set as CIE Gray, and a test pair with a separation of 0.5° visual angle in between. Each color pair involved two 1° squares with a black frame of 0.1° at the center of a 6° background, as illustrated in

* hxu@vision.tp.chiba-u.ac.jp; ** yaguchi@image.tp.chiba-u.ac.jp

  · 0277-786X/02/$15.00

Fig. 1. The total visual subtended angle size of the test stimuli was less than 4°, so the CIE1931 Standard Colorimetric Observer was used in data reduction. The background was set as Munsell N5 neutral gray and surrounded by an 8° bright border with a luminance (L^*) of 100 cd/m^2 and the chromaticity of D65. This border defined the white point for the pattern and had the CRT stimuli appear as related colors.[6-7]

The color differences of the reference pair were only the luminance variations or called gray scales along $+L^*$ direction in CIELAB space. For the test pair the color differences were the selected color distances, according to a predetermined step size by a pilot experiment, along 12 directions every 30° in (a^*, b^*)-plane and along 8 directions every 45° in (a^*, L^*)- and (b^*, L^*)-plane from the two test color centers. Hence, the test pair was formed by the center colors and those stimuli evenly distributed around them.

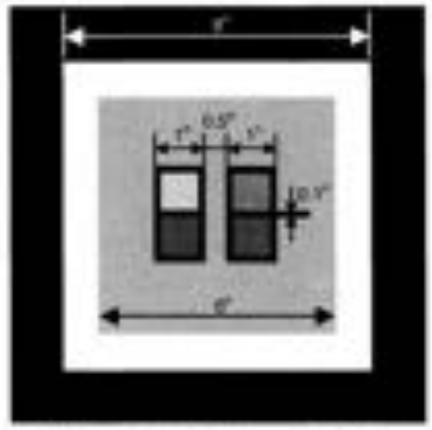


Figure 1: The test paradigm used in the present color-difference comparison experiment.

2.2 Procedure

Every trial of observation began with a 200 ms gap and ended at receiving the response from the subject with no restriction for the subject's judgment time. During gaps only the reference and test pairs were shut off with black, while the surrounding border and background remained for the subject to maintain the complete adaptation to the white point and background throughout the entire experiment.

The reference pair of samples had the required visual scales of color difference, i.e. 4.0, 8.0, and 12.0 CIELAB ΔE units in the present study. The task of the observer was to judge visually whether the color difference of test pair was greater or less than that of reference pair, and then to press one of the two keys on the keyboard, corresponding to the two judgment categories, as his/her response. The experiment was designed based on the principle of the psychophysical method of constant stimuli, so the resultant data were processed via the statistical method of probit analysis.[8-10] Using this algorithm, the equal color-difference contours for each of the reference visual scales were obtained.

For every color center, the experiment was split into three sessions, one for each measurement plane, i.e. (a^*, b^*)-, (a^*, L^*)-, and (b^*, L^*)-plane. Each session, started with 3-minute dark adaptation and 1-minute background adaptation, lasted about 20 minutes to avoid fatigue. Each test pair was assessed 20 times, in two separate trials with random orders of color stimulus presentation, by individuals on a panel of 6 observers with normal color vision. All observers were students of Chiba University, and most of them had no experience for such an experiment. During the experiment, the stimulus arrangements for the left and right position of the reference and test pair and for the upper and lower position in the two color pairs were all determined randomly for different trials by the computer program to avoid an eventual judgment bias of observers by the presenting positions of the test stimuli.

3. RESULTS

3.1 Equal color-difference contours

First of all, the visual results were fitted as chromaticity ellipses to represent the contours of equally perceived color differences around the test color centers in CIELAB space. Figure 2 shows the fitting results in (a^*, b^*)-plane for the Gray and Blue centers, together with the color discrimination threshold ellipses, measured with the method of the authors' previous study[11] under the same viewing condition, for a comparison.

The orientations of all equal color-difference ellipses, including the discrimination ellipses, were almost the same with each other at a given center. The shapes were also similar but not quite the same, and the relative volumes compared with threshold ellipses were different for the three suprathreshold equal color-difference contours. It seems that the suprathreshold color difference can be derived from enlarging the color discrimination threshold on the base of linearity for a specific direction, though the proportions differ for individual directions. In addition, the equal color-difference contours in (a^*, L^*)- and (b^*, L^*)-plane were nearly symmetric about the L^* axis for both color centers, while the colorimetric magnitudes in $-L^*$ direction were obviously larger than that in $+L^*$ direction. The visual data in other mixed directions told the same story, that is, corresponding to a same visual scales, the colorimetric values in the directions involving $-L^*$ component were larger than in the opposite ($+L^*$ component mixed) directions. It is a robust tendency, which will be further discussed in the next analysis.

3.2 Comparison of visual and colorimetric scales

For every direction in each measurement plane, the colorimetric magnitudes were compared to the corresponding visual scales of 4.0, 8.0, and 12.0 CIELAB ΔE units. It was found that they could be linearly fitted, no matter in CIELAB ΔE units or in threshold units, for any a same direction with high correlation coefficients. Table 2 summaries the linear fitting results for the a^*, b^*, and L^* axes only in all measurement planes at the CIE Gray and Blue color centers. The correlation coefficients of linear regressions in all directions (including those not listed in Table 2) were over 0.97, which implies that the linear fitting is appropriate and enough for the visual data here. The slopes of regression lines for all directions were generally very different than 45°, which represents the ideal relation of visual and colorimetric scales, except for the $+L^*$ direction at Gray center, in which case the reference and test pairs were in the completely same state. This indicates that the colorimetric magnitudes of different visual scales, ranged from moderate to large color difference studied here, were typically linear with the visual ones, but the slopes were different for individual directions, which is consistent with Witt's studies[1-2] of small color difference.

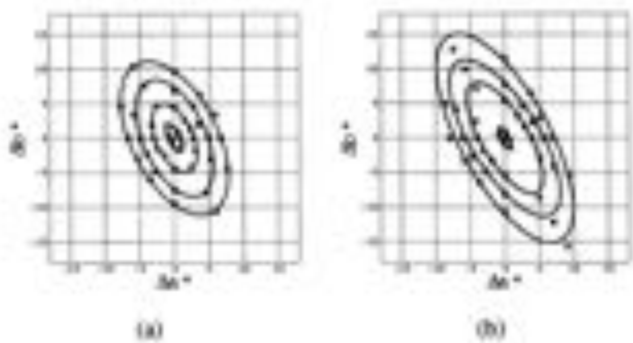


Figure 2: Chromaticity ellipses fitted in (a^*, b^*)-plane for (a) CIE Gray and (b) CIE Blue color centers. From inner to outer are threshold, equal color-difference contours for visual scales of 4.0, 8.0, and 12.0 CIELAB ΔE units, respectively, with the raw data plotted in different symbols (filled circle for threshold, open circle for 4.0-, filled square for 8.0-, and open square for 12.0-visual scale in terms of CIELAB ΔE units).

Table 2. Summary of linear fitting results for visual and colorimetric scales.

Color Center	Test Plane	Direction	Slope (deg) CIELAB ΔE Units	Slope (deg) Threshold Units	Correlation Coefficient (r)
Gray	(a^*, b^*)	$+a^*$ / $-a^*$	26 / 24	47 / 59	0.997 / 0.999
		$+b^*$ / $-b^*$	33 / 32	41 / 41	0.999 / 0.992
	(a^*, L^*)	$+a^*$ / $-a^*$	25 / 22	54 / 46	0.996 / 0.996
		$+L^*$ / $-L^*$	44 / 44	43 / 49	0.999 / 0.996
	(b^*, L^*)	$+b^*$ / $-b^*$	35 / 31	42 / 39	0.999 / 0.999
		$+L^*$ / $-L^*$	42 / 42	43 / 57	0.999 / 0.992
Blue	(a^*, b^*)	$+a^*$ / $-a^*$	21 / 27	43 / 49	0.993 / 0.999
		$+b^*$ / $-b^*$	51 / 34	47 / 39	0.990 / 0.999
	(a^*, L^*)	$+a^*$ / $-a^*$	29 / 34	57 / 55	0.993 / 0.990
		$+L^*$ / $-L^*$	31 / 41	31 / 46	0.998 / 0.996
	(b^*, L^*)	$+b^*$ / $-b^*$	38 / 33	43 / 38	0.981 / 0.993
		$+L^*$ / $-L^*$	28 / 33	34 / 45	0.999 / 0.979

As an example, the regression lines in a^* and b^* directions of (a^*, b^*)-plane and in L^* direction of (a^*, L^*)-plane are given in Fig. 3 (a)-(b) with raw data plotted in using CIELAB ΔE units and threshold units, respectively, for Gray and Blue centers. The slopes of most fitted lines were less than 45°, especially, in the case of CIELAB ΔE units except for the slope in $+L^*$ direction, which satisfactorily coincided with the ideal line of 45°, and the regression lines of opposite directions were nearly parallel for Gray center while not the case for Blue center. These are consistent with Table 2 and show that the perceptual characterization in blue region is very different from in gray region. For the L^* axis, the regression lines in $-L^*$ direction were obviously above that in $+L^*$ direction as mentioned above, so in (a^*, L^*)- and (b^*, L^*)-plane the equal color-difference contours were symmetric about L^* axis but not about a^* or b^* axis. This may be partially due to the reference gray scale being set as the luminance difference along $+L^*$ direction from CIE Gray center in the present study, but the asymmetric perception between $+L^*$ and $-L^*$ sides should be the main reason. In addition, the regression lines in the case of CIELAB ΔE units were generally below the 45° line especially in (a^*, b^*)-plane, while in the case of threshold units the circumstances were opposite. This means in CIELAB space the color difference is underestimated by the Euclidean distance compared with the visual scales, while in the relative comparison using threshold units the colorimetric magnitude was perceptually underestimated, which is consistent with other studies.[1-3] Therefore, the unit value representing the color-difference metrics is important, which is basically related to the uniformity of a color space. Almost all the fitted lines did not point to the origin of the axes but with a small positive intercept at the colorimetric ΔE axis, which reflected the influence of the color discrimination threshold.

4. CONCLUSIONS

The relationship between color discrimination threshold and suprathreshold color-difference perception was investigated using visual results ranged from moderate to large color difference from a specially designed color-difference comparison experiment. A detailed analysis shows that the colorimetric scales were linear with the visual ones but not in the same proportion for different directions. Hence, the suprathreshold color difference can be acquired by enlarging the threshold linearly, although, on the different ratio for individual directions. The equal color-difference contours were well fitted as chromaticity ellipses, but those in (a^*, L^*)- and (b^*, L^*)-plane were, in fact, not symmetric about a^* or b^* axis because of the different mechanisms of human color vision in chromatic and lightness channels and the asymmetric perception between $+L^*$ and $-L^*$ sides in the color space studied.

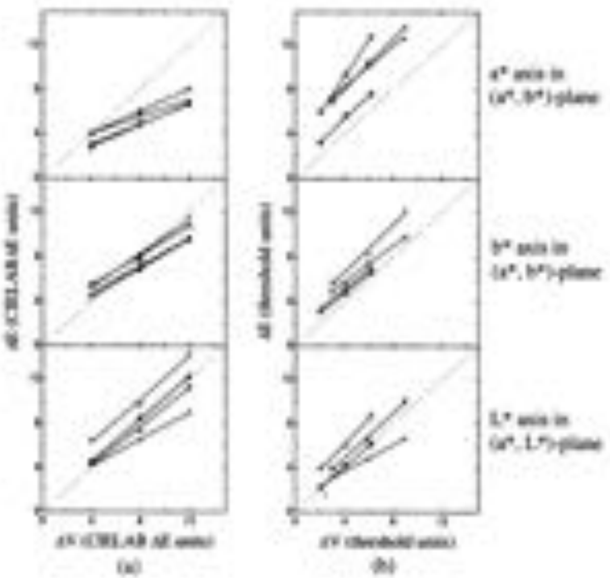


Figure 3: Regression lines in a^* and b^* directions of (a^*, b^*)-plane and in L^* direction of (a^*, L^*)-plane using (a) CIELAB ΔE units and (b) threshold units, with raw data plotted in different symbols ("•" for positive direction and "○" for negative direction at Gray center; "+" for positive direction and "×" for negative direction at Blue center).

ACKNOWLEDGMENTS

The authors would like to thank Professor M. R. Luo for providing technical guidance and all observers for their time and patience.

REFERENCES

1. K. Witt, "Linearity and additivity of small color differences," *Color Res. Appl.* **20**, pp. 36-43, 1995.
2. K. Witt, "Geometric relations between scales of small color differences," *Color Res. Appl.* **24**, pp. 78-92, 1999.
3. CIE, *Industrial colour difference evaluation*, CIE Publication No.116, CIE Central Bureau, Vienna, 1995.
4. A. R. Robertson, "CIE guidelines for coordinated research on colour-difference evaluation," *Color Res. Appl.* **3**, pp. 149-151, 1978.
5. K. Witt, "CIE guidelines for coordinated future work on industrial colour-difference evaluation," *Color Res. Appl.* **20**, pp. 399-403, 1995.
6. T. Indow, A. R. Robertson, M. von Grunau, and G. H. Fielder, "Discrimination ellipsoids of aperture and simulated surface colors by matching and paired comparison," *Color Res. Appl.* **17**, pp. 6-23, 1992.
7. M. Melgosa, M. M. Pérez, A. El Moraghi, and E. Hita, "Color discrimination results from a CRT device: Influence of luminance," *Color Res. Appl.* **24**, pp. 38-44, 1999.
8. D. H. Alman, R. S. Berns, G. D. Snyder, and W. A. Larsen, "Performance testing of color-difference metrics using a color tolerance dataset," *Color Res. Appl.* **14**, pp. 139-151, 1989.
9. T. Indow and M. L. Morrison, "Construction of discrimination ellipsoids for surface colors by the method of constant stimuli," *Color Res. Appl.* **16**, pp. 42-56, 1991.
10. R. S. Berns, D. H. Alman, L. Reniff, G. D. Snyder, and M. R. Balonon-Rosen, "Visual determination of suprathreshold color-difference tolerances using probit analysis," *Color Res. Appl.* **16**, pp. 297-316, 1991.
11. Haisong Xu, Hirohisa Yaguchi, and Satoshi Shioiri, "Estimation of color-difference formulae at color discrimination threshold using CRT-generated stimuli," *Optical Review* **8**, pp. 131-136, 2001.

Acceptability color tolerances for CRT reproductions of real objects

Yoshihiko Azuma*[a], Kouji Kitou[b], Kazuhiko Naruse[c], and Yukio Sugiura[d]
[a]Tokyo Institute of Polytechnics; [b]Hitachi Media Electronics Co., Ltd.;
[c]Minolta Co., Ltd.; [d]Meisei University

ABSTRACT

Acceptability color tolerances for CRT reproductions of real objects were measured in a psychophysical experiment. Observers visually compared colors of real objects with those of corresponding images and judged whether the differences in color between them were acceptable or not. Results showed that the distributions of the acceptability color tolerance data from the experiment were similar in shape to the MacAdam ellipses, but much larger than them.

Keywords: acceptability color tolerance, online shopping, CRT reproduction, probit analysis

1. INTRODUCTION

The number of people who use online shopping via the Internet is continuing to rise. In the online shopping, images of products are often presented on home pages and users can decide which product to buy or which color of the product to choose by viewing the images on a monitor screen. Some users may choose products by the colors of the images reproduced on the monitor screen. Thus, the images are sometimes required to have the color fidelity to the products and their colors should be controlled to be within a certain tolerance. To do this, acceptability color tolerance for CRT reproductions of actual products must be revealed.

The aim of this research is to measure acceptability color tolerance for CRT reproductions of real objects assumed as products and to provide a guideline for color management of the CRT reproductions of products in online shopping. A psychophysical experiment was designed to derive the acceptability color tolerances. Resultant data was compared with MacAdam ellipses, and was analyzed with probit analysis to estimate the acceptability color tolerances.

2. EXPERIMENT

2.1 Sample objects

Among categories of products, clothing, accessories, and cosmetics were chosen for experiment because their colors play critical role in decision of purchase and choice of products. Four polo shirts of different colors, red, yellow, blue green, and purple blue, were chosen as representative articles of clothing; three wallets of different colors, orange, yellow green, and purple blue, as accessories; three bottles of nail polish of different colors, red, yellow green, and blue green, as cosmetics. These ten articles were used as sample objects in the experiment and also as reference colors.

2.2 Image data

The sample objects were digitized by Dicomed digital camera to provide RGB data for preparing CRT images, and then the

9th Congress of the International Colour Association, Proceedings
of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

colors and resolutions of resulting images were adjusted using Adobe Photoshop™ 4.0 so that they could have the same colors and sizes on CRT as the actual objects. The background color of each object image was adjusted to match the color of the booth's interior that corresponded to the background of the object.

2.3 Apparatus

A SONY GDM2000TC 20" color monitor controlled by a Power Macintosh 8500/120 was used as the image display device. The white point of the monitor was set to D65 at the maximum luminance value of 93.2cd/m^2. A GretagMacbeth the Judge II viewing booth was used for illuminating and viewing the sample objects. A D65 light source was used for illumination in this experiment. The light intensity in the booth was reduced by partially covering the light source with gray paper such that the luminance of the sample objects could be reproduced on the monitor. These experimental apparatus were placed in a dim room with a condition for subjective assessments that conformed to ITU-R Rec.500. Colors reproduced on the monitor were measured with the Photo Research Spectra Scan PR-650.

2.4 Psychophysics

Fifteen observers with normal color vision participated in the experiment. The observers varied in age from 37 to 57, and included eleven males and four females. Their occupations were engineer, researcher, sales agent, office worker, and housewife. Five observers participated in the experiment at the same time, and three of them sat in the front raw approximately 80 in. from the viewing booth and the monitor, and the other two sat in the back row approximately 100 in. from the apparatus. The monitor screen subtended a visual angle of approximately 9° x 11° for observers in the front raw and 7° x 9° for observers in the back raw. The displayed images on the monitor were large enough to view.

Prior to the experiment, the observers were given some instructions as follows.

> Suppose you will be finding a product in the left booth that you want to buy. Then, on the right monitor, you will be able to view corresponding image that will be changed step by step in hue, chroma, or lightness, independently. After comparing colors between the product and image, you must judge whether the difference in color between them is acceptable or not, and make a yes/no answer by filling out a form.

The experiment was performed according to the following procedure:

1. Before the beginning of a session, a sample object is placed in the viewing booth, while the corresponding initial image is displayed on the monitor. The observers are not permitted to view them.
2. The experimenter notifies the observers of the start of the session, and then the session begins.
3. The observers view the sample object then the CRT image, and judge whether the difference in color between them is acceptable or not when expecting the color of the CRT image to represent that of the real object.
4. The observers record a yes/no answer by filling out a form on the judgment. When this task is finished, the observers wait without viewing till changing the color of the image is completed.
5. The above procedures 3 and 4 are repeated for each varying color of the CRT image.

Object images were cropped with Photoshop, and were manipulated so that only the principal colors of the objects could be changed, but colors of the other areas such as background image could not. The experiment consisted of ten sessions, each of which was performed for each different object. Each session included judgment tasks for sixteen increments and sixteen decrements of hue angle, chroma, and lightness of the CRT image. Thus, each observer made ninety-six judgments for one object and made nine hundred sixty judgments in total.

2.5 Analysis

Colorimetric data for a representative color of each object was used for analysis. For each observer, the colors at the furthest distance from the initial colors in hue, chroma, and lightness that were judged acceptable were taken as defining acceptance limits, or acceptability color tolerances. In addition, the statistical acceptability color tolerances were estimated using probit analysis. Hue angle h_{ab}, chroma C^*_{ab}, and lightness L^* in CIELAB color space were calculated from the colorimetric data of the images. Then the difference of H^*_{ab}, C^*_{ab}, and L^* between the initial image and the image judged acceptable were calculated. These difference data were analyzed with probit analysis to derive the acceptability color tolerances. The acceptability color tolerances were estimated as the color differences at a rejection or acceptance probability of 50%.

3. RESULTS & DISCUSSIONS

Figure1 shows the acceptance limit responses for the differences in hue and chroma of each sample object for all observers that were plotted in the CIE 1976 a*b* diagram. Letters, P1-P4, W1-W3, and N1-N3 nearby symbols in the figure represent polo shirts, wallets, and nail polish, respectively. It is indicated that low-chroma objects have narrow distributions in chroma directions, while high-chroma objects have wide distributions in chroma directions. However, the distributions in hue direction seem to depend on hue angle. MacAdam ellipses were also plotted five times actual size in the diagram. There is a tendency that these acceptance limit responses are distributed in a similar way to the spread of MacAdam ellipses, although the former are much more widely distributed than the latter.

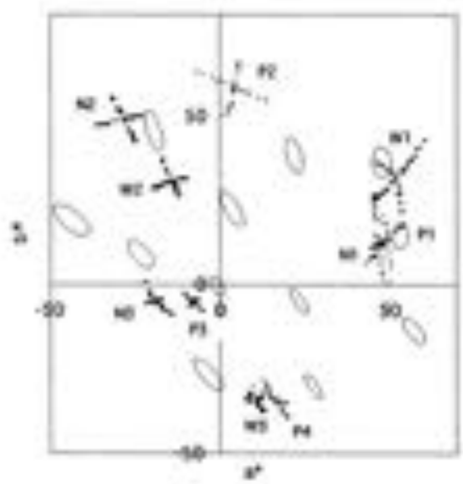


Figure1: Acceptance limits for each observer and MacAdam ellipses enlarged five times in the CIE 1976 a*b* diagram.

Figure 2 shows an example of the relationship between proportion of "accept" responses and ΔH^*_{ab}, ΔC^*_{ab}, or ΔL^*, where ΔH^*_{ab}, ΔC^*_{ab}, and ΔL^* are the differences in H^*_{ab}, C^*_{ab}, and L^*, respectively. Lines in the figure were fitted to the data using the probit analysis, from which acceptability tolerances for ΔH^*_{ab}, ΔC^*_{ab}, and ΔL^* were derived for the sample object. The results are shown in Figure 3, where linear relationships can be found for ΔH^*_{ab} vs. C^*_{ab}, and for ΔC^*_{ab} vs. C^*_{ab}. Thus, the acceptability tolerances for ΔH^*_{ab} and ΔC^*_{ab} may be represented as functions of C^*_{ab}. However, no distinct relationship could found for ΔL^* vs. L^*.

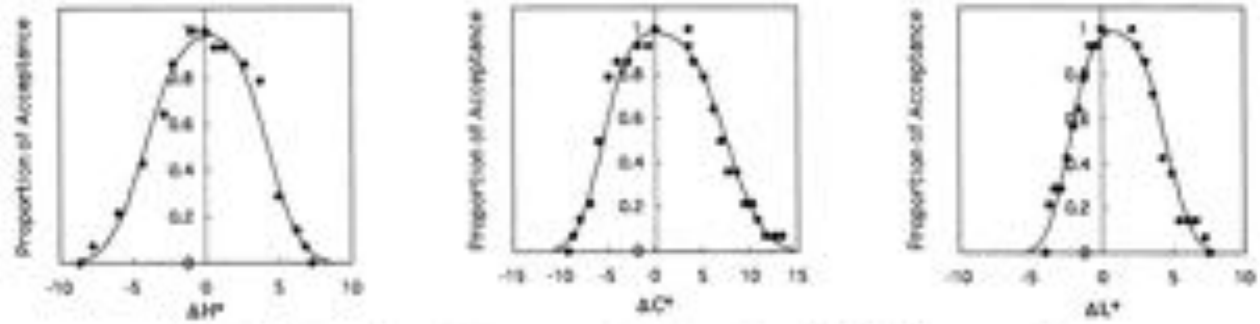


Figure2: Proportion of "accept" responses against ΔH^*_{ab}, ΔC^*_{ab}, and ΔL^* for the orange wallet.

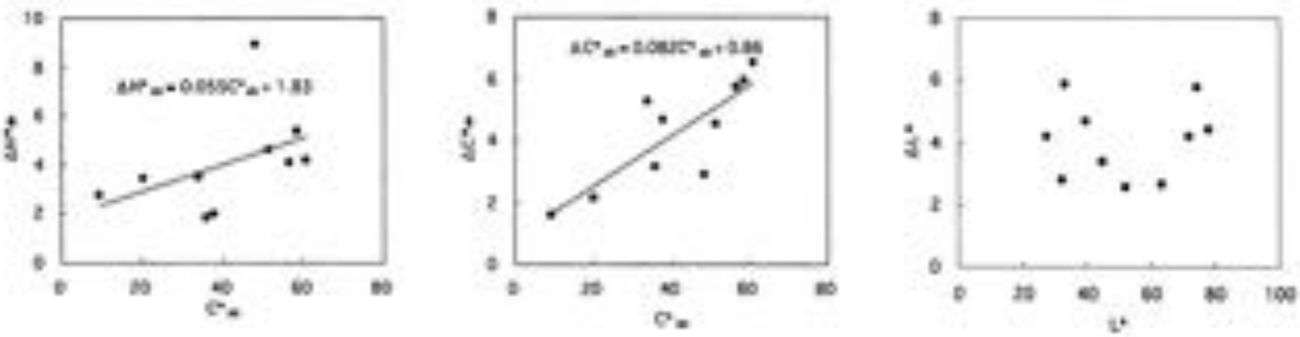


Figure3: Acceptability tolerances for ΔH^*_{ab}, ΔC^*_{ab}, and ΔL^*.

The acceptability color tolerances obtained from the current research were less than the values of $\Delta E^*_{ab} = 6.0$ that was obtained in pictorial images by Stokes et al.[1]. This is because the sample objects used were almost plain-colored, so the change in color was easily noticed.

4. CONCLUSIONS

The distributions of the acceptability color tolerance data were obtained from the visual judgment experiment and were found to be similar in shape to the MacAdam ellipses, but were several times larger than them. Results from probit analysis showed that ΔH^*_{ab} and ΔC^*_{ab} increase with C^*_{ab}. This fact agrees with results from other color tolerance experiments.

ACKNOWLEDGEMENTS

This research was supported by the advanced image technology development and promotion committee (AIM).

REFERENCES

1. M. Stokes, M. D. Fairchild, and R. S. Berns, "Colorimetrically quantified visual tolerances for pictorial images", *Proc. TAGA*, pp.757-777, 1992.

*azama@image.t-kougei.ac.jp; phone 81 46 42-9523; fax 81 46 42-9523; http://www.t-kougei.ac.jp; Tokyo Institute of Polytechnics, 1583 Iiyama, Atsugi, Kanagawa 243-0297, Japan

Instrumental colour control for metallic coatings

W. Chou, B. Han, G. Cui, B. Rigg and M. R. Luo
Colour & Imaging Institute, University of Derby

ABSTRACT

This paper describes work investigating a suitable colour quality control method for metallic coatings. A set of psychophysical experiments was carried out based upon 50 pairs of samples. The results were used to test the performance of various colour difference formulae. Different techniques were developed by optimising the weights and/or the lightness parametric factors of colour differences calculated from the four measuring angles. The results show that the new techniques give a significant improvement compared to conventional techniques.

Keywords: Colour control, colour difference formulae, metallic coatings

1. INTRODUCTION

The components and coarseness of the pigments in metallic materials have specific characteristics and pose many challenges in their applications. Some people experience frustration when using metallic paints the colour may not appear as they expect. The phenomenon is due to the optical properties of metallic coating, which makes their appearance vary when viewed from different angles. Therefore, it is very important to provide a numerical colour tolerance control, particularly in the automotive industry, and the specific geometric effects inherent in metallic coating must be taken into account.

The purpose of this study is to develop a colorimetric tool for evaluating colour differences for automotive coatings. Six advanced colour difference equations (CIELAB, CMC, CIE94, BFD, LCD and CIEDE2000 [1-7]) were tested using a newly accumulated experimental data set. Amongst these equations, the CIEDE2000 is the new CIE colour difference equation. All these formulae have a common feature, i.e. they were derived by modifying the CIELAB equation. A generic formula given in Equation (1) represents all these formulae.

$$\Delta E = [(\Delta L/K_L)^2 + (\Delta C/K_C)^2 + (\Delta H/K_H)^2 + \Delta R]^{½} \quad (1)$$
$$\text{and } \Delta R = R_T (\Delta C/K_C)(\Delta H/K_H)$$

where the ΔL, ΔC and ΔH are the general terms for each formula and are modified from the ΔL^*, ΔC^* and ΔH^* of CIELAB; the R_T is an interactive term between ΔC and ΔH, which is used in BFD, LCD and CIEDE2000 and is excluded in the CMC, CIE94 and CIELAB equations; the K_L, K_C and K_H are the lightness, chroma and hue parametric factors, which are normally optimised to give the best fit to the experimental data, or are set to one as proposed by the original formula.

Five methods were developed to test the performance for each colour difference formula. Method 1 (M1) calculates colour difference from each of the four aspect angles (20°, 45°, 75° and 110°). Method 2 (M2) uses the maximum colour difference from those calculated from four aspect angles. Method 3 (M3) calculates the mean colour difference from four aspect angles as given in Equation (2).

$$\Delta E = [\Delta E_{20}(K_L=1) + \Delta E_{45}(K_L=1) + \Delta E_{75}(K_L=1) + \Delta E_{110}(K_L=1)]/4 \quad (2)$$

The M3 method assumes that observer weight equally colour differences at the different aspect angle. The M4 is given in Equation (3) with the optimised weighting factor (w_i) for each aspect angle to fit the experimental data.

$$\Delta E = w_{20}\,\Delta E_{20}(K_L=1) + w_{45}\,\Delta E_{45}(K_L=1) + w_{75}\,\Delta E_{75}(K_L=1) + w_{110}\,\Delta E_{110}(K_L=1) \quad (3)$$

9th Congress of the International Colour Association, Proceedings
of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

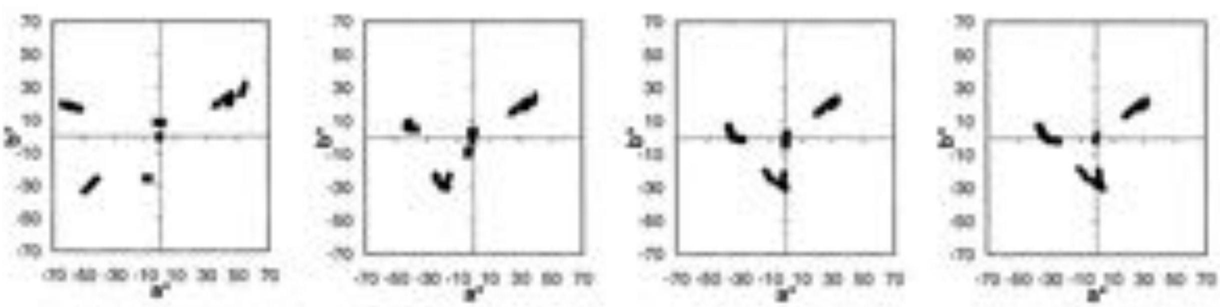
$$and\ w_{20}+w_{45}+w_{75}+w_{110}=1.$$

The M5 is given in Equation (4) by optimising the weighting factor (w_i) and lightness parametric factor ($K_{L,i}$) for each aspect angle to best fit the experimental data.

$$\Delta E = w_{20}\,\Delta E_{20}(K_{L,20}) + w_{45}\,\Delta E_{45}(K_{L,45}) + w_{75}\,\Delta E_{75}(K_{L,75}) + w_{110}\,\Delta E_{110}(K_{L,110}) \quad (4)$$
$$and\ w_{20}+w_{45}+w_{75}+w_{110}=1.$$

2. EXPERIMENT

Fifty pairs of metallic panels corresponding to five colour centres (red, green, blue, silver and black) were prepared. Their colorimetric data were measured using a *GretagMacbeth ColorEye 741* multi-angle spectrophotometer, which is capable of measuring each sample at four aspect angles: 20°, 45°, 75° and 110°. Figures 1(a)-1(d) show sample distributions in CIELAB a^*b^* diagram for 20°, 45°, 75° and 110° aspect angles, respectively. These metallic samples represent typical colour ranges of automotive coating. About 10 sample pairs for each colour centre were carefully selected to cover specific directions with different magnitudes so as to obtain accurate visual predictions. Figures 2(a)-2(d) show pair distribution in three-dimensional $\Delta L^*\Delta a^*\Delta b^*$ micro-spaces for 20°, 45°, 75° and 110° aspect angles, respectively.



(a) 20° (b) 45° (c) 75° (d) 110°

Figure 1. Sample distributions in a^*b^* diagram

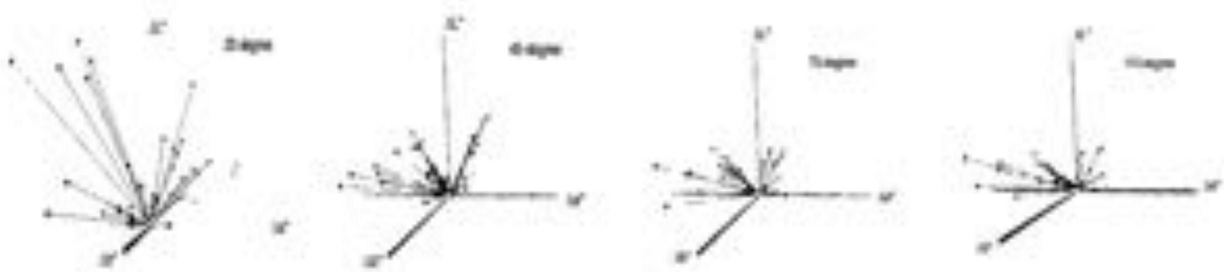


Figure 2. Pair distributions in $\Delta L^*\Delta a^*\Delta b^*$ micro-space

A psychophysical experiment was carried out. Each pair was assessed by ten normal colour vision observers and each of them repeated twice. The grey scale method was applied to scale the perceived differences. Each pair was assessed under a D65 simulator in a VeriVide viewing cabinet. Each observer was asked to first find an angle showing the largest perceived difference and then to compare that difference with the differences exhibited in a grey scale, which was similar to that used for assessing colour changes [8]. The grey scale samples were made with matte paint and were placed on the floor of a viewing cabinet with a 0/45 illuminating/viewing geometry.

The measurement results for four aspect angles for the grey scale samples are given in Table 1 in terms of ΔE^*_{ab}. The ΔE^*_{ab} value for each aspect angle was calculated between each grey scale sample and the 'standard' under D65/10 condition. (The 'standard' is almost identical to 'Grade 5' in the grey scale.) The results in Table 1 show that the grey scale samples used were not really matte due to the variations of colour differences in each aspect angle. A polynomial was derived to interrelate ΔE^*_{ab} values and grades only for 45° aspect angle because the grey scale samples were only seen in this viewing condition. Hence, all raw data were transformed to ΔV in ΔE^*_{ab} units. For each pair, the experimenter recorded not only the grade but also the angle showing the largest colour difference.

Table 1. The ΔE^*_{ab} calculated between the 'standard' and each grade in the grey scale used at 20°, 45°, 75° and 110°.

Grade	$\Delta E^*_{ab,20}$	$\Delta E^*_{ab,45}$	$\Delta E^*_{ab,75}$	$\Delta E^*_{ab,110}$
0	29.70	25.09	25.55	25.15
1	21.99	13.73	14.13	13.70
2	8.38	8.50	8.56	8.88
3	4.18	5.13	6.17	6.83
4	3.70	2.41	1.71	1.35
5	0.07	0.05	0.05	0.06

3. RESULTS AND DISCUSSION

As described in Section 1, five methods were used to test the performance of each of the five colour difference formulae. The agreement between colour difference values calculated from a particular formula and visual assessment data was indicated by PF/3, which is called performance factor derived by Luo and Rigg [4]. For example, a PF/3 of 30 represents a 30% disagreement between two sets of data investigated. Table 2 summarises the performance for each of the five methods for each formula.

Table 2. Testing the performance of each colour difference formula

		CIELAB	CMC	CIE94	BFD	LCD	CIEDE2000
M1: ΔE_{20} (K_L=1)	PF/3	55	58	68	55	64	66
M1: ΔE_{20} (K_L)	PF/3	53	57	62	53	63	65
M1: ΔE_{45} (K_L=1)	PF/3	48	51	53	42	54	52
M1: ΔE_{45} (K_L)	PF/3	47	50	53	42	54	49
M1: ΔE_{75} (K_L=1)	PF/3	80	58	69	60	69	66
M1: ΔE_{75} (K_L)	PF/3	77	58	68	59	68	64
M1: ΔE_{110} (K_L=1)	PF/3	91	70	80	72	79	78
M1: ΔE_{110} (K_L)	PF/3	89	70	79	72	79	77
M2: ΔE_{MAX} (K_L=1)	PF/3	38	33	39	33	37	33
M3: ΔE_{EQL} (K_L=1)	PF/3	44	32	38	30	36	31
M4: ΔE_W (K_L=1)	PF/3	36	24	34	21	29	26
M5: $\Delta E_{W,op}$ (K_L)	PF/3	35	20	28	19	22	22

The M1 was further divided into two methods according to the best optimised K_L (ΔE_i (K_L)) or K_L =1 (called ΔE_i (K_L=1)), where i is one of the four aspect angles. The results show that the colour measurement data at 45° gave the best fit to the visual data regardless which formula was used. There is only a small improvement of formulae performance by introducing an optimised lightness parametric factor (K_L). Comparing the performance of all the formulae tested, BFD performed the best (with a PF/3 of 42) followed by CIELAB (48). The others did not perform well with PF/3 above 50.

The M2 (ΔE_{MAX} (K_L=1)) is to select the largest ΔE value from those for the four angles for each formula, i.e. Max[ΔE_{20}, ΔE_{45}, ΔE_{75}, ΔE_{110}] with K_L =1. The results show that there is a very large improvement, by at least 10 PF/3 units for each formula.

The M3 (ΔE_{EQL} (K_L=1)) method applies equal weighting to the four ΔE values for each pair. The results show a slight improvement compared to M2 for all formulae except CIELAB. The M4 (ΔE_W (K_L=1)) method applies the optimised weighting factors between four colour differences. It is encouraging that there is further large improvement for all formulae. The BFD formula now has a PF/3 of 21, followed by CMC (24) and CIEDE2000 (26). It is also interesting to see that for all formulae except CIELAB, the weight for the 75° is zero. The findings strongly suggest that the M4 should be recommended for industrial trials. It provides much more accurate prediction than the visual assessments, i.e. PF/3 units of 21 for BFD against about 55 for observer accuracy found in this experiment (The accuracy result for each observer was calculated between each individuals results and the mean visual results. The average accuracy was obtained by averaging each observer's accuracy result.)

The M5 method uses the optimised weighting factors in M4 plus the optimised the lightness parametric factor (K_L) for each angle. The results again show small improvements for each formula comparing with M4.

4. CONCLUSIONS

Five methods were developed to evaluate the performance of five colour difference formulae using a set of experimental data based upon metallic coatings. The results showed that the BFD formula gave the most accurate prediction. Introducing optimised weighting factors for the colour difference calculated from each angle will further significantly improve the formula's performance. The present results strongly suggest that a reliable instrumental colour control method for automotive coatings can be established. However, these findings should be checked with an independent data set.

REFERENCES

1. CIE, "*Colorimetry*", 2nd Ed., CIE Pub. No. 15.2 Central Bureau of the CIE, Vienna, Austria, 1986.
2. F. J. J. Clarke, R. McDonald, and B. Rigg, "Modification to the JPC79 colour-difference formula", *J. Soc. Dyers Color,* **100**, pp. 128-132,1984.
3. M. R. Luo, and B. Rigg, "BFD(l:c) Colour-difference formula, Part II—Performance of the formula", *J. Soc. Dyers Color,* **103**, pp. 126-132, 1987.
4. M. R. Luo, and B. Rigg, "BFD(l:c) colour-difference formula, Part I—Development of the formula", *J. Soc. Dyers Color,* **103**, pp. 86-94, 1987.
5. CIE, "*Parametric effects in colour-difference evaluation*", CIE Pub. No.101. Central Bureau of the CIE, Vienna, Austria, 1993.
6. D. H. Kim, and J. H. Nobbs, "New weighting functions for the weighted CIELAB colour difference formula", *Proc Colour 97*, **1**, pp. 446-449, Kyoto, 1997.
7. M. R. Luo, G. Cui and B. Rigg, "The development of the CIE 2000 colour difference formula: CIEDE2000", *Color Res. Appl.*, in print, 2001.
8. M. R. Luo, B. Rigg, "Chromaticity-discrimination ellipses for surface colours," *Color Res. Appl.*, **11**, pp. 25-42, 1986.

Food colour and appearance measurement, specification and communication, can we do better?

John Hutchings[*a], Mark Singleton[b], Keith Plater[**b], Benjamin Dias[b]
[a] food colour and appearance consultant; [b] Unilever Research Laboratory, Sharnbrook, England

ABSTRACT

Conventional methods of colour specification demand a sample that is flat, uniformly coloured, diffusely reflecting and opaque. Very many natural, processed and manufactured foods, on the other hand, are three-dimensional, irregularly shaped, unevenly coloured and translucent. Hence, spectrophotometers and tristimulus colorimeters can only be used for reliable and accurate colour measurement in certain cases and under controlled conditions. These techniques are certainly unsuitable for specification of colour patterning and other factors of total appearance in which, for example, surface texture and gloss interfere with the surface colour. Hence, conventional techniques are more appropriate to food materials than to foods themselves.

This paper reports investigations on the application of digital camera and screen technologies to these problems. Results indicated that accuracy sufficient for wide scale use in the food industry is obtainable. Measurement applications include the specification and automatic measurement and classification of total appearance properties of three-dimensional products. This will be applicable to specification and monitoring of fruit and vegetables within the growing, storage and marketing supply chain and to on-line monitoring.

Applications to sensory panels include monitoring of colour and appearance changes occurring during panelling and the development of physical reference scales based pigment chemistry changes. Digital technology will be extendable to the on-screen judging of real and virtual products as well as to the improvement of appearance archiving and communication.

Keywords: colour measurement, total appearance, foods, digital technology, sensory panels

1. CONVENTIONAL COLOUR MEASUREMENT

When the problem of how to specify surface colour was originally posed, the obvious question that arose was what is colour? This was answered in terms of four geometrical specifications. To take one of these, if the sample is illuminated at an angle of zero degrees to the normal, light reflected at an angle of 45 degrees will contain information about the colour of the surface. This implies that a measurement employing these angles will comply with visual observations of a two-dimensional surface using similar angles. The problem of making measurements on three-dimensional objects was shelved. This originally did not matter because adequate measurements of average colour over a surface could be made on materials produced in commodity areas having the resource to invest in the research necessary to produce standard instruments and methodology.

These industries were concerned with paints, photography, textiles, and later, ceramics and plastics. The optics of the instruments developed demanded certain specific properties of the sample. This must be opaque, of uniform colour, diffusely reflecting and, of course, flat. Happily, samples of all products manufactured by these industries could be manipulated to conform approximately to this specification. This suited instrument manufacturers whom, when they had effectively saturated these markets then turned to other industries to maintain sales.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

2. THE FOOD INDUSTRY

The food business is one such industry. There are many applications for good colour measurement practice within this industry. Examples concern colour monitoring during storage and processing, in-field crop monitoring, colour communication in what is a huge global industry, and understanding how the customer behaves when faced with food on the shelf and on the plate. Presently available equipment cannot perform these tasks adequately because there are few foods that are opaque, of uniform colour, diffusely reflecting and flat. The literature contains many reports of inappropriate measurements in which this fact has apparently not been recognised. Foods are not uniform in colour and the average colour of a ripening tomato that is both green and red in inappropriate. In general, conventional colour specification instruments, although suitable for use with food materials, are inherently unsuitable for the colour measurement of many whole foods. The ideal instrument is one that can specify colour and other total appearance[3] properties of non-uniformly coloured, translucent, diffusely as well as specularly reflecting, irregularly shaped, three-dimensional objects. This description fits most natural, processed and manufactured foods.

3. THE WAY AHEAD

Conventional instruments have proved valuable for colour research on food materials, as opposed to whole foods, but the time has arrived for the industry to develop its total appearance specification methodology. Digital technology offers a solution. If successful, this will allow us to get away from the stringent illumination and viewing geometry restrictions as well as the restrictions concerning the sample. It will be possible, for example, to take a customer's eye view of fruit on the shelf, to examine the colour and colour variation, surface texture, as well as gloss qualities, and to examine, record and monitor food on the plate. It may be possible to develop techniques for international, real-time communication among grower, processor and the marketplace and to monitor all appearance factors during storage and processing. If physics, instrument and measurement problems can be overcome the future of appearance studies will be applicable not only to food but to all industries manufacturing non-uniform three-dimensional products. Work on this has been undertaken within a collaborative, industrial, academic, government project. Those collaborating were Unilever Research Laboratory Colworth House, University of Westminster, Datacolor, University of Manchester Institute of Science and Technology (UMIST), Weetabix and Digital Paradigm. The project was partially funded by the British Ministry of Agriculture, Fisheries and Food. This paper summarises the findings of the Unilever contribution.

4. METHODOLOGY AND CALIBRATION

Three experimental lighting set-ups have been used. In the first, a MacBeth SpectraLight II lighting cabinet provided nominally vertical illumination, the camera sampling at nominally 45°. A support arm was used to enable precise movements of the camera to be made relative to the sample and to the light source. The second source of illumination was a copy stand system in which two high frequency sources illuminated the sample at 45°, the camera viewing at an angle 0° to the sample. The third was designed to examine the behaviour of gloss patterns on materials as angles of illumination and detection are changed. Between them, these experimental set ups provided a complete set of sample viewing conditions and could be used to replicate ways in which we view foods in real consumer life. Extraneous light affects results so during measurements laboratory lights were extinguished. Two cameras were used, a Canon DM-XL1 digital camcorder and a Nikon Coolpix 950. Calibration and measurement software was based on the Datacolor ImageMaster system.

Lighting distribution, stability and reproducibility are important in a colour measuring system. Warm up time and stability studies of the lamps and cameras indicated that MacBeth cabinet light source stability of 0.1 ΔE^* units was achieved after a warm up time of one hour. The copy stand stability was 1.7 ΔE^* after three hours warm up. For actual colour measurement work the copy stand system was selected. The lamps used were not ideal but the geometry was more suitable and perspective problems arising when imaging samples in the SpectraLight were avoided. In both lighting set ups an area of constant surface illuminance of 75 cm^2 was defined, within which ΔL^* varied by less than one unit.

The Coolpix camera was selected for the calibration stage of the work because of its higher resolution – this being required to detect small irregularities of colour and surface texture in biological and food product surfaces. Repeatability of response of this camera could be reduced to 0.5 ΔE* by appropriate exposure and white balance setting up.

From a number of possible camera calibration methods suggested by UMIST that based on the MacBeth ColorCheker and Kodak grey scale charts was selected. The charts were calibrated using a Datacolor MicroFlash Reflectance Spectrophotometer and National Physical Laboratory tiles. Measurements on the charts after calibration yielded a mean colour difference of 4.8 ΔE* units with a mean grey scale error of 2.4 and a maximum colour error of 33 units. Clearly this degree of error is not acceptable even for variable fruit or vegetable surfaces. Therefore, calibrations have also been made using the two charts supplemented by other specific colours. These were aimed at obtaining a more precise calibration of specific regions of colour space, for example, those occupied by freshly cooked peas or fresh oranges. Mean colour differences of 20 and 17 ΔE* units for greens and oranges were in this way reduced to more acceptable 4.1 and 3.4 respectively. It is believed that even these figures could be improved by using a more suitable light source.

5. EXPLOITATION

This work has major implications for the advancement of appearance measurement and assessment technology in the food industry.

5.1 Measurement

It is possible to specify the colour and colour patterning of irregular three-dimensional objects that vary in colour, for example, the surface of a ripening fruit. Hence, the technique is applicable to all natural and many manufactured and processed foodstuffs. Measurements are performed on a pixel by pixel basis hence unwanted effects due to background and sample gloss and shadow can be eliminated. This can be done automatically with appropriate software tools, for example those developed for this project by Digital Paradigm.

Appearance measurements can now be made outside the laboratory. For example, growing and ripening patterns of plants as well as of individual fruits and vegetables can be studied and monitored in the field, store, laboratory and factory. Coupled with studies in the supermarket these techniques make possible co-ordinated studies along the complete supply chain.

There are also promising indications that this technology will also be transferable to the measurement of other appearance attributes such as surface texture, gloss and translucency. It should also be possible to exploit the technique for improved automatic on-line monitoring of food product appearance including communication and archiving.

5.2 Sensory and Consumer Studies

Studies of the sensory aspects of food appearance are hampered by the three-dimensional nature of colour itself. This has prohibited the production of physical colour scales that mimic the sequences of colour changes occurring with natural pigments. An example concerns the changes that take place in chlorophylls and carotenoids during tomato ripening. Using the new technology physical colour scales can be developed with respect to the colour and pigment science of the particular food system under examination. This work could lead to the development of a colour atlas that can be used by panellists to monitor changes in biological colour[3] easily and consistently.

The new techniques present an opportunity to examine critically the effects of time on appearance using time-lapse appearance measurements. This was used to study colour changes taking place in samples during panel testing of hot foods.

Monitor screens can be colour calibrated. Although this aspect was not fully explored it is possible that we shall be able to facilitate crop and product monitoring by establishing visual link communication and archiving between the growing and producing companies in different part of the world.

Other applications to sensory and consumer studies include:

- in-home and in-hospital studies of the effect of diet appearance on consumers,
- development studies on the effect of appearance make-up of products on the plate, on the pack and on the shelf,
- on-screen visual sensory assessments using calibrated monitor screens, and
- on-screen panel assessment of products whose virtual colour has been carefully manipulated for development studies.

Some of the implications for these on-screen studies were examined by the University of Westminster.

6. CONCLUSIONS

Digital camera technology represents the colour and appearance specification breakthrough for which the food industry has long awaited. Application and exploitation are numerous within the area of total appearance of foods and food materials. At last food colour and food colour uniformity can be properly specified and monitored and the parts played by gloss and surface texture quantified and understood in biological, food research, control, sensory analysis and consumer terms.

ACKNOWLEDGEMENTS

This work was carried out as part of a MAFF LINK British government, industry, and academia collaborative programme.

REFERENCES

1. John Hutchings, *Food color and appearance*, 2nd edition, Aspen, Gaithersburg, 1999

* john.hutchings@physics.org; phone +44 1234 376768; 6 Queens Road, Colmworth, Bedford, England MK44 2LA
** keith.plater@unilever.com; phone +44 1234 781781, Unilever Research Laboratory, Colworth House, Sharnbrook, Bedford, England, MK44 1LQ

The Process Industries- Graphic Arts, Paint, Plastics, and Textiles: All Cousins under the Skin

Frederick T. Simon, Graphic Communications, Clemson University

ABSTRACT

The origin and selection of colors in the process industries is different depending upon how the creative process is applied and what are the capabilities of the manufacturing process. The fashion industry (clothing) with its supplier of textiles is the leader of color innovation. Color may be introduced into textile products at several stages in the manufacturing process from fiber through yarn and finally into fabric. The paint industry is divided into two major applications: automotive and trade sales. Automotive colors are selected by stylists who are in the employ of the automobile manufacturers. Trade sales paint on the other hand can be decided by paint manufacturers or by individuals who patronize custom mixing facilities. Plastics colors are for the most part decided by the industrial designers who include color as part of the design. Graphic Arts (printing) is a burgeoning industry that uses color in image reproduction and package design. Except for text, printed material in color today has become the norm rather than an exception.

INTRODUCTION

Where do the colors of man-made objects come from? Who decides what colors to use? These are questions that puzzled me for a long time since I was on the receiving end as one who was concerned with the measurement of color. For more than sixty years, I was involved in the metrology of color where any color would be converted into numbers through spectral measurement so that the difference between objects could be defined or that a formula could be calculated to match a color someone else had created. Curiosity led to an understanding of the origin of the color of the materials that I had to work with and it has been fascinating to learn the similarities and differences among the industries produce colored materials.

In the main, the color of materials is affected by two factors: the creativity of the designer and is limited by the manufacturing process of the particular industry. Although there are similarities among the several process industries, the differences among them are most interesting. Not infrequently members of one industry do not understand the nuances of another industry and will make assumptions about unfamilar processes that lead to confusion. It is extremely important to realize the potential of color use in industrial applications.

TEXTILES

The indisputable leader in color is the fashion industry that has important ties to textiles. The pace of this industry demands change and innovation each season to attract customers to the latest fashion idiom. Novelty in both color and style does influence the buying public so pressure was manifest in what at times was a somewhat chaotic pace. Not only do fashion innovators create styles and patterns but will frequently set trends that are copied by slower moving manufacturing industries that do not need to develop at such a rapid rate. To understand a large segment of the textile industry that supplies the fashion market, it is necessary to divide it into the sequence of manufacturing steps that bring color to textiles from fiber to fabric. Each part of the industry that leads from fibers to finished fabric has a unique method of applying color. Starting with fibers such as cotton, wool, flax, or man-made fibers, each type of fiber is dyed with dyes or colored with pigments suited to its chemical characteristics. It is significant that dyes used to dye cotton are not suitable for wool or man-made fibers or vice versa indicating that some extensive chemistry had been done in the past to make this possible. When individual fibers are dyed, the resultant yarn and fabric give the well-known heather effect. Man-made fibers can have pigments incorporated into them that provides specialized colors that are very fast to light. The next step in manufacturing textile is to make fibers into yarn. Color can play an important part when yarns are individually dyed and are ultimately woven into many interesting fabrics. Ginghams, madras and tartans are yarn-dyed and challenge the designer to come up with new and attractive patterns. After weaving yarns into fabric, two important methods are used to color cloth: printing or piece dyeing. The print designer is always in close collaboration with the textile printer who is charged with converting a design into printed material. A large amount of solid color textiles come to the market and the special colors that are available are determined both by style and the demands of special application.

The great fashion shows in Paris and New York give an audience for known designers of clothing to show their wares and thus influence what the fashion world can look up to for the next season. Style rather than color is the dominant feature of these shows

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

but the influence on pattern and color are unmistakable. An organization such as the Color Marketing Group as its name indicates devotes a major part of its function in predicting the colors that will be used in the future fashion as well as other industries. A meeting is held of a group of knowledgeable designers who establish a consensus of colors that they believe will be important for the upcoming season. They issue a Palette of color swatches that they distribute to the members each season. There are other organizations who perform similar functions to CMG. It is up to individual designers to create designs and patterns in fabric and to decide how they will utilize the color trends in a manner that will be saleable and attractive to the buying public. This in effect limits the colors that are available in clothing and accessories at any given time.

PAINT

The paint industry is mainly divided by application into three market areas: automotive, industrial and trade sales. In each case the color of the paint is originated in a different manner. Trade sales includes the hardware and paint stores that cater to the retail trade. In the past the predominant market was ready-mixed paint where an array of colors had been selected by the paint manufacturer and this is what the consumer had to select from. At one time in the past, Faber Birren had an organization whose function was to predict the color trends and advise paint companies on which colors to make for stock. Today an important segment of the retail paint market is handled by the home improvement stores as well as specialized paint retailers who offer color matching services. In this way the householder can determine the desired color. An amount of paint can be specially formulated with a matching system tied to a pigment dispensing system. In this way, the paint manufacturer supplies what is called a tint base plus the pigment dispersions for the dispenser. The color decision is then directly in the hands of the consumer.

Industrial paint is usually manufactured to application specifications that determine the composition in terms of the needs of the buyer. In general, the colors are limited in scope and tailored to the end use. The automotive industry represents some of the highest performance paint in the entire market. Color is determined by the automobile stylist and is an integral part of the design. Colors are an important part of the marketing strategy for each model year and are an important aspect of appeal to consumers. Black, white and red are the mainstays of every year with striking hues used to attract attention. However, small nuances in the basic shades distinguish some models and are used as special promotional items.

PLASTICS

The color of plastics is predominately considered a part of the design of a product. It is usual that an industrial designer develops a product and defines the color according to the need. For the most part we associate plastic colors as fairly mundane but that is not to say that they are functionally unimportant since they attract customers to a product. For the most part, plastic objects are made colorful through the pigmentation that is generally quite fast. Included in the plastics industry is the production of vinyl and urethane films. This product is closely related to textile fabrics that are used in upholstery and wall covering. Generally the film itself is colored by pigmentation with a colored printed pattern added to provide added interest.

GRAPHIC ARTS

The Graphic Arts industry has a long history of using color in printing. In the 19^{th} century, litho stones were used to impress individual colors of a printed image that was usually a reproduction of art work. Since that time printing processes and printing presses have undergone a tremendous development. For some time most magazines and other publications have had an increasing number of pages printed in color until we have come to expect practically all publications to be printed in color. The key to this is the printing presses that use offset and gravure printing processes. More recently the specialized need s for packaging products to attract the attention of customers in the self-service retail markets to act as the silent sales person. Advertising is the prime mover in providing an air of excitement through the use of color. Graphic designers in the advertising agencies thrive on the competition to satisfy their customers who need to promote their products to the buying public. Color printing in both publication and packaging plays an important role in this area.

Graphic Arts in the past ten years has undergone a revolution since the adoption of the computer. Formerly, photography had been the medium used to separate colors so that the color of images could be reproduced through the half-tone process. Now it is possible to use computer graphics to accomplish the steps normally done through photography. The underlying principle in separating an image into the three chromatic ink components, Cyan, Magenta, and Yellow, has remained the same but the tools to accomplish this are simpler and more flexible. This is called "process color." Certain pigments, primarily the magenta and yellow, are used in printing ink but are not usually found in paint because the fastness requirements are not as important in publication and packaging. Color printing continues to grow year by year. When specific colored areas, termed "spot colors", are needed in a printed design, they are matched much like is common in paint, plastics and textiles. The Pantone © color system is frequently used to convey information between the designer and printer about the desired color. A wider range of pigments can be used in "spot colors" compared to "process colors."

CONCLUSION

No mention has been made of color in the glass and ceramics industries primarily because the author has had no experience in those fields. It is known that the processes used to introduce color into those instances is somewhat different than the industries described above. Fine Arts, painting and design. have their own approach to color that is sometimes an end in itself rather than a part of a manufacturing process. It is evident that as the impact of color from TV, advertising, and the like becomes more pervasive, color has become a way of life rather than a novelty.

NOTE

A number of illustrations will be given in color at the oral presentation of this paper to explain the processes involved.

Complex refractive index and colour of quinacridone pigments

Wilhelm H. Kettler[†], D.P.C.

ABSTRACT

Complex refractive index of pigment violet 19 (β-modification) was determined by means of an ellipsometric method within the visible spectral range. From the known complex refractive index and the particle size of the pigment, single-scattering properties (scattering and extinction efficiency, asymmetry parameter) were calculated for vehicles of different refractive indices employing an algorithm based on Mie-theory for spherical particles. These parameters were fed into a multiple-scattering model to investigate the dependence of reflectance of a semi-infinite film on particle size and refractive index of the embedding medium. Theoretically calulated results are in reasonable agreement with corresponding experimentally determined reflectance spectra of pigment violet 19 dispersed in different solvent- and water-based resin systems.

Keywords: Refractive index, quinacridone pigment, radiative transfer

1. INTRODUCTION

Understanding of the physical/chemical mechanisms involved in pigment optics has become particularly important in the recent years because of stringent demands of the market for providing exact isomeric matches of a reference colour shade in any given resin system. When switching from one resin system to another (e. g., from a solvent- to a water-based system) the requirements to be generally fulfilled are that there should not be (i) any appreciable deterioration in quality, and (ii) any visually assessable changes in colour appearance for worked out pairs of formulas. In particular, the latter requirement is generally claimed to be the case without attention being payed to the physical origin of the phenomenon colour and the natural limitations inherent in changing the embedding medium of the pigments. The elaboration of package solutions is subject to a variety of restrictions that in some cases can lead to a situation where the determination of a single master panel for working out in any given resin system is not always meaningful. It is, therefore, imperative to establish anew that under certain conditions wider acceptance solids in colour space have to be admitted.

Keeping in mind the foregoing remarks, a detailed optical study of a quinacridone pigment (CI pigment violet 19; β-modification) has been undertaken. The objective of the present study was to investigate the accuracy of available scattering models and to define a general method for predicting the reflectance properties of pigments dispersed in different vehicles that exhibit varying refractive indices and cause specific particle size distributions.

2. EXPERIMENTAL DETAILS

The complex refractive index $N = n + ik$ of a quinacridone violet pigment (pigment violet 19; β-modification) has been measured within the optical spectral range using a conventional null ellipsometer setup. The pigment powder has been pressed in a steel mould to tablets of $2cm$ diameter and $0.5cm$ thickness in a mechanical high-pressure device allowing a maximum pressure of 5 tons per cm^2. The pigment formed a hard compact mass, and the surface in contact with the stainless steel base developed a fair degree of polish. The sample was pressurized until there were no more volume contraction effects observable.

Pigment violet 19 was dispersed in different solvent- and water-based resin systems. Reflectance measurements were performed on all prepared samples within the visible spectral range using a commercial double-beam spectrophotometer equipped with an Ulbricht sphere. The refractive indices N_{med} of the different resin systems were derived from a *Fresnel* analysis of reflectance measurements carried out on black samples with the specular component included and excluded, respectively.

[†] Correspondence: DuPont Performance Coatings, Christbusch 25, D-42285 Wuppertal, FRG; phone +49-202-529-2282; fax +49-202-529-2821; E-mail: kettler@wuppertal.herberts.de

System	L^*	a^*	b^*	C^*	h_{ab}	$N_{med}(550nm)$
BC-SB (Refinish)	11.22	33.62	11.32	35.47	18.61	1.518
AS-SB (Refinish)	10.14	32.08	9.42	33.44	16.37	1.524
BC-WB (Refinish)	10.47	30.30	10.62	32.10	19.31	1.521
BC-WB (OEM)	9.56	30.38	10.40	32.11	18.90	1.505
AM-SB (OEM)	8.46	30.08	8.29	31.20	15.42	1.529
SR-SB (Refinish)	8.52	28.87	7.44	29.81	14.45	1.523

Table 1. Colour position in *CIELab* colour space of the mass-tone of pigment violet 19 dispersed in various resin systems (SB - solvent-based; WB - water-based; BC - base-coat; AS - acrylic system; AM - alkyd melamine; SR - synthetic resin). The refractive index (N_{med}) of the resin systems is collected in the last column.

3. THEORETICAL MODELS

The reader is referred elsewhere [1] for a detailed description of the Mie-theory of scattering by isotropic homogeneous spheres. Here, we recall that the extinction cross-section of a single particle represents the total power abstracted from the unit incident beam and is related by

$$C_{ext} = C_{sca} + C_{abs} \tag{1}$$

to the cross-sections for scattering, C_{sca}, and absorption, C_{abs}.

The reflectance, R_∞, is calculated from the scattering efficiency, $Q_{sca} = C_{sca}/G$, extinction efficiency, $Q_{ext} = C_{ext}/G$, and asymmetry parameter, g, for spherical particles (G=particle cross sectional area = $\pi d^2/4$ for spheres) in the film using Mie-theory. Assuming a semi-infinite diffusor, the reflectance is given by [2]

$$R_\infty = \frac{\sqrt{1-\omega_o g} - \sqrt{1-\omega_o}}{\sqrt{1-\omega_o g} + \sqrt{1-\omega_o}} \quad , \tag{2}$$

where the single-scattering albedo, $\omega_o = Q_{sca}/Q_{ext}$, is defined as the ratio of scattering and extinction efficiencies. The internal reflectance, $R_{int} = R_\infty$, has to be corrected for reflections at the boundary layer between the surrounding air and the pigmented film (Saunderson correction) according to [3]

$$R_{ext} = \alpha\, r_{ext} + \frac{(1-r_{int})(1-r_{ext})R_{int}}{1-r_{int}R_{int}} \quad , \tag{3}$$

where r_{int} (r_{ext}) represents the internal (external) reflection coefficient of the embedding medium. For measurements with included (excluded) specular component one has to set $\alpha = 1$ (0).

4. RESULTS AND DISCUSSION

Pigment violet 19 belongs to the class of polycyclic compounds free of azo-groups and metals. The β-modification under consideration is being utilized in the field of solid colours in combination with iron-oxides, molybdenum-orange, and titanium-dioxide to produce deep bordeaux and red-brown colour shades and, in the field of effect colours, to produce violet, blue, and red colour shades. Dispersing pigment violet 19 in different resin systems leads to a broad spectrum of colour positions in *CIELab* colour space (see Tab. 1).

The wavelength variation of the real (n) and imaginary (k) parts of the complex refractive index of pigment violet 19 at room temperature is shown in the left diagram of Fig. 1. The salient features of the $n(\lambda)$- and $k(\lambda)$-curves can be summarized as follows: (i) the refractive index n ranges between 1.4 and 2.2, while the absorption index k is limited to values less than 0.7, (ii) the variation of n exhibits the characteristic resonance features of dielectric behaviour, (iii) k shows a marked absorption peak at a wavelength corresponding to the resonance in n and diminishes to small values below and to negligibly small values above the resonance, and (iv) a pronounced fine-structure below the resonance peak can be observed in both $n(\lambda)$- and $k(\lambda)$-behaviour.

Fig. 1 also depicts the particle size distribution $q(d)$ of pigment violet 19 derived from the analysis of electron-microscopical images. The $q(d)$-function, based on a sample set of 730 particles, describes the size distribution of the primary particles having a mean diameter of $< d > \approx 52nm$ and a d_{50}-value of $70nm$. When dispersed in a resin system the particle size distribution function is expected to shift towards higher particle diameters and to broaden.

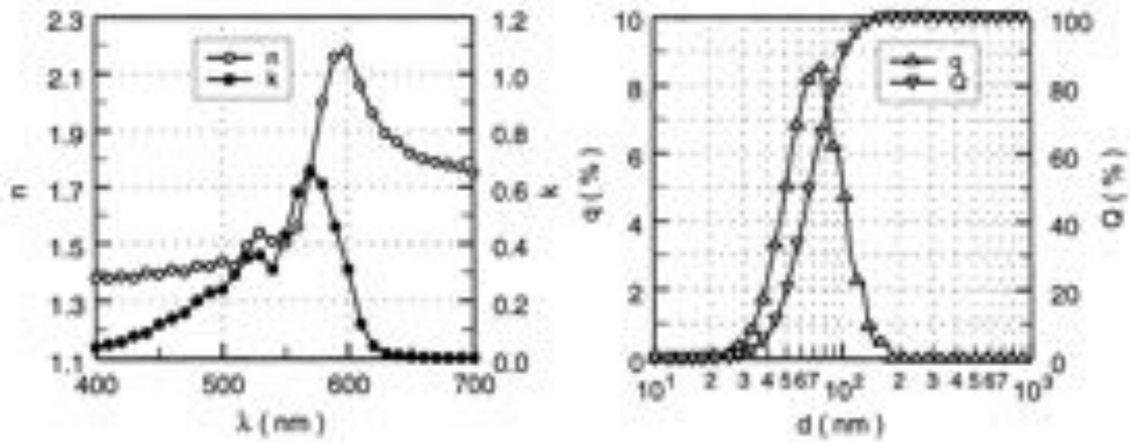


Figure 1. Wavelength dependence of both real (n) and imaginary parts (k) of the complex refractive index of pigment violet 19 within the visible spectral range (left diagram) and particle size distribution (right diagram).

The upper left diagram of Fig. 2 shows the outcome of detailed scattering calulations on pigment violet 19 in the form of reflectance spectra. The shape of the pigment particles, with diameters covering the range $50nm \leq d \leq 200nm$, have been assumed to be spherical. The refractive index of the embedding medium has been set to the typical value of $N_{med} = 1.5$ (see Tab. 1). It is noticed from Fig. 2 that the calculated reflectance spectra for pigment violet 19 in the long wavelength region are strongly dependent on the particle size. For particle diameters above the critical value of $d_c \approx 200nm$, however, the calculated reflectance spectra are only very weak functions of the particle size. The theoretically predicted reflectance spectra compare favourably to experimentally obtained spectra of pigment violet 19 dispersed in different solvent- and water-based resin systems that have been collected in the upper right diagram of Fig. 2. In consonance with observations made previously [4] on the γ-modification of pigment violet 19 a quantitative agreement between theoretical and experimental results can only be achieved if particle sizes well above the average value of the primary particles are assumed.

The above-mentioned theoretical finding of the existence of a critical particle diameter, d_c, separating two regions of strong ($d < d_c$) and weak ($d > d_c$) dependence of the calculated reflectance on d is reflected in the variation of the chroma, C^*, with particle size (see lower left diagram of Fig. 2). The $C^*(d)$-function clearly reveals that concerning the chroma an optimum particle size exists. Consequently, broad particle size distributions containing significant fines will reduce the chroma, since an increasing number of particles will contribute with chroma values less than the possible maximum value.

In all three cases of pigment violet 19 embedded in vehicles of different refractive index and depicted in the lower left diagram of Fig. 2 the $C^*(d)$-function exhibits a maximum at a particle size of $d_{max} \approx 200nm$. The maximum value increases with decreasing refractive index N_{med} of the embedding medium. Below the maximum the chroma is a quite sensitive function of particle size and decreases quickly as d decreases, while above d_{max}, C^* decreases in steps at a comparatively low rate. A close scrutiny of the diagram reveals that the refractive index of the embedding medium may have a significant impact on the macroscopic coloristic properties of pigment violet 19.

Fig. 2 (lower right diagram) also depicts the spectral variation of the asymmetry parameter, g, of the Mie-theory. For very small particles the scattering is almost isotropic, i. e., g takes values close to zero. With increasing diameter d, the particles predominantly scatter into the forward direction ($0 < g \leq 1$). Since the ratio $x = \pi d/\lambda$ determines the "optically effective size" of a particle, g continuously decreases with increasing wavelength.

5. CONCLUSIONS

A quantitative comparison between predictions of the theoretical models and experimental results concerning the influence of particle size and refractive index of the embedding medium on the optical properties of pigment violet 19 has unambigiously revealed that the agreement between experiment and theory is reasonably good. Thus, the model used for the calculations on the one hand represents a valuable tool for the chemist for optimization and estimation of general pigment optical properties, and on the other provides a clear indication of the optical behaviour of pigments

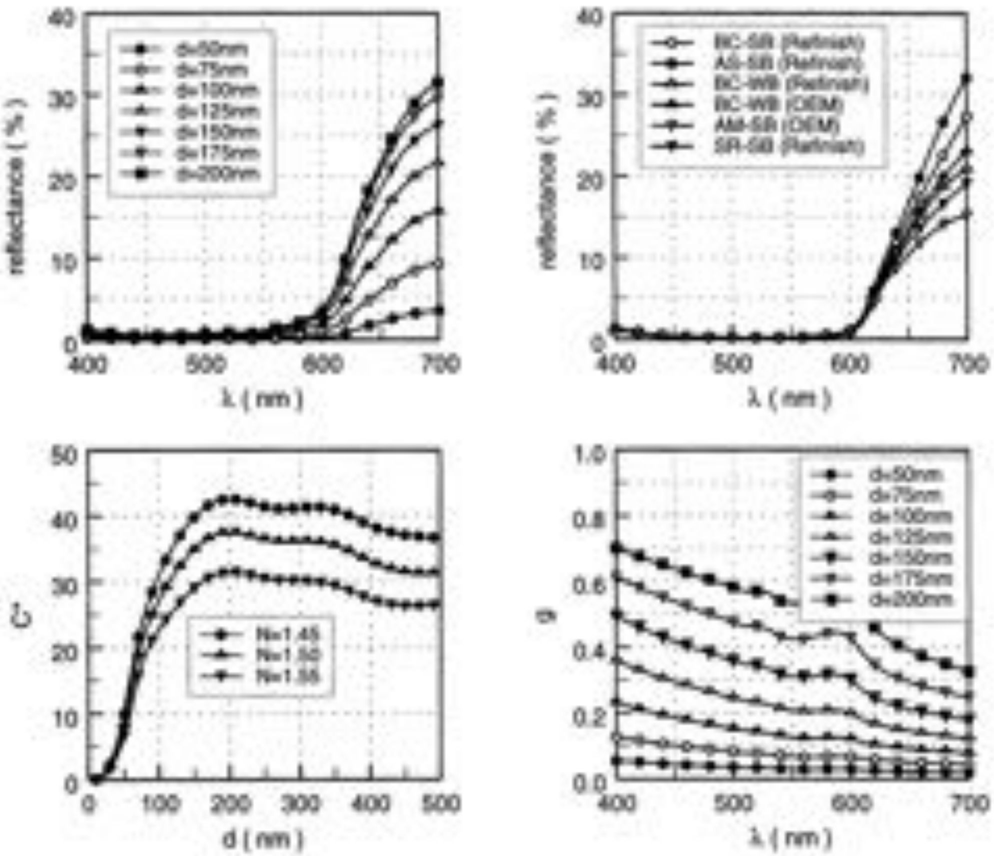


Figure 2. The upper left diagram shows plots of theoretically calculated reflectance spectra of pigment violet 19 within the visible spectral range for different particle diameters. The spectra have been calculated for spherical particles embedded in a medium of refractive index $N_{med} = 1.5$. The upper right diagram displays the wavelength dependence of experimentally determined reflectance spectra of pigment violet 19 dispersed in different solvent- and waterbased resin systems (abbreviations are explained in caption of Tab. 1). Dispersing pigment violet 19 in vehicles of different refractive indices (N) leads to the variation of the chroma, C^*, with particle size, d, depicted in the lower left diagram. In the lower right diagram theoretically calculated wavelength dispersion of the asymmetry parameter, g, of pigment violet 19 within the visible spectral range is shown.

in different embedding media. In particular, the latter experimental observation can be employed successfully by the colourist to predict whether or not a pigmentation change is required when working out pair solutions of any reference colour shade in different resin systems.

ACKNOWLEDGEMENTS

The author takes pleasure in thanking Dr. H. Schmelzer of the former Hoechst company for providing the complex refractive index data of the presently investigated sample, and Dr. H. Klee of Clariant for providing the corresponding particle size distribution.

REFERENCES

1. M. Kerker, *The Scattering of Light*, Academic Press, New York, 1969.
2. C. F. Bohren, "Multiple Scattering of Light and Some of its Observable Consequences," *Am. J. Phys.* **55**, p. 524, 1987.
3. G. Kortüm, *Reflexionsspektroskopie*, Springer-Verlag, Berlin, 1969.
4. W. H. Kettler and G. Richter, "Theoretical and practical aspects of color matching in different automotive coating systems," in *XXIV. FATIPEC congress*, pp. A–417, (Interlaken, Switzerland), 1998.

Discontinuity, bubbles and translucence: major error factors in food colour measurement.

Douglas B MacDougall, The University of Reading, UK.

ABSTRACT

Four samples of breakfast cereals exhibiting discontinuity, two samples of baked goods with bubbles and two translucent drinks were measured to show the degree of differences that exist between their colours measured in CIELAB and their visual equivalence to the nearest NCS atlas colour. Presentation variables and the contribution of light scatter to the size of the errors were examined.

Keywords: Food appearance measurement, structure, discontinuity, bubbles, translucence, visual assessment, NCS atlas.

1. INTRODUCTION

Food products have to be acceptable in appearance for the consumer and it is essential that the factors involved in selection and control of raw materials, process and product development and deterioration are understood. Foods present virtually every problem that can lead to inaccurate measurement of colour[1]. Few are truly flat and opaque and may be rough or smooth, multi-structured or translucent while liquids range from clear and coloured to cloudy translucent or near opaque and creamy. Although colour procedures have been agreed for a limited number of foods, e.g. for tomato paste, instrumental measurement often results in colour values that are far from the actual perception of the food's colour appearance. Reasons for this are several of which discontinuity, bubbles and translucence are particularly important because they are essential contributors to the food's structure but may not be taken into account in industrial colour measurement. This can readily be demonstrated by comparing the measured colour values of the product with that of the visual equivalence of reference colours.

Discontinuity may be defined as that condition where the components of the food and the inter-component spaces are arranged randomly. This situation does not lend itself to easy and reproducible measurement. The problem would appear to be intractable unless the sample is examined by video image analysis or is so manipulated to replace the random discontinuity with a uniform distribution of the particles by grinding the sample to constant particle size[2]. The resultant measurements, now reproducible and consistent, are less erroneous when compared with visual equivalence.

With bubbles the difficulties can be either obvious or hidden. In bread and other baked goods, such as sponge cakes, bubbles are intrinsic to the product's appearance e.g. the crumb structure of bread[3]. Visual assessment tends to result in observers judging product colour as a separate attribute from the bubbles. Measurement by instrument includes the bubbles with the consequence that colour values are darker than those in a colour atlas.

Of the three sources of structural error, translucency is probably the most important because it leads to confusion in both visual assessment and instrumental measurement. It has long been recognised as a confounding factor in the colour appearance of such products as fruit juice and meat[4,5,6]. Recognition of juice lightness may be in inverse order to that measured by instrument and variation in translucency-opacity in meat is associated with major faults in quality. For translucence, in addition to CIELAB, some measure of light scatter, e.g. the Kubelka-Munk (K-M) analysis[7], is required for a more adequate definition of colour appearance.

Although the author has studied some of the above phenomena the use of reference colours to define the degree of discrepancy between measurement and observation has not been reported for such foods. This paper presents the magnitude of the differences between the measured colours of such foods, their light scatter and visual estimate of their colours using NCS® colour samples under diffuse Artificial Daylight (D_{65}) and directional tungsten illumination.

2. EXPERIMENTAL

2.1 Instrumental measurement

The products selected for surface discontinuity were the breakfast cereals Shredded Wheat and Weetabix biscuits and Kellogg's Bran Flakes and Corn Flakes. The bubble structured products were French bread and Madeira cake and those exhibiting translucence were semi-skimmed milk and tomato juice. The breakfast cereals were ground in two stages, firstly with a small food processor and then, for half of the material, with a coffee grinder. The combined materials were separated into fractions of >2mm, 1-2mm, 0.5-1mm and <0.5mm with standard sieves. The samples were measured in 50mm x 50mm cells with 10mm path length. The cell was lightly tamped during filling to ensure uniform packing. Although the biscuits could be measured whole, it was impossible to measure whole flakes meaningfully. They were therefore lightly crushed by hand. The bread was measured by cutting into 20mm slices and then removing the crust. The slices were measured on both sides and then compressed between glass plates to approximately one third their thickness and measured again. Samples were also ground into crumbs and the 1-2mm fraction collected after sieving. The cake was prepared similarly to the bread except that compression was only possible to half its original thickness. The milk and the tomato juice were measured in a 20mm path cell and also in a special 1.5mm path cell with opaque white and black "Perspex" inserted into the rear of the cell for the K-M analysis. The ICS-Texicon Micromatch colour spectrophotometer was set with a 25mm aperture and the specular component excluded.

2.2 Visual judgement

The colours of the entire samples were assessed for their visual equivalence under fluorescent Artificial Daylight (900 lux) and also, for confirmation, under directional tungsten illumination. This was carried out in two stages, firstly using the NCS atlas to determine the nearest page and then with the individual 35x100mm colour samples surrounding the original selection. These were placed on top of the materials, one at a time, to select the nearest colour. Although precise matching was not possible it was sufficiently close to enable selection of the nearest colour in the atlas.

3. RESULTS & DISCUSSION

3.1 Discontinuity of breakfast cereals

The breakfast cereals' reflectance spectra are shown in Figure 1.

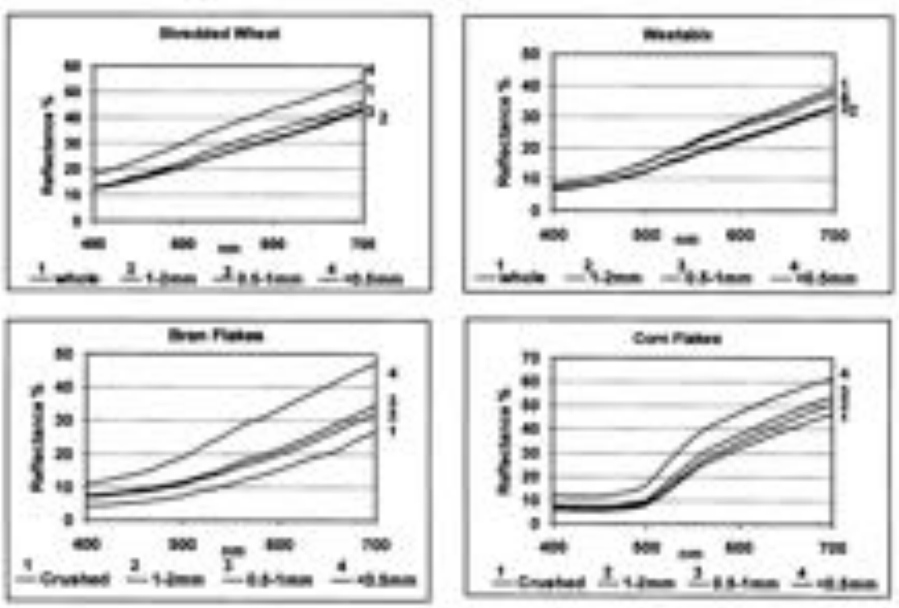


Figure 1 Reflectance spectra of breakfast cereals at different particle sizes

For the two examples of crushed and ground and sieved flakes the order of least reflective to most reflective was as expected with the finer material (<0.5mm) being most reflective. That is, with the increasing surface area and minimising gaps as the particles reduced in volume they progressively scattered more light. The 1-2mm and 0.5-1mm fractions were closest in appearance to the original flakes, and to each other, whereas the <0.5mm fraction was considerably lighter and more yellow. The order of lightness was not the same for the biscuits as for the flakes. The 1-2mm, 0.5-1mm and <0.5mm were the same order but the spectra of the whole biscuits was lighter than the 0.5-1mm and 1-2mm. The curvature of the two sides of the Shredded Wheat biscuits is different and the sides of the Weetabix biscuits exhibit different degrees of browning from the baking process. The L*C*h* values at D_{65} are given for all the original products in Table 1.

3.2 Bubbles in French bread and Madeira cake

The spectra of the French bread and Madeira cake are given in Figure 2.

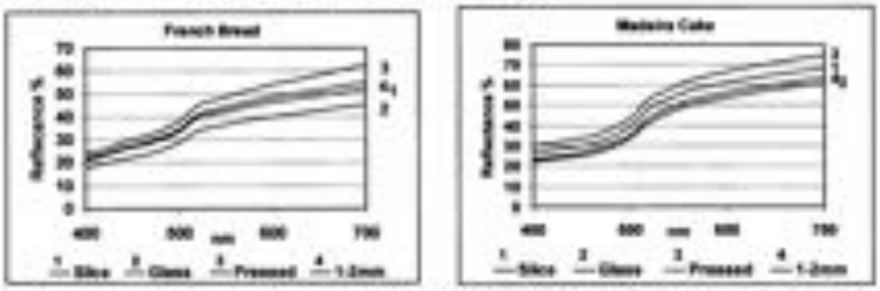


Figure 2.Reflectance spectra of French bread and Madeira cake as slices and standard particle size

In French bread the bubble size is relatively large, random and unevenly distributed. Its appearance is attractive light greyish white with the white caused by light scatter from the starch and gluten network. The bubbles can be eliminated by compressing the bread to about one third of its volume. The appearance changes markedly and is now more translucent and considerably darker. The visual judgement of bread colour usually excludes the bubbles although they are a vital part of the product's quality. Breadcrumbs produced with the food processor could not be sieved smaller that 1mm without changing the character of the crumb. The relationship of spectra of the bread, directly in contact with the aperture and behind glass, to pressed bread to 1-2mm crumb is shown in Figure 2. Madeira cake by contrast is yellow from the eggs used in its manufacture and has a more compact structure with near insignificant bubbles contributing to its appearance.

3.3 Translucency in semi-skimmed milk and tomato juice

The spectra are shown in Figure 3 along with the calculated values of the K-M coefficients.

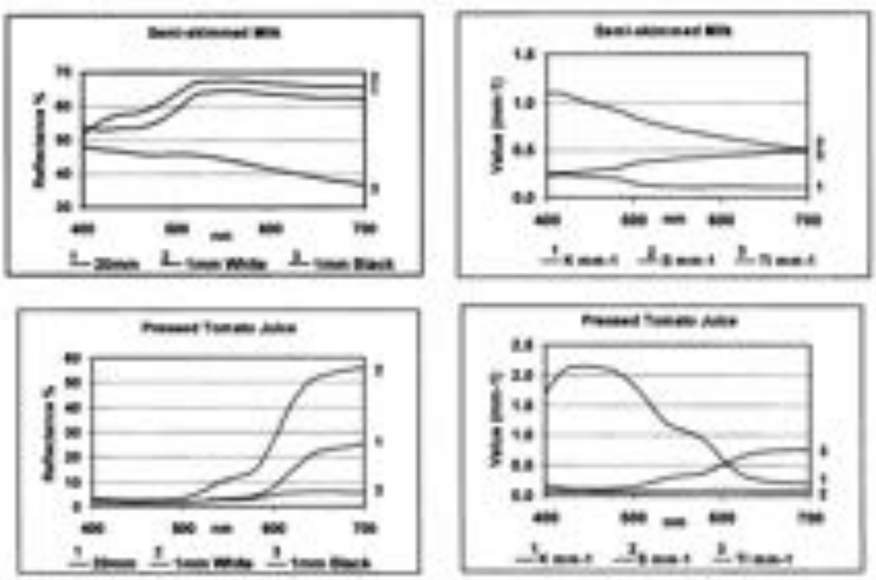


Figure 3. Reflectance spectra and Kubelka-Munk coefficients of semi-skimmed milk and tomato juice.

Although translucence is a well-recognised component of many foods it is seldom separated from the measurement of colour. Translucence is difficult to define because the visual experience lies somewhere between transparent and opaque. The semi-skimmed milk and tomato juice exhibit a divergence in their appearance. The milk is white, but not brilliant, while the tomato juice, bright red on a white background, is much darker when observed in a drinking glass. The K-M coefficients for the milk clearly differentiate between the pigmentation, predominantly carotene, and the light scatter. The absorption coefficient for the tomato juice is that of the orange-red plant pigment lycopene. The light scatter for the milk is several times greater than the tomato juice because the micelles (fat-protein globules) in the milk are regular and much smaller than the macerated plant structure that is the major component of light scattering in the juice.

3.4 Visual assessment

The nearest matches of the samples to the NCS colours are presented in Table 1 along with the D_{65} L*C*h* values and the differences. The largest differences were in L*, ranging from 7 to 21 units, and always in the same direction of the NCS colours being the lighter. The differences in C* were only <3 units and for h* the differences were <7 degrees except for the bran flakes which was 15 degrees because of the difficulty of deciding which atlas page the product most resembled. The greatest contribution, therefore, to ΔE* was ΔL* with chroma and hue contributing <1 unit to ΔE*. Typical differences in L* between adjacent colours, with the same C* and h*, in the atlas are approximately 10 units which shows that the visual discrepancy in colour assessment of the products for most of the foods was greater than the one NCS L* step.

Sample	L*	C*	h*	NCS Match	L*	C*	h*	ΔL*	ΔC*	Δh*	ΔE*
Shredded Wheat	61.0	21.4	76.2	2020 Y30R	74.1	22.8	69.2	-13.1	-1.4	7.0	13.5
Weetabix	54.1	25.5	73.3	3020 Y30R	67.7	22.5	68.4	-13.7	2.9	4.9	14.1
Bran Flakes	40.4	23.4	66.0	4030 Y50R	55.3	26.0	50.7	-14.9	-2.7	15.3	16.5
Corn Flakes	53.6	44.0	68.4	1050 Y30R	74.8	47.8	64.2	-21.2	-2.8	4.3	21.8
French Bread	70.3	19.6	85.9	1010 Y10R	88.8	16.4	86.2	-18.4	3.2	-0.3	18.7
Madeira Cake	77.7	26.7	82.9	1020 Y10R	84.6	25.2	83.5	-6.9	1.5	-0.6	7.1
Semi-Skimmed Milk	83.3	8.3	103.3	S0502 Y	93.0	6.5	98.9	-9.7	1.8	4.3	9.9
Tomato Juice	25.5	34.3	39.5	4060 Y80R	38.1	33.7	33.2	-12.7	0.6	6.3	13.3

Table 1. CIELAB D65 values for raw samples, nearest match NCS atlas colours and colour differences.

4. CONCLUSIONS

This study has shown clearly that instrumental colour values, although indicative of the colour as perceived, may not be related accurately to the equivalent colours in a standard atlas. The consequence of this for the food industry may not be fully recognised. Translucence, difficult to define psychologically because of its indeterminate range between transparency and opaque, continues to be a problem in industries other than the agri-food area, e.g. toiletries and plastic. Discontinuity is also a problem for of some industries, e.g architecture and building where materials may be difficult to measure.

ACKNOWLEDGEMNTS

The author wishes to thank the Food Biosciences Department, The University of Reading, UK for travel funds.

REFERENCES

1. J. B. Hutchings, *Food Colour and Appearance*, Lippincott Williams & Wilkins, Philadelphia, 1999.
2. M. Kent, "Collaborative measurements on the colour of lightscattering foods". In: *Physical Properties of Foods*, eds. R. Jowitt, F. Escher, M. Kent, B. McKenna and M. Roques, vol. 2, 277–294, Elsevier, London, 1987.
3. G.M. Campbell, C. Webb, S.S.Pandiella, and K. Niranjan, *Bubbles in Food.* Eagan Press, St. Paul, 1999.
4. D. B. MacDougall, "Changes in colour and opacity of meat", *Food Chemistry*, **9**, 75–88, 1982.
5. D. B. MacDougall, "Optical measurements and visual assessment of translucent foods". In: *Physical Properties of Foods*, eds. R. Jowitt, F. Escher, M. Kent, B. McKenna and M. Roques, vol. 2, 319–330, Elsevier, London, 1987.
6. D.B. MacDougall, "Principles of colour measurement for food". In: *Instrumentation and sensors for the food industry,* ed E. Kress-Rogers, 39-62, Butterworth Heinemann, Oxford. 1993.
7. D. B. Judd, and G. Wyszecki, *Color in Business, Science and Industry*, 3rd edn, Wiley, New York, 1975.

Contact author: douglas.macdougall@talk21.com. Home address: 4 Japonica Close, Wokingham, RG41 4XJ, UK.

The role of digital printing and color technology in the digital revolution for the textile world

Patrick Chong, Quality Engineering Associates, Inc.

ABSTRACT

The digital revolution in the textile world has already started in a globalized manner in digital design and digital sampling, digital production and digital commerce underpinned by digital technology. This paper addresses on the present status of the digital printing technology underpinned by the digital color technology and its impact to the digital revolution process in the textile world.

Keywords: Textile, market trend, digital printing, analog printing, color technology, future prospect

1. INTRODUCTION

It has been a market trend for the last decade that the product cycle lifetime has shorten continuously and this trend is expected to accelerate in the next decade. In particular, it is a heavy financial burden to keep inventory whether it is parts or finished products. To minimize such difficulty and to cope with demand for new product designs frequency, the manufacturers are faced with smaller and smaller lot size for each design. These market trends will require a much higher efficient and accurate business and production information flow along the textile supply chain to enable super quick response to the market, globalized transactions, as well as to support customized and un-conventional shopping. On top of all these challenges, the world is also demanding for an environmental conscious and energy efficient manufacturing practice. The traditional analog printing technology, including screen printing and roller printing is developed to carry out mass production with abundant capacity. It consumes significant resources in pre-process and in-process preparation prior to production printing. This includes pre-process fabric preparation, colorant formulation, screen engraving and in-process fine tuning for color and engraving appearance for the print results. In particular, the screen engraving process is costly and time consuming that contributes to the major print process bottle-neck. In recent years, the use of computer aided design system, computer colorant formulation system, digital color and image communication as well as colorant dispensing system have helped to streamline the pre-production process. Nevertheless, the analog printing technology is essentially a mechanical process that creates a "mechanical gap" in the entire digital information highway along the textile complex. This has rendered the textile printers to be in a much inferior position to react to the various market challenges. In addition, the analog printing technology has the following limitations.

- Large space utilization for production machines and for screen inventory
- High consumption of water and energy
- Design limitations in terms of repeat size, design colors, and design resolution
- Difficult to realize the "print on demand" concept to minimize inventory and to produce short lot size economically
- Costly process to treat waste colorants and chemicals

2. DIGITAL PRINTING TECHNOLOGY

Advances in digital printing technology from ink jet printing to electrophotographic printing has been tremendous over the last decade and the details on this subject is widely published[1,2]. For textile industry, due to the physical and chemical nature of the substrate, ink jet printing is an important digital printing technology adopted by the industry. Most developments are based on either drop-on-demand type or continuous ink jet type. Of the drop-on-demand type, digital printing systems have been built using the piezo inkjet head technology or the thermal inkjet head technology. However, such technology development must be synchronized with both ink and media development as a pre-requisite for success.

Digital printing for the textile industry differs from conventional analog printing technology in which the digitally printed substrate is produced directly from the information system with a digitally controlled printing engine. In this aspect, the key digital information fed to the print engine is design image with colorimetric data. Thus, this offers the option of variable information printing to support mass customization. A few suppliers have already incorporated the digital printing system as a module of the entire integrated sampling system to combine cut/print/sew in one location for fashion products to add value in time to market. In addition, the information driven system offers the advantage of print-on-demand at flexible lot size. More importantly, these features allow the open digital linkage with the external manufacturing and business digital pipeline along the textile complex. The rapidly developing information networks and digitized manufacturing processes will no doubt revolutionize the textile business implementation. As a consequence, the new opportunity offers by the digital printing technology is pretty much limited by the individual company's imagination, knowledge level, business strategy and its commitment. While digital printing technology provides an opportunity to eliminate or minimize the various difficulties associated with analog digital printing technology, it offers another interesting opportunity to complement with conventional printing in the area of sampling. Sampling or table-strike-off is an expensive process for both the customers and the manufacturers as either party normally makes no or little profit at this stage while a lot of resources have to be invested in both the engraving and color development as well as other materials preparation. At the same time, the table-strike-off activity is very intensive immediately before any major trade show, as it is customary for most converters to delay such process as much as possible. This results in major bottleneck with the conventional table-strike-off process. The screen-less print-on-demand flexible lot size digital printing technology offers a tremendous opportunity here. In short, digital printing technology offers a revolutionary role in creating new products, new services, new digital business chain as well as providing an opportunity in complementing the conventional technology in sampling and short-run

3. CHALLENGES FOR DIGITAL PRINTING TECHNOLOGY

While digital printing technology is a fairly mature technology for the paper printing industry, yet such developed technology cannot be treated as a direct drop-in technology for the textile printing industry because of the differences in physical and chemical nature of the media as well as the process variations. Nevertheless, this has presented a number of challenges as listed in the following.

System Design: Variations from paper printing in colorant volume loading, spot colors versus process colors, substrate texture, substrate flexibility, and substrate chemical nature requires careful system design and balance for various system parameters such as ink viscosity, gray levels, drop size, drop frequency, number of print heads, data communication that will impact on the resulting print speed and print resolution.

Color Reproduction: This is a major challenge for both the paper printing and the textile printing processes due to imperfect solutions or improper execution in color calibration, color profiling, color gamut matching, color instrumentation and measurements. In particular, it is more severe with textile printing if digital printing technology is employed to substitute the table-strike-off process. The use of process color and inks with physical-chemical properties differ from the analog printing process will enhance the color matching difficulty.

Print Mark Reproduction: In a similar fashion with color reproduction, digital prints must simulate the engraving appearance of the analog production prints if it is adopted for the table-strike-off process. Print quality attributes in terms of dots, lines, large area including tonal gradations and print growth must have reasonable resemblance between the two processes. In this aspect, the printers and the engravers must work closely together to provide the digital printing system with the necessary knowledge about each analog print process.

Color Fastness: The physical and chemical properties of the ink must be designed to fit the substrate quality in order to achieve an acceptable level of various color fastness properties such as crocking, washing, and light fastness. In addition, the proper treatments of the fabric before and after the printing process are essential to ensure good fastness properties.

Fabric Quality & Properties: Digital printing cannot by-pass the knowledge intensive fabric pretreatment and fabric post-treatment steps especially if it is intended for production purpose. Proper pretreatment promote satisfactory print appearance while proper post-treatment allows fashionable effects and provides additional values such as improved handle, luster, color fastness or soil resist property to the fabric. On the contrary, in-consistent or poor treatment will result in color and print mark variations. These two value-add on steps also present a logistic supply issue if users do not have such facilities. In addition, any inconsistent fabric speed, fabric wrinkling, loose fibers and the touching of the ink jet nozzle will present great challenge to the print quality result.

Ink Issues: The textile printers prefer inks to be compatible with colorants used in the analog printing process to facilitate co-ordination and to maintain similar color effects. At present, inks for digital printing are available in reactive inks for cellulose, acid inks for protein fibers, disperse inks for polyester and pigment inks for all types of fibers. However, due to the physical parameter restrictions for ink jet printing, some ink may not perform satisfactory in terms of fastness or color range requirements.

Printing Speed: In an absolute sense, the print speed of digital printing is extremely slow in comparison with the analog printing. Typical speed for rotary screen printing is up to about 60 m/min. while for digital printing is up to about 60 m/hour for drop-on-demand type printer. The speed of digital printer is restricted by various factors including the number of color heads and its nozzles, the type of ink jet technology, the capacity of data handling rate and the desired print resolution etc.. For digital printers that adopt thermal print head has an additional critical issue of limited head lifetime. However, if we consider the total picture including the time saved in screen engraving and the fact that digital printing is a more efficient, flexible and creative process, the print speed issue is less critical. On the other hand, some users are adopting a "multiple printers" concept where many digital printers are employed to carry out the production to enhance the print capacity in a way similar to a weaving operation.

Print Width: Most digital printers are designed with print width up to about 1.6m and this present a challenge to the domestics market that requires print width of about 3m.

Printing Cost: The present high cost of inks for digital printing couple with other factors such as the low machine throughput have rendered digital printing not suitable for long production run.

User Knowledge: In many instances, the users expect to purchase a digital printing system that will perform as a turn-key system and quickly experience disappointment.

4. COLOR TECHNOLOGY

As far as digital printing is concerned, one can consider the color technology as a pillar technology for digital printing. As a matter of fact, a major challenge reported for both digital and analog printing is color reproduction. The advances in both basic colorimetry and advanced colorimetry have contributed significant value to the digital printing technology. The International Commission on Illumination (CIE) basic colorimetry includes the objective specification of colors based on tristimulus values (1931) as well as the CIELAB and CIELUV systems (1976) for both color and color difference specifications. More advanced and recent color difference formula includes the CMC formula (ISO 105-J03:1995) widely adopted in the textile industry as well as the CIE94 formula that is also an ISO standard (ISO/DIS 7724 Part 6) for the paint industry. In the mean time, CIE TC1-47 is focusing on the modification of the CIELAB formula following the format of CIE94 and CMC to develop the new CIEDE2000 color difference formula. The CIE advanced colorimetry includes the color appearance model for prediction of changes in color appearance according to different viewing conditions. In 1997, the CIE adopted the CIECAM97s color appearance model. In cross media color reproduction for digital printing application, the CIE basic colorimetry is important in device characterization model as well as the provision of a device independent color space for profile connection. In addition, the International Electrotechnical Commission (IEC) TC100/TA2 is developing standard method for characterizing various input/output devices. On the other hand, the CIECAM97s is important for predicting color appearance under different viewing conditions in cross media color reproduction. Due to the variations of viewing conditions in practice, the use of spectral based device characterization could minimize metamerism. Another challenge to cross media color reproduction is the usual mis-match of color gamuts for various media, CIE TC 8-03 is developing a universally applicable gamut mapping model. The industry standards on device profile format (International Color Consortium, ICC) and the TIFF 6.0 image file format (Computer Integrated Textile Design Association, CITDA) provide an important basis for the textile industry to exchange digital files for digital printing applications. CITDA has also formed a Color Standards Committee to improve the communication and management of color for the manufacturing of soft goods, from initial design through to final product on the retail floor.

Since the fifties, color measuring instruments have evolved from large, heavy, slow measurement speed, low precision, costly and cumbersome data reduction task to portable, high speed, high precision, affordable and very user friendly. Such advancement has rendered textile retailer to communicate color quality by "numbers" as oppose to the use of "physical colors" to accelerate the time to market cycle. The success of this method requires a highly standardized method and procedure to be adopted by all partners in the complex. More recently, this method has been supplemented with digital color image communication[3] using calibrated and characterized color monitors to provide instant color communication along the entire textile supply chain providing an opportunity for distributed digital printing operations around the world. On the other hand, it can be a challenge, in terms of reliability, repeatability and productivity, to use standalone color measuring instruments for digital printer characterization for textile application simply because of the large number of colors to be measured manually. To resolve this issue, automatic color scanning system has been developed to carry out the color profiling task automatically[4].

5. FUTURE PROSPECTS FOR DIGITAL PRINTING TECHNOLOGY

A recent market study report[5] shows the market growth potential for digital textile printing is very attractive in comparison to the other industries. Worldwide installation of digital printing systems for textile application in sampling and short run production is expected to reach a growth rate of 52% during the period 1999 to 2004. This is consistent with the market trend and demand as elaborated in sections (1) and (2) of this paper. There is great incentive for digital printing system developer to address the various technical and business challenges to satisfy the market. However, the success can only be achieved via a partnership approach technology-wise and market-wise among the print engine suppliers, the ink suppliers, the media suppliers, the CAD/color system suppliers, the information technology suppliers, the users as well as the thorough understanding of the end customers. The recent textile shows at the Heimtextil in Frankfurt, Germany (Jan. 2001) and the ATME-I in Greenville, USA (Apr. 2001) have demonstrated significant advances in addressing the various technical challenges including print speed, print width, print head height flexibility, more user friendly inks, options of spot colors, increase in print head colors, in-line printed fabric finishing and the use of conventional roll to roll flat-bed table top for smooth transportation of fabric.

Both the rapid market development and the rapid technology development will have great impact to the textile industry in the foreseeable future. The textile printing industry will become a knowledge intensive manufacturing operation that will require a much higher education level production personnel to operate the future textile plant. Here, the textile colleges, the government and the textile industry must play an active role to invest in technical education. The recent announcement of the Philadelphia University in building a Center of Excellence in Digital Ink Jet Printing at the School of Textiles and Materials Technology is an exciting development. It is the people's knowledge that will render success or failure in the new Millennium. The advances in digital infrastructure and the digital printing system will allow globalized product development and production. Companies can determine the most effective domestic-offshore manufacturing mix to determine the quickest response to the market and generate the best financial reward. Mass production textile print centers will be more demanding for quality as oppose to quantity and its locations will shift to the developing countries particularly in places where the growth in consumers is significant. There will be numerous one-stop imaging, color and textile print servicing centers around the world with major focus in mass customization flourishing initially in developing countries and then spreading elsewhere. The future textile printing industry is exciting. Are you ready?

ACKNOWLEDGEMENT

I wish to express my sincere appreciation to Spartan International for continuous support during my career in the textile world. Without its encouragement and inspiration, this paper could not have been completed.

REFERENCES

1. R. N. Mills, Ink Jet Printing – Past, Present, and Future, IS&T 10th International Congress on Advances in Non Impact Printing, pp. 410-413, 1994.
2. R. A. Work, III, Direct Digital Printing Technology – Beyond the Office! Where Will it Go Next?, IS&T 16th International Congress on Digital Printing Technologies, pp 427-429, 2000.
3. P. A. Rhodes, M.R. Luo, A System for WYSIWYG Colour Communication, Displays, **16**, No. 4, pp. 213-221, 1996.
4. M.K. Tse, P. Chong, Color Quality Monitoring of Thermal Dye Sublimation Film, QEA Pub., 2001, Quality Engineering Associates (QEA), Inc., 99 South Bedford Street, #4, Burlington, MA01803, USA.
5. Worldwide Printer & Supplies Market Report, IT Strategies Pub., 2001, IT Strategies, Inc., Hanover, MA 02339, USA.

*Correspondence: Patrick.Chong@qea.com; phone 781-221-0080; fax 781-221-7107; http://www.qea.com; Quality Engineering Associates, Inc., 99 South Bedford Street, #4, Burlington, MA 01803, USA.

Colored light application in retail display window

M. Simeonova and N. Narendran
Lighting Research Center, Rensselaer Polytechnic Institute, Troy, NY12180

ABSTRACT

A laboratory experiment was conducted to investigate the usefulness of colored LEDs in retail display window applications. Human subjects viewed two side-by-side, identical mock-up display windows, and rated their preference. Subjects showed strong preference for the colored background, compared to the white background. In general, subjects disliked the modulated intensity background. Furthermore, the use of colored light (static red and blue) on the background allowed the accent light to be decreased without sacrificing visual appeal, ability to capture attention, and ability to see displayed objects clearly. It appears from this initial laboratory study that the amount of accent light can be reduced significantly, which could provide energy savings. We believe a field study would be greatly beneficial for further confirming these results and for quantifying the total energy savings in an actual store.

Keywords: Retail, colored light, LEDs

1. INTRODUCTION

A retail display window is typically designed to attract potential customers, and to convey a message. In a shopping mall display, windows compete with one another to capture the attention of potential customers by using higher light levels and high luminance contrast between the accented merchandise and the background. A majority of the retail display windows use halogen PAR or MR lamps. Presently, retail lighting guidelines recommend illuminance contrast ratios in the range 15:1 to 30:1 to produce theatrical effects [1]. The direct impact of retailers increasing the overall light levels in their stores is increased energy use. The shortage and rising cost of energy in the United States has triggered many local governments to implement energy conservation programs. Identifying alternate lighting solutions that can result in lower energy consumption is one motivation for this study.

Spatial discontinuities and luminance modulations often contribute to visual interest in a given scene. There are a number of research publications that suggest the use of color, and the use of color modulation in a space can produce similar results [2,3]. Although there are many research studies that have addressed the issue of colored light in a variety of applications [4,5] there are no studies that have systematically explored the use of colored light in a retail setting, and have quantified their performance. In the past, colored light was generally created using absorption filters, which wasted energy. In recent years, high brightness Light Emitting Diodes (LED) have entered the market place. These LEDs can be effectively utilized to generate colored light [6]. Unlike filtered white light sources, LEDs produce colored light efficiently. As an example, LED traffic signals save over 80% of the energy compared to their filtered incandescent counterpart [7]. Therefore, the goal of this study is to find out whether colored LEDs offer significant advantage in retail window display in terms of energy savings, visual appeal, and attention gathering capabilities.

2. EXPERIMENT

2.1 Experimental setup

A laboratory experiment was conducted to investigate the usefulness of colored LEDs in window display application. As shown in Figure 1, two side-by-side mock-up display windows were used as the experimental setup. The dimensions of the mock-up display windows were based on creating a 40-degree by 40-degree viewing field, typically subtended by display windows in a realistic setting. The overall dimensions of each structure were 7-feet high by 3-feet wide by 3-feet deep. Black fabric covered the sides of the display window to prevent spill light. The back wall of the display window was covered by a 3-feet by 3-feet white, matte finish foam board. Viewing the windows from a 7 feet distance subtends a 40-degree by 40-degree field of view.

Both display windows were constructed identically and they both carried identical display objects. In experiment 1 a loosely meshed scarf, a pair of bright colored gloves (stripes of red, blue, green and yellow), and a white knit hat were placed on top of a white pedestal that was located at the center of the window. In experiment 2 the display was of an abstract hay hat, fish net and see shells, all in earth and sand muted colors. Figure 2 illustrates the displays used in experiment 1 & 2.

Two six-inch wide lighting coves were created in front of the back wall, at the top and at the bottom, for a linear array of color LEDs (series of red, green, and blue LEDs). The linear LED arrays spanned the entire width of the window display at the top and at the bottom. The total power consumption of the LED arrays in a window was 15 watts. In addition, two 75-watt incandescent PAR30 lamps were placed in the lower cove to light up the background of the display. This setup allowed the background to be lit either by the halogen or LEDs to create white and colored backgrounds respectively. The displays in the scene were accent lighted by two 50-watt MR16 (7 degree, narrow spot) lamps. The measured light levels inside the display windows are summarized in Table 1.

Figure 1: Experimental setup, composed of two side-by-side display windows

Figure 2: Display window in experiment 1 (left) with bright striped colors, and in experiment 2 (right) with earth and sand muted colors

	Illuminance (vertical fc.)			**Luminance (cd/m^2 at 100% accent light)**			**Luminance (cd/m^2 at 20% accent light)**	
	White	Red	Blue	White	Red	Blue	Red	Blue
Display	500			1200				
Background	25	28	17	70	10	7	2.1	1.23

Table 1: Measured light levels inside the display windows. (Average illuminance at floor level in the passageway was 10 fc.)

2.2 Human subject evaluation

Two human subject experiments were conducted. The objective of experiment 1 was to determine if colored light on the window background, static or modulated, has the capability to be more visually appealing and can capture attention more than the white light window display. The objective of experiment 2 was to determine if static colored light on the window display would allow for the decrease in accent light without sacrificing visual appeal, ability to capture attention, and ability to see displayed objects clearly.

<u>Experiment 1</u>

All human subjects who participated in the experiments were tested for color vision deficiencies. None of the subjects had formal lighting education. Each subject viewed the two display windows simultaneously. One of the windows had the colored background while the other had the white background. Both windows had identical white accent light. The subjects answered an ordinal ranking (or a forced choice preference) questionnaire in which they selected yes or no, indicating their preference, but not the magnitude of their preference. There was no choice for equal preference for both display windows in the comparison pair. For each comparison pair the subject was given one minute to observe both window displays as presented, and then exit the testing space and answer the questionnaire. Meanwhile, the experimenter changed the lighting condition on the background. Five background lighting conditions were presented in this experiment: white static light, red static, blue static, red modulated and blue modulated light. Modulated refers to a slow sinusoidal variation of intensity (6 seconds per cycle). The testing session for each subject lasted approximately 45 minutes with a 10 minute break to prevent fatigue. Altogether, ten comparison pairs were presented in random order to seven subjects in experiment 1. Subjects' responses were simultaneously graded on four indicators: attention capture (or eye catching), visual clarity (or see clearly), aesthetics (or like), and conveyed message (expensive vs. inexpensive).

The results of experiment 1 are shown in Table 2. In general, colored light on the background is preferred and scored higher than the white light for all four indicators. For "eye catching," the red and the blue static light scored higher compared to their respective modulated light. For "see clearly," the red and the blue modulated light were distracting and graded unfavorably. For "like more," the colored light scored high above the white light with the blue static light being the most liked, and again the modulated red and blue light was disliked. For "expensive," the static colored light scored higher than the white light with the blue static light being slightly preferred. Modulated light was considered inappropriate.

Lighting condition	Eye catching yes scores	See clearly yes scores	Like more yes scores	Expensive Yes scores
White static	2.5 (4%)	10 (14%)	10.5 (15%)	9 (12%)
Red static	20 (29%)	19.5 (28%)	17 (24%)	21 (30%)
Blue static	18 (26%)	18.5 (26%)	22 (32%)	23 (34%)
Red modulated	12 (17%)	9.5 (14%)	8 (11%)	10 (14%)
Blue modulated	17 (24%)	12.5 (18%)	11.5 (18%)	7 (10%)

Table 2: Experiment 1 results.

Experiment 2

The objective of experiment 2 was to determine if static colored light on the background of the display window would allow for the decrease in accent light without sacrificing visual appeal, ability to capture attention, and ability to see displayed objects clearly. The accent light was reduced from its full output (100%) to no accent light condition (0%) in seven steps: 100%, 70%, 55%, 35%, 25%, 10%, 0%. A continuous, nine-step rating scale was used to record and quantify the responses of nine subjects. Once again, all subjects were tested for color vision deficiencies. None had formal lighting education. The protocols used in this experiment were very similar to experiment 1.

The results for experiment 2 are shown in figures 3 a-d. To keep the graphs legible the error bars were not included. The average standard deviation of all the points was 46. It can be seen from these graphs that the results for red and blue color light are very similar, and are significantly more preferred, compared to the white background. In general, the display window with colored light remained more eye catching, more liked, and appeared more expensive, compared to the white light display until the accent light intensity went below 25 percent. The displays were seen equally clear in the colored and white windows for the most part, except at the very last instant when the accent light went below 35%.

3. SUMMARY

An experimental study was conducted to investigate the usefulness of colored LEDs in retail display window applications. Human subjects viewed two, side-by-side mock-up display windows, and rated their preference. Results of this study show that the majority of the subjects showed strong preference for the static colored background, red and blue, for attention capture and visual appeal, compared to the white background. Although modulated colored backgrounds scored slightly higher than the static white background, they performed worse, compared to the static colored background. The use of colored light (static red and blue) on the background allowed the accent light to be decreased without sacrificing visual appeal, ability to capture attention, and ability to see displayed objects clearly. It appears from this initial study that the amount of accent light can be reduced significantly, which could provide energy savings. However, further investigation is needed, especially a field study, to confirm the effects observed in this laboratory study.

FURTHER STUDY

Some of the limitations of this present study include neutral colored display objects and achromatic area surrounding the display windows. As a result, red and blue colors in the scene may have added the dimension of interest. In an actual mall, the display windows can carry multicolored objects, and the adjacent windows can have colors in them as well. As part of the on-going research, further investigations are being planned with multicolored displays. A field study will be carried out in the future to confirm the laboratory findings.

4. ACKNOWLEDGMENTS

The authors gratefully acknowledge Color Kinetics for establishing a graduate student scholarship at the Lighting Research Center (LRC) and donating LED lighting equipment for the study. In addition, the authors wish to thank Lighting Services Inc. for donating lighting equipment. Martin Overington of the LRC is thanked for the support provided to build the experimental setup. Valuable advice given by Prof. Peter Boyce of the LRC is also gratefully acknowledged.

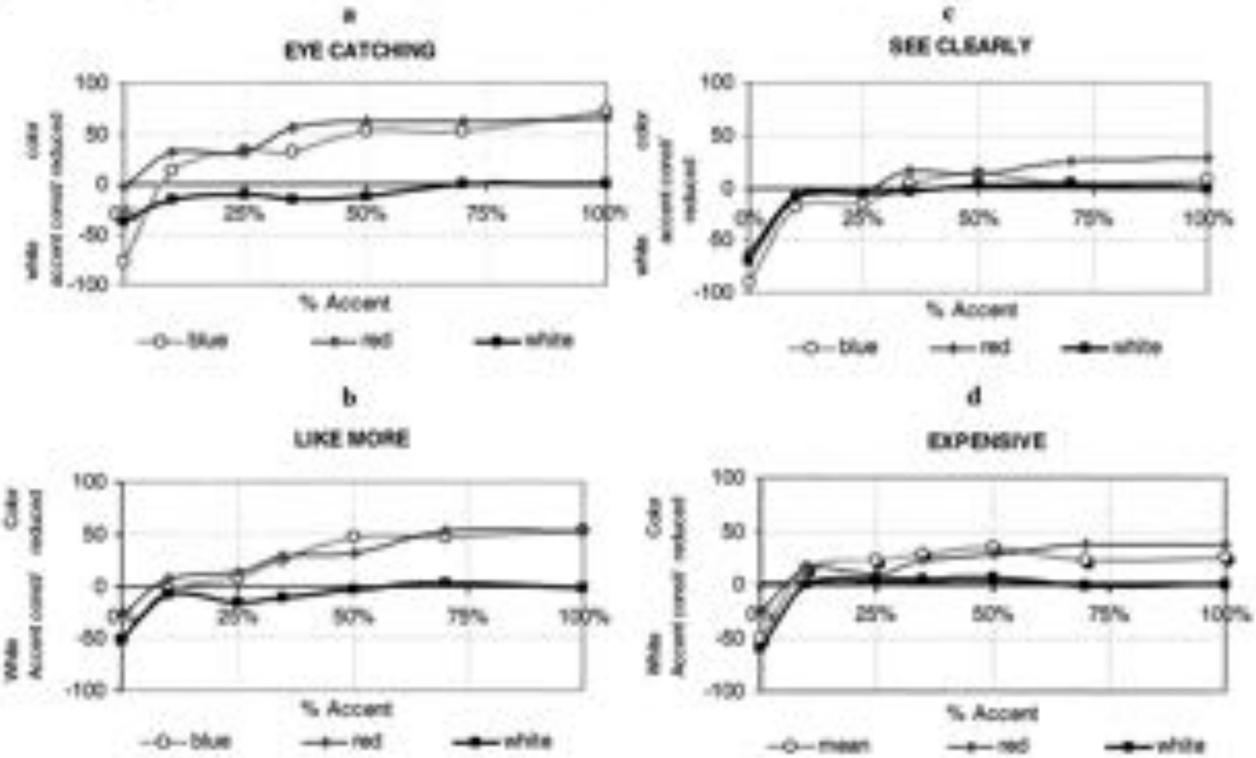


Figure 3: Subject ratings for red, blue and white background: a) eye catching (or attention grabbing) b) like more (or visually appealing), c) clearly see display objects, d) looks expensive

5. REFERENCES

1. Philips Lighting Company, "Retail lighting application guide", NJ, 1998.
2. Barbara A. Steinman, Scott B. Steinman, Stephen Lehmkuhle, "Transient visual attention is dominated by the magnocellular stream", *Vision Res.*, Vol. **37**, pp.17-23, 1997.
3. Hans-Christoph Nothdurft, "Salience from feature contrast: additivity across dimensions", *Vision Res.*, Vol. **40**, pp.1183-1201, 2000.
4. P. Wong, "The beneficial effects of light", *CIBSE National Lighting Conference*, UK, 1994.
5. K van Creveld MSc, "An investigation into the relationship between luminance and brightness of strongly chromatic light sources", *CIBSE national Lighting Conference*, UK, 1998.
6. Mark S. Rea, editor, "*Light Emitting Diodes*", IES Handbook 9th Edition, Ch. **6**, pp.65-66, NY, 2000.
7. Kathryn M. Conway, John D. Bullough, "*Will LEDs transform traffic signals as they did exit signs?*" IESNA Annual Conference, New Orleans, LA, 1999.

Evaluating the quality of daylight simulators using metameric samples

H. Xu, M. R. Luo and B. Rigg, Colour & Imaging Institute, University of Derby, UK

ABSTRACT

An experiment was carried out to evaluate daylight simulators. The colour differences of seventy wool metamers were assessed 20 times by a panel of observers under six D65 simulators. The results were used to test various colour difference formulae, to evaluate the quality of these simulators and to compare the results between the present method and the CIE method which calculates a metamerism index using virtual metamers.

Keywords: Daylight simulator, metamerism Index, colour difference, metamer

1. INTRODUCTION

Illuminant metamerism is a well known visual phenomenon for which a visual match of a pair of samples (metamer) under one illuminant (say D65) could become a large mismatch under a second illuminant (say illuminant A). It has long been realised that different daylight simulators could significantly affect visual results on colour matching or colour appraisal. This is caused by different spectral power distributions (SPD) between simulators. The current CIE method[1] for evaluating the quality of daylight simulators first calculates CIELAB colour differences for five visible (400-700nm) and three UV (300-400nm) virtual metamers using the SPDs of the test simulator and target CIE daylight illuminant. (The virtual metamers were provided as part of the CIE method. They have almost zero colour difference calculated under a particular CIE illuminant.) The mean ΔE values for the visible and UV virtual metamers are then calculated and are denoted as MI_{vis} and MI_{uv}, respectively. The index is categorised into A to E categories for ΔE values less than 0.25, 0.25-0.5, 0.5-1.0, 1.0-2.0 and larger than 2, respectively. The final result is expressed by MI_{vis} followed by MI_{uv} such as AB. If there is no fluorescent content, only MI_{vis} is reported. The method has been widely used in the lighting and surface colour industries. However, some doubts have been raised because the CIE method applies virtual metamers which might not be representative of the typical metamers in practice. An experiment was carried out here to test this.

2. EXPERIMENTAL

2.1 Daylight Simulator

Six D65 simulators were collected of which five are fluorescent lamps made by four different manufacturers (GretagMacbeth, GE, Toshiba, VeriVide) and one is a filtered tungsten lamp situated at a GretagMacbeth SpectraLight II viewing cabinet. The fluorescent lamps were evaluated in a purpose-built viewing cabinet made by VeriVide. Each simulator was measured using a Minolta CS1000 tele-spectroradiometer against a PTFE white tile with a 0/45 geometry. The instrument traced to the NPL standard with measured wavelength range from 380 nm to 780 nm at 1 nm increment and 5 nm bandwidth. Each fluorescent simulator had been fired for about 100 hours before commencing the experiment and was measured three times (before, during and after the experiment) over a period of three months. All simulators were stable with a maximum variation of 0.001 in u' v' units and 4.5% in luminance (cd/m^2). Figure 1 shows the SPDs for each simulator and the CIE D65 illuminant. Table 1 summarises the engineering data for each simulator.

Table 1 Information for the six D65 simulators

D65 simulator	Make	Band type	L (cd/m^2)	u'	v'	CCT(K)	MI_{vis}
VeriVide (VV)	F20F12/D65	Broad band	564.4	0.1965	0.4653	6788	B
GretagMacbeth (GM)	F20T12/65	Broad band	551.3	0.1989	0.4700	6333	C
GE	F20W/AD	Broad band	536.9	0.2006	0.4676	6356	C
Toshiba-1 (T1)	FL20SS-EX-D/18-H	Three bands	987.4	0.2013	0.4641	6513	E
Toshiba-2 (T2)	FL20S-D-EDL-D65	Broad band	480.4	0.2018	0.4700	6145	B
GretagMacbeth SPL-II (GMS)	Filtered tungsten lamp		410.7	0.1970	0.4696	6480	A

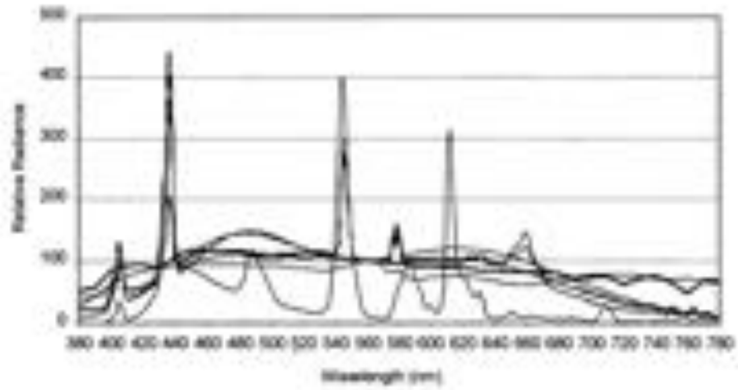


Figure 1 The relative SPDs for the six D65 simulators studied and the CIE D65 illuminant (in bold). Note that the SPDs of all simulators except that of T1 were scaled to 100 at 560 nm. T1 (three-band) was scaled to 400 at the maximum radiance.

2.2 Sample Preparation

Seventy metameric pairs prepared by Kuo and Luo[2] were again used. These samples were made by dyeing plain wool serge and were mounted two layers on a stiff card (3" by 3"). A grey scale with five grades was also prepared using matte paint with the same size as that of textile samples. (The darkest grade was duplicated. One was used as the 'standard'.) All samples were measured three times (before, during and after the experiment) using a GretagMacbeth ColorEye 7000A spectrophotometer from 400-700 nm at a 10 nm interval. The measuring condition was large aperture, specular included and UV included. For all samples, the Mean/Maximum colour differences (CIELAB) calculated between different measurement periods were 0.3/0.8. This indicates that the colours of the samples used were stable during the whole experimental period. For 70 metamers, the Mean/Maximum colour differences were 2.5/4.6 under CIE D65 illuminant and 6.0/13.1 under CIE A illuminant. Figure 2 shows the sample distribution in CIELAB a^*b^* diagram.

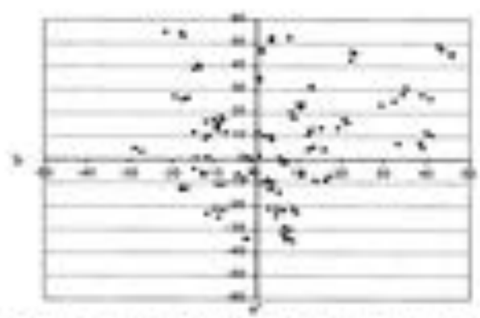


Figure 2 Sample distribution in *CIELAB a^*b^* diagram* under D65/10° condition

2.3 Psychophysical Experiment

A panel of 10 observers, 4 males and 6 females, aged between 23 to 38, participated the psychophysical experiment. All observers were students or staff in the Institute. They all had normal colour vision according to the Ishihara test. The grey scale method, which has been widely used by many researchers[2, 3], was again employed for assessing colour differences. Each observer was asked to judge the colour difference of a metamer in terms of grade (G). For each D65 simulator, observers repeated the experiment twice and 20 observations were accumulated for each metamer.

3. DATA ANALYSIS

As the raw experimental data in terms of grade value is not directly proportional to the visual colour difference ΔV, a fourth-order polynomial was constructed to correlate G to ΔV as given in Equation (1). The coefficients of the equation were derived by fitting the CIELAB ΔE and the corresponding G values between the 'standard' and each grade.

$$\Delta V = 0.54117\,G^4 - 1.97900\,G^3 + 10.28683\,G^2 - 26.18400\,G + 22.82700 \qquad (1)$$

The Performance Factor (PF/3) given in Equation (2) was used to indicate the agreement between two sets of data. The measure was originally developed by two of the authors[3] and has been extensively used by many researchers. It combines

$$PF/3 = 100\ (\gamma - 1 + V_{AB} + CV/100\ )\ /\ 3 \qquad (2)$$

three different statistical measures (Coefficient of Variation (CV), Gamma Factor (γ) and (V_{AB})) with suitable weight for each one.

4. RESULTS

The reliability of the visual results was evaluated in terms of observer accuracy and repeatability in PF/3 units. For each simulator, the PF/3 measure was calculated between each observation and mean visual results for all metamers. Each observer's two PF/3 values were averaged to represent his or her accuracy. The repeatability is calculated between two repeated results for each observer. Table 2 gives the accuracy and repeatability results for each observer.

Table 2 Observer accuracy and repeatability results (PF/3)

PF/3 (Observer Accuracy)								PF/3 (Observer Repeatability)							
Obs.\Ill.	GMS	VV	GM	GE	T1	T2	Mean	Obs.\Ill.	GMS	VV	GM	GE	T1	T2	Mean
1	27	38	33	26	24	27	29	1	30	30	31	25	24	26	27
2	52	32	36	34	41	29	37	2	31	35	32	31	27	33	31
3	35	40	32	40	29	34	35	3	26	24	24	20	27	26	25
4	38	40	45	48	41	40	42	4	22	22	21	24	17	16	20
5	42	41	30	32	25	40	35	5	30	33	27	37	30	34	32
6	32	32	43	39	27	24	33	6	21	34	34	33	25	22	28
7	29	23	29	35	20	25	27	7	26	21	21	31	17	22	23
8	36	43	31	24	37	22	32	8	29	24	28	25	29	29	27
9	35	41	32	25	33	21	31	9	26	31	23	17	13	15	21
10	37	36	32	27	26	29	31	10	23	32	27	21	26	26	26
Mean	36	37	34	33	30	29	33	Mean	26	29	27	26	23	25	26
Max.	52	43	45	48	41	40		Max.	31	35	34	37	30	34	
Min.	27	23	29	24	20	21		Min.	21	21	21	17	13	15	

The results given in Table 2 show an excellent agreement between this study and Kuo and Luo's study[2] with the mean observer accuracy of 33% and similar range of spread. The results also indicate not much difference between the six simulators investigated. The typical repeatability is 26%, which is 7% smaller than the typical accuracy.

The experimental results were used to test four colour difference formulae (CIELAB[4], CIE94[5], CMC[6] and CIEDE2000[7]). CIE tristimulus values calculated using the appropriate energy distribution for each simulator were used to calculate the ΔE values. The PF/3 value was calculated between the ΔE values predicted by a formula under a specific simulator and the visual differences, ΔV. These are given in Table 3 together with the mean values for each formula and for each simulator. The results show that for the six simulators studied, all colour difference formulae give a similar performance, quite close to the typical observer accuracy of 33%.

The PF/3 measure was also calculated for the visual differences ΔV between all possible combinations of two simulators. The results are given in Table 4. It was found that T2 and T1 is the most and least representative simulator, respectively. This was expected for the latter due to the fact that T1 is a three-band fluorescent lamp unlike the others are broad-band. In general, the visual results obtained from all simulators except T1 are quite similar and have small disagreements of about 21% between them.

Table 3 Testing colour difference formulae (PF/3)

	GMS	VV	GM	GE	T1	T2	Mean
CIELAB	35	35	39	38	41	35	37
CIE94 (1:1:1)	36	35	35	32	30	36	34
CMC (1:1)	36	34	35	36	34	36	35
CIEDE2000 (1:1:1)	39	35	32	34	33	36	35
Mean	37	35	35	35	35	36	

Table 4 Comparing every two simulators (PF/3)

	VV	GM	GE	T1	T2	Mean
GMS	16	20	17	44	11	21
VV		18	17	52	13	23
GM			17	44	13	22
GE				39	11	20
T1					39	44
T2						17

The final analysis was carried out to test the CIE method for evaluating daylight simulators. Firstly, the PF/3 measure was calculated between the visual results (ΔV) for each simulator and the CIELAB ΔE values using the SPD of CIE D65 illuminant. The results are given in Table 5 under the title of 'PF/3 - ΔV (Simulator) vs. ΔE (Illuminant)'. In addition, the PF/3 measure was again computed between pairs of CIELAB ΔE values calculated by the SPD of each simulator and CIE D65 illuminant. The results are also given in Table 5 under the title of 'PF/3 - ΔE (Simulator) vs. ΔE (Illuminant)'. Finally, the actual MI_{vis} values (the mean CIELAB ΔE calculated from the CIE method using virtual metamers) are also listed in Table 5 together with the predicted category and rankings of performances from the earlier three sets of results.

The results in Table 5 show that there is an excellent agreement between all three methods, i.e. they all give almost the same ranking results. It indicates that the CIE method is a reliable measure in evaluating the quality of daylight simulators. However, it was also found that the CIE method might be too strict for evaluating high quality daylight simulators. For example, the VV simulator has a MI_{vis} of 0.26, only 0.01 ΔE unit outside the 'A' Category. However, this small difference is unlikely to be noticeable.

Table 5 Comparing the results from CIE method and two new methods

	GMS	VV	GM	GE	T1	T2
PF/3 - ΔV (Simulator) vs. ΔE (Illuminant)	33	36	44	39	59	37
PF/3 - ΔE (Simulator) vs. ΔE (Illuminant)	9	17	41	36	87	19
MI_{vis}	0.18	0.26	0.70	0.82	2.30	0.33
Ranking - ΔV (Simulator) vs. ΔE (Illuminant)	1	2	5	4	6	3
Ranking - ΔE (Simulator) vs. ΔE (Illuminant)	1	2	5	4	6	3
Ranking - MI_{vis}	1	2	4	5	6	3
MI_{vis} Category	A	B	C	C	E	B

5. CONCLUSIONS

An experiment was conducted to assess metamers under six D65 simulators. The observer variation results showed a great accuracy and repeatability in the experimental data. The results were used to test different colour difference formulae. It was found that all formulae gave similar degree of accurate performance in predicting visual data. All simulators studied in general agree each other well except for one simulator having a three-band SPD, unlike broad-band for the others. Finally, two methods were developed to evaluate the quality of simulators against the CIE D65 illuminant. The results showed that these new methods agree well with the CIE method.

ACKNOWLEDGMENTS

The authors would like to thank the support from the Society of Dyers and Colourists and also the observers who took part in the experiment.

REFERENCES

1. CIE Publication No. 51 (1981). A method for assessing the quality of daylight simulators for colorimetry.
2. W. G. Kuo and M. R. Luo, "Methods for quantifying metamerism. Part 1 – Visual assessment", *J. Soc. Dyers Col.*, 112, pp. 312-320, 1996.
3. M. R. Luo, "New Colour-Difference Formulae for Surface Colours", Ph.D. thesis, University of Bradford, 1986.
4. CIE Publication No. 15.2 (1986). CIE Colorimetry.
5. R. McDonald and K. J. Smith, "CIE94 - a new colour-difference formula", *J. Soc. Dyers Col.*, 111, pp. 376-379, 1995.
6. F. J. J. Clarke, R. McDonald, and B. Rigg, "Modification to the JPC79 Colour-difference Formula", *J. Soc. Dyers Col.*, 100, pp. 128-132, 1984.
7. M. R. Luo, G. Cui, and B. Rigg, "The Development of the CIE 2000 Colour Difference Formula: CIEDE2000", *Col Res Appl.*, in print, 2001.

A perception-referenced method for comparison of radiance ratio spectra and its application as an index of metamerism

J A Stephen Viggiano, Principal Imaging Scientist, RIT Research Corporation

ABSTRACT

A metric for comparison of radiance ratio (e.g., reflectance) spectra, based on colorimetric principles, is described. In essence, the metric is a linear approximation to the sum of a series of ΔE^*_{ab} values wherein the two spectra differ only within a single narrow wavelength band. This metric has previously been suggested as a measure of lack-of-fit between a spectral-based color model and experimental observations, as well as an optimization criterion in modeling the color behavior of color output devices.

In this paper, the application of the metric as an index of metamerism is presented. Unlike the current CIE-recommended special metameric indices, the new proposal does not require the specification of a single set of trial conditions. Further, unlike previous spectrum-based proposals, it provides results in familiar units of ΔE^*_{ab}.

Keywords: metamerism, general index of metamerism, metameric index, spectral comparison index.

1. INTRODUCTION

Color stimuli are termed metameric if they match in color under a set of reference conditions, such as the 1931 Standard Observer and Illuminant D65, but possess radiance ratio spectra which are different. A metameric index quantifies, in some sense, the extent to which the two spectra differ.

Current CIE recommendations for evaluating metamerism include the special metamerism indices for change in illuminant [1] and change in observer. [2] These consist of, in essence, the total color difference (ΔE or ΔE^*) between the two stimuli under a set of conditions which differ from the reference conditions under which the two stimuli match in color. The change in conditions is limited to either a change in illuminant (in the case of the special metameric index for change in illuminant) or change in observer (for the special metameric index for change in observer).

While there are some instances in which a single change in test conditions is of interest, there are many more for which several test conditions bear on the acceptability of a metameric match. For example, goods which are purchased under cool white fluorescent lighting, for example, would be expected to match also under other types of fluorescent lighting, incandescent lighting, various daylight conditions, and as viewed by a number of observers.

Naturally, in such situations, the special metameric indices may be computed for a variety of observer/illuminant test conditions, and the results presented in tabular form. In order to arrive at a single-valued result, the maximum of the tabulated values may be taken and reported.

There have been instances where, in assessing the extent to which a predicted (as by a model such as Kubelka-Munk) spectrum differs from the actual spectrum, researchers have used some norm of the difference between the radiance ratio spectra [3] or the log radiance (density) spectra. [4] Another suggestion [5] was based upon the correlation coefficient between the two spectra. These techniques provide a single number for each spectrum pair, but, because they afford equal weight to all wavelengths (the first is also radiometrically linear), they cannot be regarded as being referenced to the human visual system.

Nimeroff and Yurow [6] developed a spectral-based metameric index which was based upon a weighted sum of the absolute differences between the two radiance ratio spectra. The weights were computed based on the color matching functions used in the 1964 U* V* W* uniform color space, and depended upon the tristimulus values of the stimuli under the reference conditions. Thus, a different set of weights was used for each metameric pair. Unfortunately, this metric does not report results in familiar units, and, while an improvement over unweighted norms of the difference spectrum, is not perceptually uniform.

It is highly desirable, then, to possess a metamerism index which is perceptually-referenced, produces results in familiar units of ΔE^*_{ab} (or a more modern version), and provides a single-valued result which is the maximum difference to be encountered under practical conditions.

2. A PERCEPTION-REFERENCED METHOD FOR COMPARISON OF RADIANCE RATIO SPECTRA

A method has been proposed by this author for the comparison of two radiance ratio spectra which are reported at regular wavelength intervals. [7] In concept, the method is based upon the sum across the wavelengths of the ΔE^* values between the two spectra, wherein they differ at only that particular wavelength. In practice, a linearized approximation to these ΔE^*s is used. The result is a weighted sum of the absolute values of the differences between the two spectra.

The Spectral Comparison Index is computed as:

$$M_v = \sum_\lambda w(\lambda) \cdot |\Delta\beta(\lambda)| \tag{1}$$

where $\Delta\beta(\lambda)$ is the difference between the two radiance ratio spectra, and

$$w(\lambda) = \sqrt{\left(\frac{dL^*}{d\beta(\lambda)}\right)^2 + \left(\frac{da^*}{d\beta(\lambda)}\right)^2 + \left(\frac{db^*}{d\beta(\lambda)}\right)^2} \tag{2}$$

The derivatives of L*, a*, and b* with respect to $\beta(\lambda)$ are computed via the chain rule:

$$\begin{aligned}
\frac{dL^*}{d\beta(\lambda)} &= 116 \cdot k \cdot s(\lambda) \cdot \bar{y}(\lambda) \cdot \frac{d}{dY} f\left(\frac{Y}{Y_n}\right) \\
\frac{da^*}{d\beta(\lambda)} &= 500 \cdot k \cdot s(\lambda) \cdot \left[\bar{x}(\lambda) \cdot \frac{d}{dX} f\left(\frac{X}{X_n}\right) - \bar{y}(\lambda) \cdot \frac{d}{dY} f\left(\frac{Y}{Y_n}\right)\right] \\
\frac{db^*}{d\beta(\lambda)} &= 200 \cdot k \cdot s(\lambda) \cdot \left[\bar{y}(\lambda) \cdot \frac{d}{dY} f\left(\frac{Y}{Y_n}\right) - \bar{z}(\lambda) \cdot \frac{d}{dZ} f\left(\frac{Z}{Z_n}\right)\right]
\end{aligned} \tag{3}$$

and, further:

$$\frac{d}{du} f\left(\frac{u}{u_n}\right) = \begin{cases} \dfrac{7.787}{u_n}, & \dfrac{u}{u_n} \le 0.008856 \\[2ex] \dfrac{1}{3 \cdot u} \cdot f\left(\dfrac{u}{u_n}\right), & \dfrac{u}{u_n} > 0.008856 \end{cases} \tag{4}$$

where u is replaced by, in turn, X, Y, and Z, and u_n by the corresponding tristimulus value of the specified white object.

Table 1 contains the weights for three stimuli, by way of example. The first is for a medium-dark neutral, with an L* of 30. The second is for a light neutral, with an L* of 80. Notice how the weights for the lighter neutral are always smaller than those for the darker. The ratio, greater than 4, is precisely the ratio of the luminances of the two stimuli raised to the power of -2/3. This illustrates the dependence of the weights on the overall darkness or lightness of the stimulus. (The relationship is close to that proposed by Nimeroff and Yurow, but slightly refined.) The third set of weights are for a Yellow stimulus, with the same L* and a* as the light gray. Note that the weights for the Yellow stimulus are larger than those for the light gray stimulus below 500 nm. This illustrates the dependence of the weights upon the color of the stimulus.

Figure 1 contains the data from Table 1 in graphic form.

L*:	30	80	80
a*:	0	0	0
b*:	0	0	60
wl, nm	w1	w2	w3
400	2.779	0.638	1.394
410	8.036	1.845	4.034
420	25.816	5.927	12.995
430	51.926	11.922	26.306
440	74.887	17.194	38.391
450	82.826	19.017	43.335
460	75.115	17.246	40.641
470	52.604	12.078	30.287
480	28.659	6.580	18.053
490	22.193	5.096	9.722
500	36.133	8.296	8.756
510	56.895	13.063	12.654
520	75.079	17.238	16.895
530	84.474	19.395	19.173
540	82.170	18.866	18.741
550	73.411	16.855	16.793
560	59.123	13.575	13.542
570	45.085	10.351	10.331
580	39.214	9.003	8.988
590	42.891	9.848	9.840
600	51.047	11.720	11.716
610	53.733	12.337	12.336
620	47.830	10.982	10.981
630	36.252	8.323	8.323
640	25.556	5.868	5.868
650	16.004	3.675	3.675
660	9.333	2.143	2.143
670	5.079	1.166	1.166
680	2.561	0.588	0.588
690	1.155	0.265	0.265
700	1.152	0.264	0.264

Table 1. The weights for three stimuli, for the reference conditions 1931 Standard Observer, Illuminant D65.

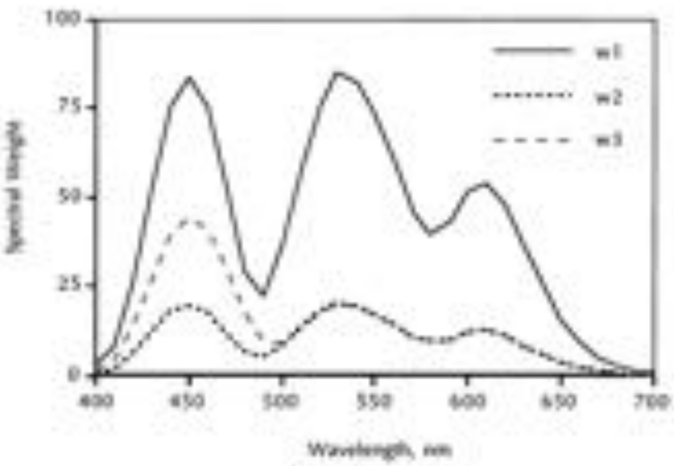


Figure 1.
The weights from Table 1 are plotted.

3. APPLICATION AS AN INDEX OF METAMERISM

When computing a metameric index, one is, in a manner of speaking, comparing the extent to which two spectra are different. In fact, there have been some instances in which investigators have utilized a CIE special metameric index as an indication of how visually different two spectra are. [3] The relationship between the two applications of assessment of metamerism and difference between two spectra are closely related.

We propose that the M_v index, in Equation (1) above, be used as a metameric index. It has the advantage of being firmly rooted in visual perception, and is based upon the familiar units of ΔE^*_{ab}. Further, our practical experience with this index suggests that the M_v index represents an upper bound for all special metameric indices computable under practical conditions.

3.1 Parameric Decomposition

If the test spectrum is a strict metamer of the standard (tristimulus values equal), the formula given above may be used directly. If, on the other hand, the test spectrum is a paramer (tristimulus values approximately equal), the method proposed by Fairman [8] may be used to compute the difference spectrum to be used in Equation (1).

4. CONCLUSIONS

A general index of metamerism has been presented. The index is based upon a linearized approximation to a CIELAB color difference computed on a wavelength-by-wavelength basis. Unlike special indices of metamerism, it does not depend upon one or more test conditions (i.e., observer/illuminant combination).

Like the index proposed by Nimeroff and Yurow, the new index is the weighted sum of the absolute difference between the standard and a trial spectrum. Also in agreement with Nimeroff and Yurow, the weights for the new index are computed using a set of color matching functions, and are higher for darker standard stimuli and smaller for lighter standards. Unlike this previous index, the new index provides results in familiar units of ΔE^*_{ab}.

LITERATURE CITED

1. *Colorimetry, second edition: CIE Publication 15.2.* Vienna: Central Bureau of the CIE, 1986. p 35 - 36.

2. *Special Metamerism Index: Change in Observer:* CIE Publication 80. Vienna: Central Bureau of the CIE, 1989.

3. See, for example, Burningham, Norman W, and Roy S Berns, Analysis of color in electrophotographic images. *Advanced Printing of Conference Summaries. SPSE's 40th Annual Conference & Symposium on Hybrid Imaging Systems*, p 91.

4. See, for example, Viggiano, J A S, *Models for the prediction of color in graphic reproduction technology.* ScM Thesis, Rochester Institute of Technology, 1987.

5. ISCC Project Committee 27, *Indices of Metamerism.* Undated typescript.

6. Nimeroff, I, and J A Yurow, Degree of metamerism. *Journal of the Optical Society of America*, 1965. 55 : 2 : 185 - 190.

7. Viggiano, J A Stephen, The Comparison of Radiance Ratio Spectra: Assessing a Model's "Goodness of Fit". *Advanced Printing of Conference Summaries: SPSE's 43rd Annual Conference*, 1990. Springfield, VA: SPSE – The Society for Imaging Science and Technology, p 222 – 225.

8. Fairman, Hugh S., Metameric correction using parameric decomposition. *Color Research and Application*, 1987. 12 : 5 : 261 - 265.

A study of skin colors of Korean women

Byung-tae Ahn*, Eun-bae Moon**, Kyung-suk Song***

ABSTRACT

Native Korean women skin colors were classified to 30 standard colors. Research was conducted using spectrophotometer to show CIE $L^*a^*b^*$ values. Color palette for the products of cosmetics was created. Numerical value indicates lightness and change in hue.

Keywords: Korean women, skin colors, standard, CIE La*b*, cosmetics, Color palette, lightness, hue

1. INTRODUCTION

This research is intended to survey the different types of skin colors of Korean women and to develop the optimum color makeup. 700 native Korean women were surveyed using Spectrophotometer to overcome the distinction made with the naked eye.

2. EXPERIMENTAL

The research process involved making direct contact to the skins of women between 18 and 45 years of age. The surveyed body parts included the face, upper hand and inner arm and the average measurements were derived after three checkups. The subjects numbers were 700 and comprised a variety of people ranging from university students, housewives and working women. The color measuring formula used in this research is Hunter Lab, CIE $L^*a^*b^{*1}$. To express the fine changes in skin color, the eye-checkup was only used for double checks and this data is standardized on the CIE $L^*a^*b^*$.

* btahn@mm.ewha.ac.kr; Ewha Womans University,Seoul,Korea;

** mooncd@koreacolor.net; Moon color design research Institute;

*** kssong@pacific.co.kr; Pacific co. Ltd

1) Skin color analysis

The average measurements were derived after three checkups using CM-508i(Minolta). According to the research on color of Korean women's exposed skin , we can make a basic color to develop new brand products and color schemes to be manufactured.

2) Production of color sheets based on skin color

According to the color values obtained from research, we determined the standard register number of products for the practical use. We selected 30 colors and enumerated them as the 30 standard register numbers, which will be used as the basic colors for cosmetics. The color sheets were produced by a paint company in Korea and manufactured as Magic-Coat.

3) The measurement of the palette of actual products

Using a spectrophotometer, we measured the colors of makeup products in Korean cosmetic market. To increase reproducibility to a new product the values from the concentrated area in the distribution of measured values were expressed after several times of measurements. The measurement was carried out under the conditions of light source A or D 65. The color measuring formula used in this research was from CIE L*a*b*[1] and L*C*h system.

4) Production of color sheets.

In this color tones, colors which can be produced with certain pigments for color cosmetics were produced as color sheets, and colors cannot be produced were just expressed to numerical values. 13 pages of tables, which express color distribution, were produced to understand total proportion and distribution of colors easily. Color sheets whose color can be produced were made to the extent of the minimum unit that is distinguishable, and the other color sheets were produced at each L* value20s. Special lusterless paints (luster degree 40) were used for color sheets.

3. DATA ANALYSIS

We could find that each age's hues are distributed evenly. But 40's hues (pink color) are a little higher than the others. The ranges of other targets are similar. Light colors are mainly distributed at low-hue area while dark colors are mainly distributed at high-hue area. Besides hue values become higher as a*b* values keep the balance. In intermediate light area, the colors of the lighter side appear a little yellowish and ones of the darker sides appear reddish. The colors of faces are distinguished from light ones to dark ones across the saturation. This means the more saturation, the more darkness. Comparison between the standard skin colors(large dots) and the colors of cosmetic products(small dots) were displayed on same CIE $L^*a^*b^*$ space as in Figure 1. Distribution of colors of upper hand's, inner arm's, and face's were analyzed. The colors of upper hand and inner arm are more yellowish than face's and have the same hue distribution. Each color polygon indicates areal distribution value per appearance frequency. The lightness values are distributed from 50 to 75. The most concentrated range is around 65 and its neighborhood. The higher the hues, the lower the saturation, the reverse is the same. We found that lightness values(L*) of skin color are distributed between 50-75 range without any intervals. The most concentrated range is around 65 irrespective of age. Hue values (a*b*) of face are distributed centering around 15 value. Brightness and hues of skin colors of normal Korean women who live in cities are distributed evenly. To distinguish colors from each other, color distance is selected as four units of one of its attributes (L* or a*b*) for standardization. Makeup's colors are not directly matched with face color. According to measurements and results, it is advisable to design L* values of colors higher than those by certain units.

4. SUMMARY

According to the measurements and results, we could arrange the brightness and hue distribution of skin colors and find a consistent pattern in the change from light to dark complexions. Using the results, we completed a color checklist that even average people can use easily for verification and application. The composition on the checklist is made up of 8 colors for easy selection.

The 8 colors were derived from an intermediate color that is neither reddish nor yellowish and is presented in the distribution graph. The complete distribution of the skin color is used as a back-ground for color cosmetics. The 8-color checklist is expected to be used for fashion, accessories, and designs related to direct contact with the human body. 30 standard Korean women skin color sheets were produced for cosmetic application. Cosmetic color sheets were produced on CIE L*a*b* color space for practical use.

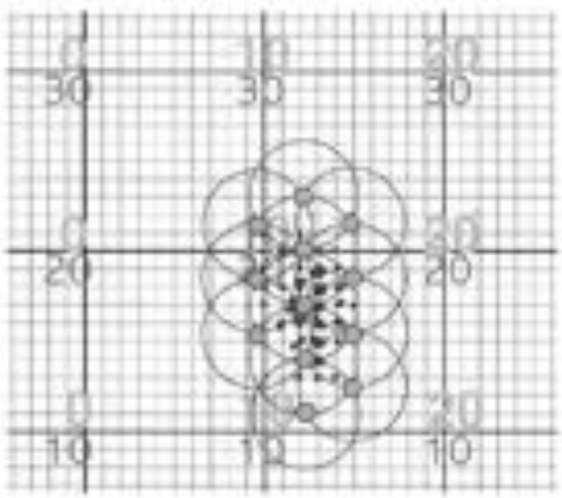
ACKNOWLEDGMENT

We wish to express our sincere appreciation to the following institution for the generous support: Ewha Color Design Research Institute, Pacific Co. Ltd.

REFERENCES

1. Richard Hunter, " Color and Appearance" , Hunter Color Inst., 1998
2. Faber Birren, " The Principles of Harmony and Contrast of Colors" , West Chester Schiffer Publishing Co., 1987

Figure 1 : standard skin colors on L*=65



Color Matching Techniques

Muhammad Akbar
Textile Chemist & Colorist, Shahkam Industries Pvt.Ltd Pakistan

ABSTRACT

Computer color match prediction has shown tremendous commercial growth within the past 40 years. Until recently, very little progress had been made in improving and developing the conventional color matching methods. The present study is aimed at how can we control color matching and how should we teach color matching.

1. INTRODUCTION

Considering all of the technology available regarding color matching, visual color matching is still considered pivotal in quality control acceptance. How a sample appears will always be the underlying decision. So for a colorist whether he is affiliated with processing, quality control or merchandising, it is essential for him to learn and understand the behaviour of different colours in different combinations. The objectives of the study was to provide complete information about how can we control color matching and how should we teach color matching.

2. HOW CAN WE TEACH COLOR MATCHING

2.1 Colour Map.

Most shades can be produced by use of trichromatic colours of yellow, red and blue component colours. In practice, dyes or colours of intermediate shades close in shade to the shade pattern are also used for improving the reproducibility, and brilliant dyes for bright shades.

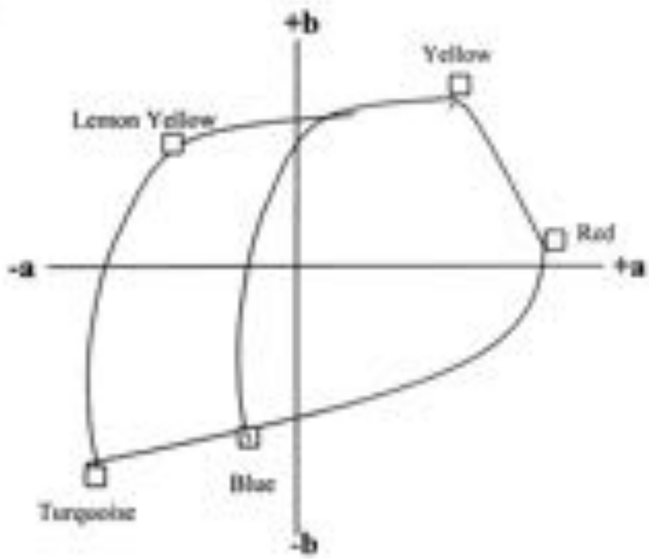


Figure 1 : Color Map

As shown in figure.1, the addition of lemon yellow and turquoise enables further production of shades. Thereby these five colors can cover almost the whole range of shades. The maximum possible trichromatic combinations of these five colours are as follows:

Combination no	1	2	3	4	5	6	7	8	9	10
Trichromatic Combination Colours	YELL RED BLUE	YELL RED L.YEL	YELL BLUE L.YEL	YELL L.YEL TURQ	YELL BLUE TURQ	L.YEL RED BLUE	L.YEL BLUE TURQ	YELL RED TURQ	L.YEL RED TURQ	RED BLUE TURQ

Where,

YELL = Yellow
L.YELL = Lemon Yellow
TURQ = Turquoise

9th Congress of the International Colour Association, Proceedings
of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

2.2 Trichromatic combination charts

Most shades can be produced by use of trichromatic colours of yellow, red and blue component colours. Figure.2 shows how these three colors combine together in different concentrations and produce almost the whole range of shades.

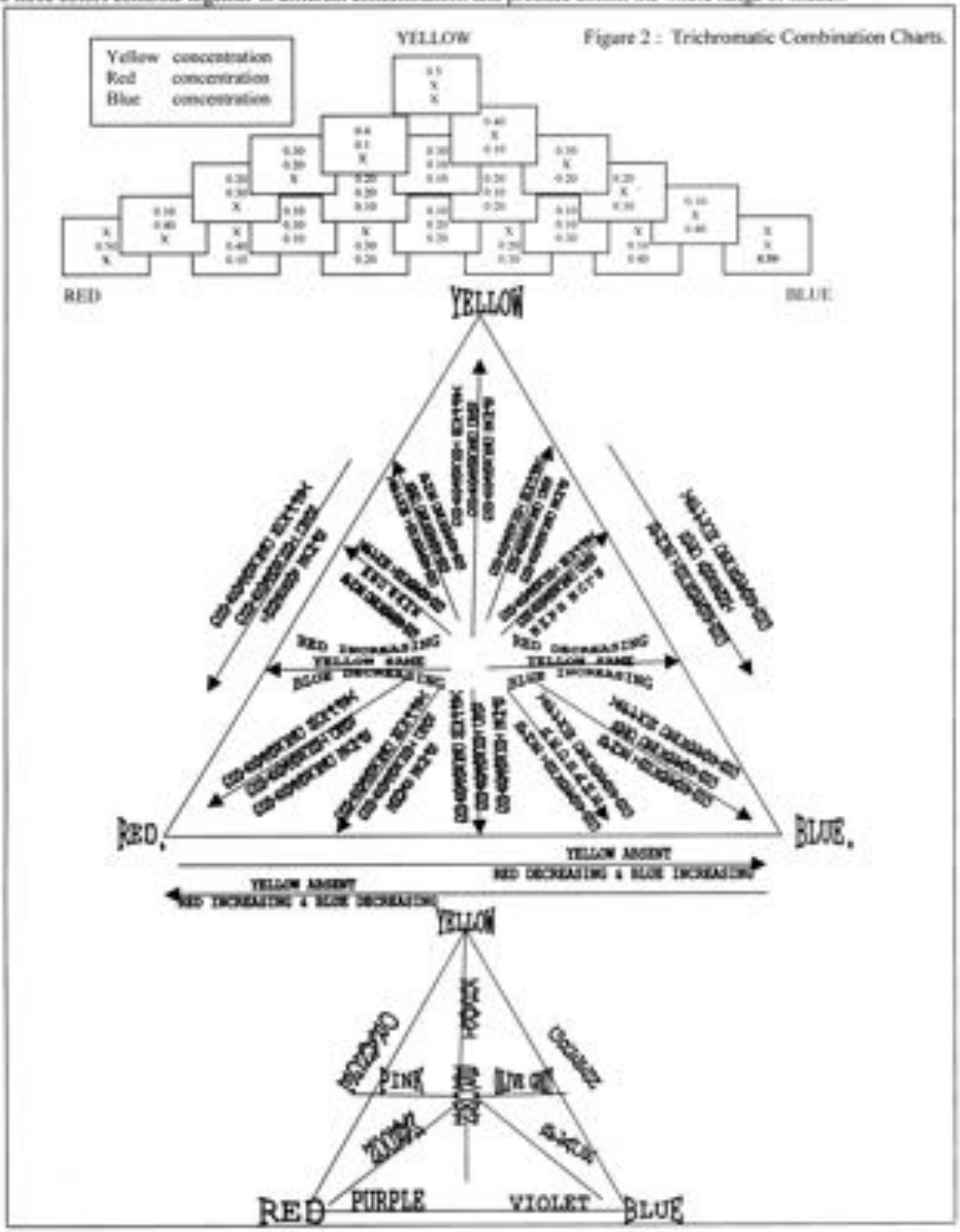


Figure 2 : Trichromatic Combination Charts.

3. HOW CAN WE CONTROL COLOR MATCHING

3.1 Akbar's shade options chart

There are several shades present in a trichromatic combination chart and each shade has different concentrations of dyes or colors. So for a colorist it is necessary to learn the behaviour of different shades having different trichromatic combinations or different concentration of dyes.

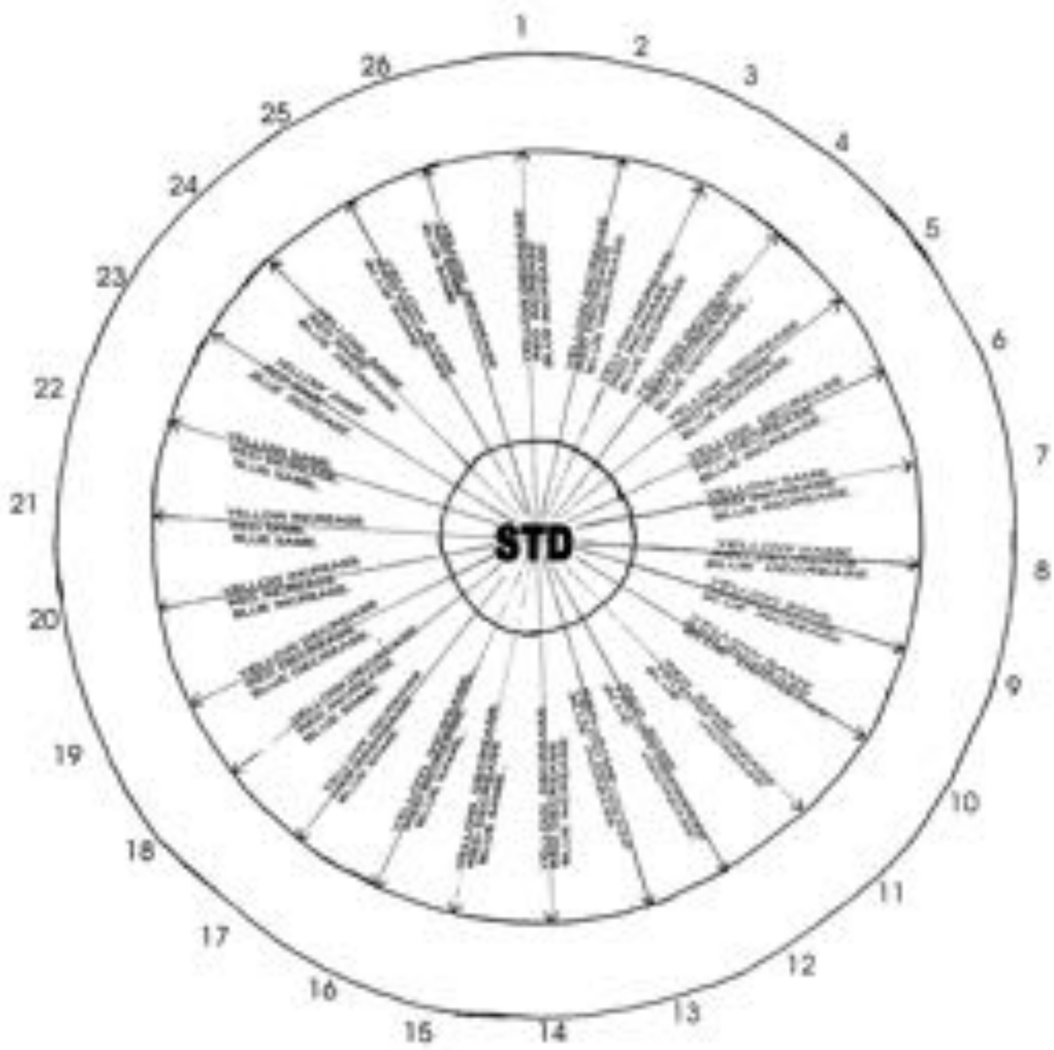
There are a minimum of 26 possible options of a trichromatic shade. So with the help of these options a colorist can easily control color matching. As shown in Table 1, suppose our trichromatic shade has yellow, red & blue colors in a ratio of X%, Y% AND Z% respectively, then the minimum 26 possible options for this shade are as follows:

When,

(>) means color concentration % value increases as compared to the standard % value
(<) means color concentration % value increases as compared to the standard % value
(=) means color concentration % value increases as compared to the standard % value

COMBINATION	STD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
YELLOW	X%	<	>	>	>	<	<	...	...	...	...	>	<	<	>	<	>	>	<	<	>	>	...	...	...	...	<
RED	Y%	>	<	>	<	>	<	>	<	<	>	...	...	...	...	<	>	>	>	<	>	...	>	...	...	<	...
BLUE	Z%	>	>	<	<	<	>	>	<	>	<	>	<	>	<	...	...	...	...	<	>	...	...	>	<	...	...

TABLE 1 : Akbar's shade options chart



3.1 Explanation

As shown in Table 1, Option no 1 shows that the concentration of the yellow color component decreases and the concentration of both red & blue color components increase as compare to the standard shade.
Similarly Option no 2 shows that the concentration of yellow & blue color components increase and concentration of the red component decreases as compare to the standard shade.
Option no.18 ; concentration of the yellow component decreases, concentration of the red component increases and concentration of the blue component remain the same as compared to the standard shade.

3.2 Importance of controlling external variables (light booth)

The function of the light booth is not simply to shine light on a sample. It is to produce a particular spectrum of light that will reflect the proper colors off the sample. If there are any shifts in the spectral output, the samples may or may not match due to metamerism.
There are many items that contribute to shifting spectral outputs. These items include the age of the lamps in the light booth, the color of the inspector's shirt being worn during the inspection process, ambient light, and sample size, just to name a few. We can expect a higher level of quality in color appearance by controlling these items. The only way to verify that the light booth is producing the correct spectral output is to measure the color temperature and footcandles of the booth. If these readings are not within the specifications, proper corrective action should be taken to ensure the correct spectral output.

4. RESULTS AND DISCUSSION

4.1 Trichromatic combination chart & Akbar's shade options chart

A colorist can utilize these shade charts for the following purposes:-

- Colourists and dye manufacturers can learn and assess the behaviour of different dyes in different trichromatic combinations, also fresh colorists or students can learn the color matching technique with the help of these shade charts.
- During lab-dipping or dyeing process, colorists or dyers can quickly select the initial recipes and colour combinations for their standard shades.
- Colorists can develop several new shades in a systematic order with the help of these shade charts. For example a colorist can develop a wide range of green colours having different shade depths, tones and hues by utilizing the trichromatic combination chart.
- Colorists , especially dye manufacturers can develop a complete range of shades present in their trichromatic dyes. Also by utilizing the options chart they can assess the compatibility of their dyes when used in combinations, ensure that all three exhausts migrate and fix as a single dye, maintaining a similar hue angle throughout the process.
- These shade charts are very useful for dyers during the re-dyeing process. Especially the options charts can minimize the errors of colour matching.
- Colorists can prepare a complete and wide range of (COLOR PALLETS) with the help of these trichromatic combination charts. So the dyes or color manufacturers can attract their customers by providing them a wide range of shades.

5. CONCLUSIONS

Considering all of the technology available regarding color matching , visual color matching is still considered pivotal in quality control acceptance. How a sample appears will always be the underlying decision. So for a colorist whether he is affiliated with processing, quality control or merchandising, it is essential for him to learn and understand the behaviour of different colours in different combinations.

ACKNOWLEDGMENTS

The author is greatly indebted to Mr.Kamil Butt, the chairman of the Shahkam Industries for very helpful support & co-operation. Thanks are also due for the support given by the all colleagues of Shahkam Industries.

AUTHOR'S ADDRESS

Muhammad Akbar, 647-F2 Johar Town, Lahore- Pakistan ; telephone 92-42-5301950 ; e-mail. m_akbar1000@hotmail.com

Measurement of skin colors of world population and its application for preparing make-up products

Sadaki Takata[a], Makio Akimoto[b], Kiyoshi Kawada[a], Motoji Takahashi[a] and Shigenori Kumagai[a]
[a]Cosmetic Product Research Laboratory, [b]Customer Satisfaction Research Center,
Shiseido Research Center (Shin-Yokohama)

ABSTRACT

We attempted to analyze the skin color of women from the world using identical apparatuses and under identical conditions. The data was used for developing cosmetic products. The skin colors of a total of 1703 women over the world were measured to clarify the characteristics of skin color. Skin color measurement was done by using a spectrometric colorimeter. We modified the conventional erythema and melanin indices and established new respective indices which can reflect various spectral information of whole visible region. The present results were used to design new cosmetics in consideration of the optical properties of skin.

Keywords : Skin color, world population, skin pigments, cosmetic research

1. INTRODUCTION

Recently, cosmetic research has enabled make-up to become a high technology product, claiming some similar cosmetic properties to those of skin care products as well as new physical properties. Although qualitative evaluation is commonly used and remains indispensable in proving the effects of make-up products, there is a need to associate more quantitative data with the evaluation. The most studied and explored field is color assessment, which is achieved either by spectrophotometry of the optical spectrum of visible light reflected by the skin or by reflectance tristimulus colorimetry. In the development of make-up cosmetics it is important to reflect basic properties of skin color on cosmetic design. The requirement of color design which is applicable to the native skin colors of various nations in the world has been increasing as the recent globalization of cosmetic business. We measured skin colors under an identical condition using an identical instrument and analyzed the data to clarify the determinants of skin color. Two kind of novel powders were developed, and it was applied to the development of new make-up cosmetics.

2. OPTICAL PROPERTIES OF SKIN

Skin is a stratified tissue. At the surface is the epidermis and under this is cutaneous tissue. The epidermis is avescular and translucent. The junction between the epidermis and the dermis is deeply undulating. Here for the purposes of light scattering we propose a two layer model of skin tissue. Layer one is poorly perfused with blood so that attenuation in this layer approximates to that of excised upper dermis. Scattering dominates attenuation in this tissue and neither scattering nor absorption coefficients change by more than 50% over the range of wavelengths we shall consider. As the blood content of layer one increases absorption becomes more significant at wavelengths less than 600 nm. Layer two is well perfused with blood so that its optical characteristics are strongly influenced by those of whole blood. The differences in scattered light isotropy and intensity from the two layers. The subpapillary plexus is primarily responsible for the color of fair skins. The two reflected components of light are generally produced when the incident light goes into the skin. One is surface light reflected from the skin surface and the other is diffuse reflected light that goes out again from the skin surface after absorption and scattering to the pigments in the skin[1,2]. These two components carry vastly different information about the skin. About 5% of incident light is reflected from the surface of skin due to the large increase in refraction index in going from air to stratum corneum (n_{skin}=1.37~1.55)[3]. This specula reflectance component is essentially independent of wavelength and therefore has little or nothing to do with our appreciation of skin color. Allowing for 5% surface reflectance, about 95% of normally incident light penetrates into the skin, where it is absorbed by tissue pigments and scattered by nonhomogeneous tissue structures. Skin colors derive from the spectral character of visible radiation backscattered from within the tissue. A simple, clinically useful model can be used to describe this backscattered radiation.

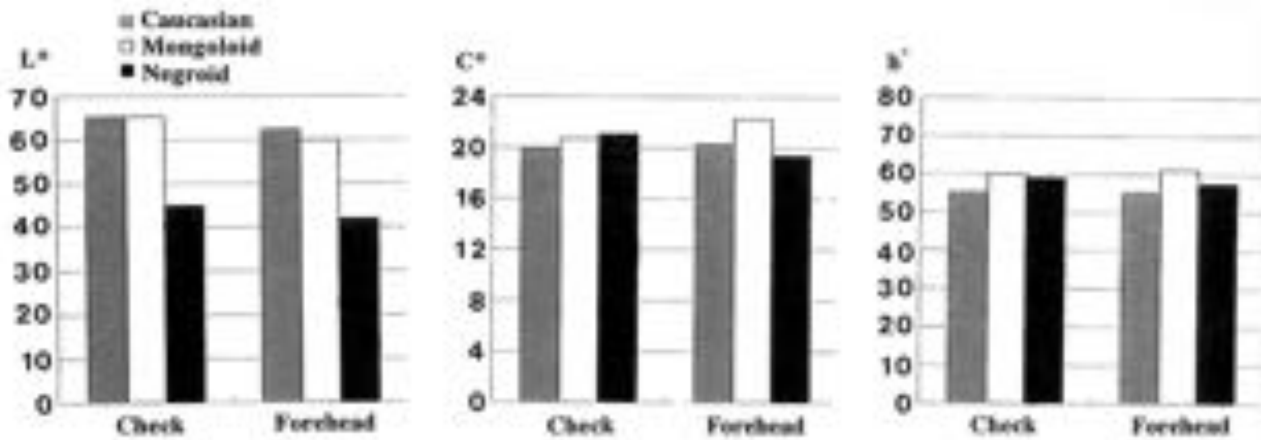
3. EXPERIMENTAL METHODS

A total of 1703 women at 20~40 years of age including 316 Caucasian, 1304 mongoloid, and 83 Negroid were used for color evaluation at an identical skin site. The skin colors at right and the left sites on the check and the forehead were determined under the same conditions for a period as long as seven years from 1992.

Skin color measurement was performed by using a spectrometric colorimeter (CM-1000RH, Minolta, Osaka, Japan). Spectro reflectance was measured for each interval of 10 nm in a range of 400~700 nm. The light reflected from an area of approximately 12 mm in diameter is received. Measurement was performed three times at each site in the above mentioned sites excluding uneven-colored and damaged one and the respective mean values were used for analysis. To measure the skin color with accuracy, the face was washed before the measurement and photograph was taken as a record. The contact pressure was kept constant to minimize the measurement error due to the head contact.

4. RESULTS AND DISCUSSION

The skin color distribution expressed by Munsell color system for the representative 800 women chosen from 1703 in the whole world. The mean value of Munsell scale was 3.1YR6.4/3.7 for the Caucasian women, 4.9YR6.2/3.8 for the Mongoloid, and 4.8YR4.1/3.4 for the Negroid. To obtain a color representation close to that of eye vision, we expressed the L*a*b* uniform color space. The skin colors for the subjects in terms of the L*a*b* color parameters are shown in Figure 1 as histograms. It is thought that the differences in skin color among races were due to the differences in the amount of melanin pigment produced by melanocytes in the epidermis. Thus, the hue of Negroid women's skin is shifted to yellow because internal red light due to blood hemoglobin in dermal capillaries is interrupted by melanin pigment. Whereas for Caucasian women's skin, melanin distributed in the epidermis is less and the red hue of hemoglobin in the dermal layer is more perceptible the internal reflected light, resulting that the skin color becomes reddish in general. These facts suggest that melanin pigment and blood hemoglobin in the skin might be the important determinants of skin color.



Quantitative evaluation was made to clarify the effects of melanin pigment and hemoglobin on skin color. Conventional erythema and melanin indices have been well known as such determinants. An erythema index of the skin can therefore be based on the retio between the reflection of red and green light. Erythema index[4] can be defined as follows:

Erythema index=log{(Intensity of reflected red light)/(Intensity of reflected green light)} (1)

Melanin pigmentation of the skin will lead to an increased absorption both in the green and the red parts of the spectrum, and a melanin index[5] may be defined as follows:

Melanin index=log (Intensity of reflected red light) (2)

These indices can be deduced from an equation considering the light reflection in the various layers of the skin. These determinants were defined on the basis of pigment absorption, which varies with wavelength, but no data of all visible light range were taken into consideration. Therefore, we modified those conventional indices and defined new respective indices which reflect various spectral information of whole visible region:

$$\text{Hemoglobin factor} = \frac{\log(1/Rg)}{\log(1/Rr)} \quad (3)$$

$$\text{Melanin factor} = \log(1/Ro) \quad (4)$$

Spectral reflectance at 400, 560, and 600 nm (Ro, Rg, and Rr) were chosen focusing on the wide range absorption specific to melanin pigment and hemoglobin-specific absorption spectra. Figure 2 shows relationships between the two indices. There was very close correlation between the factors related to melanin and hemoglobin, indicating that skin color differences between Caucasian and Negroid women could be expressed with two factors as to hemoglobin and melanin. We re-examined the problem due to the pigment caused in skin of high hemoglobin factor and skin of melanin factor each other. In addition, we discussed the method to improve the problem. In the skin of Caucasian and the high hemoglobin factor skin of Mongoloid, incident light is scattered in dermis layer, resulting red light go out through the epidermis. Then skin color are act to more reddish. Therefore, to make up a natural beautiful skin it is needed to reduce the reddish color. Meanwhile, for high melanin factor skins of Negroid and Mongoloid women, it is likely that the incidence light can hardly reach the dermis or the light which come back to the skin surface is poor even if the light can reach the dermis because melanin pigment is rich in the epidermis. Thus, such skin has a tendency of unnatural bad complexion. However, the skin with such complexion would be improved by correcting the red hue.

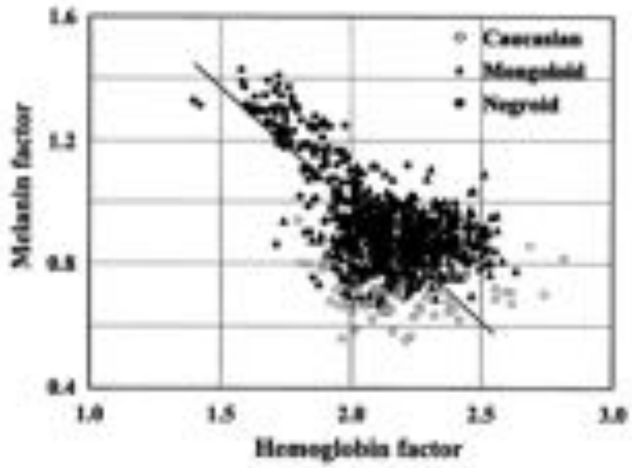


Figure 2 Relationship between the hemoglobin factor and the melanin factor of world populations. The open circle(○), the closed triangle(▲), and the closed circle(●) represent the skin of Caucasian, Mongoloid, and Negroid, respectively. The line shows the regression line.

Generally, make-up of high hemoglobin factor skin is carried out by correcting its color with a slightly yellow colored foundation, in which the red hue is reduced by compounding with yellow iron oxide. On the other hand, less-reddish skin with a high melanin factor is generally corrected with a foundation containing much amount of red iron oxide. However, such skin color correction by subtracting color mixing method gives rise to a reduction of lightness and a loss of feeling of vivid skin, resulting in unnatural make-up face. Therefore, we here attempted skin color correction by additive color mixing method based on light interference effects but not color correction with pigment.

Two kinds of mica powders coated with thin titanium dioxide were used as the basement of powder materials for adjustment of interference light. For color correction of high hemoglobin factor skin, powders attached with fine spherical Polymethylmethacrelate powder (diameter:5~30 μ m) after coating with titanium thin film (thickness:80~100 μ m) on mica of a granular size ranging 0.3 μ m was used. A scheme of the powder model named as prismatic powder A is presented in Figure 3 (a). As transmitted interference light of prismatic powder A was green light, the light was absorbed by hemoglobin in dermis layer. As the result, excess red light was reduced. The color of high melanin factor skin was corrected using prismatic powder B which produces strong reflected interference light of red color. Thus, poor reddish skin could be improved. A scheme of powder model named as prismatic powder B is presented in Figure 3 (b). The optimal combination of these two powder was examined to produce a foundation suitable for each skin color.

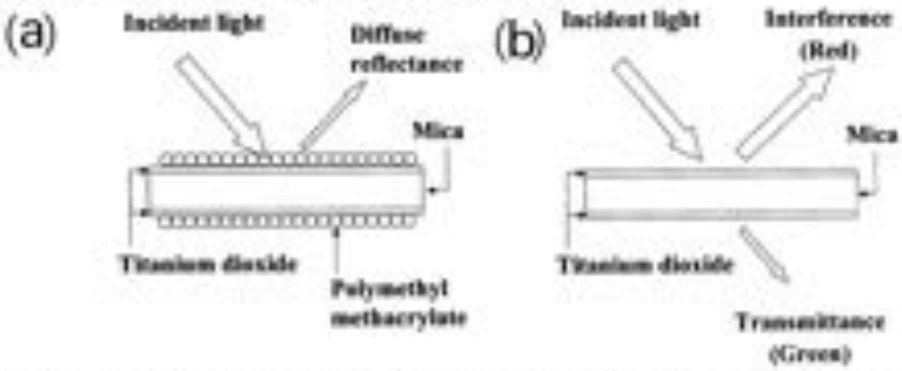


Figure 3 Schematic model of prismatic powder A and B. Note that prismatic powder A are many small particles (diameter: 0.3 μ m) on mica coated with titanium dioxide thin film.

5. CONCLUSION

We evaluated skin colors of a total of 1703 women over the world under identical conditions to clarify the characteristics of skin color. It was demonstrated that the skin color can be expressed with two factors; hemoglobin factor and melanin factor. The present results were applied to formulate new cosmetics in consideration of the optical properties of skin. Thus, it became possible to correct the skin problem and produce translucent and beautiful skin of high lightness by using make-up cosmetics formulating the two novel powders.

REFERENCES

1. RR. Anderson, JA. Parrish, The Optical Human Skin, J Invest Dermatol, 77, 13-19 (1981).
2. N. Kollias, The Physical Basis of Skin Color and Its Evaluation, Clinics in Dermatol, 13, 361-367(1995).
3. FP. Bolin, LF. Preuss, RC. Taylor, RJ. Ference, Refractive index of some mammalian tissues using a fiber optic cladding method, Appl. Opt, 28, 2297-2303 (1989).
4. BL. Diffey, RJ. Oliver, PM. Farr, A portable instrument for quantifying erythema induced by ultraviolet radiation, Br. J. Dermatol, 111, 663-672 (1984).
5. PH. Andersen, P. Bjerring, Spectral reflectance of human skin *in vivo*, photodermatol. Photoimmunol. Photomed, 7, 5-12 (1990).

Correspondence: Shiseido Research Center, 2-2-1, Hayabuchi, Tsuzuki-ku, Yokohama 224-8558, Japan.

Colour reproducibility and dyestuff concentration

Sándor Csányi*
Dept. of Printing Industry, Technical College of Budapest

ABSTRACT

The purpose of this study was to develop a new sensitivity index connected with colour matching, which makes it possible to investigate the effects of dyestuff concentration deviations in a larger part of the colour space in a comprehensive manner. By the help of computer simulation and experimental design, we examined the colour differences resulting from minor concentration changes in approximately 500 formulas of different compositions, altering their total concentration and the proportion of the individual dyes in them. The new sensitivity index makes it possible for the colourist to select the recipe that is the least sensitive to concentration deviations from among the computer colour formulas, as well as to add a new aspect to the ranking applied in colour matching so far.

Keywords: colour sensitivity, computer colour matching, experimental design, colour measurement, dyeing

1. INTRODUCTION

Most of the factors affecting the reproducibility of textile dying may be traced back to diversions from the original concentration of dyestuff. A specific colour may be matched by the application of several dyestuff combinations and the individual combinations may differ significantly in their sensitivity to dyestuff concentration deviations. Apart from expectable minor differences in colour, greater sensitivity has an unfavourable effect on the reproducibility of a given colour and/or on the accuracy of a specific colour obtained. Thus, considering it from the point of view of reproducibility, sensitivity to minor changes in the concentration and - through this to accidental mistakes made in the course of different dying technologies may be an important factor of computer colour formulation. By way of determining an appropriate sensitivity index (S) the sensitivity of the different formulas to concentration may be made quantitative, and the formulas may thus be ranked by these values as well. Sluban[1] gave a detailed analysis of the notion "sensitivity index", and demonstrated a possible mathematical method for developing it, while Sluban and Nobbs[2] completed this with a few practical results, however, these researches covered only a relatively small space of colours.

The purpose of this study was to develop a new sensitivity index connected with colour matching, which makes it possible to investigate the effects of dyestuff concentration deviations in a larger part of the colour space in a comprehensive manner.

2. EXPERIMENTAL

From the point of view of the applicability of the sensitivity index the most important prerequisites include that it could be calculated simultaneously with computer colour matching, in a simple manner and quickly, it should be based on the same data bases as are used for formulation, however, it should also make use of the experience obtained in the field of visual colour matching.

The system we have developed determines the concentration sensitivity of computer colour formulas based on the above listed considerations, along the following lines: (1) computer colour simulation, (2) experimental design, (3) sensitivity index calculation.

In our research we made use of the computer colour formulation system of ICS -Texicon TCM4, while colour changes were determined in CIELAB colour space (colour measuring at D65, 10°).

We used a palette of 12 reactive dyestuffs as a database, and dyeing were made on a bleached cotton material (120 g/m^2) by way of a pad-roll technology.

In the course of the experiments we examined formulas made up of two and three dyestuff components, and we changed the proportion of only one of the components within a formula for each of several different total concentration values. The total concentrations chosen included: 2; 3; 5; 9; 10; 15; 30 g/l, while the dyestuff proportions were 1:1, 1.5:1, 2:1, 3:1, 5:1, 10:1.

We chose a yellow (Y1), a red (R1) and a blue (B1) dye from the palette of dyestuffs, and sub-combinations were then composed of them. (For example Y1:R1 for two-component formulas and the reverse, R1:Y1.) We always increased the proportion of only the dye standing in the first place, while we kept the total concentration of the combination constantly at

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

the same level. In case of three components, we started with increasing the rate of Y1, went on to increase R1, and then B1, in a way that by a constant value for total concentration - the other two components should be present in equal proportions. Our next step was to exchange the basic dyestuffs of the basic combination one by one for another yellow (for example Y2 or Y3 etc.), red, blue or green dye of the palette. Finally we ranked alternative formulas we obtained according to their sensitivity indexes.

2.1 Computer colour simulation

We used the different colour synthesising possibilities given in several colour matching software programs for determining the colours of the combinations of different rates and total concentration, for these are easy means of determining the data of the colours that may be produced by any optional value of concentration from any dye combination.

2.2 Experimental design

We established a mathematical model for the system by applying the so called complete factorial experimental design method - frequently used in modelling chemical processes - to the colour changes resulting from the concentration changes of the individual components.

Taking the practical experiences of computer colour matching as well as the linearity of the model into consideration, we decided to choose a concentration modification of ± 20 % as a variation interval.

We calculated those colour differences and colour attribute differences that result from the perturbation $/c = (c_1, \ldots c_n)^T/$ of an actual, non-pertarbed formula consisting of n number of dyes $/c = (c_1, \ldots c_n)/$ in a pre-determined T extent (±20 %).

In cases of two and three components (n = 2, 3), setting up the entire factorial experimental design thus meant that we synthesised 4 and 8 colours, respectively. By way of an experimental design computer program the line equation describing the system may be determined in the following general form for three components (the most frequent case):

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_1x_2x_3 + b_5x_2x_3 + b_6x_1x_3 + b_7x_1x_2$$

so that

y = the colour difference or the colour attribute difference,
b_o = average divergence,
$b_1 \ldots b_m$ = the effect and joint effect factors of the dye components,
x_n = concentration unit of the n-th dye.

The value of the effect factors thus determines the extent of the change that takes place as a result of the concentration change in a dye component unit, while the positive or negative sign determines the direction of the change.

2.3 Calculation of the sensitivity index

The experimental results indicated that the alterations of the joint effect factors follow the changes caused by the modifications of the total concentration and/or of the rates of components quite closely, thus they may be used for characterising concentration sensitivity. The experiments also indicated that the most significant change is the alteration of the joint effect factors. Figure 1 depicts the changes that take place in the effect factors of three dye components (Y1:R1:B1) in combinations of different proportions when the rates of the yellow dyestuff is modified.

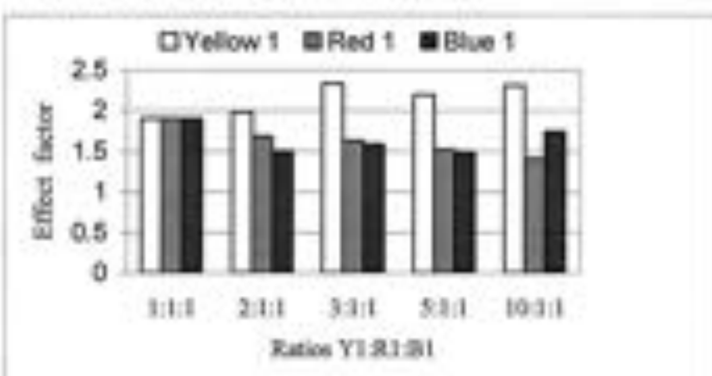


Figure 1: Change of effect factors for ΔE^*_{ab}

The sensitivity index (the maximum effect that is assigned to a unit of change) of the individual colour attribute ($S_{\Delta A}$) changes may be set up as follows:

$$S_{\Delta A} = \sqrt{\sum_{i=1}^{n} (b_n)^2}$$

so that ΔA index indicates that it refers to the change any of the attributes (ΔL^* or ΔC^*_{ab} or ΔH^*_{ab}). Weighting the three values that refer to the deviations of colour attributes as per CIE94 gives the value of the sensitivity index (S).

3. RESULTS

The experience obtained in the course of synthesising approximately 500 colour formulas may be summarised as follows:
- With respect to the components, the greatest sensitivity in the colour space can be observed if dyes falling the farthest apart from each other are combined.
- With regard to total concentrations, the greatest sensitivity is seen in the middle component ranges of the gamut (between 10 and 15 g/l). Figure 2 illustrates the changes that take place in the sensitivity indexes at recipes with two dye components (B1:Y1) in combinations of different concentrations when the rates of the B1:Y1 is 2:1.

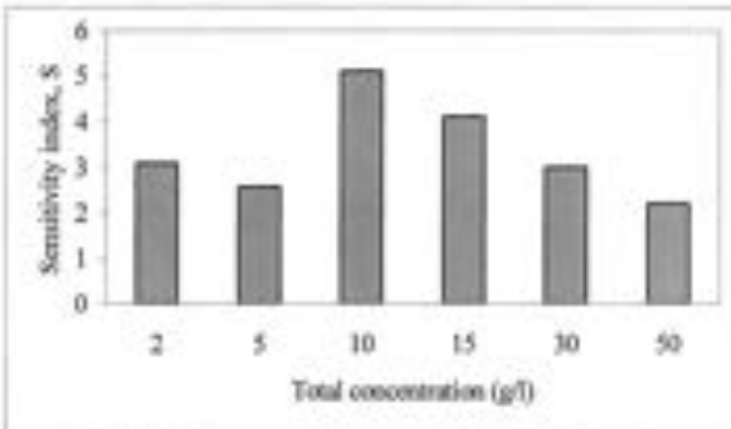


Figure 2: Sensitivity indexes of B1:Y1 (dye ratio 2:1) at different concentrations

- The least sensitivity was observed when the dyes are of the same proportion.
- The more the proportion of a dye is increased, the more characteristic its impact on the colour attributes becomes (for example, if the proportion of yellow is increased, primarily it is chroma that changes, while in the case of blue, it is mainly brightness that will be affected). Figure 3 illustrates the changes that take place in the sensitivity indexes of colour attributes ($S_{\Delta L}$, $S_{\Delta C}$, $S_{\Delta H}$) at recipes with three dye components (B1:Y1:R1).
- The sensitivity indexes of alternative colour formulas reflect the changes in the composition of the formulas very well. For example the Figure 4 shows the different between the number of recipes and number in rank of sensitivity four alternative recipes had got by computer colour matching for an olive colour sample.
- Sensitivity index makes it possible for the colourist to select the formula that is the least sensitive to concentration deviations from among the computer colour formulas, as well as to add a new aspect to the ranking applied in colour matching so far. However, it should be noted that the values of sensitivity indexes always refer to a given data base and therefore allow for a relative comparison only, nevertheless, this is entirely acceptable in colour matching practice.

The method proposed is based on an unambiguous mathematical statistical calculation, it can be calculated simply and quickly, therefore it hardly extends the time needed for colour formulation.

Based on the results it could be prepared a computer program for sensitivity indexes (CSS, Colour Sensitivity Software), which may also be used independently of the formulating system, if one knows the correction matrixes derived from colour matching.

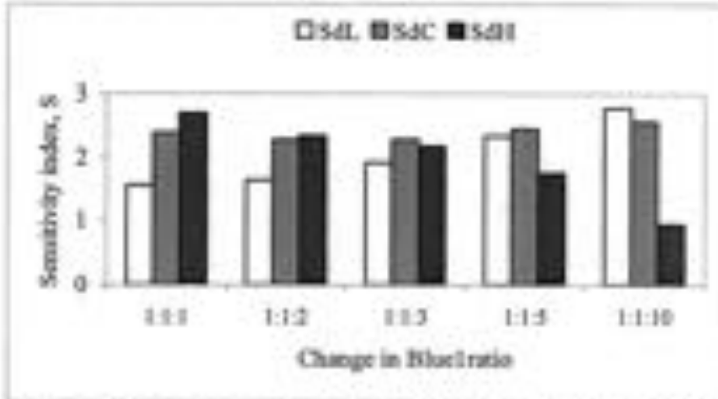


Figure 3: Change in sensitivity at different dyestuff ratio in Y1:R1:B1

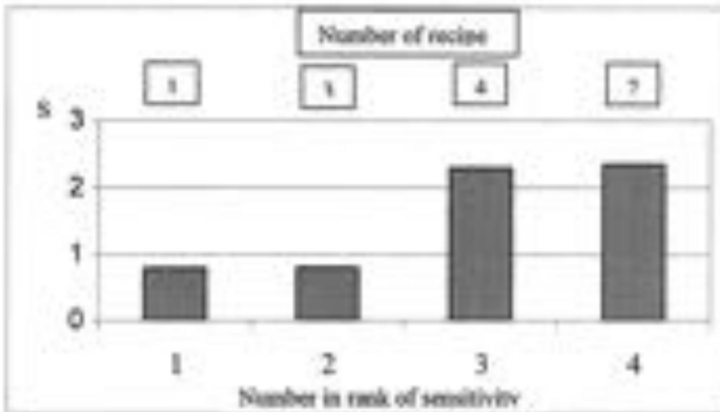


Figure 4: Sensitivity index and order of rank of alternative recipes for olive colour

4. SUMMARY

Mistakes due to dye concentration deviations bear a considerable impact on the accuracy of textile dying. By the help of computer simulation and experimental design, we examined the colour differences resulting from minor concentration changes in approximately 500 formulas of different compositions, altering their total concentration and the proportion of the individual dyes in them. By the experimental design model we determined a sensitivity index for each formula, and based on this sensitivity index, we ranked the alternative formulas. We are going to develop a computer program for the calculation of the sensitivity index, which may also be used independently of the formulating system, if one knows the correction matrixes derived from colour matching system.

REFERENCES

1. B. Sluban, Quantifying the sensitivity/robustness of a predicted colour match, *Die Farbe* **39**, pp. 247-252, 1993.
2. B. Sluban, J. H. Nobbs, The colour sensitivity/robustness of a predicted colour matching recipe, *Color Res. Appl.*, **20**, pp. 226-234, 1995.

* Correspondence: drcsanyisandor@freemail.hu; phone (+36) 1 250 0333/104; Department of Printing Industry, Technical College of Budapest, 6 Doberdó str., Budapest, H-1034, Hungary.

Color quality control of sewing thread production for the automotive industry

Vera Golob*, Darko Golob, Simona Rogan
University of Maribor, Faculty of Mechanical Engineering, Textile Department, Slovenia

ABSTRACT

The producers of sewing threads used for interior car furnishings have to comply with stringent car industry regulations. In regard to thread color the specific requirements are good color fastness to light at high temperatures and nonmetameric recipe match prediction. The use of selected 1:2 metal complex dyes is recommended for the dyeing of PA sewing threads. Eight dyes were tested and their dyeing properties and light fastness were evaluated in an attempt to find appropriate dyes marked by high light fastness. The light fastness of dyed samples was tested according to the standard ISO 105-B06 which specifies severe testing conditions as they appear in car interiors during summertime and cause photo-degradation of non-fast dyes. Suitable 1:2 metal complex dyes were selected and used for computer recipe prediction for the dyeing of PA 6.6 sewing threads for the car industry based on the results of experimental work.

Key words: PA sewing threads, metal complex dyes 1:2, colorimetry, computer match prediction, light fastness.

1. INTRODUCTION

Sewing threads used for car interior furnishings are exposed to strong sunlight, particularly in summertime. High temperatures inside the car and the energy of UV radiation may cause a fading of thread color. Good color fastness to light at high temperatures is therefore required. Color fastness to light depends on the dyestuff constitution used for sewing thread dyeing and for Polyamid 6.6 threads good light fastness can only be achieved using selected metal-complex dyes 1:2. The market offers trivalent chromium and cobalt complexes, a combination of a metal ion and two dye molecules as ligands. To find appropriate dyes marked by high light fastness, eight dyes were tested from the range of BEMAPLEX dyes (Bezema). Their dyeing properties were evaluated and light fastness was tested according to the standard ISO 105-B06.

The seat covers are made from various materials such as leather, artificial leather, and textiles. To follow the demands of the market for PA 6.6 threads in a variety of colors, we had to apply at least three dyes (yellow, red and blue), and the additional black dye for neutral gray, black and dark shades. For this purpose we selected, on the basis of the experimental results, from two yellow, red, blue and black dyes only those, which were suitable for dyeing PA 6.6 threads for use in the car industry. Various shades of sewing threads were dyed using computer recipe predictions for leather standards, and the colors of the dyed samples and metamerism were colorimetrically evaluated.

2. EXPERIMENTAL

2.1 Dyeing of PA threads

Eight 1:2 metal complex dyes BEMAPLEX were tested for the dyeing of PA threads of fineness Nm 40/3, of which two are Co (III) complexes and six Cr (III) complexes: Yellow C-4R (Cr), Yellow C-BR (Co), Rubin C-B (Cr), Bordeaux C-GT (Co), Navy Blue C-3R (2,5% Cr), Navy Blue C-RD (2,7% Cr), Black C-R (2% Cr), Black C-2B (3% Cr). The samples of PA threads were dyed with various concentrations of each dye: 0,05%, 0,1%, 0,5%, 1% 2%; and with black dyes also 3% and 4%. The exhaustion dyeing process was carried out according to dye-producer procedure at liquour ratio 20:1, using a laboratory machine TURBOMAT (Ahiba). The dye baths were made of 1% anionic leveling agent, 0-2 g/l acid dispenser (depending on concentration of dye), pH value at the start was 8 and ended as 5.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

2.2 Light fastness testing

ISO 105-B06 specifies a method for determining the color fastness and ageing properties under the action of an artificial light simulating the natural daylight D65 and under the simultaneous action of heat. This test method gives special consideration to the light and heat conditions occurring in the interior of a motor vehicle. These conditions are:

- Black-standard temperature: 100 ± 3°C
- Test chamber temperature: 65 ± 3°C
- Relative humidity in test chamber: 20 ± 10%
- Irradiance E(300 –400 nm): 45 – 60 W/m^2
- Irradiance E(420 nm): 1.0 – 1,4 W/m^2 nm
- Radiant exp.H(300-400nm):12-16MJ/m^2
- Radiant exp.H(420nm):250-300kJ/m^{2}nm

The specimens of dyed sewing threads were exposed to artificial light for a certain period under the prescribed conditions, together with a set of blue wool references 4-8 for light fastness testing and with reference 6 for ageing test, respectively. The measure for one exposure period is the color change of blue reference 6 that visually corresponds to the gray scale 3 or colorimetrically to CIELAB value of 4.3 ± 0.4 DE*.

2.3 Computer match prediction

To follow the demands of the market for PA 6.6 threads in a variety of colors, we have to apply the "trichromi" system, the mixing of three dyes (yellow, red and blue), and the additional black dye for neutral grey, black and dark shades. When preparing the data basis for computer match prediction only these dyes were selected from the two tested yellow, red, blue and black which offer better dyeing properties and light fastness. The reflectance of primary dyeing was measured using spectrophotometer SF 600+ (Datacolor) and the recipes for PA sewing thread were calculated. Colorimetric values of various leather samples were used as standards. The color of the dyed samples was determined using CIELAB color values.

3. RESULTS

The dye concentration left in the dye bath after dyeing was analyzed using UV-VIS spectroscopy according to Lambert-Beers law. In this way the quantity of the dye on the PA fiber was indirectly determined and established which dyes offer the best dye bath exhaustion. In Figure 1 the results are presented for exhaustion of dye bath containing 1% of each dyes.
These results show great differences in the dyeing properties between the two yellow dyes. The dye Yellow C-BR exhausts the dye bath much better than the dye Yellow C-4R (only 39%) at given dyeing conditions. The dye Bordeaux C-GT shows much better exhaustion results than the dye Rubin C-B, thus the color yield of the dye Bordeaux C-GT exceeds 98%, while the color yield of the dye Rubin C-B is only 38% at 1% dye concentration in the dye bath. Both blue dyes are chromium complexes, but a distinctive difference in the exhaustion of the two dyes is obtained. PA 6.6 better absorbs dye Navy Blue C-3R, since the exhaustion exceeds 95%, while the loss of the dye Navy Blue C-RD exceeds 40% at a 1% dyeing. The two tested black dyes are also chromium complexes. At higher concentrations in the dye bath both dyes show poorer exhaustion results, but the result of the dye Black C-2B is better than the result of Black C-R.

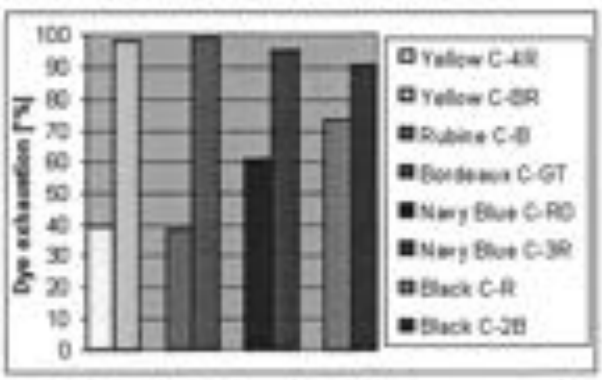


Figure 1: Dyebath exhaustion of 1% dye concentration

The Color fastness to artificial light assessed by colorimetry in accordance with ISO 105-A05 presented results in Table 1.

Table 1: Light fastness values of the used dyes for individual concentrations

BEMAPLEX	0,05	0,1	0,5	1	2	3	4
Yellow C-4R	2	4	5	3	1-2	/	/
Yellow C-BR	6	6-7	7	7	7-8	/	/
Rubine C-B	3-4	4-5	6	6	6-7	/	/
Bordeaux C-GT	7	7-8	8	8	7	/	/
Navy Blue C-RD	5-6	6	7	6-7	6-7	/	/
Navy Blue C-3R	6	6-7	7-8	7	6-7	/	/
Black C-R	5-6	5-6	6	6	6	6	6-7
Black C-2B	5	6	6	6-7	7	7-8	7-8

The light fastness of the dyed sewing threads were tested using the apparatus Alpha LM High Energy, where the testing conditions were adjusted to the radiation through car windows. The samples were exposed to light for one period, which corresponded to approximately 85 hours. The evaluated light fastness results show that of all the tested yellow and red dyes only the cobalt complexes fulfill the requirements of the car industry. Their light fastness under prescribed conditions (T = 65 °C) is ≥ 4. In the case of the tested blue dyes the dye Navy Blue C-3R, which contains less chromium, has better light fastness than the dye BEMAPLEX Navy Blue C-RD, while in the case of the black dyes both have similar fastness and reach the required values.

The reflectance curves for three leather standards (1- beige, 2- gray, 3- dark gray) and respective PA sewing threads, dyed after predicted recipes, are presented in Figure 3. From the shapes of the spectral curves it is obvious that metamerism exists between pairs of standard and match, since the standards are matt, surface structured leather, and PA sewing threads are made from glossy PA filament. Due to substrate differences various dyes were also applied for the dyeing of standards and PA threads.

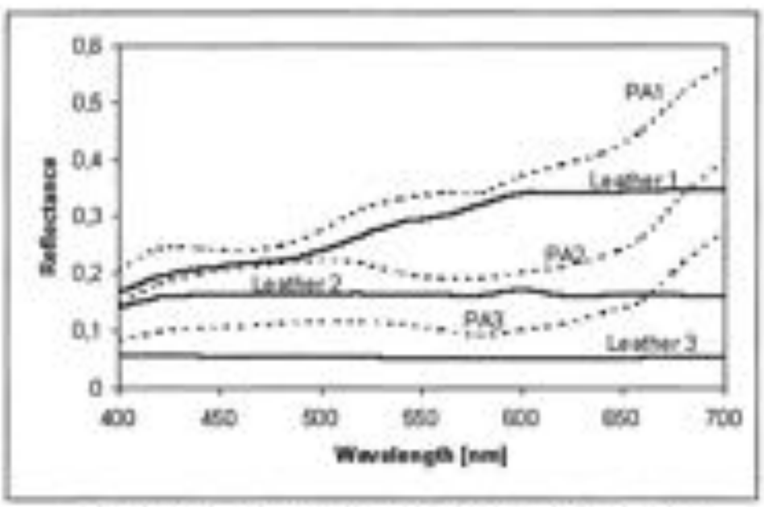


Figure 2: reflectance curves of standards and PA sewing threads

The color differences between the standards and PA threads (Table 2) indicate that all PA threads are too light, but under illuminant D65 the chromaticity coordinates match well. The color appears different at illuminant changes to A. Such metamerism is unacceptable for the automotive industry.

Table 2: CIELAB color differences (leather as standard)

Samples		ΔE^*	ΔL^*	Δa^*	Δb^*
PA1	D65	3,204	3,203	-0,079	-0,002
	A	3,319	3,227	0,744	0,220
PA2	D65	5,018	4,880	-1,102	-0,386
	A	4,997	4,763	1,089	-1,047
PA3	D65	11,502	11,466	-0,105	0,900
	A	11,818	11,564	2,343	0,679

4. CONCLUSION

This paper presents the use of colorimetry in the manufacturing process of PA 6.6 threads for the needs of the car industry. The key characteristics of threads used in the car industry in regard to color, are high light fastness and nonmetameric match. The ISO 105-B06 prescribes severe testing conditions which should correspond to the real conditions in cars during summertime causing photo-degradation of non-fast dyes.

Dyes suitable for dyeing PA 6.6 threads to be used in car industry were selected from 1:2 metal complex dyes on the basis of an experimental analysis of eight metal complex dyes. The results of spectroscopic analysis of the dye baths and light fastness tests reveal the following:

- The cobalt complex dye BEMAPLEX Yellow C-BR offers a better color yield than the chromium complex dye BEMAPLEX Yellow C-4R, which is confirmed by a high exhaustion of this dye from the dye bath and by the transfer on PA 6.6 fibers. It also reaches the required fastness properties to light.
- The red cobalt complex BEMAPLEX Bordeaux C-GT shows much better exhaustion results and has better color fastness than the chromium complex dye BEMAPLEX Rubine C-B.
- The tested blue dyes are chromium complexes, but a better exhaustion and fastness are observed with dyes BEMAPLEX Navy Blue C-3R.
- In the case of black dyes, both dyes have similar good fastness to light, but PA 6.6 threads better absorb BEMAPLEX Black C-2B.

The dyes Bemaplex Yellow C-BR, Bordeaux C-GT, Navy Blue C-3R, and Black C-2B were used to prepare a data base for computer match prediction and recipes for three standards were performed. The color differences and metamerism were evaluated. These dyes are due to their good exhaustion properties interesting also from the ecological and economical aspects

The implementation of systems for colorimetry and computer match prediction in the production of sewing threads is crucial for any modern and competitive textile factory, which needs a quick response to market demand.

REFERENCES

[1] VW 501 05: 1997-06

[2] Shore, J.(ed.): Colorants and auxiliaries, Vol. 1, Society of Dyers and Colourists, Bradford, 1990

[3] Skoog, D.A., Holler, F.J., Nieman, T.A.: Principles of Instrumental Analysis, Harcourt

[4] McDonald, R. (ed.): Colour Physics for Industry, Society of Dyers and Colourists, Bradford, 1997

* Correspondence: vera.golob@uni-mb.si; phone +386 2 2207891; fax +386 2 2207990; University of Maribor, Faculty of Mechanical Engineering, Smetanova 17, SI-2000 Maribor, Slovenia.

Dyeing Fabrics with Metals

Georgia Kalivas
Fashion Institute of Technology, New York, USA

ABSTRACT

Traditionally, in textile dyeing, metals have been used as mordants or to improve the color produced by a natural or synthetic dye. In biomedical research and clinical diagnostics gold colloids are used as sensitive signals to detect the presence of pathogens.

It has been observed that when metals are finely divided, a distinct color may result that is different from the color of the metal in bulk. For example, when gold is finely divided it may appear black, ruby or purple. This can be seen in biomedical research when gold colloids are reduced to micro-particles. Bright color signals are produced by few nanometer-sized particles.

Dr. William Todd, a researcher in the Department of Veterinary Science at the Louisiana State University, developed a method of dyeing fabrics with metals. By using a reagent to bond the metal particles deep into the textile fibers and actually making the metal a part of the chemistry of the fiber.

The chemicals of the fabric influence the resulting color. The combination of the element itself, the size of the particle, the chemical nature of the particle and the interaction of the metal with the chemistry of the fabric determine the actual hue. By using different elements, reagents, textiles and solvents a broad range of reproducible colors and tones can be created. Metals can also be combined into alloys, which will produce a variety of colors.

The students of the ISCC chapter at the Fashion Institute of Technology dyed fabric using Dr. Todd's method and created a presentation of the results. They also did a demonstration of dyeing fabrics with metals.

1. BACKGROUND/ HISTORY

Dyeing is a process of coloring textiles, in order to make the coloring matter part of the fiber. Dyes are soluble components, which can be both absorbed and retained by the fiber or chemically combined with it.
The use of dyes has been dated back to 2600 BC, in countries such as Egypt, Persia, India and China. Before 1856 only natural materials were used to dye fabric. Roots of the herb madder were used for red dye, and the indigo plant for the blue dye. In the Roman Empire garments were colored with Tyrian purple, which was extracted from a small gastropod mollusk called Trumpet Shell or Purple Fish. It took 8,500 shellfish to produce a single gram of dye, because of the high cost; only royalty wore cloths dyed in purple. In the 13th century a new, less expensive purple dye was discovered, it was produced from a species of lichen called achil. Three centuries later explorers coming from the Americas brought back dyes such as cochineal and logwood. During that time other sources of natural dyes were extracted from quercitron weld, rustic, Brazil wood, and safflower.
In 1856, William Henry Perkin, while searching for a cure for malaria, discovered "Mauve", the first synthetic dye. It was developed using coal tar. Since then many more have been created and the use of natural dyes has almost ceased.

2. DYE CLASSIFICATION

Natural dyes are normally classified according to the hue produced and by the source they are obtained from. The three categories of sources are animals (i.e. Cochineal), plants (i.e. Indigo)
and minerals (i.e. Ocher). Most of the plant dyes require the use of a mordant to either fix the color to the fiber or enhance the color produced. A mordant is an element, which aids the chemical reaction that takes place between the dye and the fiber so that the dye is absorbed. Common mordants are alum, iron, tin, blue vitriol and tannic acid. Typically, a mordant does not serve as the color source by itself.

Synthetic dyes are fiber selective and are normally classified by chemical class. The important groups include substantive or direct dyes, naphthol or azoic dyes, vat dyes & sulfur dyes, acid dyes & mordant dyes or metallic dyes, basic or cationic dyes, disperse dyes, fiber reactive dyes & pigment.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

There are thousands of different synthetic dyes, which have been developed, as a result of the many different types of substrates to which dyes are applied, the different performance characteristics for which dyes are selected, and the cost that a particular user can bear.
Two of the synthetic dye classes, pre-metalized acid dyes and mordant dyes (also called chrome dyes) make use of metal in the dyeing process. Pre-metalized acid dyes are actually acid dyes with a metal complex in the dye molecule. They produce less bright colors than acid dyes but have better colorfastness to laundering, perspiration and light.

They are used for protein fibers (silk and wool); nylon, spandex and special type acid-dyeable acrylic fibers.

Mordant or chrome dyes have properties common to acid dyes except, they do not have affinity to fibers by themselves. They gain affinity through the use of a mordant, which is a chemical substance that has a mutual affinity to both the dye and the fiber and acts as a vehicle. The mordant used is potassium dichromate, a chromium salt. This is where the name, chrome dyes, comes from. Mordants are commercially available, commonly in the form of salts from metals such as tin, chrome, iron, copper, and aluminum.

This metal reacts with the dye to form a relatively insoluble dyestuff that produces dull colors with excellent colorfastness to light, washing and perspiration. These are the fastest wool dyes attainable.

3. MORDANT DYEING PROCESS

There are three ways that mordant dyeing can be done:

Bottom Chrome - The textile is first treated with the mordant and then dyed.
This is the slowest and most expensive method but it results in the best uniformity of shade and fastness of color.

Top Chrome - The textile is first dyed and then treated with the mordant.
This is the easiest and least expensive method with the least satisfactory results.

Bi Chrome – The dye and mordant are applied together, simultaneously.
This method requires exercising great care and caution in temperature control. Otherwise the dichromate may precipitate.

4. MATERIALS

• Test Fabrics (4 types)

(1) Multifiber fabrics (contains 13 fibers):
1) Acetate
2) SEF (modacrylic)
3) Arnel (triacetate)
4) Cotton
5) Creslan 61 (acrylic)
6) Dacron 54 (polyester)
7) Dacron 64 (polyester)
8) Nylon 66
9) Orlon 75 (acrylic)
10) Spun Silk
11) Polypropylene (Polyolefin) *
12) Viscose Rayon
13) Wool

*some test strips contained Verel A (Modacrylic)

(2) Multifiber fabrics (contains 6 fibers):
1) Spun Acetate
2) Bleached Cotton

3) Spun Nylon 6.6
4) Spun Silk
5) Spun Viscose (Rayon)
6) Worsted Wool

(3) Cross Dye Fabrics (type 1) Acetate and Rayon

(4) Cross Dye Fabrics (type 2) Cotton and Rayon

- Silk Fabric
- Spun Silk Skeins
- Iron (Ferrous Sulfate)
- Copper (Cupric Sulfate)
- Silver (Silver Nitrate)
- Gold (Chloroauric Acid)
- Distilled Water
- Tannic Acid

5. PROCEDURE

Step I

- Incubate the textile in a nucleating agent, a 0.1% aqueous solution of tannic acid. The incubation time varies, depending on how long it takes the nucleating agent to penetrate throughout the fibers. It could either be heated for 30 min at 80 F or left overnight at room temperature.
- The method depended on the density of the fiber and the amount of heat it could withstand (i.e., nylon has a lower melting point than most fibers).
- The textile was then removed from the nucleating agent, and then rinsed in distilled water.
- To complete the incubation process we dried the fabric by leaving it overnight or baking it at 60 C for about an hour. This allows the tannic acid to be completely attached to the cloth. If not completely dried the tannic acid will still be in the solution, rather than part of the fiber.

Step II

- Immerse the treated textile into a solution containing the metal (either gold, copper, iron or silver) in order to generate the color in situ in the fibers.
- The concentration of the metal was about 0.01% Weight/Volume in water, with an effective range extending at least over the interval from about 0. 001 % to 0.1%. In order to produce visible colors the incubation time varies widely, depending on the metal ion, the nucleating agent, the temperature, the pH, and the type of fabric. It could range from a few seconds to overnight (i.e., gold required the most time).

6. RATIONALE

Metals have traditionally been used in the textile industry as ionic components of organic-metal dye complexes and as agents to attach dyes to fabrics. They have also been used as coatings to protect fibers from damage due to photo bleaching. Metals have been deposited on the surface of textiles to form metallic coatings.

Sometimes metals are incorporated into the construction of yarns. When used this way the metal is not well integrated into the chemical structure of the fiber, but only adsorbed on the fiber surface. The appearance of the metal is typically similar to that of the native metal, whether on the surface or within the fabric; i.e., gold appears as the color of metallic gold and silver appears as the color of metallic silver.

Dr. William Todd's invention pertains to a method of dyeing fibers by first attaching a nucleating (i.e., reducing) agent to the fiber and forming insoluble, colored micro-particles at the attachment site of the nucleating agent. The resulting color may be distinctly different from the color of the metal in bulk. When gold is finely divided for example, it may appear purple, reddish or black.

The cost of this process is economical, one ounce of gold will color about 380 yards of spun viscose yarn. Combined with other elements, the cost is less than a penny per liter of the solution.

In this method of dyeing with metal, the metal is the color source as opposed to traditional mordant dyeing where the metal aids in the fixing of the dye to the fiber or just enhancing the produced color.
This is what inspired our group to want to do research and testing of Dr. Todd's method.

7. RESULTS

Various colors were produced including pink, purple, yellow, beige, brown, gold, peach, silver, gray, green, and black. Colors vary by changing the size and spacing of the micro particles, the metal or metal complex used, and the characteristics of the fiber. Other changing variables, which affect the produced color, are time incubated, temperature, pH, and the amount of metal or tannic acid used.

Since different fibers result in different colors, we were able to achieve cross-dye affects with silver on rayon and acetate, which produced a dark gold and beige. Iron produced a light and dark gray on cotton and rayon.

We also tried dyeing with more than one metal. Using iron and gold together, then first using iron and then gold, and finally using gold first and then the iron. We obtained three different colors. When the same procedure was done with iron and copper, the colors though still different were similar

The following table gives the results of using one metal at a time, according to the steps given in the procedure section. The incubation in step two was done at room temperature and again at 6O C.

<u>Visual Colors Produced Using Individual Transition Metals, One at a Time</u>

Element	Spun Acetate	Bleached Cotton	Spun Nylon	Spun Polyester	Spun Silk	Spun Viscose	Worsted Wool
Gold (Chloroauric Acid)							
Without heat	Very Light Pink	Light Pink	Pink Gray	Very Pale Pink	Pink-Beige	Pink	Beige
With heat 60 C	Very Light Purple	Light Purple	Gray-Purple	Very Pale Purple	Brown	Mauve	Gray-Brown
Copper (Cupric Sulfate)							
Without heat	Pale Cream	Light Beige	Pale Cream	No Color	Beige	Gold-Beige	Light Beige
With heat 60 C	Cream	Golden Beige	Gray Cream	No Color	Dark Beige	Dark Gold-Beige	Beige
Iron (Ferrous Sulfate)							
Without heat	Light Gray	Gray	Pale Gray	Pale Gray	Brown-Gray	Dark Gray	Lt. Brown-Gray
With heat 60 C	Silver Gray	Dark Gray	Light Gray	Pale Gray	Dark Brown-	Very Dark Gray	Brown-Gray
Silver (Silver Nitrate)							
Without heat	Very Pale Cream	Cream	Pale Cream	No Color	Dark Beige	Beige	Brown
With heat 60 C	Cream	Gray	Gold	Light Gray	Dark Gold	Dark Gold	Rusty Brown

7. CONCLUSIONS

One important thing that we learned is that it is much easier to get even, uniformity of color, when dyeing yarns as opposed to fabric. The larger the piece of fabric the harder it is to get even color.
The largest piece we dyed was about 1 sq. ft.

Finding the perfect temperatures was difficult, especially with gold. It needs heat to produce color but too much heat (i.e., over 140 F) causes the solution to precipitate.

Prediction of colors is possible when using one metal at a time. With more than one metal it becomes very unpredictable and does not conform to "conventional" color theory.

Going forward, there is still much to do including colorfastness tests, and trying to control the variables more efficiently. Do I think that it would be feasible to use this dyeing method? Perhaps in a high-end specialty market, we could find a special niche for it.

Quantifying the Quality of D65 Simulator

Y M Lam*, John H Xin*, and K M Sin*
Institute of Textiles and Clothing, The Hong Kong Polytechnic University

ABSTRACT

This study investigated the influence of various D65 simulators on visual color matching seen under five D65 simulators. These five D65 simulators were categorised by CIE No.51 method from A to D. The gray scale rating method was used to assess the visual difference of 77 textile metamers. The instrumental color difference of each metamer was calculated using SPD of CIE illuminant D65 and real SPDs of D65 simulators. The performance factor (PF/3) was used to indicate the agreement between visual differences under five D65 simulators as well as instrumental color difference and visual difference. The observer accuracy and observer repeatability were also analysed by PF/3 measure. The experiment results showed that the visual data obtained from category A and B D65 simulators had a good agreement in PF/3 measure. The results also indicated that better agreement between instrumental and visual color difference was obtained if the real SPDs of D65 simulator were used instead of the CIE illuminant D65 data. The general color rendering index, Ra, for each D65 simulator was calculated by CIE No.13.3 method. However, this index was inconsistent with MI(vis) in CIE No.51method.

Keywords: Spectral Power Distribution, CIE Illuminant D65, D65 Simulator, Visual Range Metamerism Index, General Color Rendering Index

1.INTRODUCTION

The International Commission on Illumination (CIE) recommended daylight illuminants for visual assessment and instrumental measurement[1]. CIE illuminant D65 is adopted by majority of colorimetric applications since the recommendation. Many attempts have been made to simulate CIE standard illuminant D65. However, the simulations are still not close enough to the CIE illuminant D65[2,3]. On the other hand, CIE does not recommend any daylight simulator to be a CIE illuminant D65[4]. This leads to the situation where various D65 simulators, from various light source manufacturers, are used in the commerce and industry. Such a variation in D65 simulators results in the lack of precision in the colour evaluation. The present study focused on investigating the influence of various D65 simulators on visual colour matching using gray scale rating method. The quality of D65 simulators was quantified by CIE No.13.3[5] and No.51 methods[6]. The performance factor (PF/3) measure is taken to analysis visual different (ΔV) data obtained from five D65 simulators.

2. ASSESSING THE QUALITY OF DAYLIGHT SIMULATORS

The CIE No.51 method quantifies the quality of daylight simulators in terms of how well they approximate the CIE daylight illuminant, D55, D65 or D75[6]. In 1999, the CIE D50 illuminant was added to the daylight illuminant list of the above method. CIE No.51 method requires the determination of the relative SPD of the daylight simulator over the range of 300nm to 700nm. The chromaticity coordinates of daylight simulator are calculated from measured relative SPD. These coordinates are then used to check whether they are within the allowable limits, which is specified by the CIE 1976 Uniform Chromaticity Scale.

The essence of the method is the calculation of the special metamerism index because of the differences between the SPDs of the sources and illuminants. Two metamerism indices are calculated using SPD within both visible spectrum (400nm - 700nm) and ultraviolet spectrum (300nm - 400nm), i.e., MI(vis) and MI(uv), given by Eq.(1) and Eq.(2) respectively.

$$MI(vis) = \sum_{i=1}^{5} \frac{\Delta Ei}{5} \quad (1) \qquad MI(uv) = \sum_{j=1}^{3} \frac{\Delta Ej}{3} \quad (2)$$

The calculation of MI(vis) uses five pairs of metamers comprising of ten hypothetical spectral reflectance factors. Each pair of metamer is perfectly matched under CIE daylight illuminants. When the SPD of a daylight simulator is used, the mean of the resultant color difference will be larger than zero because of the difference of the SPD from the CIE daylight illuminant. This mean color difference gives an indication of the quality of the daylight simulator within visible spectrum. The calculation of MI(uv) uses the other three virtual metamer pairs. Each pair is also perfectly matched under CIE daylight illuminants within the ultraviolet spectrum. The mean color difference for these three pairs is an indication of the conformity to the CIE daylight illuminant within the ultraviolet spectrum. The CIELAB or CIELUV color difference equation can be used in determining the color differences of virtual metamer pairs for both indices.

In interpretation of both metamerism indices, the CIE No.51 method established a rating scale for categorizing the quality of daylight simulator. The five categories of the daylight simulator are given in Table 1. Category A daylight simulators are the best, whereas category E simulators are the worst. This method states that a daylight simulator with MI(vis) of B or above and MI(uv) of C or above is recommended for visual color matching. In this study, only MI(vis) was calculated for D65 simulators as the available measurement wavelength range of the spectroradiometer used is limited within 380nm to 780nm.

Table 1. Daylight Simulator Categorization.

CIELAB MI(vis)	CIELAB MI(uv)	Category
<0.25	<0.32	A
0.25 to 0.50	0.32 to 0.65	B
0.50 to 1.00	0.65 to 1.30	C
1.00 to 2.00	1.30 to 2.60	D
>2.00	>2.60	E

3.EXPERIMENTAL

3.1Spectroradiometery Measurement

Five D65 simulators were obtained and measured using a PR-704 spectroradiometer against a barium sulphate tile with a 0/45 illuminating/viewing geometry in viewing cabinet. The SPD were recorded from 380 to 780nm at 2nm intervals. For each source, visible range metamerism index, colour rendering index[3], lamp group and type[4] are given in Table 2. Fig 1 plotted SPD values against wavelength for the GretagMacbeth D65, VeriVide F20T12/D65, Philips TLD 36W/965, GCE 6500K 40W-SD D65 and Sylvanna F36W/154-T8 D65 simulators. They were selected to represent the typical D65 simulator used in this study. In the following discussion, the commercial names of these sources will be abbreviated to M V, P, G and S. The word "illuminant" will be used only for those specified by the CIE, i.e. the CIE illuminant D65.

Table2. Colourimetric Specifications for CIE Illuminant D65 and Five D65 Simulators.

Illuminant/ D65 Simulator	L(cd/m^2)	Chromaticity Coordinates		CIE No.51 Method		CIE No.13.3 Method	Type*	Group*
		x	y	MI(vis)	Category	Ra		
CIE illuminant D65	-	0.3138	0.3310	0.00	A	100	-	-
GretagMacbeth - (M)	495	0.3216	0.3395	0.24	A	95	-	-
VeriVide - (V)	450	0.3217	0.3371	0.34	B	97	F7	B
Philips 965 - (P)	516	0.3234	0.3338	0.52	C	97	F7	B
GE 6500K - (G)	640	0.3286	0.3532	1.86	D	71	F7	N
Sylvanna - (S)	630	0.3240	0.3454	1.78	D	73	F7	N

*CIE has divided the fluorescent sources into three groups: normal (N), broad (B) and three (T) bands and twelve types: F1 to F12; CIE illuminant D65 and M D65 simulator are not classified as fluorescent source[4].

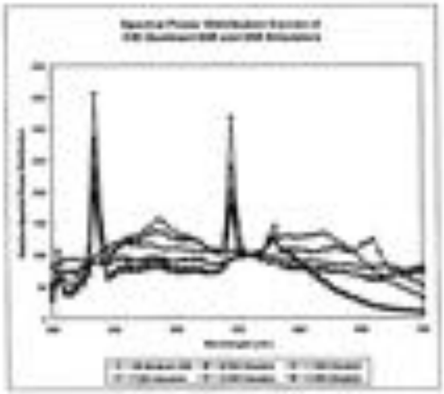


Figure 1. The Spectral Power Distribution of CIE Illuminant D65 and D65 Simulators.

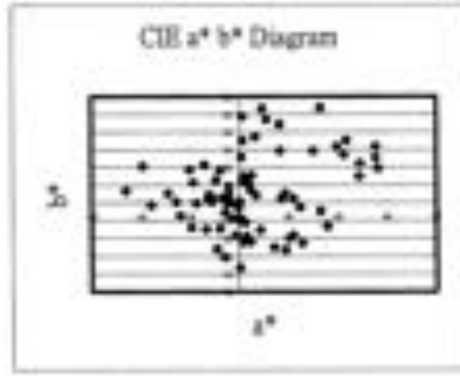


Figure 2. 77 Metameric Pairs for Visual Assessment.

3.2 Sample Preparation

Seventy-seven textile metameric pairs were produced by dyeing cotton woven fabric. These samples were measured by using GretagMacbeth 7000A spectrophotometer in large aperture, specular and UV included measuring conditions from 400 to 700nm at 10nm intervals. The average color different of 77 textile metamers was 0.66 CIELAB unit. Fig. 2 shows the samples on a CIE a* b* diagram. It is seen from the figure that these samples give a good coverage of colour space. Each sample was mounted on a 7.6cm square of stiff cardboard for visual assessment corresponding to 10° field of view.

3.3 Visual Assessment

Thirty experienced observers took part in the visual assessment in the 26 to 47 age ranges, 15 men and 15 women, between the ages of 26 and 37 participated in visual assessment to determine the visual difference (ΔV) under 5 D65 simulators in viewing cabinet. They passed a screening for congenital colour vision deficiencies in Ishihara Pseudoiso-chromatic Plates[7] and rated as having "superior" colour discrimination in the Farnsworth Munsell-Hue 100 Test[8]. In psychophysical experiment, reliability is very importance. For this reason, seven out of thirty observers took the second visual assessment following the previous procedures. In total, 30 observers took 14245 visual assessments.

3.4Conversion Of Gray Scale To Visual Difference

In this study, the gray scale (GS) method was employed to scale the metamer ΔV seen under D65 simulators by using the AATCC Gray Scale for Colour Change. As the GS ratings are not directly proportional to ΔV, GS should be correlated to ΔE. Therefore, a standard curve-fitting technique was used to derive a forth-polynomial equation (Eq.3) to correlate GS to ΔE. Thereafter, observer's GS rating was transformed to ΔV (Eq.4).

$$\Delta E = 0.0143(GS)^4 - 0.4293(GS)^3 + 3.8453(GS)^2 - 15.356(GS) + 25.375 \qquad (3)$$

$$\Delta V = 0.0143(GS)^4 - 0.4293(GS)^3 + 3.8453(GS)^2 - 15.356(GS) + 25.375 \qquad (4)$$

3.5 Measure Of Fit

Performance Factor (PF/3) measure was used to indicate the agreement between the calculated colour difference and visual difference, visual difference values among five D65 simulators, observer accuracy and observer repeatability. The PF/3 measure combines four statistical measures: correlation coefficient r, coefficient of variation CV, V_{AB} and γ, which was developed by Luo and Rigg[9] given in Eq. 5.

$$PF/3 = 100[(\gamma - 1) - V_{AB} + CV/100] \qquad (5)$$

4. RESULTS AND DISCUSSION

The CIELAB color difference equation was used to calculated instrumental color difference of each textile metamer pair. The agreements between ΔE^*_{CIELAB} and ΔV were shown in Table 3 and Table 4. ΔE^*_{CIELAB} in Table 3 was calculated using the SPD of CIE illuminant D65, whereas in Table 4, ΔE was calculated using real SPDs of D65 simulators. In both Tables, V performed the best, followed by M and the worst one was G. It is noticed that D65 simulators M and V have similar PF/3 values. G and S also have similar PF/3 values but larger than those of M and V. Furthermore, smaller PF/3 values were obtained by using real SPDs of the D65 simulators instead of the SPD of the CIE D65 illuminant in ΔE^*_{CIELAB} calculation.

Table 3. Performance of CIE Illuminant D65.

D65 Simulator	M	V	P	G	S
PF/3	42.95	42.13	50.61	62.01	60.55

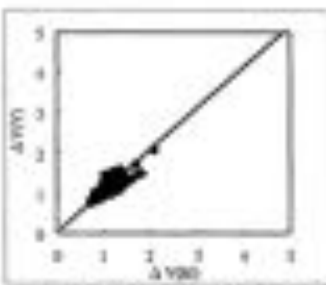
Table 4. Performance of D65 Simulators.

D65 Simulator	M	V	P	G	S
PF/3	42.27	40.99	45.41	48.59	47.69

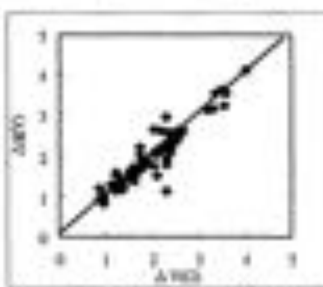
The ΔV performance under five D65 simulators were compared in Table 5. M and V D65 simulators have the best agreement, followed by G and S D65 simulators, which are 11.04 and 13.80 PF/3 units separately. Figures 3a-b plotted the ΔV data of M against V and G against S D65 simulator. Two sets of ΔV data have an good agreement as all data points should lie around 45° line. It indicates that M and V, as well as G and S have little disagreement by means of ΔV data. Figure 3c plotted the ΔV data of M against G. It has larger disagreement than previous.

Table 5. Summary Performance of ΔV D65 simulators.

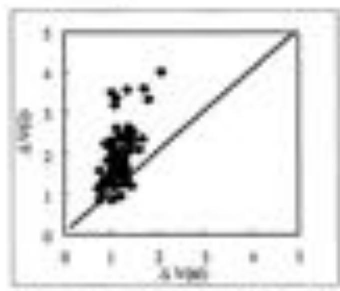
	M	V	P	G
S	32.26	33.51	34.47	13.80
G	30.91	33.01	33.24	
P	21.18	22.00		
V	11.04			



Figures 3a. ΔV data of M against V



Figures 3b. ΔV data of G against S



Figures 3c. ΔV data of M against G

The mean performance of observer precision in terms of PF/3 units are 27.0, 28.5, 25.4, 24.3 and 27.1 for M, V, P, G and S D65 simulators respectively. The range is between 19.4 and 29.6 PF/3 units. The mean observer precision is 26.5 PF/3 units for all simulators. This small variation indicates that the observer metamerism is small. The mean observer repeatability is 24.5, which is smaller than mean observer precision. The range is between 20.9 and 31.1. Each observer's results are repeatable.

5. CONCLUSION

D65 simulator is not exactly the same as CIE illuminant D65 by means of SPD but it is a real source. D65 simulators with different SPDs influence visual colour match judgement. With reference to experimental results, better agreement between ΔE and ΔV is obtained when the real SPD of D65 simulator is used for calculating ΔE. If the final acceptance of color matching is depended on instrumental judgment, it is more appropriate to use real SPD of D65 simulator. The uncertainty in applying CIE No.51 method is lack of visual data for supporting. The findings in visual assessments seen under M and V show that there is a good agreement in PF/3 measure. However, they are categorised in different categories. Identical results are also obtained from two D category D65 simulators. Further work is recommended to examine the statistical significance of the difference of the visual data among five D65 simulators. In addition, Table 2 shows that the evaluation for D65 simulators by CIE No.51 method does not directly related to the evaluation of color rendering properties by CIE No.13.3 method. Therefore, use of Ra units might not be a good indicator of quality for visual color matching. The present study is only concentrated the influence of different categorised D65 simulators on visual colour matching. It is interesting to conduct other psychophysical experiments to investigate the visual influence using other phases of daylight simulator such as D50, D55 and D75.

ACKNOWLEDGMENTS

The authors wish to acknowledge the funding from The Hong Kong Polytechnic University for this project (G-V667). Special thanks to 30 observers who took part in this work.

REFERENCES

1. D. B. Judd, D L Macadam, and G Wyszecki, Spectral Distribution of Typical Daylight as a Function of Correlated Color Temperature, J Opt. Soc. Am., **54**, 1031-1040 1964.
2. C. .S. McCamy, Relating Colorimetry to Visual Observations, Die Farbe, **37**, 43-53 1990.
3. R. W. G. Hunt, Standard Sources to Represent Daylight, Color Res. Appl., **17**, 4, 293-294, 1992.
4. Publication CIE No.15.2 Colourimetry, 1986.
5. Publication CIE No.13.3, Method of Measuring and Specifying Colour Rendering Properties of Light Sources, 1995.
6. Publication CIE No.51, A Method for Assessing the Quality of Daylight Simulators for Colourimetry, 1981.
7. S. Ishihara, The Series of Plates Designed as a Test for Colour-Blindness, Kanehara Shuppan Co., Tokyo.
8. D. Farnsworth, The Farnsworth Munsell-Hue 100 Test for the examination of Colour Discrimination Manual, Munsell Colour Company, Inc., 1957.
9. M. R. Luo, and B. Rigg, BFD(l:c) colour-difference formula Part 1- Development of the formula, Journal of the Society of Dyers and Colourists, **103**, p.86, 1987.

*Correspondence: [illegible]; phone: 852-2766 6521; The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong.

Relation between Blocking Property against UV-rays by Dyed Fabric and Its Color Fastness to light

Tomoko Mima* , Masako Sato**

Seian College of Art and Design, ** Osaka City University

ABSTRACT

It is predicted if the dye strongly absorbed the ray in shorter UV wavelength, the ray energy might destroy the dye structure. Color fastness of dyed fabric is also an important character from a viewpoint of aesthetic sense and textile end use.

The purpose of this study is to investigate the relation between the blocking property of dyed fabric against UV-rays and its color fastness to light. The cotton fabrics dyed with different types of direct dyes (red, blue and yellow) and their dye solutions were respectively irradiated by xenon arc lamp. The results were as follow. Color fading of dyed fabrics depended on the structure of dyes. Even the dye having lower fastness property to light, the darker shade fabrics dyed with them were examined still remaining higher UV blocking property.

Keywords: blocking property against UV-rays, dye and dyed fabric, color fastness to light

1. INTRODUCTION

As increasing of the environmental destruction, the radiation of electromagnetic wave, especially harmful ultraviolet (UV) wave, has been suspected to influence the human health (1). Dye might be expected as a superior blocking material against the harmful UV-rays, because the dye on the fabric could absorb not only visible ray but also UV-ray. In the previous studies the authors reported the characteristics of direct dyes on absorption from 200nm to 800nm of wave length, molar absorption coefficients respectively in visible region, UV-A and UV-B region, dying properties, and UV-ray blocking efficiency of dyed fabrics (2,3).

As the shorter wavelength of rays in UV region, UVA, UVB and UVC might have higher energy than the ray of visible region, the degradation of dye might be supposed. In this study the relation between UV ray blocking property of dyed fabric and its color fastness was investigated.

2. EXPERIMENTAL PROCEDURE

2.1. Fabric and dye materials

Plain cotton fabric woven with 40' yarn in thickness was used for the substrate of dyeing. Table 1 shows the C.I.dye name and number, and its molar weight of direct dyes used. They are the same fabric and dyes used in the previous study (3). These dyes are purity known reagent grade by Aldrich Chemical Company. Test pieces of fabric were dyed in the seven levels of concentration of dying baths. The dyed fabric swatches resulted in different depths of colors from pale to dark shade.

Table 1. Direct dyes used

Dye name	C.I.No.	M.W.
Red23	C.I.29160	814
Red28	C.I.22120	670
Red75	C.I.25380	991
Red80	C.I.35780	1373
Red81	C.I.28160	676
Blue1	C.I.24410	993
Blue14	C.I.23850	961
Blue53	C.I.23860	961
Blue71	C.I.34140	1030
Violet51	C.I.27905	720
Yellow4	C.I.24890	625
Yellow8	C.I.13920	519
Yellow50	C.I.29025	957
Yellow59	C.I.49000	476

2.2. Examination of fastness property of dyed fabric and dye solution.

The fastness properties of dyed fabric and dye solution were examined as function of irradiation time by xenon arc lamp using Super Xenon Weather Meter-SC-750-WA (SUGA Weathering Technology Co. Japan). Pieces of blue scale (light fastness standards) were used for the indicator of light blocking by dyed fabric. That is to say, the dyed fabric attaching a piece of blue scale in the back (see Fig.1) was fixed on the window of device for irradiation. After irradiation the dyed fabrics were measured on the luminance reflectance and examined fastness properties of grade by visually

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) · 0277-786X/02/$15.00

comparing to the blue scale swatch. The dye solution in the quartz cell was also irradiated using the same xenon weather meter.

2.3. Evaluation of UV blocking property of dyed fabric.

UV blocking property of dyed fabric was examined by two methods. The one is the measuring of the spectral transmittance of dyed fab before and after irradiation using UV-VIS SPECTRO PHOTO METER (UV-3000, SHIMADZU, Japan) and the other is the examinati of color difference between the two areas, B_1 and B_2 of a blue scale (showed in Fig.1). The later $\Delta E_{B1\text{-}B2}$ shows the blocking property dyed fabric indirectly. The reflection property of fabric was also examined at the region from 200 to 800 nm.

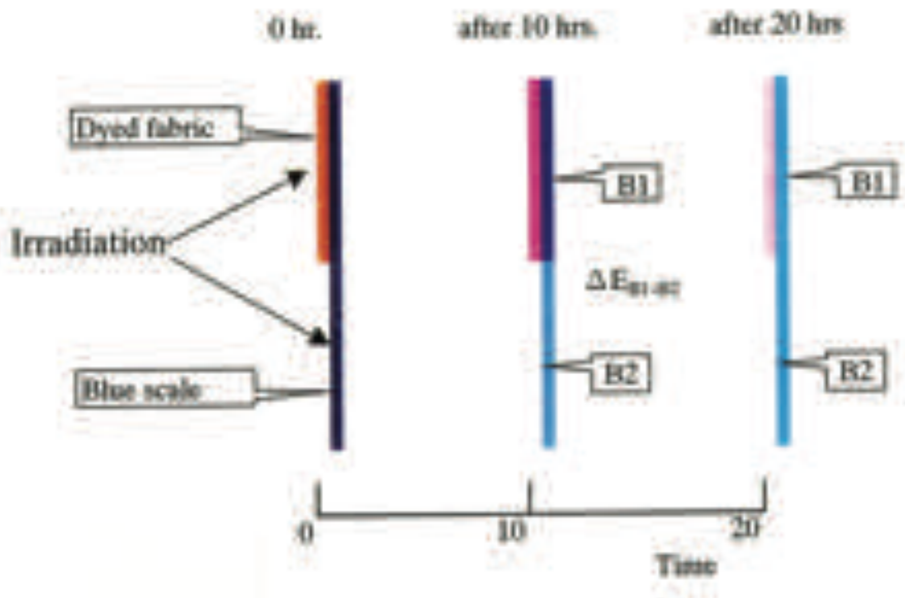


Fig.1 The dyed fabric and blue scale fixed on the window of the irradiation.

Table 2. Color fastness to light of dyed fabrics

Sample	Dye conc. of dying bath / Time	0.05×10^{-4} mol/l (3)	0.2×10^{-4} mol/l (5)	1×10^{-4} mol/l (7)
Red23	0 hr			
	10hrs	[3]	[5]	[3]
	20hrs	[3]	[5]	[3]
Blue71	0 hr			
	10hrs	[3-4]	[3-4]	[5]
	20hrs	[3-4]	[3-4]	[5]
Yellow50	0 hr			
	10hrs	[6]	[6]	[6]
	20hrs	[6]	[6]	[6]

The number in square bracket indicates the fastness property to light after irradiation.

PRINT IN COLOR

3. RESULTS AND DISCUSSION

3.1 Effects of irradiation time on the color fastness property of dyed fabrics.

Table 2 shows the color fastness to light of dyed fabrics of Red23, Blue71 and Yellow50. The number in round bracket in the line title shows the level number of the dye concentration of dying bath, namely they are 0.05 × 10^{4} mol /l(3), 0.2 × 10^{4} mol /l(5) and 1 × 10^{4} mol /l(7). The influences of irradiation time on the difference of color fastness between two irradiation hours in the same dye of Red23, Blue71 and Yellow50 respectively, were not recognized from the graded number by visually comparing to the blue scale swatch. The fabrics dyed with Red23 were examined lower color fastness to light as compared to the fabrics dyed with other dyes. The fabrics dyed with Yellow50 showed the highest color fastness to light in all of the dyes used in this experiment. It was investigated in general that Yellows might be excellent and Blues might be worth against the color fading.

3.2 Effects of irradiation time on the absorption of dye solution.

Fig. 2 shows the effects of irradiation time on the absorption of dye solution of Yellow50 at the concentration of 1.67 × 10^{5}mol /l. The curves show the decreasing of absorption by influence of degradation of dye structure. Not only in the region of VIS but also UVA and UVB, it was investigated that the absorption of dye solution decreased with increasing irradiation time. The other dyes show nearly the same tendency as of Yellow50.

3.3 Effects of irradiation time on the transmittance of dyed fabrics

Fig.3 shows the spectral transmittance curves of the dyed fabric as an example of Yellow50. The numbers in round bracket 3 or 7 shows the dye concentration of dying bath as sample in table 1. Number 3 means pale shade, and number 7 means the dark shade dyed fabric respectively. On the dark shade fabrics, the influences of irradiation on the transmittance were not so clear, but on the pale dyed fabric might be influenced by irradiation.

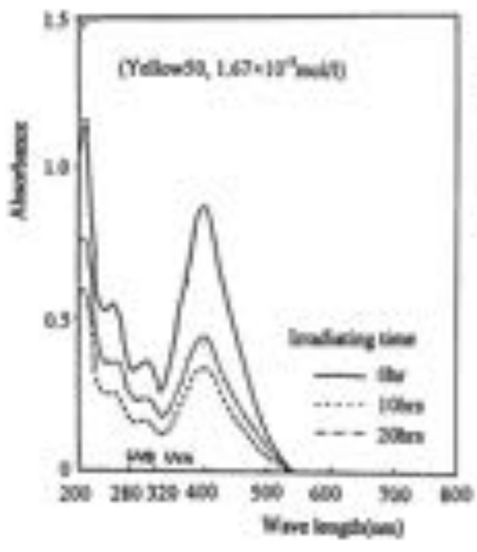


Fig. 2. Spectral absorption curve of the dye solution

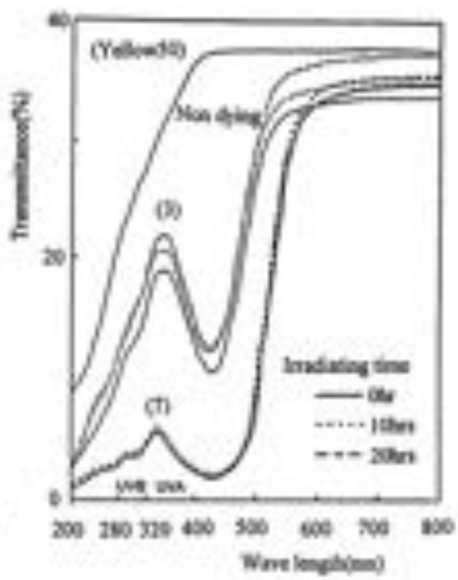


Fig. 3. Spectral transmittance curve of dyed fabrics

3.4 The relation between the character of dye, color fastness and blocking property of dyed fabric.

Table 3 shows the characters of dye molecular, color fastness and blocking property of dark shade fabrics after irradiation for 20 hrs. The higher the absorption coefficient of dye at UVA and UVB, it might be more expected to be excellent on UV- rays blocking property. The ratio of UVA/VIS or UVB/VIS might predict the coloring effect on the UV-rays blocking with dyes. The colorfastness of Yellow50 was the most excellent of fourteen dyes used .The difference of the luminous reflectance (Y %) of dyed fabrics before and after irradiation indicates the color fastness of them. There is a significant difference of Y% on Red23, that is to say, Red23 is inferior to Blue71 and yellow50. It was found that even the dye having low fastness property, the dark shade fabrics dyed with them would be able to block the UV ray.

Table 3. Characters of dye, color fastness to light and blocking property of dark shade dyed fabrics after 20 hrs irradiation.

Dye	Molor absorption coefficient	UV/VIS	Color fastness	Before irradiation(0 hr)		After irdiation(20 hrs)	
				Y(%)	Blocking (%)	Y(%)	Blocking (%)
Red23	UVA : 17460 UVB : 32250 507nm : 59800	0.292 0.539	3	39.0	97.9	46.9	97.8
Blue71	UVA : 12880 UVB : 24700 586nm : 58540	0.220 0.422	5	21.0	87.8	22.4	87.9
Yellow50	UVA : 35040 UVB : 22110 400nm : 54780	0.640 0.404	6	60.4	95.8	60.8	95.6

Y(%) indicates luminous reflectance

Blocking(%) indicates blocking efficiency against UVT(280~380nm)

4. CONCLUSION

The results were as follow. 1)The absorption of dye solution decreased with increasing irradiation time. 2) The influences of irradiation time on color fastness property of dyed fabrics were small difference between two irradiation hours, 10hrs and 20hor. 3) Even the dye having low fastness property to light, the dark shade fabrics dyed with them were examined still remaining high UV blocking property.

ACKNOWLEDGMENTS

One part of this study was undertaken with the support of SUGA Weathering Technology Foundation.

REFERENCES

1) P.C. Crews, S. Kachan and A.G. Beyer, Influences on UVR Transmission of Undyed Woven Fabrics, Textile Chemist and Colorist, Vol.31,No.6, pp. 17-26, 1999

2) T. Mima and M. Sato, Studies on Ultraviolet Rays Shielding Properties of Dyed Fabrics,Part1: Cotton Fabrics Dyed with Direct Dyes, Jpn. Res. Assn. Text. End-Uses, Vol.. No3, pp. 36-46 , 2000

3) T. Mima and M. Sato, Ultraviolet rays Shielding by Dyed Fabrics, AIC Color 2000, Proceedings of AIC 2000 Meeting Seoul, Korean Society of Color Studies , p.p. 260-263, 2000

AUTHOR,S ADDRESS

Tomoko Mima*, Masako Sato**

*Seian College of Art and Design
1-25-1, Choshi, Nagaoka City, Kyoto, 617-0844, JAPAN
Phone: +81-75-953-1111
Fax : +81-75-953-1904
E-mail mima@std2.life.osaka-cu.ac.jp

**Graduate School of Human Life Science, Osaka City University
3-3-138,Sugimoto, Sumiyoshi-ku, Osaka City, 558-8585, JAPAN
Phone: +81-6-6605-2825
Fax : +81-6-6605-2824
E-mail sato@life.osaka-cu.ac.jp

Reproduction of various colors on Jacquard textiles by only eight kinds of color wefts

Keiji Osaki

International Christian University

ABSTRACT

By making use of the information of the textile color blocks, reproduction of high-precision colors on fabrics that we call 'Color Image Fabrics' could be woven by Jacquard loom. Color components for each pixel on digitized original image are transformed into weaving data on textile by minimizing the color difference in CIEL*a*b* representation between the original image color and the simulated textile color.

Keywords: Keywords: textile color block, CIEL*a*b*, high precision color, textile color simulation

1. INTRODUCTIOIN

Excellent quality of Hakata-ori weaving (that is well known as one of Japanese typical silk fabrics) has been in the combination of various colors of threads and elaborate patterns of textile weaving. Traditional weaving craftsmen's technique was first imported from Ming Dynasty China to Hakata (which is located in western part of Japan) in the 13th century. Western weaving technology and equipment (which were Jacquard loom and etc.) were introduced in the 19th century. Though traditional hand-woven fabrics required time-consuming and labor-intensive work, this new innovation yielded the reduction of costs and offered the opportunity to design gorgeous patterns on fabrics woven by Jacquard looms. Unfortunately successors of these traditional arts are rarely found nowadays. In order to preserve traditional arts, some projects have started to record the technique in a certain kind of knowledge database. However, most of traditional technique for making complex colors on textile remains secret. With an encounter of a traditional craftsman and his generous aid, we could gradually advance to make "textile color block database" which contains important know-how for reproducing fantastic colors on textile. It is well known that mismatches lie in color handling among different devices such as between cathode ray tube(CRT) monitors and color printed papers. Even in the most advanced color technology, it is still difficult to reproduce accurate color on a device and to transform color among different devices. The difficulty is mainly caused by device-dependent color representation as in RGB color components. The CIEL*a*b* color space which was established as a uniform color space in 1976 has been successfully used to convey image data in a device-independent manner. We have also manifested that the CIEL*a*b* color representation is very effective to reproduce high precision colors on textile by the combination of jacquard color textile arts with computer color handling. To accomplish color matching between display monitors and textile, we made simulation program in CIEL*a*b* color representation which was developed on X-Window system. The encounter of traditional craftsman's technique in Hakata-ori weaving with the computer color handling system made it possible to develop precise reproduction of colors on textile for the first time. We could successfully achieve to reproduce more than hundred of colors on textile where the color of each pixel of the original digital image matches. High

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

precision color reproduction on textile by combination of only eight kinds of wefts (lateral threads) was achieved by the encounter of traditional weaving craftsmen's' technique with the high-end color management and database technique in computer for the first time. Textile color block table that contains almost a thousand colors was created and implemented on UNIX workstation system. It has made it possible to produce within a few to five hours the present color image fabrics whose width is 50 cm and length is 75cm woven by Jacquard loom from the original digital images.

2. TEXTILE COLOR BLOCK TABLE

More than hundred sets of textile color blocks and their attributes were integrated to form a textile color block database and were used as an available color matching table between textile color and original image color. Figure .1 shows a page of textile color block sample book which is to be digitally converted to a database and implemented on the computer. The size of a real woven textile sample is 4x4 square cm. The sample book contains more than a few hundred pages. Possible colors reproduced on textile were thoroughly investigated by checking various combinations of fundamental textile weavings. Minimum basic colors of wefts(lateral threads) were fully investigated and only eight colors are now selected which are"white","black","vermilion","yellow","green","blue"," prussian blue", and "magenta". Their color attributes are listed in Table 1. The color of warp(lengthwise thread) was also investigated and "dark deep green" is now selected as the best for the color of warp in that this color does not disturb the color tone of wefts. The number of textile weaving patterns is almost a few hundred. These patterns are ascribed to various combinations of basic patterns, namely, flat("hira"), twill("aya"), satin("shusu") and composite textile("dokuchi"). The composite textile is woven by passing two wefts of different colors among eight color wefts into aperture of warp. Weave patterns with 4,5,8,10 and 12 harnesses are used. In Figure 2, magnified photo of composite textile pattern ("Dokuchi") is shown. These composite textile patterns are frequently use to reproduce additive colors on the textile in addition to primary colors. The textile color block database contains about a thousand records, which contain three color component values measured by spectral colorimeter in CIEL*a*b* representation, instruction of weaving patterns and other necessary information. The creation of the database for

Table 1. Color attributes for eight kinds of wefts

Wefts' color	L*	a*	b*	C*	h*
Black	18.20	-0.64	-0.44	0.78	214.51
White	71.35	-0.58	0.20	0.61	160.97
Vermillion	41.48	43.71	21.05	48.51	25.71
Yellow	69.75	-10.87	42.68	44.04	104.29
Green	41.22	-30.64	3.77	30.87	172.99
Blue	49.17	-19.25	-24.52	31.17	231.87
Prussian Blue	32.75	5.32	-38.17	38.54	277.93
Magenta	40.63	39.27	-7.13	39.91	349.71

$$L^* = L^*,$$
$$C^* = \sqrt{(a^*)^2 + (b^*)^2},$$
$$h^* = \tan^{-1}(b^*/a^*)$$

Figure 1. Part of sample book of textile color blocks

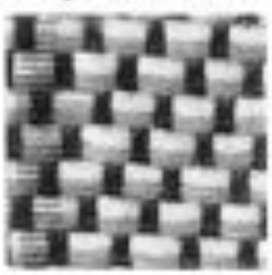


Figure 2. Magnified photo of composite textile ("Dokuchi")

Figure 3. Textile weaving patterns with 2, 4 and 5 harness

textile color blocks has led us to the new creative world where various colors with high precision can be reproduced on textile. Actually from the textile color block database, we could successfully develop a new technique for conversion of original digital image data to fabric weaving instruction data for Jacquard machine. Numbers of textile color block records were gradually increased to a few thousands to improve the quality of fabrics. One might say that the encounter of traditional weaving craftsman's technique with high-end color management technique in computer gave birth to a new color reproduction field where abundant variety of colors is generated on textile not by inks but by limited kinds of dyed threads.

3. FLOWCHART OF COLOR IMAGE FABRICS

Figure .2 shows how the color image fabrics are created. The textile color block pattern samples created by the craftsman's skilled technique are systematically measured by the spectral colorimeter and then the results are accumulated into a database on computer. Color components for each pixel on digitized original image are transformed into weaving information on textile by minimizing the color difference in CIEL*a*b* representation between the original image color and the simulated textile color. The color difference introduced here is defined by the following formula:

$$a = \sqrt{(\Delta L)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

where ΔL, Δa^*, Δb^* are respectively defined by the difference between value in the original image and that in the simulated textile. We could also succeed for the first time in proposing new criteria to estimate the completed woven products quantitatively and objectively in contrast to the previous way of estimation depending on human eye that is subjective and ambiguous. The quantity of color difference in uniform color space CIEL*a*b* has shown to be fairly good criteria for objective way of estimation of completed color image fabrics.

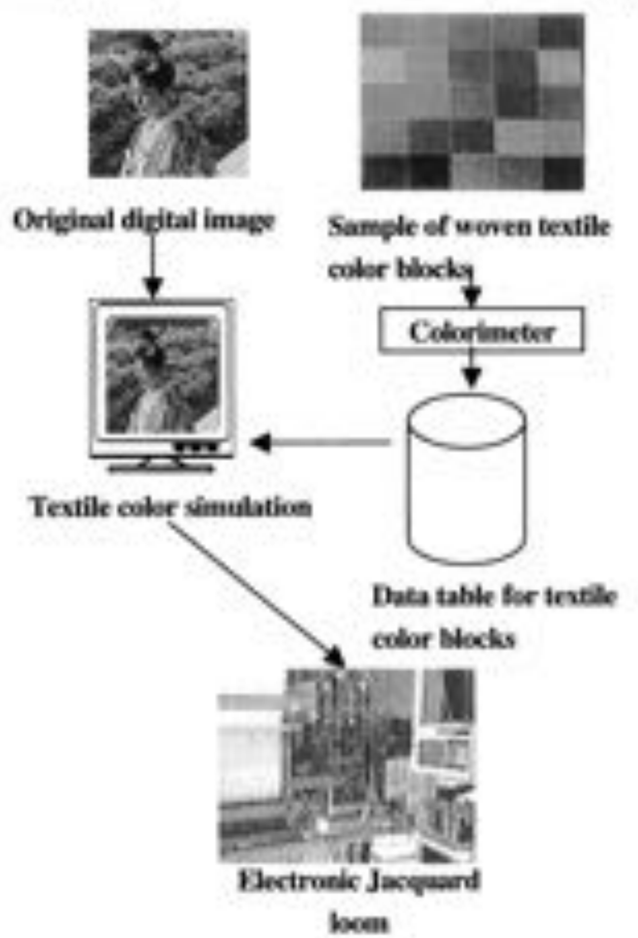


Figure 4. Reproduction process of colors on textile and the flow for creation of color image fabrics

4. TEXTILE COLOR SIMULATION ON X-WINDOW SYSTEM

The application program for simulation of color reproduction on textile has been originally developed by us on the UNIX workstation with the help of X-Window(X11R5 later) 's color management system. Arithmetical operation for the simulated color reproduction on textile for original image with size of 900x1200 pixel requires about 69 billion computations in floating point numbers. It is undeniably far from a practical use. In order to speed up the simulation program, we have developed novel algorithm. After the refinement of the program we could drastically achieve one 40th of computation time. As a result of the improvement, it takes only just a few minutes to complete the whole processing for the simulated color reproduction on textile for the image with the above size. Figure 5 shows the screen dump image on X-Window during execution of the improved simulation program of reproduction of colors on textile. Photo of magnified textile color block is seen in the lower right part of Figure 5. The top rectangle on the right shows the color of the original image and the middle rectangle shows that of the textile color block that is searched and selected among the database so as to minimize the color difference between the two. In the middle of the bottom in Figure 5, the digital photo of textile color pattern is shown as reference for help of checking when it is woven. Products of color image fabrics with excellent quality show the average color difference per pixel whose values lie below 10 in CIEL*a*b* uniform color representation. Almost of all good 'color image fabrics' show the average color difference of around 10, and contain more than 500 kinds of textile color blocks selected among 812 kinds. In order to estimate the quality of the fabric products before weaving them, various quantities are deployed. Distribution of color difference between original image and textile simulated image is shown in Figure 6. The darker the color is, the smaller the color difference between them appears in Figure 6. Since the upper limit of brightness of color of silk wefts is fairly low (< 71), brighter area in the image shows larger color difference in CIEL*a*b* space. Another deduced quantities for analysis of the quality of 'color image fabrics' appear in Figure 7. Left half par of the figure shows the plot of L*(Lightness) distribution on h and right half part shows C(Chroma) distribution. The upper horizontal part in Figure 7 indicates L* and C distribution plot for original image, the middle part for 812 textile color blocks and the lower part for textile simulated image, respectively. As you can see in Figure 7, the original image contains almost full range of L* for entire range of h(hue). It seems rather difficult to reproduce high precision colors on textile for this original image due to the restricted numbers of textile color blocks. However, the average color difference per pixel for the image is calculated to be 9.26 in CIEL*a*b* space and 766 kinds of textile colors appear in the 'color image fabrics'.

Textile color simulated image

Figure 5. Screen dump image on X-Window during execution of the improved simulation program of reproduction of colors on textile

Figure 6. Distribution of color difference between original image and textile simulated image

5.CONCLUSION

Excellent features of the present research and resultant products are summarized as follows:High precision color reproduction on textile by combination of only 8 kinds of wefts(lateral threads) was achieved by the encounter of traditional weaving craftsman's technique with the high-end color management and database technique in computer for the first time in the world. Textile color block database that contains almost a thousand colors was created and implemented on UNIX workstation system. With the usage of dark deep green color for warp(lengthwise thread) and of various weaving patterns, it became successful for the first time in removing undesirable effect of warp which caused the color tone of the completed fabrics grayish. With the success of drastic speeding up of the textile color simulation program, it became possible to produce within a half day the present color image fabrics whose width is 50 cm and length is 75cm woven by Jacquard loom, from the original digital images.

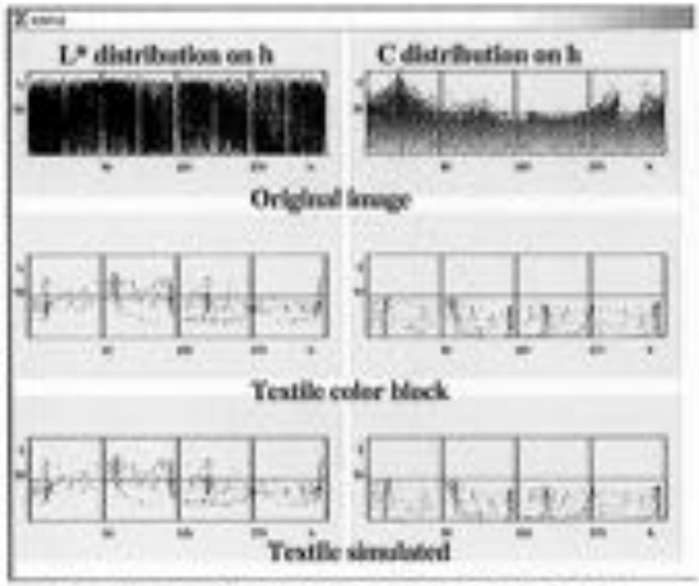


Figure 7. L* and C distribution on h for original, textile color block and textile simulated images

Kubelka-Munk or Neural Networks for Computer Colorant Formulation?

Stephen Westland[*a], Laura Iovine[a] and John M Bishop[b]
[a]Colour & Imaging Institute, Derby University, Derby, UK;
[b]Department of Cybernetics, Reading University, UK.

ABSTRACT

Traditionally *Computer Colorant Formulation* has been implemented using a theory of radiation transfer known as *Kubelka-Munk* (K-M) theory. Kubelka-Munk theory allows the prediction of spectral reflectance for a mixture of components (colorants) that have been characterised by absorption *K* and scattering *S* coefficients. More recently it has been suggested that *Artificial Neural Networks* (ANNs) may be able to provide alternative mappings between colorant concentrations and spectral reflectances and, more generally, are able to provide transforms between colour spaces. This study investigates the ability of ANNs to predict spectral reflectance from colorant concentrations using a set of data measured from known mixtures of lithographic printing inks. The issue of over-training is addressed and we show that the number of hidden units in the network must be carefully selected. We show that it is difficult to train a conventional neural network to the level that matches the performance that can be achieved using the K-M theory. However, a hybrid model is proposed that may out-perform the K-M model.

Keywords: colour, Kubelka-Munk theory, artificial neural networks, colour recipe prediction.

1. INTRODUCTION

Traditionally *Computer Colorant Formulation* has been implemented using a theory of radiation transfer known as *Kubelka-Munk* (K-M) theory[1-4]. Kubelka-Munk theory allows the prediction of spectral reflectance for a mixture of components (colorants) that have been characterised by absorption *K* and scattering *S* coefficients. It has been shown that the Kubelka-Munk coefficients *K* and *S* are related to, but not equal to, the fundamental optical coefficients for absorption ε and scattering σ[4]. More recently it has been suggested that *Artificial Neural Networks* (ANNs) may be able to provide alternative mappings between colorant concentrations and spectral reflectances[5-7] and, more generally, are able to provide transforms between colour spaces[8,9]. This study addresses two key issues; firstly, it presents a quantitative comparison of K-M theory and ANNs for a given problem domain; secondly, it suggests that significant advances may be made by combining both K-M and ANNs to form a hybrid ANN-KM model. Quantitative data are presented for the prediction of spectral reflectance for a set of known mixtures of printing inks.

1.1 Kubelka-Munk model

The Kubelka-Munk theory characterises colorants according to two coefficients, *K* and *S*, the absorption and scattering coefficients respectively. The K-M theory is a two-flux version of a multi-flux method for solving radiation-transfer problems. Although more exact theories exist[10] the continued use of the K-M theory is due to its simplicity and the ease by which the coefficients *K* and *S* can be estimated. The application of K-M theory varies depending upon whether the application is for the prediction of the colour of textiles, (opaque) paints or (translucent) printing inks. The version of the theory that is considered in this study is that designed for translucent printing inks where the values of *K* and *S* must each be determined absolutely[11]. Using this model, the K_i and S_i contributions for each colorant *i* are assumed to be additive for mixture *j* thus

$$K_j = \Sigma_i \, c_{ij} \, K_i \text{ and} \quad (1)$$
$$S_j = \Sigma_i \, c_{ij} \, S_i$$

[*] For correspondence contact s.westland@derby.ac.uk

where K_j and S_j are the K and S values for mixture j, c_{ij} is the concentration of colorant i in mixture j, and K_i and S_i are the K and S coefficients for colorant j. Of course, equation 1 is repeated for each wavelength interval so that K_j, S_j, K_i, and S_i are all functions of wavelength. The values of K_i and S_i need to be computed from measurements of the reflectance of the mixture. Many methods are available to determine the values of K_i and S_i but the method used in this study involves computing K_i and S_i from two measurements of each mixture; a measurement of the ink printed over white and a measurement of the ink printed over black. Once the values of K_i and S_i are known at each wavelength and for each colorant i, equation 1 can be used to predict the K and S values of any mixture defined by a concentration vector **c** and the reflectance R_j of the mixture can then be easily computed.

1.2 The Neural Network model

The K-M theory allows a mapping between a colorant vector **c** and a reflectance vector **r** that defines the colour-prediction problem. A class of ANNs known as multi-layer perceptrons (MLPs) have been shown to be capable of approximating any continuous function to any degree of accuracy[12]. An MLP is a layered structure of simple processing units. The units in the first or input layer take their input from a real-world vector and the output of the units in the last or output layer provide the output of the network. There may be one or more hidden layers of units between the input and output layer. Most MLPs are fully connected; that is, each unit provides a weighted input to each unit in the next layer. Each unit in the network is also associated with a transfer function that maps the input of the unit to its output and many different transfer functions are available. Information is thus processed from the input layer to the output layer in order to perform a mapping from an input vector **i** to an output vector **o**. MLPs can learn to perform an arbitrary mapping if they are presented with sufficient examples of the mapping problem **i** → **o**. Learning, in an MLP, is a process of optimisation (during which changes are made to the weights in the network) to minimise the RMS error between the desired output vector $\mathbf{o}_t$ and the actual vector $\mathbf{o}_a$. MLPs thus require a training set of input-output pairs. Once suitably trained, however, the network can perform the mapping **i** → **o** for input vectors **i** that were not used during the training of the network – this important property is known as generalisation. The Kolmogorov theorem[12] states that a single hidden layer of units is sufficient to solve any problem. Thus, a three-layer network can learn the colour-prediction problem **c** → **r**. However, although the dimensionality of the input and output layers is determined by the problem (specifically by the length of the vectors **c** and **r**) the number of hidden units that are required to solve any given problem can only be determined empirically. Further, the choice of transfer function, learning rule (for changing the weights), and the number of training examples required must all be determined empirically.

2. METHODOLOGY

2.1 Printing ink set

Experiments were conducted using a set of lithographic printing inks printed onto leneta opacity charts. A set of six components (clear resin, white, black, cyan, magenta and yellow) were used and 108 unique recipes were prepared and printed over white and black portions of the opacity charts. The spectral reflectance values for each sample were measured (over white and over black) using a commercial reflectance spectrophotometer at 10 *nm* intervals in the range 400-700 *nm*. An additional set of reductions with the clear resin were additionally produced to calibrate the K-M model.

2.2 Characterisation of Kubelka-Munk model

For each colorant in the set a number of pairs (over white and over black) of reflectance measurements were used to determine K and S at each wavelength for a range of colorant concentrations. Saunderson correction values (internal 0.60, external 0.04) were applied to all measured reflectance values before use in computations. The reflectance (over white substrate only) of each of 33 of the known mixtures was predicted and compared with the known reflectance for that mixture. Prediction performance was quantified using computations of CIELAB ΔE between the known and predicted spectra using illuminant D65.

2.3 Training of Neural-Network model

The neural networks were used to approximate a function between a colorant vector **c** describing six components (pigments) and a reflectance vector **r** containing 31 reflectance values (400-700 *nm*). Therefore the topology of the MLPs chosen for the colour prediction problem require 6 input units, each corresponding to the concentrations of one of the six printing inks used in the mixture. The output layer requires 31 units, each corresponding to reflectance at 400 *nm*, 410 *nm*, 430 *nm* .... 700 *nm*. A training set of 75 mixtures was used to train the neural networks and the performance of the networks was tested on a set of 33 test mixtures. Prediction performance was quantified both using standard measures of root-mean square RMS error and computations of CIELAB ΔE between the known and predicted spectra using illuminant D65.

Networks were trained using the back-propagation algorithm with momentum. The algorithm (implemented by the training function *traingdm* in Matlab) requires two parameters: the learning rate and momentum term. The momentum term was fixed at 0.9 and the learning rate was fixed at 0.2. Networks were trained using 5, 10, 15, and 20 units in the hidden layer each for a total of 500,000 epochs. One epoch is a term used to describe the case where the samples in the training set are each presented to the network, the errors at the output layer computed, and small changes made to the weights in the network according to the back-propagation algorithm. Each network was trained six times starting each time with a randomly chosen set of weights. We chose the Tan-Sigmoid transfer function for units in the hidden layer and the Log-Sigmoid function for units in the output layer.

The network reached the best performance with 10 units in the hidden layer. A modified version of the algorithm was then used whereby the learning rate linearly reduced during training from 0.2 to 0.05 (algorithm implemented by the training function *traingdx*). This network was trained four times each from different random starting weights.

3. RESULTS

The neural network was trained six times for each condition and the average RMS errors are shown in Figure 1 (for the training set) and Figure 2 (for the test set) each for different numbers of units in the hidden layer. As expected the error for the training set decreased with increasing numbers of units in the hidden layer. However, the ability of the network to generalise can only be tested by a separate data set that was not used during training. Thus, Figure 2 shows that when the number of hidden units exceeds 10, the error on the test set begins to increase. This is evidence of over-training and indicates that the networks is starting to learn the noise in the training set rather than the relationship between colorant concentration and reflectance.

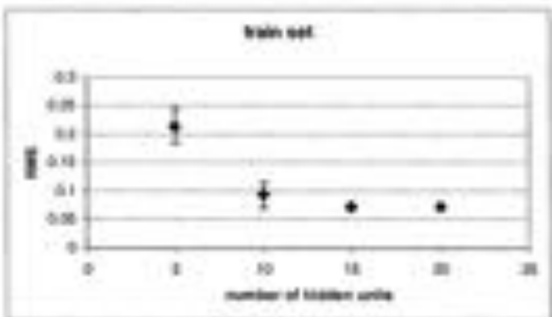


Figure 1: RMS error for training set

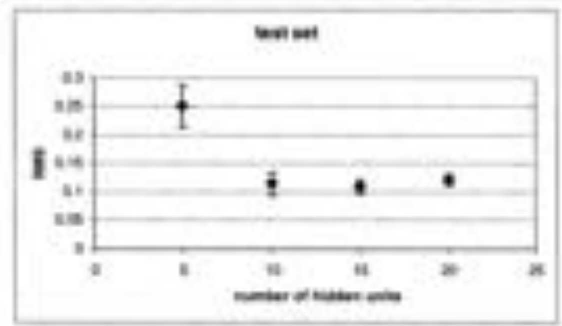


Figure 2: RMS error for test set

The data shown in Figures 1 and 2 suggest that 10 hidden units are appropriate for this particular problem and that RMS errors of about 0.1 can be achieved on the test set. However, there are other parameters such as the choice of activation function, the training algorithm, and the learning rate that will affect performance. Consequently, a network was trained with 10 hidden units using an algorithm that allows the learning rate to be reduced during training. Results are shown for four trials (each starting from different random values for the weights) of this network in Table 1.

Table 1 shows that the use of a learning rate that reduces during training produces an average RMS error of 0.05. Nevertheless, if the performance of the networks is recast in terms of a CIELAB ΔE value then the average ΔE between actual and predicted reflectance for the test set is 8.23 units which is much greater than the value of 2.9 that can be obtained using the K-M model.

Trial	training set	test error
1	0.0373	0.0665
2	0.0262	0.0743
3	0.0358	0.0455
4	0.0281	0.0304
mean	**0.0319**	**0.0542**
stdev	0.0048	0.0173

Table 1: RMS errors for networks trained using varying learning rates during training.

4. DISCUSSION

The results presented show that although in principle ANNs can learn to map between colorant concentrations and spectral reflectance, in practice the optimisation of the various parameters of the network is difficult and consequently it is not easy for the ANN to out-perform the K-M model. We have demonstrated that the proper use of separate training and test sets is essential in order to correctly assess the generalisation performance of trained networks. Experiments are underway that utilise a hybrid model based upon an ANN but maintaining some key features of the K-M model. Initial results suggest that this model can outperform both ANN and K-M approaches. These experiments are still underway and data are not available at this time. Results from these experiments will, however, be included in our presentation at *AIC01*.

ACKNOWLEDGEMENTS

This work is supported by Colourware Ltd (www.colourware.co.uk).

REFERENCES

1. P. Kubelka, "New Contributions to the Optics of Intensely Light-Scattering Materials Part I", *JOSA*, **38** (5), pp. 448-451, 1948.
2. P. Kubelka, "New Contributions to the Optics of Intensely Light-Scattering Materials Part II: Nonhomogeneous Layers", *JOSA*, **44** (4), pp. 330-335, 1954.
3. E. Allen, "Prediction of Optical Properties of Paints from Theory", *Journal of Paint Technology*, **45** (584), pp. 65-72, 1973.
4. J.H. Nobbs, "Kubelka-Munk theory and the prediction of reflectance", *Review of Progress in Coloration* (SDC), **15**, pp. 66-75, 1985.
5. J.M. Bishop, M.J. Bushnell and S. Westland, "Application of neural networks to computer recipe prediction", *CRA*, **16** (1), 3-9, 1991.
6. S. Westland, J.M. Bishop, M.J. Bushnell and A.L. Usher, "An intelligent approach to colour recipe prediction", *JSDC*, **107**, pp. 235-237, 1991.
7. T. Tokunanga and Y. Honda, "CCM system utilising a neural network", *Kako Gijutsu* (Dyeing & Finishing Technology), **26** (8), pp. 553-557, 1991.
8. H.R. Kang and P.G. Anderson, "Neural network applications to the colour scanner and printer calibrations", Journal of *Electronic Imaging*, **1** (1), pp. 125-134, 1992.
9. S. Tominaga, "Color notation conversion by neural networks", *CRA*, **18** (4), pp. 253-259, 1993.
10. H.C. Van de Hulst, "Multiple Light Scattering: Tables, Formulas, and Applications", Academic Press (NY), 1980.
11. J.H. Nobbs, "Colour-match prediction for pigmented materials", in *Colour Physics for Industry*, R McDonald (ed.), Society of Dyers and Colourists, 1997.
12. K. Funahashi, "On the approximate realization of continuous mappings by neural networks", *Neural Networks*, **2**, pp. 182-192, 1989.

A Reference Tristimulus Colorimeter

George P. Eppeldauer
Optical Technology Division
National Institute of Standards and Technology
Gaithersburg, MD 20899-8441

ABSTRACT

A reference tristimulus colorimeter has been developed at NIST with a transmission-type silicon trap detector (1) and four temperature-controlled filter packages to realize the Commission Internationale de l'Eclairage (CIE) $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, and $\bar{z}(\lambda)$ color matching functions (2). Instead of lamp standards, high accuracy detector standards are used for the colorimeter calibration. A detector-based calibration procedure is being suggested for tristimulus colorimeters where the absolute spectral responsivity of the tristimulus channels is determined. Then, color (spectral) correction and peak (amplitude) normalization are applied to minimize uncertainties caused by the imperfect realizations of the CIE functions. As a result of the corrections, the chromaticity coordinates of stable light sources with different spectral power distributions can be measured with uncertainties less than 0.0005 (k=1).

Keywords: Color measurement, tristimulus colorimeters, spectral response, chromaticity coordinates, calibration

1. Introduction

Tristimulus colorimetry is based on light measurement using three or more channels with spectral responsivities matched to the Commission Internationale de l'Eclairage (CIE) $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, and $\bar{z}(\lambda)$ color matching functions (2). The channels are realized with silicon photodiodes and attached filter packages. Usually, the spectral mismatch between the realized and the CIE functions give the dominant uncertainties in tristimulus measurements.

Up until now, tristimulus colorimeters were calibrated with standard lamps. The accuracy of the standard lamp influences the photometric accuracy of the tristimulus colorimeter. The wavelength dependent (e.g. burning time caused) changes of the standard lamp influence the colorimetric accuracy of tristimulus colorimeters.

In contrast to source standards, cryogenic radiometers can measure radiant power with an uncertainty of 10^{-4} (3). Silicon detectors, in a light-trap arrangement, can be calibrated against primary standard radiometers with a spectral responsivity uncertainty of 0.03 % between 406 nm and 920 nm (4). Achievable total uncertainty of spectral transmittance measurements on high quality color filters is reported to be 2 x 10^{-4} (5).

If the uncertainties of the channel response measurements are very small, the spatial response non-uniformities of the filter-detector packages can limit the accuracy of the color measurements. This problem can be avoided if apertures are used in front of the filter-detector packages and the apertures are overfilled with the uniform field of a (point) source to be measured. Aperture areas were measured with an uncertainty of 0.026 % (6).

In the procedure described here, broad-band calibration factors for all tristimulus channels can be worked out to minimize measurement uncertainty. If the spectral responsivity determination of the channels is accurate, application of the calibration factors for different source distributions will result in high colorimetric accuracy.

2. Theoretical Basis

In order to determine x, y chromaticity coordinates of a light source, the CIE tristimulus values of the source are to be obtained by

$$X = k\int_\lambda S(\lambda)\,\bar{x}(\lambda)\,d\lambda$$
$$Y = k\int_\lambda S(\lambda)\,\bar{y}(\lambda)\,d\lambda \qquad (1)$$
$$Z = k\int_\lambda S(\lambda)\,\bar{z}(\lambda)\,d\lambda \quad ,$$

where $S(\lambda)$ is the spectral power distribution of the source to be measured; $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, and $\bar{z}(\lambda)$ are the 1931 CIE color-matching functions; and k is a normalization factor. In practice, $\bar{x}(\lambda)$ is realized by two receivers, $\bar{x}_L(\lambda)$ and $\bar{x}_S(\lambda)$:

$\bar{x}_S(\lambda) = 0$ and $\bar{x}_L(\lambda) = \bar{x}(\lambda)$ if the wavelength is longer than 504 nm, and
$\bar{x}_L(\lambda) = 0$ and $\bar{x}_S(\lambda) = \bar{x}(\lambda)$ if the wavelength is shorter than 504 nm.
(Note that the subscripts L and S mean long and short, respectively.)

The CIE tristimulus value X can be written as:

$$X = X_1 + X_2, \qquad (2)$$

where $X_1 = k\int_\lambda S(\lambda)\,\bar{x}_L(\lambda)\,d\lambda$, and
$X_2 = k\int_\lambda S(\lambda)\,\bar{x}_S(\lambda)\,d\lambda$.

Y in Eq. (1) will give an absolute photometric quantity (e.g. in lux) (8) if

$$k = K_m = 683 \text{ lm/W}. \qquad (3)$$

The measured photodiode output currents of the four separate color measuring channels are

$$I_{X1} = \int_\lambda S(\lambda)\,s_{XL}(\lambda)\,d\lambda$$
$$I_{X2} = \int_\lambda S(\lambda)\,s_{XS}(\lambda)\,d\lambda$$
$$I_Y = \int_\lambda S(\lambda)\,s_Y(\lambda)\,d\lambda \qquad (4)$$
$$I_Z = \int_\lambda S(\lambda)\,s_Z(\lambda)\,d\lambda$$

where $s_{XL}(\lambda)$, $s_{XS}(\lambda)$, $s_Y(\lambda)$, and $s_Z(\lambda)$ are the absolute spectral responsivities of the channels.

When measuring a light source of known spectral power distribution $S(\lambda)$, the channel calibration factors can be determined from the ratio of Eq. (1) to Eq. (4):

$$k_{X1} = \frac{X_1}{I_{X1}} = \frac{K_m\int_\lambda S(\lambda)\,\bar{x}_L(\lambda)\,d\lambda}{\int_\lambda S(\lambda)\,s_{XL}(\lambda)\,d\lambda} = \frac{1.06291\,K_m\,F_{X1}}{s_{XL}(599)}$$

$$k_{X2} = \frac{X_2}{I_{X2}} = \frac{K_m\int_\lambda S(\lambda)\,\bar{x}_S(\lambda)\,d\lambda}{\int_\lambda S(\lambda)\,s_{XS}(\lambda)\,d\lambda} = \frac{0.3501\,K_m\,F_{X2}}{s_{XS}(442)}$$

$$k_Y = \frac{Y}{I_Y} = \frac{K_m\int_\lambda S(\lambda)\,\bar{y}(\lambda)\,d\lambda}{\int_\lambda S(\lambda)\,s_Y(\lambda)\,d\lambda} = \frac{K_m\,F_Y}{s_Y(555)} \qquad (5)$$

$$k_Z = \frac{Z}{I_Z} = \frac{K_m\int_\lambda S(\lambda)\,\bar{z}(\lambda)\,d\lambda}{\int_\lambda S(\lambda)\,s_Z(\lambda)\,d\lambda} = \frac{1.78297\,K_m\,F_Z}{s_Z(446)}.$$

The right side of the equations was obtained after normalizing the color matching functions to their peak values and introducing the color correction factors:

$$F_{X1} = \frac{\int_\lambda S(\lambda)\ \bar{x}_{1,n}(\lambda)\ \mathrm{d}\lambda}{\int_\lambda S(\lambda)\ s_{X1,n}(\lambda)\ \mathrm{d}\lambda}$$

$$F_{X2} = \frac{\int_\lambda S(\lambda)\ \bar{x}_{2,n}(\lambda)\ \mathrm{d}\lambda}{\int_\lambda S(\lambda)\ s_{X2,n}(\lambda)\ \mathrm{d}\lambda}$$

$$F_Y = \frac{\int_\lambda S(\lambda)\ V(\lambda)\ \mathrm{d}\lambda}{\int_\lambda S(\lambda)\ s_{Y,n}(\lambda)\ \mathrm{d}\lambda} \qquad (6)$$

$$F_Z = \frac{\int_\lambda S(\lambda)\ \bar{z}_n(\lambda)\ \mathrm{d}\lambda}{\int_\lambda S(\lambda)\ s_{Z,n}(\lambda)\ \mathrm{d}\lambda},$$

where $s_{X1}(599)$, $s_{X2}(442)$, $s_Y(555)$, and $s_Z(446)$ are the absolute responsivities of the realized channels at the peak wavelengths of the color matching functions; and $s_{X1,n}(\lambda)$, $s_{X2,n}(\lambda)$, $s_{Y,n}(\lambda)$, and $s_{Z,n}(\lambda)$ are the relative responses of the realized channels normalized also at the peak wavelengths of the color matching functions. The peak wavelengths of the realized channels are not necessarily equal to the peak wavelengths of the color matching functions. A color correction factor will be unity if the normalized channel-response and CIE-function are equal.

Once the tristimulus colorimeter is calibrated for k_{X1}, k_{X2}, k_Y, and k_Z, the tristimulus values of a test light source can be measured as

$$X' = X_1' + X_2' \qquad \text{where } X_1' = k_{X1} I_{X1}' \text{ and } X_2' = k_{X2} I_{X2}'$$
$$Y' = k_Y I_Y' \qquad (7)$$
$$Z' = k_Z I_Z'$$

where I_{X1}', I_{X2}', I_Y', and I_Z' are the measured output currents of the tristimulus channels.

The calibration procedure can be applied to various measurement geometries (e.g., illuminance, luminance, luminous flux, or luminous intensity) depending on the units in which $s_{X1}(599)$, $s_{X2}(442)$, $s_Y(555)$, and $s_Z(446)$ are expressed. Also, existing tristimulus colorimeters can be calibrated with the described method, where the spectral responsivity of the channels can be measured.

3. Calibration and accuracy

The reference tristimulus colorimeter with the common aperture at the front, is substituted for an irradiance-type transfer standard silicon trap detector when both measure the same spectral irradiance. This spectral irradiance responsivity calibration is being done at the NIST Spectral Irradiance and Radiance Response Calibrations with Uniform Sources (SIRCUS) Facility where an integrating sphere is illuminated by tunable lasers (7).

Another way for spectral responsivity determination of the tristimulus channels is to separately measure the spectral transmittance of the filter packages and the spectral power responsivity of the trap-detector of the colorimeter. This power responsivity determination also works well because the tunnel-trap detector does not reflect light back to the filters. Also, expensive tunable-laser sources (such as the SIRCUS Facility) are not needed for this spectral power responsivity determination. The spectral irradiance responsivity of the channels will be equal to the product of the aperture area and the spectral power responsivities.

The reference tristimulus colorimeter will be calibrated in luminance measurement mode as well. In this case, an input tube with a second (front) aperture produces a 5.7° radiance measurement (full) angle and the measured (target) spot will be within the exit port of the integrating sphere source of the SIRCUS Facility. The exit port radiance is determined against an irradiance-type transfer standard Si trap detector.

In order to obtain the highest color measurement accuracy, the channel calibration factors are to be redetermined for all $S(\lambda)$ source distributions to be measured. The spectral mismatch of the channels, relative to the CIE functions, should be small to allow for relatively large uncertainties when determining $S(\lambda)$ (8). The final $S(\lambda)$ for tungsten lamps, which are more or less similar to Planckian radiators, can be obtained by iterating the Planckian function (at different temperatures) and the tristimulus measurements, until the highest color measurement accuracy is reached. For other types of sources with smoothly varying spectral power distribution (e.g. many kinds of paints, color tiles, etc.), $S(\lambda)$ can be measured with a low accuracy spectroradiometer, and the color measurement accuracy still remains high.

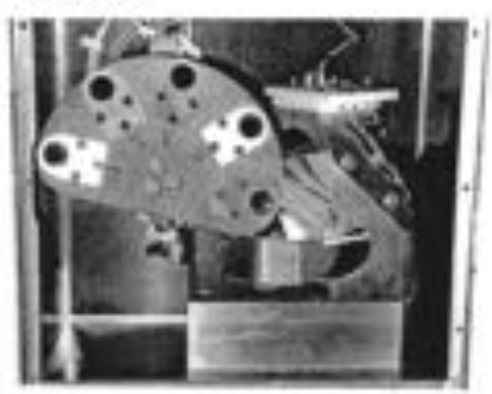
The uncertainties of the tristimulus values propagate to the uncertainties of the chromaticity coordinates. The chromaticity coordinates can be calculated from the tristimulus values via

$$x = \frac{X}{X+Y+Z}, \qquad y = \frac{Y}{X+Y+Z}. \tag{8}$$

Now, assume that the relative uncertainties of X, Y, and Z are all 0.05 %. For a Standard Illuminant A, where x=0.4476 and y=0.4074, the worst case scenario (ΔX=+0.05 %, ΔY=-0.05 %, and ΔZ=0 %) shows a chromaticity coordinate change of ±0.0002 for both x and y, resulting in a ±5 K change in the correlated color temperature. These expanded uncertainties are similar to those reported for the source-based NIST color temperature scale (9).

REFERENCES

1. G. P. Eppeldauer and D. C. Lynch, "Opto-mechanical and electronic design of a tunnel-trap Si-radiometer", J. Res. Natl. Inst. Stand. Technol. Vol. 105, No. 6, p. 813-828, 2000.
2. Publication CIE No 15.2 (1986). CIE Central Bureau, A-1033 Vienna, P.O.Box 169, Austria.
3. J. E. Martin, N. P. Fox, and P. J. Key, Metrologia, **21**, 147-55 (1985).
4. T. R. Gentile, J. M. Houston, and C. L. Cromer, Realization of a scale of absolute spectral response using the NIST high accuracy cryogenic radiometer, Appl. Opt. **35**, 4392-4403 (1996).
5. K. L. Eckerle, J. J. Hsia, K. D. Mielenz, and V. R. Weidner, NBS Special Publication 250-6, Regular Spectral Transmittance, p. 34 (1987).
6. E. Ikonen and P. Toivanen, A new optical method for high-accuracy determination of aperture area. Preprint.
7. K. R. Lykke, P. S. Shaw, L. M. Hanssen, and G. P. Eppeldauer, "Development of a Monochromatic Uniform Source Facility for Calibration of Radiance and Irradiance Detectors from 0.2 µm to 12 µm", Metrologia, Vol. 36, p. 141-146, 1999.
8. C. L. Cromer, G. Eppeldauer, J. E. Hardis, T. C. Larason, Y. Ohno, and A. C. Parr, The NIST Detector-Based Luminous Intensity Scale, J. Res. Natl. Inst. Stand. Technol. **101**, 109-132 (1996).
9. Y. Ohno, Photometric Calibrations, NIST Special Publication 250-37, 1997.



The xyz filtered tunnel-trap detector with radiance measuring tube (left) and without front-cover.

Broad-band color filters with arbitrary spectral transmittance using a Liquid Crystal Tunable Filter (LCTF)

Kanae Miyazawa*[a], Kazuhiko Kurashiki[b], Markku Hauta-Kasari[a] and Satoru Toyooka**[b]

[a] Department of Computer Science, University of Joensuu,
P.O.Box 111, FIN-80101 Joensuu, FINLAND
[b] Graduate School of Science and Engineering, Saitama University,
255, Shimo-okubo, Urawa, Saitama 338-8570 JAPAN

ABSTRACT

We propose an experimental setup for an imaging system using a liquid crystal tunable filter (LCTF) to implement rewritable transparent broad-band color filters with arbitrary spectral transmittances. Holding-time for each transmitting wavelength of the LCTF is controlled corresponding to a computationally designed filter function, and a time-integrated intensity image is taken with a monochrome CCD camera through the LCTF. The averaged norm error between the implemented and the expected filter functions was about 10%. The system can be applied to spectral estimation, spectral based classification and spectral based parameter estimation.

Keywords: spectral imaging system, broad-band color filter, liquid crystal tunable filter (LCTF).

1. INTRODUCTION

Spectral image analysis has recently progressed rapidly, and is now used for environmental sensing,[1] machine vision,[2] telemedicine,[3] agrobiology,[4] art painting reproduction,[5-7] and so on. Spectral images can be obtained, for example, with a CCD camera through narrow-band interference filters.[8] In this method, multispectral image is measured precisely for each wavelength range. Many images, however, have to be taken depending on spectral resolution, and copious image data have to be processed to extract characteristic features.

Most of the multispectral image analysis is finally used to distinguish objects under pertinent rules or criteria. It is not always required to know row data of spectral distribution of the objects. In many cases, statistical characteristics of the objective spectral database can be known experientially in advance. If we construct a subspace that reflects spectral features of the objects, and if basis vectors of the subspace can be implemented by a set of filters, images of an object through the filters will give us important information that is enough to distinguish different classes of objects.

In this paper, we propose an experimental setup for an imaging system using a liquid crystal tunable filter (LCTF) to implement transparent broad-band color filters with arbitrary spectral transmittances. The system realizes to take intensity images of objects through color filters whose spectral transmittance corresponds to designed filter functions such as basis vectors of subspace. The filter function can be arbitrarily changed. The experimental results of the filter implementation are presented and they are compared with the expected ones.

2. EXPERIMENTAL SETUP

An experimental setup for a proposed imaging system using the LCTF (CRI, VariSpec™ VIS3) is shown in Fig.1. An intensity image of an object illuminated by a white light source is taken with a monochrome CCD camera (SONY XC-73, 768×494 pixels) through the LCTF. The LCTF, which is a Lyot filter consists of fixed retarders and liquid-crystal tunable retarders, is attached just in front of the lens aperture of the camera. The transmittances of the LCTF measured for every 10-nm interval are shown in Fig. 2. Each curve has Gaussian shape with half width of 5 to 10nm, and peak values are not uniform. The central wavelength of transmitting light of the LCTF can be randomly selected by a computer.

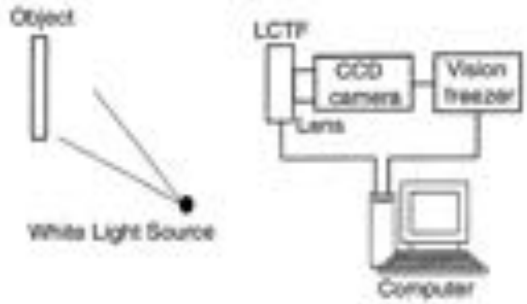


Figure 1. Experimental setup using the LCTF

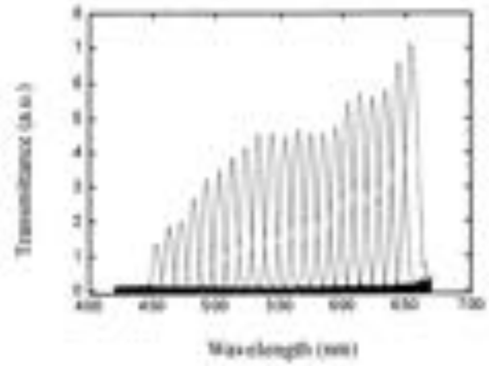


Figure 2. Transmittance of the LCTF

In order to implement broad-band filters with arbitrary spectral transmittance, we controlled holding-time for each narrow-band corresponding to a computationally designed filter function, and a time-integrated intensity image was taken with the camera. Test filter functions used in this experiment are shown in Fig. 3. In our previous study, the filter functions designed over the unsupervised neural network for the database of 1269 Munsell spectra were used for spectral estimation of natural objects[9,10] and spectral based classification.[11] The filter set in Fig. 3 is the same as that we used in Refs. 9-11. Holding-times for each narrow-band of the LCTF are shown in Fig. 4. They are inversely proportional to the integral values of transmittance curves shown in Fig. 2.

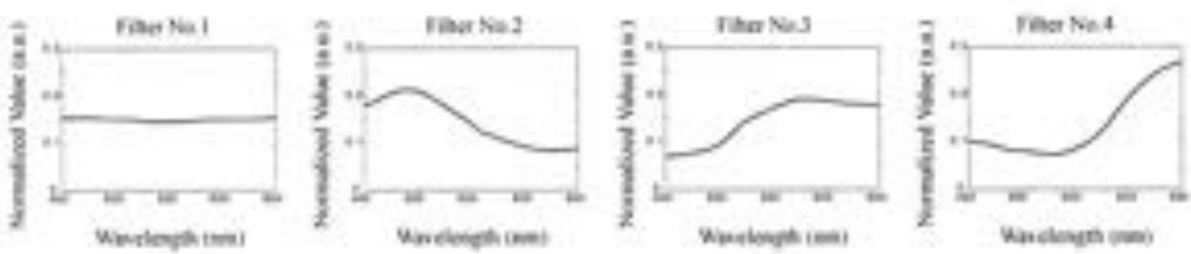


Figure 3. Test filter functions designed over the unsupervised neural network

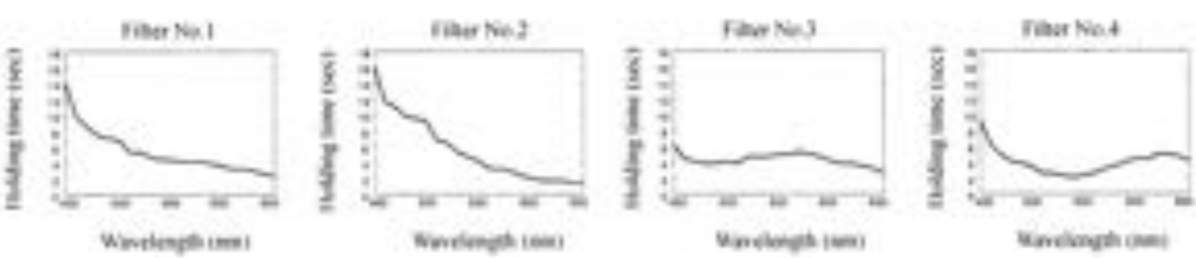


Figure 4. Holding-times for each narrow-band of the LCTF

The procedure for taking an intensity image through a broad-band filter is as follows: Here we use one filter function that is Filter No.1 in Fig.4 as an example. At first, the central wavelength of transmitting light of the LCTF was set to 450nm, and the shutter of the camera was opened for 14 seconds. Then the LCTF was set to 460nm and the shutter was opened for 10 seconds. The similar procedure was repeated until 650nm, then the shutter was closed, and one intensity image was obtained. In this experiment, total exposure time for one filter was 120 seconds.

3. EXPERIMENTAL RESULTS

We did experiments to implement broad-band color filters. A standard white board was placed on the object plane and it was illuminated by a halogen lamp. The purpose of this experiment was just to compare the measured spectra with expected filter functions. At first we measured spectral intensity of the lamp. 21 intensity images of the standard white board were taken through the narrow-band LCTF filters ranging 450 to 650 nm at 10-nm intervals. The spectral intensity was determined by averaging the intensity inside the window of 10×10 pixels. Figure 5 shows the spectral intensity of the white light source through the standard white board.

To know the spectral intensity of the light that passes through the proposed system, the optically implemented 21-component color filter functions were constructed by averaging the intensity inside the window of 10×10 pixels in each of the 21 intensity images.

Figure 6 shows the experimental results. Solid lines are the normalized spectral intensities of the light through the implemented filters. Dotted lines are the normalized expected filter functions that are the products between the four color filter functions in Fig. 3 and the spectral intensity of the white light source in Fig. 5. Implemented spectral intensities almost coincided with those expected.

To evaluate the accuracy of this system, we calculated norm errors defined in the following equation:

$$\text{norm error (\%)} = \| P(\lambda) - O(\lambda) \| \times 100$$
$$= \sqrt{(P(450) - O(450))^2 + (P(460) - O(460))^2 + \ldots\ldots + (P(650) - O(650))^2} \times 100, \quad (1)$$

where $P(\lambda)$ is the normalized expected filter function and $O(\lambda)$ is the normalized spectral intensity of the light through the implemented filters depending on the wavelength λ. Calculated results are shown in Table 1. Averaged norm error was about 10%. The results show that the proposed filter system works well. The accuracy of this system was comparable to that of the systems proposed in Refs. 9, 10.

Table 1. Norm errors over four samples for the normalized expected filters and the normalized spectral intensities of the light through the implemented filters

Filter number	Norm error (%)
1	6.39
2	9.28
3	10.26
4	13.62
Average	9.89

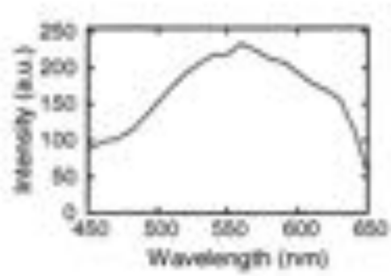


Figure 5. The spectral intensity of the white light source

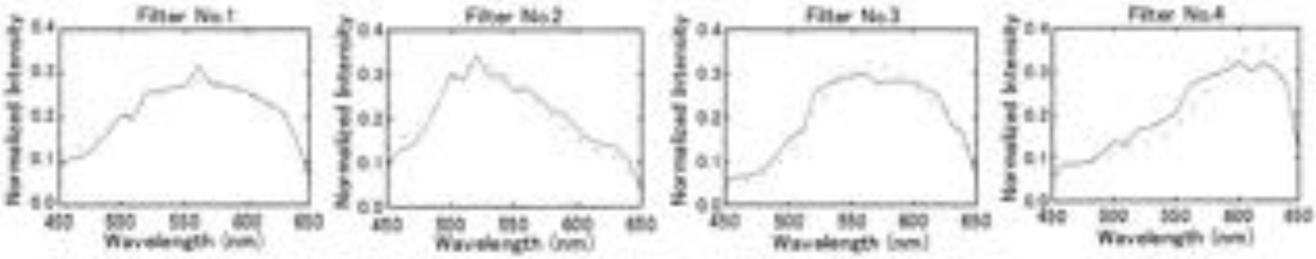


Figure 6. Experimental results. Solid lines: the normalized spectral intensities of the light through the optically implemented filters. Dotted lines: the normalized expected filter functions that are the products between the four color filter functions and the spectral intensity of the white light source.

4. CONCLUSIONS

We presented an optical imaging system to implement rewritable broad-band color filters with an arbitrary spectral transmittance using the LCTF. To realize broad-band filters, we controlled holding-time for each narrow-band of the LCTF, and a time-integrated intensity image was taken with the camera. The optically implemented color filters almost coincide with the expected ones in the average error less than 10%. This system can be applied to spectral estimation, spectral based classification, spectral based parameter estimation,[12] and so on.

ACKNOWLEDGMENTS

Kanae Miyazawa was supported by travel allowance from the Academy of Finland. The Munsell spectral database is available at the www server of the University of Joensuu, Finland, http://cs.joensuu.fi/~spectral/.

REFERENCES

1. B. N. Rock, J. E. Vogelmann, D. L. Williams, A. F. Vogelmann and T. Hoshizaki: BioScience **36** (1986) 439.
2. T. Hyvarinen, E. Herrala and A. Dall'Ava: Proc. SPIE **3302-21** (1998) 165.
3. M. Yamaguchi, R. Iwama, Y. Ohya, T. Obi, N. Ohyama and Y. Komiya: Proc. SPIE **3031** (1997) 482.
4. M. Takeya, N. Tsumura, H. Haneishi and Y. Miyake: Appl. Opt. **38** (1999) 3644.
5. S. Baronti, A. Casini, F. Lotti and S. Porcinai: Appl. Opt. **37** (1998) 1299.
6. N. Tsumura, H. Sato, T. Hasegawa, H. Haneishi and Y. Miyake: Opt. Rev. **1** (1999) 57.
7. H. Maître, F. Schmitt, J.-P. Crettez, Y. Wu and J. Y. Hardeberg: *Proc. of the 4th Color Imaging Conference: Color Science, Systems and Applications* (1996) p.50.
8. S. Kawata, K. Sasaki and S. Minami: J. Opt. Soc. Am. A **4** (1987) 2101.
9. M. Hauta-Kasari, K. Miyazawa, S. Toyooka and J. Parkkinen: J. Opt. Soc. Am. A **16** (1999) 2352.
10. K. Miyazawa, M. Hauta-Kasari and S. Toyooka: Opt. Rev. **8** (2001) 112.
11. M. Hauta-Kasari, K. Miyazawa, S. Toyooka, J. Lehtonen, J. Parkkinen and T. Jaaskelainen: in Proceedings, Color Forum Japan (2000) p59.
12. S. Toyooka, N. Hayasaka, M. Kataguchi and F. Kobayashi: Opt. Rev. **4** (1998) 207.

Correspondence: * kanae@cs.joensuu.fi, ** toyooka@mech.saitama-u.ac.jp

Colorimetric characterization of pearlescent coatings

Maria E. Nadal* and Thomas A. Germer†
National Institute of Standards and Technology
100 Bureau Dr., Stop 8441
Gaithersburg, MD 20899-8441

ABSTRACT

This paper describes recent developments at the National Institution of Standards and Technology in the colorimetric characterization of pearlescent coatings. The goal of this research is to develop a measurement protocol for the accurate color characterization of these coatings using an understanding of their scattering mechanism as a guide. The bi-directional reflectance of a series of samples has been measured for the visible region at incident angle of 15°, 25°, 45°, 65°, and 75° and viewing angles of ±80° at 5° steps. This large ensemble of measurements show general trends in the color variations with incident and viewing angles that are being used to define a preliminary subset of measuring geometries that will provide sufficient information to characterize the angle dependent color travel in pearlescent coatings.

Keywords: *Color; Gonioapparent coatings; Pearlescent coatings; Reflectance colorimetry*

1. INTRODUCTION

Appearance greatly influences a customer's judgement of the quality and acceptability of manufactured products. For example, appearance is reported to be a major factor in about half of automobile purchases.[1] The Optical Technology Division at the National Institute of Standards and Technology (NIST) has established a program for the characterization of the appearance of objects. We are presently working in several areas of reflectance colorimetry including establishing a national calibration facility to provide color standards and developing standard measurement protocols to characterize the color of gonioapparent materials such as pearlescent coatings. These coatings exhibit differences in their perceived color with changes in the illumination and viewing angle and are very important to the generation of many new and unique effects used in the printing of currency, formulation of cosmetics, and application of paint for automobiles.[2] The traditional single-geometry techniques are not capable of adequately characterizing the perceived color variations. We are conducting a series of experiments in order to determine the minimum set of illumination and viewing geometries needed to accurately characterize the color of these coatings utilizing the bi-directional spectral reflectance. An improved measurement protocol would make it possible to gain better control over raw materials, processes, and final product quality.

2. EXPERIMENTAL

2.1 Samples

A series of pearlescent samples supplied by several coatings manufacturers were chosen for the study described in this paper. Table 1 shows a comparison of the optical characteristics of conventional absorption and gonioapparent coatings. For all of these coatings, the front surface is a clear, smooth coat. The reflective properties of this overcoat are investigated at the specular geometry. The perceived color in absorption pigments is due to absorption and diffuse scattering and is independent of geometry. In contrast, the primary interaction of light with metal-flake pigments is specular reflection from the flakes, and the perceived brightness depends on the geometry. Pearlescent pigments usually consist of thin metal oxide layers on transparent mica platelets, and their perceived chroma, hue, and brightness depends on both the incident and viewing angles.

* Maria.nadal@nist.gov; phone 1-301-975-4632; fax 1-301-869-5700
† Thomas.germer@nist.gov; phone 1-301-975-2876; fax 1-301-840-8551

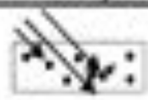
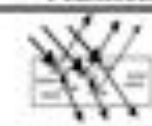
Type of pigment	Absorption	Metallic	Pearlescent
Optical principle of pigments (first order)	 Scattering	 Specular reflection	 Thin-film interference
Perceived chroma and hue	Independent of geometry	Independent on geometry	Dependent on geometry
Perceived brightness	Independent of geometry	Dependent of geometry	Dependent on geometry

Table 1. Optical Principles of absorption, metallic, and pearlescent pigments

2.2 Optical reflectance measurements

The in-plane bi-directional spectral reflectance for a series of pearlescent samples was measured using the NIST spectral tri-function automated reference reflectometer (STARR).[3,4] The incident radiant flux is a collimated, monochromatic, polarized beam with a diameter of 14 mm and bandwidth of 15 nm. Two rotation stages determine the incident angle of the beam on the sample and the viewing angle of the detector. Reflectance is calculated from the ratio of the reflected to the incident radiant fluxes. The incident flux is measured with the sample positioned out of the beam path and the receiver positioned to accept the incident beam. The reflected radiant flux is measured with the sample positioned in the beam path, with the sample and the detector positioned at the desired geometry. The geometry is denoted by θ_i / θ_r with respect to the normal of the sample so that, for example, the specular condition $\theta_i = 30°$, $\theta_r = -30°$ is represented by 30°/-30° and the aspecular angle is the viewing angle measured from the specular angle. The reflectance of the interference pigmented coatings were measured at wavelengths from 380 nm to 780 nm at increments of 10 nm for incident angles of 15°, 25°, 45°, 65°, and 75° and viewing angle from -80° to 80° in steps of 5°. For each geometric condition, colorimetric values such as Lightness (L), a, b, hue (h_{ab}), and chroma (C^*_{ab}) were calculated utilizing the CIELAB system, with the CIE D65 standard illuminant and the CIE 10° standard observer. The uncertainties were calculated according to the procedures outlined in Ref. 5. The type A uncertainty components, which are calculated by statistical methods, include source stability and detector noise. Type B sources of uncertainty were assumed to have a normal probability distribution and include uncertainties in the wavelength, incident and viewing angles, and stray light levels. The expanded uncertainty in the measured values was obtained from the root-sum-square of the uncertainty contributions multiplied by a coverage factor $k = 2$. The expanded relative uncertainty for the reflectance factors is 0.7% and for the colorimetric quantities is ~2%.

3. RESULTS AND DISCUSSION

Selected results of the spectral reflectance measurements for a sample consisting of a red-blue pearlescent coat applied to a bright red basecoat are shown in this section. The results for other samples at the same geometries show similar trends. The magnitude and spectral shape of the reflectances of pearlescent samples vary with both the incident and viewing angles. Therefore, the colorimetric quantities including L, a, b, h_{ab}, and C^*_{ab} exhibit a strong dependence on the measuring geometry. As described below, several steps were taken to determine a subset of geometries to uniquely characterize pearlescent coatings. A subset of incident angles was determined by investigating CIE ab angle dependent color travel diagrams, shown in Figure 2(a) – (c). The subset of viewing angles was determined by investigating the behaviors of L, h_{ab}, and C^*_{ab} as a function of aspecular angles as shown in Figures 3(a) – (c) and 4(a) – (c).

Figure 2(a) – (c) shows the CIE ab angle dependent color travel for a pearlescent sample at incident angles of 15°, 25°, 45°, 65°, 75° and viewing angles of -80° to 80° at 5° steps. The color travel observed here results from the different scattering mechanisms that are present in these samples. The directional reflected light from pearlescent coatings is composed of a specular component from the clear coat, a component from the pearlescent pigments, and a diffuse component.[6,7] The clear coat reflects light in a specular manner from the clear coat/air interface, and is relative colorless (a, b ~ 0). The specular component results in a measurement of the glossiness of the clear coat. Pearlescent pigments, which are aligned roughly parallel to the surface, reflect part of the light in a specular manner. The part that is not reflected is transmitted to the next layer, where further specular reflection occurs. This process results in a distribution of scattering angles near the specular geometry where the color of the pearlescent component is observed. For incident angles close to the normal of the sample (15° and 25°) shown in Fig. 2(a) and viewing angles close to the specular geometry, the blue pearlescent component is seen. Finally, the pigments in the base coat reflect light diffusely at all angles. The color in the base coat can be observed at all geometries but is dominant at geometries far away from the specular condition. As shown in Fig. 2(a) – (c), the diffuse component of the bright red basecoat component is accessed at grazing angles for the small incident angles and at large incident angles (65° and 75°). Figure 2(b) shows an intermediate incident angle of 45°; this geometry starts to show the interaction of both components resulting in a purple color and becoming more pronounced at near specular geometries for grazing angles as seen in Fig. 2(c). Since the measurements cluster in three different groups (pearlescent, basecoat, and the interaction of both components), we selected three angles, 15°, 45°, and 65°, as the minimum number of incident angles for the complete characterization of pearlescent coatings.

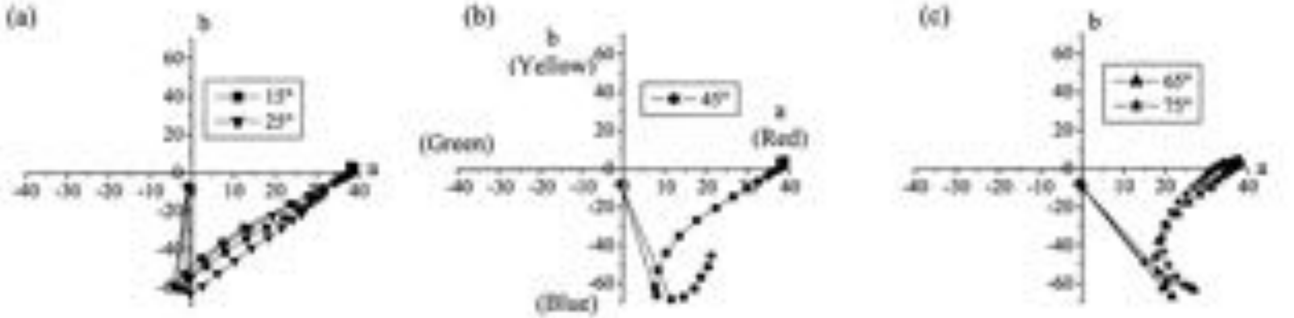


Figure 2. CIE ab angle dependent color travel for a red-blue pearl coat and bright red basecoat sample at the incident angles of (a) 15° and 25°, (b) 45°, and (c) 65° and 75° and viewing angles of -80° to 80° at 5° steps.

For selecting the viewing angles, we investigated the behaviors of L, h_{ab}, and C^*_{ab} as a function of aspecular angles, as shown in Fig. 3(a) – (c), respectively, at the three selected incident angles (15°, 45°, and 65°). Since the same trend is observed for all incident angles, we selected a fourth order polynomial model to fit the complete set of viewing angles for each incident angle and then, systematically reduced the number of viewing angles. Then, we compared the fitting of the polynomials for each subset of viewing angles to the original fit and selected a combination of viewing angles that will minimize the residual errors. Since the minimum number necessary to define a fourth order polynomial is five viewing angles, we found that the subset of 15°, 35°, 45°, 70°, and 85° aspecular angles for each incident angle is the minimum number of geometries that are needed for the colorimetric characterization of these pearlescent coatings. An example of the fitted subset of aspecular angles is presented in Fig. 4(a) – (c) for the incident angle of 15°. The residual errors represent the information not captured by the fits. In addition, these fittings will allows us to estimate colorimetric values at other geometries without the need for time consuming and expensive measurements at all geometries.

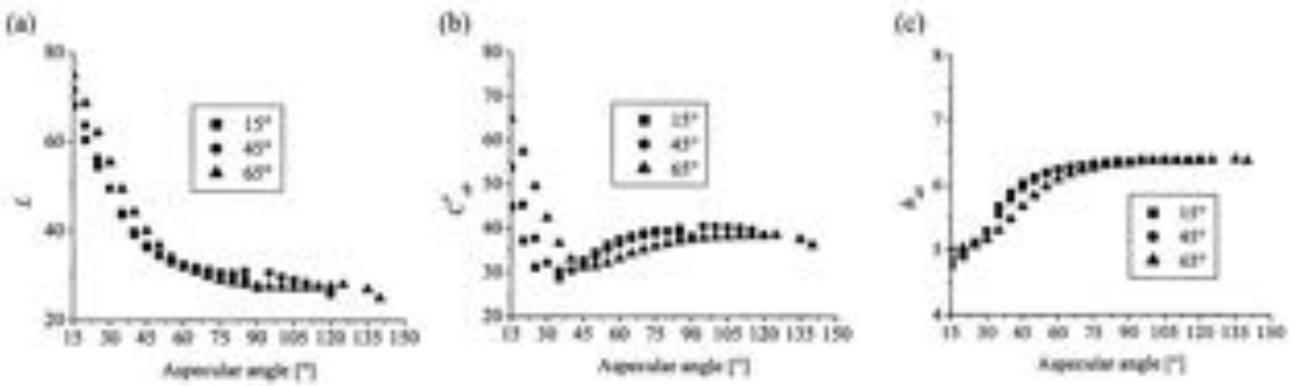


Figure 3. (a) L, (b) C^*_{ab}, and (c) h_{ab} as a function of aspecular angles for the incident angles of 15°, 45°, and 65° for a red-blue pearl coat and bright red basecoat sample.

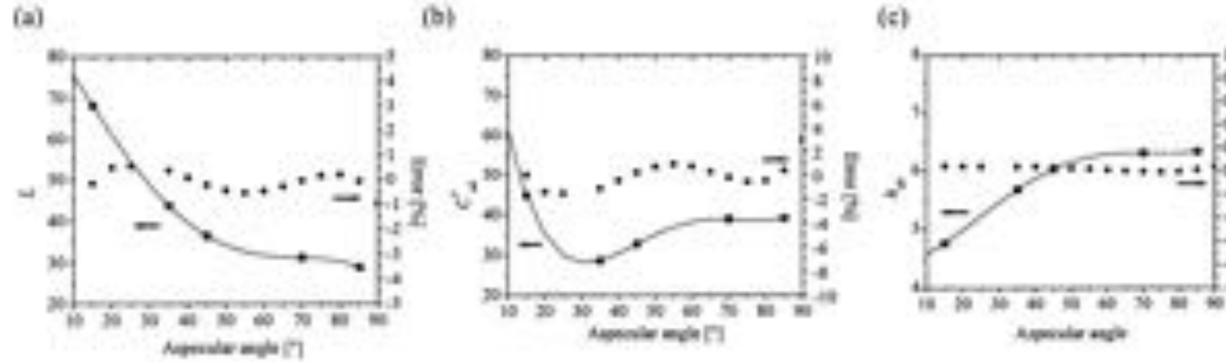


Figure 4. (a) L, (b) C^*_{ab} and (c) h_{ab} as a function of the selected subset of aspecular angles (15°, 35°, 45°, 70°, and 85°) for the incident angle of 15° for a red-blue pearl coat and bright red basecoat sample. The lines represent the fourth order polynomial fits. The percent error is the difference from the fittings of the complete set and the subset of aspecular angles.

3. SUMMARY AND FUTURE WORK

This paper describes recent efforts at NIST for the development of a measurement protocol for the colorimetric characterization of pearlescent coatings using an understanding of their scattering mechanisms as a guide. We demonstrated that measurement of the bi-directional spectral reflectance is a powerful technique for characterizing the scattering components and concluded that the directional reflected light from pearlescent coatings is composed of a specular component from the clear coat, a pearlescent component, a diffuse component, and the interaction of these mechanisms. From the systematic study presented here, we selected a preliminary subset of measuring geometries (incident angles: 15°, 45°, and 65° and aspecular angles: 15°, 35°, 45°, 70°, and 85°) that are needed for the characterization of these coatings.

Currently, we are utilizing polarized light scattering to separate the contributions of the different scattering mechanisms in order to develop physical models that will predict the intensity, polarization, and spectral dependence of the scattering. Specific measurements to test the methodologies described in this paper and the models are being performed using paint systems designed to enhance or mask specific scattering sources, such pearlescent coatings on white and black background with different coating thicknesses.[8]

ACKNOWLEDGMENTS

The authors wish to express special thanks to the Advanced Technology Program at NIST for support and to the collaboration with the NIST researchers who are working on the Measurement Science for Optical Reflectance and Scattering Project and members of the ASTM subcommittee E12 for providing the pearlescent paint samples.

REFERENCES

[1] M. Maynard, "Automaker's color guard not spinning its wheels," USA Today, p. 12B, October 26, 1998.

[2] C. S. McCamy, "Observation and Measurement of the Appearance of Metallic Materials. Part I. Macro Appearance," *COLOR Research and Application* **21**, pp. 292-304, 1996.

[3] P. Y. Barnes, E. A. Early, and A. C. Parr, "Spectral Reflectance," *NIST Special Publication* **250-48**, 1998.

[4] J. E. Proctor and P. Y. Barnes, "NIST High Accuracy Reference Reflectometer-Spectrophotometer," *J. Res. Natl. Inst. Stand. Technol.* **101**, pp. 619-627, 1996.

[5] B. N. Taylor and C. E. Kuyatt, "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results," *NIST Technical Note 1297*, U. S. Government Printing Office, Washington, DC, 1994.

[6] G. Baba, "Gonio-Spectrophotometric Analysis of Pearl-Mica Paint," *Die Farbe* **37**, pp. 99-110, 1990.

[7] A. B. J. Rodrigues, "Measurement of Metallic and Pearlescent Colors," *Die Farbe* 37, pp. 65-78, 1990.

[8] T. A. Germer and M. E. Nadal, "Modeling the Appearance of Special Effect Pigment Coatings," to appear in proceedings of the SPIE 46th annual meeting, 2001.

The Effect Of Instrument Design On Diffuse Reflectance Measurements

Dr Helen White* & Dr Julie Taylor

ABSTRACT

This work forms part of an ongoing investigation to increase understanding of the sources of error associated with the measurement of diffuse reflectance by national reference instruments. Measurements of diffuse reflectance are performed at the National Physical Laboratory (NPL) via two possible routes: gonioreflectometric or integrating sphere based technologies. This work investigated the sources of anomalies found between reflectance measurements made on different sphere based instruments, by looking at the link between the uniformity of the integrating sphere employed, and the measured spatial distribution of light reflected from a range of samples. The results were then used to demonstrate the effect of integrating sphere design on the resulting diffuse reflectance measurement, and to comment on possible limitations to the current sphere error correction systems.

Keywords: Diffuse reflectance, integrating sphere, reflectometer, spectrophotometer, gloss, specular peak, colour

1. INTRODUCTION

Integrating spheres are commonly used in colour measurement when total diffuse reflectance, or transmittance, measurement is required. However, errors can arise from the use of integrating spheres, which result from the necessary divergence of the practical sphere design away from an "ideal sphere" [1]. This work utilised the measurement of samples on the NPL Gonio Reference Reflectometer to reveal the differences between two sphere-based spectrophotometers, each containing integrating spheres of differing designs. The investigation was wide ranging and looked in depth at the design of the spheres, the uniformity of the spheres, and the interaction of each sphere with the spatial distribution of the light reflected from the samples being measured. The work lead to the consideration of the various options for the correction of the errors that can arise from integrating sphere design [1,2,3], however, only a discussion of linearity and specular beam/gloss trap error will be presented within this paper. Linearity corrections are currently performed in one of two ways: either a white sample is measured while the incident beam is altered by placing a set of neutral density filters in the beam path [1,2], or, a calibrated series of grey samples are measured with no alteration to the incident beam [3]. Correction methods for gloss trap and specular beam errors have been proposed, which involve either the measurement of a calibrated mirror against a matt white standard [1,2], or, the measurement of a calibrated series of glossy grey tiles [3]. This paper outlines the advantages, and possible disadvantages, of these correction systems.

2. EXPERIMENTAL

2.1 Samples

A set of samples was chosen which exemplified a range of surface finishes:

1. From the NPL colour tile sets: Gloss white, Gloss 50% grey, Gloss deep grey, Matt white, Matt 50% grey, Matt deep grey, Matt white (WT43), Gloss white (WT53).
2. Other materials used during the course of calibrations: Mirror (GH95), Spectralon (99%), Spectralon (60%), Spectralon (40%), Barium Sulphate
3. Other materials of various surface finishes: Haze/Gloss standards, Enamels, Plastics etc.

2.2 The National Reference Reflectometer [4]

The Reflectometer was set-up in diffuse reflectance mode[4] and measurements were made with the incident beam at 8^0 to the sample (to match a typical sphere geometry). A nominal wavelength of 520 nm was employed. The scattering profile of each sample was measured at 2^0 intervals around the hemisphere above the sample. The total diffuse reflectance for each sample was calculated from the Reflectometer data via the following strategy:

---

1. For each detection angle, the radiance factor was calculated by considering the ratio of the radiance of a surface element in a given direction, to that of a Perfect Reflecting Diffuser identically illuminated [4,5].
2. Diffuse and specular components were separated by curve fitting of the diffuse component.
3. The diffuse reflectance (due to the diffuse component of the total only) was calculated by integrating over the hemisphere of collection, assuming symmetry about the normal to the sample [4].
4. The specular reflectance (due the specular component of the total only) was calculated by integrating over the specular peak, assuming symmetry about the specular angle.
5. The total reflectance was calculated through the summation of the diffuse and specular components.

2.3 The Sphere Based Spectrophotometers

Two commercial sphere-based, double-beam, spectrophotometers were used during the course of this investigation – for the purposes of this paper they will be designated as A and B. The main difference between the two instruments lay in the design of the integrating spheres attached. All of the samples were measured on both instruments in specular included and excluded geometries. The samples were measured in the sequence (reference, sample, reference), with a matt white reference being used with the matt samples and a gloss white reference being used for the glossy samples. A set of measurements was made with the samples in a particular orientation, on a separate day a second set of measurements was taken with the sample in a different orientation; the mean of the two measurement sets was then calculated. Results were taken within the wavelength range of 320 nm to 780 nm, at 5 nm intervals.

3. RESULTS AND DISCUSSION

3.1 Linearity

When measuring "linearity" we are usually considering factors such as detector linearity and photoelectronic zero offset – both of which can cause a bias in results. The linearity of the spectrophotometer systems has been measured by placing a white standard at the reference port and attenuating the incident beam via a calibrated set of neutral density filters placed at the entrance port. For both systems it was found that no correction for detector linearity was needed (a dark reading is taken as part of the measurement routine to account for the photoelectronic zero offsets). It has been suggested that the same assessment of linearity could be made by measuring the reflectance of a calibrated grey series of Matt standards – and indeed a correction system based on this premise is being considered [3]. However, the two correction mechanisms do not achieve the same evaluation of the "linearity" of the system, which suggests that these two methods are not measuring exactly the same thing. This research has put forward a potential reason for this discrepancy.

The scattering profile of a range of neutral matt standards has been measured on the National Reference Reflectometer – Figure 1 shows an example of this in the form of three grey Spectralon standards. Note that the shape of the scatter profile produced by the samples is not the same for all – most notably, the "100%" white Spectralon produces a profile with a larger curvature than the other two samples. When a white tile is placed at the port, and the incident light level changed via filters, the angular scattering profile "curvature" will remain the same because the sample has not changed, and detector linearity is measured. When the grey samples are measured the interaction of the angular scatter profile from the samples with the integrating spheres becomes an issue, as the profile is not constant through the series. Therefore, this correction system is not only looking at detector linearity but is also taking into account factors relating to the "general integration error"[1] of the sphere system. This could be an advantage as the "linearity" being considered is now taking into account the whole of the sphere system rather than one aspect of it i.e. the detector system. A problem could arise, however, if a wide variety of matt samples are being measured with scatter profiles that are different to the samples used to make the initial "linearity" correction. With this in mind, work is continuing in this area to establish the best practice in the use of these current correction systems, and to consider ways of obtaining a clearer division between linearity and general sphere error issues.

3.2 Gloss-Trap Inadequacy and Regular Reflectance Errors

When a glossy sample is measured on a sphere-based spectrophotometer two different geometries are important – specular included or excluded. A specular port is employed to either include or exclude the specular peak from the measurement and extra baffles must be included into the sphere design to shield the detector from a direct view of the specular reflection at the port [1,6]. This arrangement leads to four possible sources of error [1]:

1. The size of the port is not large enough to totally exclude the specular peak.
2. The exclusion mechanism (i.e. gloss trap) is inadequate.

3. The baffle arrangement is not adequate enough to shield the detector from the specular patch.
4. The coating on the specular port does not match the rest of the sphere wall coating and therefore does not weight the specular component appropriately (a further section of this work looked at the uniformity of the spheres, particularly in terms of sphere wall coating, and the results indicated that for the two spheres employed the port coatings matched that of the sphere walls).

The range of samples measured on the Reference Reflectometer included samples with a variety of specular peak shapes. The analysis methods employed on the Reflectometer data (described briefly in section 2.3 of this paper), allowed the specular reflection to be separated from the diffuse component revealing the shape of the peaks – Figure 2 gives an indication of the range of peak "shapes" across the samples included in the study.

The angular extent, and position, of the ports associated with each sphere had been mapped as part of another section of this investigation. This information was then combined with the Reflectometer data so that the area of the ports could be "modelled" and the extent of the peak falling outside of specular port could be quantified (see Figure 3). The specular port on sphere A in considerably smaller than that of sphere B and Figure 3 demonstrates that it is less efficient at excluding the broader peaks.

The measure of total reflectance from the Spectrophotometers was taken away from the measure of total reflectance calculated from the Reflectometer data. When this difference was plotted against the calculated extent of the peak falling outside of the specular port area, a very distinct trend was revealed (Figure 4). The difference between the Reflectometer and Spectrophotometer results was dependant on both the breath and height of the peak. This was attributed to the effectiveness of the baffles within the integrating spheres employed. As the peak becomes wider the baffling is no longer of sufficient size to be able to adequately shield the detector and a bias comes into the results – this bias will be more apparent the brighter the specular patch being considered. This effect is seen in both spheres when the ports are closed although it is slightly less prevalent with sphere B, and indeed a more extensive baffle system is included within that sphere design. When the ports are opened the overall difference decreases; this is far more obvious for sphere B. As mentioned earlier, the Specular port on sphere B is larger than that of sphere A and is therefore far more effective at excluding the peak area. It was noted, particularly for sphere B, that if this trend is visible with the port closed, but dramatically reduced when the port is opened, that the detector could have the port itself within its field of view.

Correction methods for gloss trap and specular beam errors have been proposed, which involve the measurement of a calibrated mirror against a matt white standard [1,2]. A further correction method has been developed involving the measurement of a series of neutral glossy ceramic tiles, which combines the gloss trap/specular beam error with the assessment of linearity discussed in section 3.1 [3]. Given that the effectiveness of the baffles is so dependant on specular peak shape, both in terms of width and height, a problem could arise with either system if the samples being measured have a different peak shape to the artefacts used to make the correction. Work is already in progress looking at the effectiveness and limitations of both the correction systems mentioned, and the results discussed during the course of this paper are being used as part of that assessment.

4. CONCLUSION

This work has emphasised the sensitivity of integrating sphere based systems, used to measure total diffuse reflectance, to the angular scattering profile of the sample being measured. The impact of these observations on current sphere error correction systems is under consideration.

ACKNOWLEDGEMENTS

The author would like to thank the following for their advice and assistance during the course of this investigation:
Dr Julie Taylor, Dr Frank Clarke, Mr Andrew Hanson, Dr Peter Clarke, Mrs Emma Woolliams, Dr Bill Hartree, Dr Eric Usadi, Dr Stuart Windsor, Ms Paula Knee, Dr Peter Harris.

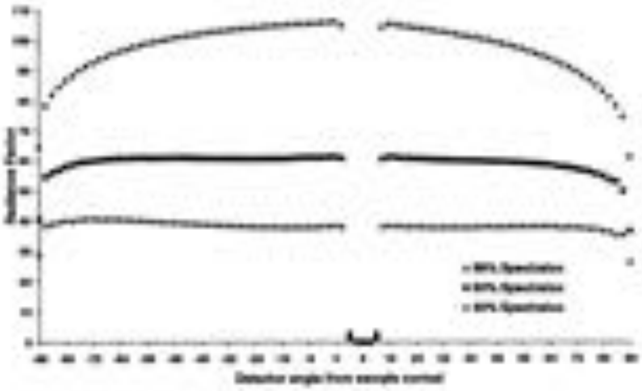


Figure 1. A Spectralon grey series measured on the National Reference Reflectometer (results presented in Radiance Factors).

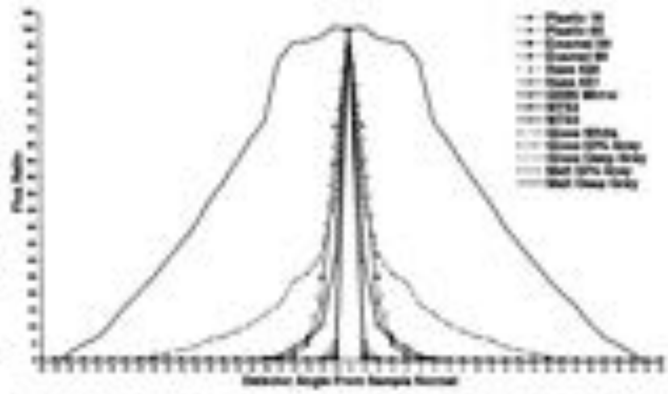


Figure 2. The shape of the specular peaks (normalised data).

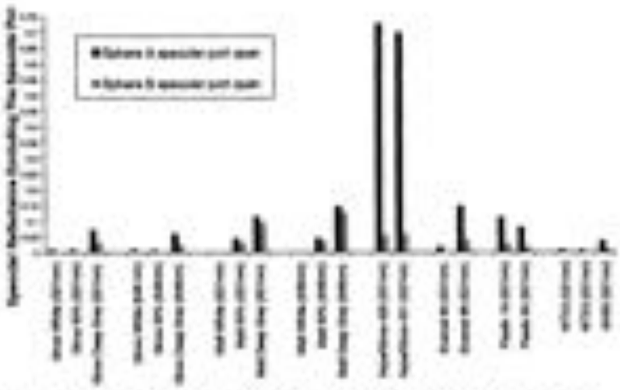


Figure 3. The extent to which the specular peaks fall outside the area of the specular ports.

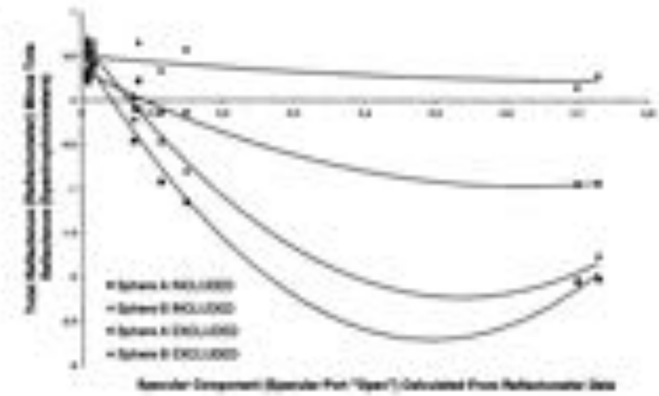


Figure 4. The difference between Reflectometer and sphere-based results plotted against specular peak "extent".

REFERENCES

1. F.J.J.Clarke, J.A.Compton, Correction Methods For Integrating-Sphere Measurement Of Hemispherical Reflectance, Colour Research and Application, Volume 11, Number 4, Winter 1986.
2. P.J.Clarke, A.R.Hanson, J.F.Verrill, Determination Of Colorimetric Uncertainties In The Spectrophotometric Measurement Of Colour, Analytica Chimica Acta 380, 277-284, 1999.
3. P.J.Clarke, Methods For Improving Uncertainty In Industrial Colour Measurement, To Be Published in the Proceedings of the CIE Expert Symposium On Uncertainty Evaluation, January 2001.
4. D.C.Williams, Establishment Of Absolute Diffuse Reflectance Scales Using The NPL Reference Reflectometer, Analytica Chimica Acta 380, 165-172, 1999
5. International Electrotechnical Vocabulary: Chapter 845: Lighting, CIE Publication 50(845)
6. K.F.Carr, Integrating Sphere Theory And Applications (Part 1), Surface Coatings International (8), 380-385, 1997

* Correspondence: helen.white@npl.co.uk, National Physical Laboratory, Centre for Optical and Environmental Metrology, Queens Road, Teddington, Middlesex, TW11 0LW (UK). Phone: (+44) 020 8943 6646

The effect of gloss on perceived lightness

Kazuomi Sakatani and Tetsuya Itoh, Minolta Co., Ltd.

ABSTRACT

In this paper, we propose a calculation model that gives a unique metric-lightness for object-colors, which is independent of different kinds of colorimeters and also matches the actually perceived lightness. Each colorimetric result with different types of measuring geometry, for example, 0/45, d/8(SCI), and d/8(SCE), can be considerably different from others, because of the influence of the component reflected normally from the sample surface. In order to investigate the difference between the actual sensation and each output of measuring geometry, we have made a subjective experiment for many achromatic samples that are composed of various levels of reflectance and those of gloss. As a result, the measured results with d/8(SCE) are shown to be closest to human perception. However, by relating the correlation of gloss to the metric-lightness for any measuring geometry, these differences for the same sample can be decreased.

Keywords: metric-lightness, subjective evaluation, gloss

1. INTRODUCTION

Colorimeters are generally classified into two types of measuring geometry as 45-degree (0/45) and integrating sphere (d/8). The latter is furthermore classified into two modes, namely, specular component include (SCI) and specular component exclude (SCE). However, due to the difference in these geometric conditions, each colorimetric value for the same sample can be considerably different from others. It becomes conspicuous, in particular, when a dark sample is glossy. It appears strange that one sample has different colorimetric values under the same CIE standard illuminant. This has become extremely confusing, not only when each of us uses a different colorimeter, but also when all of us use the same one, that is, using the identical geometric condition. As is often the case with a copier, for example, if the gloss of a copy is quite different from that of the original, then their color sensations will perhaps not be the same with each other, even if their colorimetric results with a certain geometric condition are equal. A type of measuring geometry, 0/45, is recommended by ISO standard, but there is an issue that the effect of diffuse reflection (lighting) is not considered at all. On the other hand, the SCE mode of integrating sphere (d/8) is designed to eliminate the component of specular reflection by opening a light trap, but there is also an issue on its aperture size. This is because the spatial distribution of specular reflection has a wide spread and is known to vary with the surface condition of the sample, or its gloss level[1]. Therefore, we have examined the differences of metric-lightness with these geometric conditions, and come to the conclusion that any measured results for dark and glossy samples should be related to a correlation of gloss in order to match human perception.

2. EXPERIMENTS

We prepared 28 sheets of sample on which a grayscale of 12 tone was printed, yielding 336 achromatic patches in total. As printing devices, five types of Electro-photography, an Ink Jet, and a Thermal were used. By combining each of these printers with some plain papers, coated papers, and exclusive papers, we obtained a number of achromatic patches with various levels of gloss from light patches to dark ones. All patches were measured with two colorimeters (three geometric conditions) and a glossmeter, which are listed in Table 1. This means, we measured four physical values for one patch. Figure 1 shows the measured results of metric-lightness according to each measuring geometry plotted versus its gloss level. As shown in Figure 1, if the surface of patch is mat (i.e. measured gloss<10), then the measured results are practically not different from one another, and also if the level of lightness is high (i.e. metric-lightness>70), then the results are almost equal regardless of the gloss level.

Table 1: Measuring instruments list

	Name	Manufacture	Geometry
Colorimeter (2°, D_{65})	CM-2002	Minolta	d/8 (SCI)
			d/8 (SCE)
	X-Rite938	X-Rite	0/45
Glossmeter	GMX-202	Murakami	75/75

2.1 Subjective evaluation

First, in order to carry out a subjective evaluation experiment efficiently, the patches with the lightness level

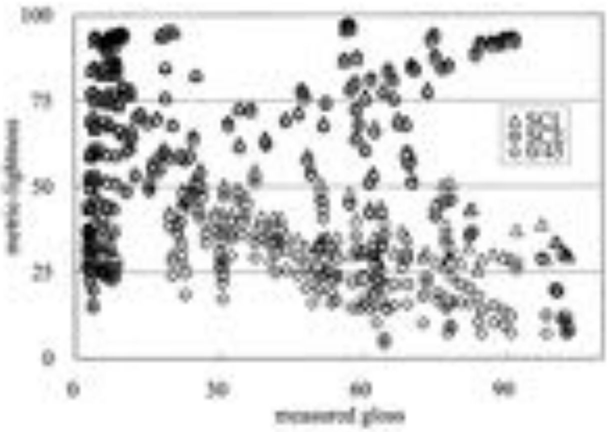


Figure 1. The measured lightness of all 336 patches with different geometric conditions versus the measured gloss.

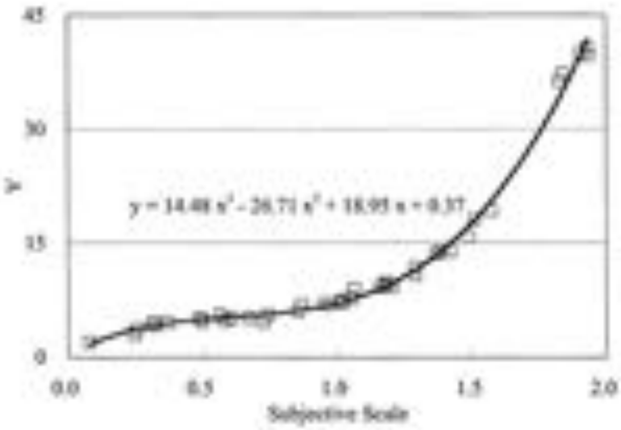


Figure 2. The relationship between Y of tristimulus value and subjective scale for mat 39 patches.

higher than 70 were excluded from all 336 patches. Secondly, we selected 126 patches from the rest with consideration of the gloss levels. Thirdly, for presentation to the observers, these 126 achromatic patches were cut and mounted on index cards separately. The cards were made of thick, white, and mat paper, of size approximately 70 mm by 100 mm. Then, they were masked with the same type of paper which has a 10 mm by 10 mm window. In this experiment, we adopted a method of paired comparisons by Scheffé[2], in which the relative levels of all samples were obtained by comparative judgements. These paired comparisons can make up a psychological scale for all 126 patches by comparing relatively all possible pairs, like A over B, for instance. In general, it is believed that the paired comparisons enable more detailed judgements than the absolute evaluation in which one sample is shown and judged. Five observers assessed 126 achromatic patches by 7875 (=126×125/2) pairs of relative comparisons respectively under the illuminated conditions of a general office environment (about 500 *lx*), with a diffused lighting. The judge's preferences were expressed on a 3-point scale, 0 (darker), 1 (almost same), and 2 (lighter). The experimental results were represented as the mean preference for each patch. Because each person's result did not vary significantly from others, the average values of five observers were designated as the subjective scales.

2.2 Ideal lightness scale

As mentioned before, if the patches are mat, then the colorimetric results with any measuring geometry become almost equal. Thus, their tristimulus values Y can be regarded as the targets. In this study, the 39 mat patches (measured gloss<10) were used to get the relationship equation between their subjective scales and the tristimulus values Y. Here, the average value for three geometric conditions (SCI, SCE, and 0/45) is used as the target. Figure 2 shows the relationship between subjective scale and Y for 39 mat patches. Using equation (1) obtained by fitting the curve to a polynomial expression, all subjective scales independent of its gloss level can be transformed into target values which correspond to Y, and designated as Y_s, where the subscript "$_s$" refers to "subjective" tristimulus value. Monotonous increasing is necessary for this equation (1), and because its derivative always has a positive value, it satisfies that condition.

$$y = 14.48\,x^3 - 26.71\,x^2 + 18.95\,x + 0.37 \quad (1)$$

In Figure 3, three kinds of measured metric-lightness for 126 patches are plotted versus the perceived lightness, that is calculated from Y_s according to CIE definitions. This figure shows that the measuring geometry of SCE, as indicated with gray circles, is the closest to the actual sensation under a diffused lighting in which print samples are usually observed.

3. PREDICTION FROM THE MEASURED LIGHTNESS

3.1 Prediction from measured gloss

Our purpose is to calculate a new Y_s number from the measured Y of tristimulus value by relating to its gloss. First, we assume that the common logarithm of $Y_s/100$ can be expressed by an equation (2), in terms of the common logarithm of Y/100 and a power *k* of gloss, G_{75}, measured by using a glossmeter with a measuring geometry of 75-degree. In

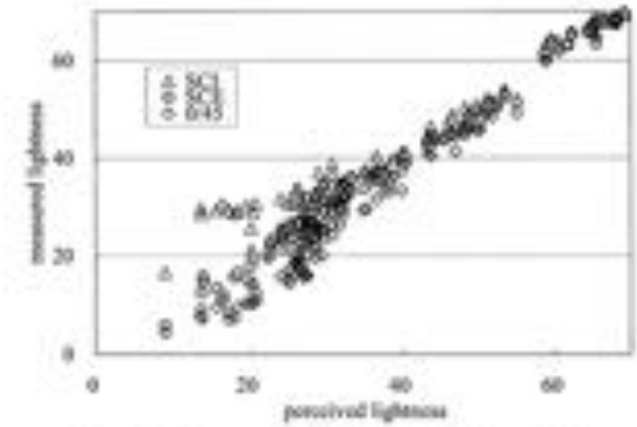


Figure 3. The measured lightness versus the perceived lightness.

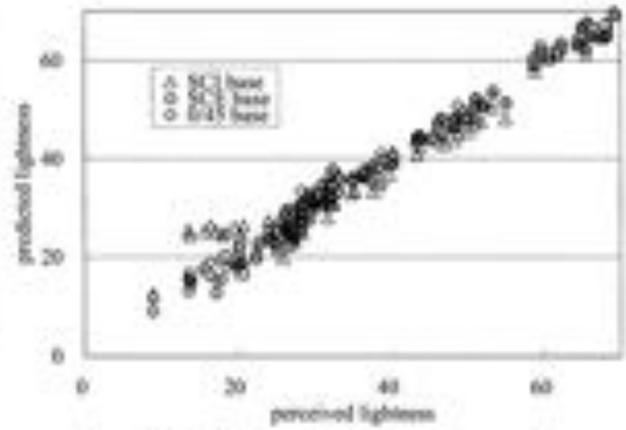


Figure 4. The lightness predicted from G_{75} versus the perceived lightness.

Table 2: Fitted results (G_{75})

Geometry	s	t	u	k
d/8 (SCI)	1.10×10^{0}	-2.45×10^{-2}	4.08×10^{-2}	0.088
d/8 (SCE)	8.82×10^{-1}	-2.17×10^{-3}	8.70×10^{-2}	1.69
0/45	7.31×10^{-1}	2.45×10^{-4}	1.63×10^{-1}	1.34

Table 3: Fitted results (G_{dY})

Geometry	s	t	u	k
d/8 (SCI)	9.74×10^{-1}	4.83×10^{-1}	-1.19×10^{-1}	0.28
d/8 (SCE)	9.79×10^{-1}	-2.90×10^{-1}	4.08×10^{-2}	0.61
0/45	8.92×10^{-1}	-3.94×10^{-1}	1.19×10^{-1}	0.51

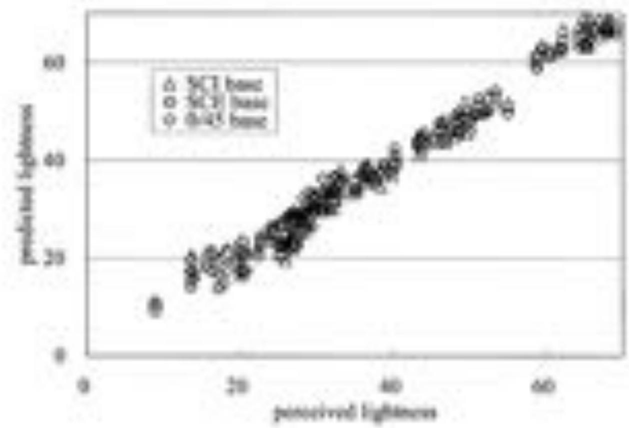


Figure 5. The lightness predicted from G_{dY} versus the perceived lightness.

Table 4: Lightness difference

	Measured	Predicted(G_{75})	Predicted(G_{dY})
Maximum	22.3	12.4	6.7
Average	6.0	2.9	2.7

$$-\log_{10}\left(\frac{Y_L}{100}\right) = s\cdot\left(-\log_{10}\left(\frac{Y_X}{100}\right)\right) + t\cdot G_{75}{}^{k} + u \qquad (2)$$

$$-\log_{10}\left(\frac{Y_L}{100}\right) = s\cdot\left(-\log_{10}\left(\frac{Y_X}{100}\right)\right) + t\cdot G_{dY}{}^{k} + u$$
$$\text{where}\quad G_{dY} = \left|\log_{10}\left(\frac{Y_{SCI}}{100}\right) - \log_{10}\left(\frac{Y_{SCE}}{100}\right)\right| \qquad (3)$$

equation (2), the subscript X denotes *SCI*, *SCE*, or *0/45*. Table 2 is the fitted results of parameters, s, t, u and k, according to the output of each geometric condition. Each predicted metric-lightness is plotted versus the perceived lightness in Figure 4. Comparing with Figure 3, each result becomes closer to the actual sensation, although for SCI, a considerable difference still remains for the dark areas in particular. As the character of SCI, which integrates whole reflection including specular components, the difference for very glossy and dark samples cannot be detected, so the output of SCI cannot be compensated sufficiently for dark samples.

3.2 Prediction from a correlation of gloss

Secondly, as expressed with equation (3), a characteristic value G_{dY}, correlated to gloss, instead of G_{75}, is used to fit the common logarithm of $Y_L/100$. Because the difference between SCI and SCE outputs can be regarded as a correlation of gloss, the absolute value of their difference is defined as G_{dY}. The fitted results are shown in Table 3, and each predicted metric-lightness is plotted versus the perceived lightness in Figure 5. Comparing with Figure 4, each result becomes much closer to the actual sensation represented by the target line of $y=x$, and the dispersion of the three, SCI, SCE, and

0/45, becomes smaller. Table 4 shows the maximum and the average difference of measured or predicted metric-lightness for the three geometric conditions shown in Figure 3 to Figure 5. By relating the correlation of gloss to each measured result, the fluctuation due to the measuring geometry is greatly reduced, and a unique metric-lightness, which matches human perception, can be obtained.

4. APPLICATION RESULTS AND DISCUSSION

In accordance with equation (3), we applied this calculation model to some grayscale samples. An example is shown in Figure 6, for one sample printed with electrophotography on coated and glossy paper. The measured and predicted metric-lightness (i.e. SCI base), and the measured gloss, are plotted versus the tone number. This figure shows that there is a large variation in the shadowy area, but in the highlight area, the metric-lightness levels, including the predicted results, are almost equal in spite of the high gloss levels. Strictly speaking, there is a small variation even in the highlight area, and for the same sample, the relationship of SCI>SCE>0/45 for lightness level almost holds for whole lightness range in varying degrees. Conceptionally, the level of lightness can be considered as the total amount of light detected with the sensor in a colorimeter. In integrating sphere, the measured result of SCE with an open light trap, becomes usually more or less darker than that of SCI. For a mat or light sample, the difference is small enough to be disregarded, but when a dark sample is glossy, the difference will be large and cannot be disregarded. These may be explained by the notion like signal to noise ratio. The signal and the noise can be associated with the uniform diffuse reflection and the specular surface reflection, respectively. If the sample is light, the signal is so large that the measurement value cannot be influenced significantly regardless of its noise. But if the sample is dark, the signal becomes small and it is easy to be influenced by the noise. This noise, or specular component, is known to change according to the gloss levels. Thus, it is difficult to specify uniquely the light trap size, and the measured results should be compensated with a correlation of gloss.

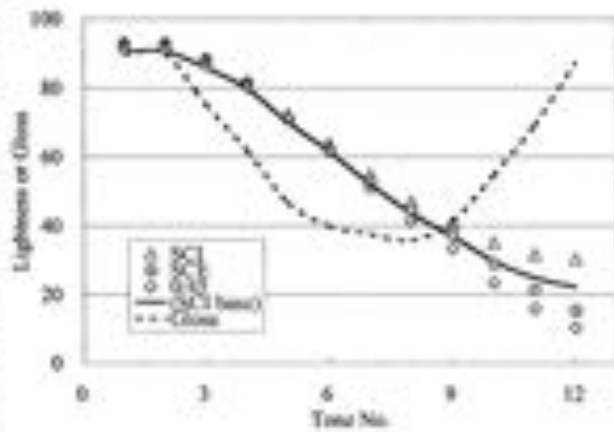


Figure 6. Application example of grayscale printed on coated paper with electrophotography.

5. CONCLUSIONS

It is undesirable in color management to have different colorimetric values for a given sample. However, when a sample is dark and glossy in particular, there will be a considerable difference in the colorimetric values because of the geometric conditions even for the same illuminant. In most cases of common printings, the levels of gloss differ more or less according to its tone, so their color difference (ΔE) with a certain geometric condition may be considered a meaningless value, and may not match human perception. Therefore, for achromatic samples with various levels of gloss, we have derived an ideal lightness scale from a subjective evaluation experiment with a method of paired comparisons. For different kinds of measuring geometry, by relating the correlation of gloss to each measured result, we have shown that almost an ideal or a unique metric-lightness can be calculated from any measured results. In the future, more consideration about chromaticity, in addition to lightness, needs to be included in this calculation model, and this idea will also be expanded to the spectral reflectance in contact measurement.

ACKNOWLEDGMENTS

The authors wish to thank Yoshio Yuasa, Kenji Imura, and Sanjirou Murakami for their helpful discussions.

REFERENCES

1. K. Suzuki and G. Baba, "Study on Geometric Conditions for Reflection Measurement (3)," Proc. Color Forum Japan'98, pp. 21-24, 1998.
2. H. Scheffé, J. Am. Stat. Ass., 47, pp. 381-400, 1952.

Study on geometric conditions for reflection measurement (2).

Effects of light trap size of integrating sphere.

Gorow Baba* and Kenichi Suzuki
MURAKAMI Color Research Laboratory

ABSTRACT

Many samples with various color and gloss grades were measured by the spectrophotometer with integrating sphere, of which light trap size was variable. Samples include white plaques, ceramic tiles, paint panels, ink-jet printings, textiles and metal surfaces. For these samples, lightness and chromaticness change with light trap size, which is relate to the elimination of surface reflection, was examined. In case of color measurement, using integrating sphere, colorimetric values are affected by the light trap size, when gloss grade of sample is different.

Keywords: Colorimetry, Integrating sphere, Light trap, Specular gloss

1. INTRODUCTION

Generally speaking, the reflected light from a non-metal (dielectric) surface consists of spectrally non-selective part, reflected from the boundary surface, and spectrally selective part, reflected from the inner layer. The surface reflected light is distributed according to the shape of the surface, and the inner reflected light is, in many cases, almost uniform. The ratio of the surface reflected light and the inner reflected light changes with the direction of reflection. In case of metal surface, all reflected light comes from the boundary surface, and the spatial distribution depends on the surface roughness. In the former report[1], we studied the spectral and spatial characteristics of reflected light by bidirectional measurements. In this report, we study the spectral characteristics of diffusely reflected light without specular component.

Most of color measuring spectrophotometers uses integrating sphere for reflection measurement. In this case, illuminating and viewing geometric conditions are 8 deg/diffuse, or diffuse/8 deg. Usually the integrating sphere has four ports, entrance, exit, sample and light trap, and the sum of areas of these ports is not exceed 10 percent of total inner surface area of the integrating sphere. When the surface of specimen is flat and smooth, the surface reflected light is concentrated to the specular direction, and absorbed by the light trap. But in case of semi-glossy or matt specimen, the surface reflected light is broaden, and not absorbed perfectly. In this study, effects of light trap size to the colorimetric values of various surfaces are experimentally examined.

2. MEASUREMENTS

2.1 Instrument

For this experiment, MURAKAMI Model CMS-35SP spectrophotometer with integrating sphere of 200 mm diameter was used. Spectral and geometric conditions are as follows;

1) spectral conditions — wavelength range: 390 to 730 nm
wavelength interval: 10 nm
bandpass: ca. 10 nm

2) geometric conditions — diffuse illumination, 7 degree viewing

light trap size:

diameter, φ (mm)	0	10	14	21	28	35	42	49	56	63	70	77
cone half-angle, κ (deg)	0.00	1.44	2.02	3.03	4.03	5.04	6.04	7.04	8.03	9.02	10.00	10.98

2.2 Specimens

1) Achromatic samples
- A-1 $BaSO_4$, by Merck, pressed by Zeiss powder press.
- A-2 $BaSO_4$, by Daikin, pasted using PVA.
- A-3 EVERWHITE, by EVERS, with polished and roughened surfaces.
- A-4 SPECTRALON, by Labsphere, white, gray75, gray50 and black.
- A-5 White ceramic tiles, by INAX, of which 60deg-Gs are 80, 60,40, 20 and 10.

2) Chromatic samples
- B-1 SPECTRALON, by Labsphere, blue, green, yellow and red.
- B-2 Ceramic Colour Standards Series Ⅱ, by Ceram Research, 12 tiles.
- B-3 Paint panels, blue, green, yellow, red, white and black, glossy, semi-glossy (+), semi-glossy (-) and matt, each.
- B-4 Ink-jet printings, magenta ink, with density of low, medium and high, on fine paper, glossy paper and glossy film.
- B-5 Textiles, blue and brown satin.
- B-6 Coloured paper, blue, green, yellow and red.

3) Metal samples
- C-1 Polished metal plates, brass, coppeer, aluminium and stainless steel.

2.3 Measurement

Using the above instrument, spectral reflectance factors of samples for each geometric condition were measured, and tristimulus values for CIE 1931 system, Ill. D65, and colorimetric values for CIELAB system were calculated.

3. RESULTS

Fig. 1-a shows the relation between lightness L* and cone half-angle κ, subtended at the center of sampling aperture by the radius of the light trap, for A-5 white ceramic tiles, of which 60 degree specular gloss are 80, 60, 40, 20 and 10. Fig. 1-b shows the relation between metric chroma C* and cone half-angle of light trap. Figs. 2-a and 2-b show the relations between lightness L* or metric chroma C* and cone half-angle κ of the light trap, for CCS II (BCRA) tiles, yellow, orange and red. Figs. 3-a and 3-b show the relations between lightness L* or metric chroma C* and cone half-angle of the light trap, for green paint panels with 60 degree specular gloss 85, 60, 35 and 10. Figs. 4-a and 4-b show the relations between lightness L* or metric chroma C* and cone half-angle of the light trap, for high concentration magenta ink-jet printings on fine paper, glossy paper and glossy film.

4. CONSIDERATIONS

a) The reflected light distribution from white reference surface, i.e. pressed $BaSO_4$ or PTFE surface, is almost uniform, and lightness L* and metric chroma have no relation to light trap size. In glossy white working standard, e.g. polished EVERWHITE, the surface reflected light is concentrated into the narrow (κ < 2 deg) specular direction.

b) In case of white ceramic tiles, L* changes with κ, but C* does not change with κ, because both surface and inner reflection are almost spectrally non selective.

c) Concerning to CCS tiles, surface reflected light is concentrated within 4 deg, then if κ is larger than 4 deg, L* and C* are not affected by light trap size. But in case of green paint panels, surface reflected light disperses into more wider range, so both L* and C* change gradually with light trap size.

d) In magenta ink-jet printings, when ink is applied on fine (matt) paper, the reflected light from printing is almost uniform diffuse, but if applied on glossy (art) paper, L* and C* are affected by light trap size.

e) In color measurement of achromatic or colored reference materials, light trap size is not so important, when cone half-angle of light trap is as large as 4 deg or so. But in practical application, actual samples have various surface roughness, so the measured lightness and chromaticness are strongly affected by light trap size. Therefore, if integrating sphere is used, light trap size should be more strictly specified.

REFERENCE

1. G. Baba and K. Suzuki, "Gonio-spectrophotometric analysis of white and chromatic reference materials", *Analytica Chimica Acta* **380**, pp.175-182, 1999.

*contact: gro-baba@mcrl.co.jp; phone 81 3-3532-3011; fax 81 3-3532-2056; http://www.mcrl.co.jp
MURAKAMI Color Research Laboratory, 3-11-3, Kachidoki, Chuo-ku, Tokyo, 104-0054 JAPAN

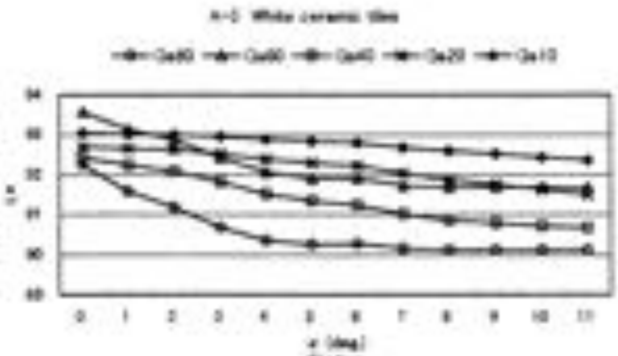


Fig.1-a

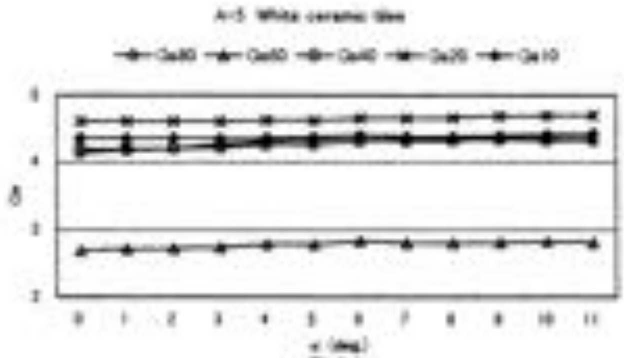


Fig.1-b

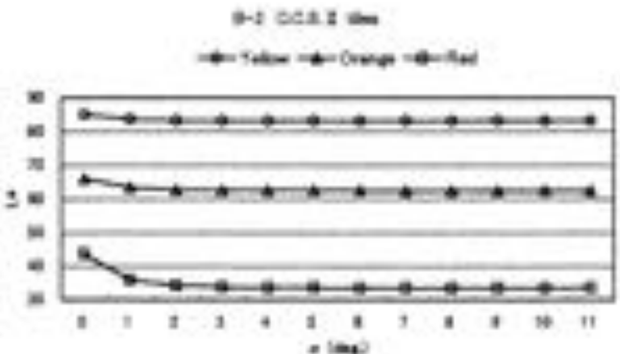


Fig.2-a

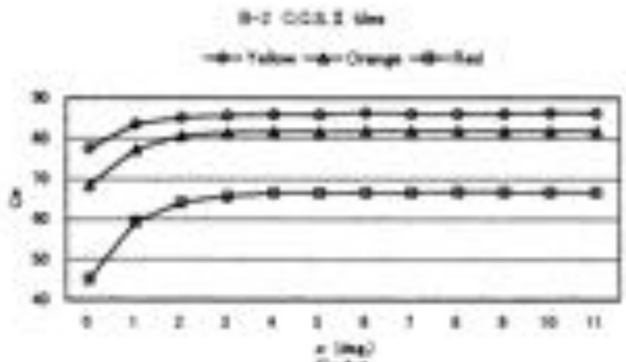


Fig.2-b

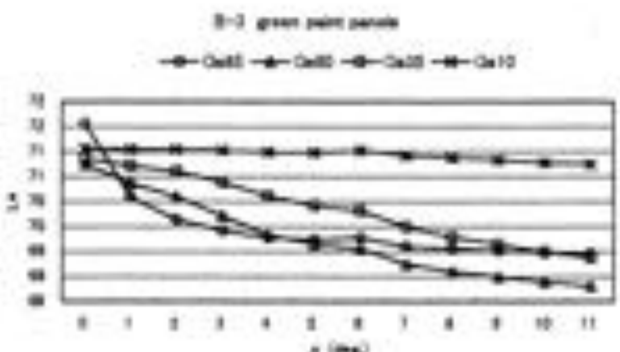


Fig.3-a

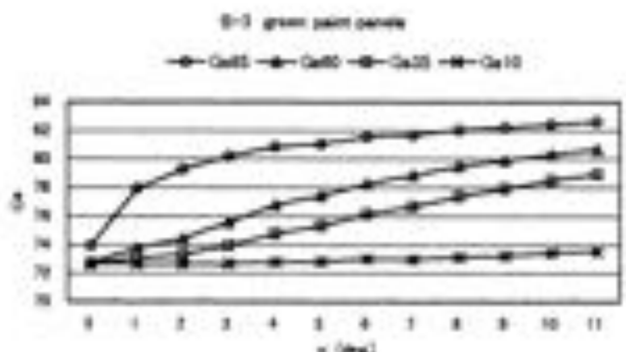


Fig.3-b

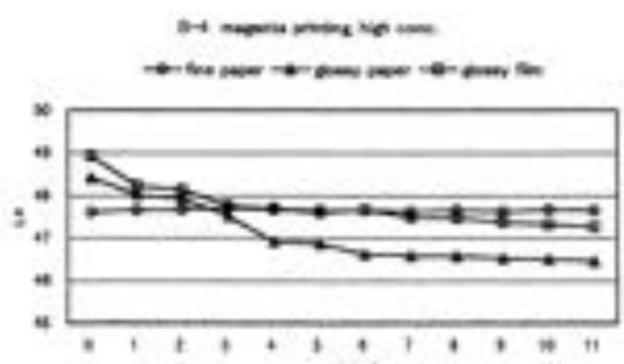


Fig.4-a

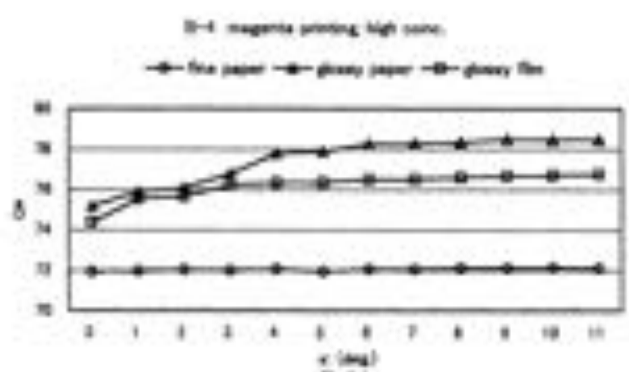


Fig.4-b

Industrial Colour Measurement - the State of the Art

Robert Hirschler* and Jennifer Gay**, SENAI/CETIQT, Rio de Janeiro, Brazil

ABSTRACT

Modern industrial colour measuring instruments are grouped into three levels according to their performance (in terms of *accuracy, reproducibility and repeatability*) and technical specifications: top-of-the-line, mid-range and entry-level. Due to advances in the design, manufacturing and control of the instruments, top-of-the-line specifications are no longer achievable only for bench-top instruments: portable and on-line spectrophotometers are also available at this level. Recent advances made special features such as *spectrogoniometry* and double-monochromator *spectrofluorimetry* - formerly encountered only in research laboratories - available in industrial instruments. Entry-level instruments have become more rugged and affordable than ever. The authors tested over 30 colour measuring spectrophotometers in laboratory and industry, and found that the performance of well-maintained and well-operated instruments is within the original specifications provided by the manufacturers.

Keywords: Colour measurement, spectrophotometer, instrument performance, spectrogoniometry, spectrofluorimetry

1. INTRODUCTION

"Classical" scanning colour measuring reflectance spectrophotometers were huge, slow and rather expensive, and the no-fuss, matter-of-fact, everyday application of instrumental colour control and colorant formulation started only in the second half of the 1970's, when microprocessor-controlled, fast and relatively inexpensive instruments were first introduced. The most important characteristics of the instruments are their *performance* (*accuracy, reproducibility and repeatability*) and their *measurement capabilities (geometry, size of measured area, UV calibration of the light source, sample holder – operator comfort)*. For mainstream industrial spectrophotometers three levels of sophistication may be defined, as listed in Table 1. Classifying instruments into these levels is rather arbitrary, more recent models launched as "mid-range" or "entry-level" may in many cases have many of the top-of-the-line features and also approach their performance.

	Top-of-the-line	*Mid-Range*	*Entry Level*
Wavelength range (nm):	360-740	400-700	400-700
Wavelength interval (nm):	5 - 10 (reported)	10	10 or 20
Geometry (CIE standard):	Sphere or 45/0°	Sphere or 45/0°	Sphere or 45/0°
Area view (∅ mm):			
Large Area View (LAV)	25-30	18-25 mm	5-10 mm
Medium Area View (MAV)	5-15	5-10	n/a
Small Area View (SAV)	3-5	n/a	n/a
Light source:	D_{65}-simulator with UV calibration	D_{65}-simulator with UV cut-off	Xenon flash or tungsten lamp
Transmittance capability:	yes	optional	n/a
Typical performance: (CIELAB- 12 CERAM Research tiles):			
Short term repeatability (MCDM):	< 0.05	< 0.1	< 0.1
Reproducibility (MCDM):	< 0.1	< 0.3	< 0.3
Reproducibility (Worst tile):	< 0.15	< 0.5	< 0.7
Accuracy ($DE_{measured\ vs.\ nominal}$)	< 0.5*	<0.7-0.8	<1.0

Table 1: Main characteristics of the three levels of colour measuring spectrophotometers
*Depending on verification standards may be 0.3-0.4

9th Congress of the International Colour Association, Proceedings
of SPIE Vol. 4421 (2002)

2. SPECTROPHOTOMETER FEATURES

Technical details of the basic design of colour measuring instruments are described in textbooks (e.g. Burns[2]), so we shall only mention some of the novel and special features here. The race between competing designs seems to be - at least for the time being - over, today's "typical industrial spectrophotometer" is very likely to have pulsed xenon flash (in some cases tungsten) source(s), replica grating monochromator(s) with diode array detector(s). They are built as *bench-top, portable* or *on-line* instruments. Table 2. below lists the major manufacturers of each type.

Supplier	Web page	(a)	(b)	(c)	(d)
Accuracy Microsensors, Inc.	www.accuracy.com	•	•	•	
AutoVision, Inc.	www.autovision.net			•	
Avian Technologies / Murakami CRL	www.aviangroupusa.com	•		•	•
Barco	www.barco.com			•	
BYK-Gardner	https://byk-gardnerusa.com	•	•		•
ColorPartner GmbH	www.colorpartner.de		•		
Color Savvy Systems Limited	www.colorsavvy.com	•	•		
ColorTec	www.color-tec.com	•	•		
CVI Spectral Products	www.cvilaser.com	•			•
Datacolor	www.datacolor.com	•	•		
EVS Elbit Vision Systems Ltd.	www.evs.co.il			•	
ezColor, Inc.	www.ezcolorinc.com				
Graphics Microsystems, Inc.	www.gmicolor.com			•	
GretagMacbeth	www.gretagmacbeth.com	•	•	•	
HunterLab Associates, Inc.	www.hunterlab.com	•	•	•	•
IHARA Electronic Industries, Ltd.	www.ihara-group.com		•		
Instrument Systems	www.instrumentsystems.com	•			•
Labsphere, Inc.	www.labsphere.com				•
Mahlo	www.mahlo.com	•	•	•	
Massen Machine Vision Systems	www.massen.com			•	
Minolta	www.minoltausa.com	•	•	•	•
Ocean Optics, Inc.	www.OceanOptics.com	•	•		•
Opticolor, Inc.	www.opticolor.com			•	•
PerkinElmer Instruments	www.perkinelmer.com	•			
TECHKON GmbH	www.techkon.com		•		
Technidyne Corp.	www.technidyne.com	•	•		
X-Rite, Incorporated	www.xrite.com	•	•	•	•

Table 2: Summary of the major instrument manufacturers, showing product group(s) and contact address
(a) Bench-top; (b) Portable/DTP; (c) On-line; (d) Special (Spectrogoniometer, Spectrofluorimeter, Multi-angle, Gloss)

1. Bench-top spectrophotometers

While analytical / research spectrophotometers (such as the PerkinElmer Lambda Series) have 0.5 - 4 nm **spectral resolution**, most of the top-of-line industrial instruments use 40-element detectors for 10 nm sampling and reporting in the visible range. The Datacolor instruments based on the MC-90 analyser have 128 point sampling and 10 nm (the SF600 Plus CT model 5 nm - 69 points) reporting interval. Instruments with CCD detectors, such as the CVI Spectral Products SM100 and SM 120 models, can have very high spectral resolution (2 nm in the range of 380-1000 nm), but no precision data are as yet available. At the other end of the range, with a limited number (currently max. 15) of measurement channels, LED-based instruments - so far mostly used in portable applications - have appeared also in bench-top version (e.g. the AT-series of Accuracy Microsensors, Inc.)

UV calibration for the measurement of fluorescent samples and the calculation of Ganz-Griesser or CIE whiteness is available in all top-of-the-line instruments, HunterLab's LabScan XE being the first commercially available 45°/0° spectrophotometer with this capability. (This geometry is considered more adequate for the measurement of fluorescent samples than the integrating sphere, because of the possibility of "back-illumination" inside the sphere.) GretagMacbeth introduced a new entry-level desktop instrument, the Color-Eye 2180UV which, except for the aperture size, fulfils all the requirements of a mid-range instrument, including UV calibration. The UV-content of the illumination is normally regulated by moving a filter, except for the X-Rite (Optronik) Colorflash UV and the Minolta CM-3600d models, which adjust the relative illumination level from two light sources: one with and another without UV.

For the full characterisation of fluorescent samples **dual monochromator, bi-spectral instruments** are required, but until recently their complexity, expense, and general unavailability precluded their consideration for general use. This may have changed now with the introduction of two industrial instruments: the Minolta CM-3800d Spectro-Fluorimeter and the Labsphere BFC-450 Bispectral Fluorescence Colorimeter. The CM-3800d, developed by Minolta and Nisshinbo is a double-monochromator, sphere geometry spectrophotometer. The sample is illuminated by monochromatic light from the first grating monochromator, scanned from 300 to 730 nm in 10 nm intervals, and the true reflectance, together with the fluorescence, is measured by a 38-element photodiode array from 360 to 730 nm. CIE co-ordinates, and thus whiteness value can be determined for any illuminant with accurate software simulation. The BFC-450 operates in an annular bi-directional 45°/0° geometry, using both monochromatic illumination and monochromatic detection in 10 nm intervals, with 10 nm effective bandwidth in the 300 - 780 nm range for excitation and 380 - 780 nm for the emission.

The **measurement geometry** of most bench-top instruments is sphere (d/8), but some manufacturers, such as BYK-Gardner and HunterLab, offer also 45/0 models. The exclusion of the specular reflection of the sample (on sphere instruments) is automated for most of the top-of-the-line models, the Minolta CM-3600d is the first bench-top spectrophotometer with the simultaneous SCI/SCE measurement capability (a similar feature is implemented in the portable ColorEye XTH model of GretagMacbeth). The BYK-Gardner CG-9005 ColorView has circumferential 45°/0° geometry and additionally measures 60° gloss, and X-RITE now markets the (former Optronik) Multiflash M 45 instrument with 8 illumination angles (+25°, +20°, +10°, 0°, -10°, -20°, -30° and -70°) and 45° observation. The Datacolor SF 600 Plus CT is the first instrumen having 5, automatically identified and selected viewing apertures between 2.5 mm and 26 mm.

The Murakami Color Research Laboratory (see Avian) offers two fully-fledged **goniospectrophotometric** colour measurement systems: the GCMS-4 and the GCMS-3, allowing for complete angular and spectral characterization of any colour. The GCMS-3 is a double beam geometry, diode array (10 nm interval from 390-730 nm) spectrophotometer, with the lamp housing rotating from 16°-180° to -16°, at 1° intervals; and the receiver angle changeable over 180° at 1° steps.

2. Portable and hand-held instruments

Not so long ago "portable colour measuring instrument" meant tristimulus colorimeter, later entry level spectrophotometer, and today some of these tiny technological wonders are entering the top league both in the versatility of features and in performance. 10 nm **spectral resolution** is becoming quite common, with some instruments (e.g. the Datacolor Mercury, ColorPartner's ColorScout and the Spectronic MINIMatch) measuring 256 or more points and reporting at 10 nm intervals. The performance claimed for many of today's portable instruments is top-of-the-line level, the inter-instrument agreement (reproducibility) being better than 0.2 MCDM or even 0.15 (CIELAB) for the average of the 12 CERAM Research tiles.

Special features offered by portable/handheld instruments include

- Color and 60° gloss with one reading (BYK-Gardner: color-guide gloss)
- Integration into a Palm Pilot and optional UV calibration (Datacolor: Mercury)
- Simultaneous SCI/SCE and SAV/MAV reading and 3-D targeting for measuring curved surfaces (GretagMacbeth ColorEye XTH)
- Three-angle measurement: 25°, 45°, 75° (Minolta: CM-512m3)
- Simultaneous numerical gloss control and numerical UV control (Minolta: CM-2600d)
- Both reflectance and transmittance measurement; PC docking station (Spectronic Instruments: MINIMatch)
- Multi-angle measurement: 15°, 25°, 45°, 75°, 110° (X-RITE: MA68II)

A whole new class of portable and hand-held instruments is based on LED application: instead of dispersing the light reflected from the sample these instruments use monochromatic illumination provided by 6 to 15 LED-s, and reporting 20 nm or even 10 interval spectral data through curve fitting and integration. For some models the manufacturers claim repeatability and inter-instruments agreement performance as good as those of the instruments using traditional technology.

3. On-line colour measurement

For many products, such as ceramics, food, glass, paints, paper, plastics and textiles, on-line colour measurement for QC or shade sorting has been used for a long time. The simplest applications, such as the Eye-Opener "shade detection system" of BARCO measure only lightness differences, filter or CCD-based instruments, such as the ColourBrain-tex (Massen) measure tristimulus values, but most of the instruments available today (Table 2.) measure spectral reflectance data. The SpectraProbe XE of HunterLab is a *Level 1.* instrument, the first on-line spectrophotometer with UV calibration (for whiteness control). For textile shade-control Mahlo has developed two on-line spectrophotometers, the Colorscan CMS-10 is a high-resolution (512 element diode array) flash instrument with circular 0°/ 45° geometry, while the CIS-10 measures at 256 points between 380 and 780 nm, using a tungsten-halogen lamp as light source.

Recent advances in imaging technology promise highly accurate and precise on-line measurements based on imaging spectrographs, like the Autovision ColorProfiler, but no actual performance data are as yet available.

3. SPECTROPHOTOMETER PERFORMANCE

The performance figures shown in Table 1. are based on the manufacturers' specifications, and on the experience of our laboratory, obtained by regularly checking our own instruments (4 top-of-the line and 16 entry-level bench-tops and 4 portables), and those of our clients (9 different bench-top, portable and on-line instruments at 14 companies).

Short, medium and long-term **repeatability** of modern instruments is much better than the uniformity of most of the samples. **Reproducibility** (inter-instrument agreement) for top-of-the-line models has improved much, most of the manufacturers quote figures which not so long ago were only available with specially calibrated (what Datacolor calls "close tolerance") instruments. The "**accuracy**" (bias) depends on the white calibration standard and on the verification standards used. On our reference instrument (Minolta CM-3720d), calibrated with an NPL matte ceramic white tile at 25±0.5°C, the average DE_{CIELAB} was 0.32/0.29 (SCI/SCE) for 12 NPL calibrated matte tiles and 0.34/0.33 for the glossy tiles. Using the same glossy white (opal glass) standard for calibrating our 4 bench-top instruments, we achieved DE<0.5 accuracy for the NPL matte tiles, while the glossy tiles gave average DE = 0.6-0.9 (SCI) resp. 0.4-0.7 (SCE).

The current generation of instruments leave the factory with high-level performance, but it can only be maintained if the user is fully aware of the requirements of correct instrument calibration and operation as well as sample preparation and presentation for measurement. GretagMacbeth has recently announced an interesting concept called the *NetProfiler*, a system of calibrating spectrophotometers through the Internet to ensure that instrument performance remains always at the targeted level.

ACKNOWLEDGEMENTS

The authors wish to thank all the suppliers mentioned in this paper for kindly having provided technical information on their instruments. The financial support of the *Centrum für Internationale Migration* (CIM) for one of the authors (JG) is gratefully acknowledged. The SENAI/CETIQT Applied Colorimetry Laboratory is supported by technical co-operation projects of the *United Nations Industrial Development Organisation* (UNIDO).

REFERENCES

1. R. McDonald and B. Rigg, *Selecting Surface-Colour Measuring Instruments and Monitoring their Performance* J. Soc. Dyers & Col. **96** 587-589 (November 1980)
2. R. S. Berns, *Billmeyer and Saltzman's Principles of Color Technology*, John Wiley & Sons, Inc., 2000

Correspondence: SENAI/CETIQT Applied Colorimetry Laboratory, Rua Dr. Manuel Cotrim, 195, Riachuelo, Rio de Janeiro, 20961-040, Brazil, Fax: 55-21-2410495, *thirschler@unido.org, phone 55-21-582-1029; **jgay@cetiqt.senai.br, phone: 55-21-582-1017

Colorimetric control of photographic prints: the problem of fluorescence.

Klaus Witt*
Federal Institute of Materials Research and Testing (BAM), Germany

ABSTRACT

The colorimetric control of photographic prints is an important issue of colour reproduction quality. Concentration series of the three photographic dyes Yellow, Magenta and Cyan on photographic paper are very often measured without considering the optical quality of the substrate. However, this substrate, the photographic paper, produces problems for colorimetry because it emits luminescent light from optical brighteners. Many instruments used in colorimetry are not adapted to measure such an output correctly. Here, an experimental investigation is presented which quantifies systematic shifts of spectral curves and colorimetric values of photographic paper and dyes for various measuring parameters. Several spectrophotometers equipped with different sources for irradiation such as Tungsten halogen lamp, Xenon flash lamp, D65 simulator, and two Xenon lamps with adjustable UV-filter were referenced against the results of a two-monochromator spectrophotometer. In the photographic paper the largest colour-difference extended to approximately 10 CIELAB-units between irradiation by a Tungsten halogen and a Xenon lamp. These differences diminished with increasing concentration of the photographic dyes, however, did not die away at the highest concentration of the dyes used. The correct colorimetric values for D65 irradiation were halfway between those for the two former lamps and near to measures received from Xenon lamp irradiation with adjustable UV-filter. Therefore, such spectrophotometers may be used for colorimetric control of photographic prints to attain an accuracy below 3 CIELAB units, or else, two measurements with a Tungsten halogen and a Xenon lamp should be averaged.

Keywords: fluorescence, photographic prints, colorimetry

1. INTRODUCTION

Colour reproduction processes more and more need colorimetric control for high quality colour imaging. In photographic prints such a control is tried with colour measurements of concentration series of Yellow, Magenta and Cyan on photographic paper. These papers throughout contain optical brighteners that serve for luminescent emission of light superimposed on the regular reflected light by the photographic dyes and the photographic paper. The amount of luminescent light added to that of regular reflectance depends on the thickness of the dye layer and its absorptive qualities on top of the paper substrate. Therefore, in photographic prints the differently coloured parts of the image may emit different amounts of luminescence.

Accurate colorimetric measurement has to consider this effect. For viewing photographic prints illumination with standard illuminant D65 is defined in DIS ISO/IEC 19839-2[1]. Therefore, in colorimetric measurements a source of irradiation must be used that simulates this illuminant. However, commercial colour measuring instruments rarely are equipped with a D65 light source. Xenon flash-lamps or Tungsten halogen-lamps are commonly used as sources, and more recently, new spectrophotometers are equipped with Xenon-lamps in combination with an adjustable UV-filter to reduce the too large UV content of irradiation to that of D65. A correct measure of total radiance factors for D65 irradiation is given from a two-monochromator spectrophotometer[2-4] (2MM). An experimental study was started to investigate the effect of more or less well adapted D65 sources on systematic bias of colorimetric values with reference to 2MM results, and to give advice how to attain a good technical solution.

* Klaus.Witt@bam.de; phone +49 30 8104 1916; fax. +49 30 8104 3047; http://www.bam.de; Federal Institute of Materials Research and Testing (BAM), D-12200 Berlin, Germany

2. EXPERIMENTAL

Three different types of two-monochromator spectrophotometers were used for taking measures of the photographic paper (the notation of measuring geometries follows a draft of CIE Publ. 15.3):

- BAM-2MM, 45°x:0° geometry
- CM-3800d, de:8° geometry, Minolta,
- BFC-450, 45°a:0° geometry, Labsphere.

For intercomparison different types of spectrophotometers were used equipped with an irradiation source as follows:

- Tungsten halogen lamp, 45°x:0° geometry (microscope-spectrophotometer, Zeiss),
- Xenon flash lamp, 45°x:0° geometry (gonio-spectrophotometer GK 311/M, Zeiss),
- D65-simulator, 45°x:0° geometry (BAM-constructed)
- Xenon flash lamp with adjustable UV-filter, 0°:45°c geometry (LabScanXE, Hunterlab)
- Xenon flash lamp with adjustable UV-filter, de:8° geometry (SF600PLUS, Datacolor international)

Adjustable UV-filters are used in combination with a Xenon lamp to reduce the amount of too large UV-radiation from such a source to a level typical for D65 radiation. The UV-filters are partly moved into the illumination beam until a reading of a reference sample with known luminescent output for D65 indicates the correct value. It performs a control of the total energy absorbed for luminescence, however, does not adapt for the form of the spectral curve of D65 radiation in the UV-range. Insofar, such an adjustment is valid for a specified luminescent molecular species only, here: the optical brightener.

Concentration series of photographic dyes on photographic paper were printed at BAM using the file output on a photoprinter. The sample sizes were too small for the measurement with some of the above mentioned spectrophotometers. Therefore, complete measures of all concentration series were possible only with three instruments: the microscope-spectrophotometer equipped with a Tungsten halogen lamp, the GK 311/M equipped with a Xenon flash lamp, and the LabScanXE equipped with a Xenon flash lamp combined with an adjustable UV-filter. In the latter case the UV-filter was adjusted with the aid of a white, luminescent reference sample for defining whiteness of papers. The photographic paper was measured with all instruments cited. In every case the samples were backed by an 8-fold layer of the photographic paper.

3. RESULTS

The matrices of bispectral radiance factors of the 2MM-spectrophotometers for the photographic paper were converted to total spectral radiance factors for standard illuminant D65. Their results were nearly identical within uncertainty of measurements. In Fig. 1 the total spectral radiance factors of BAM-2MM and of 5 other types of spectrophotometers equipped with different measuring geometries or irradiation sources are shown.

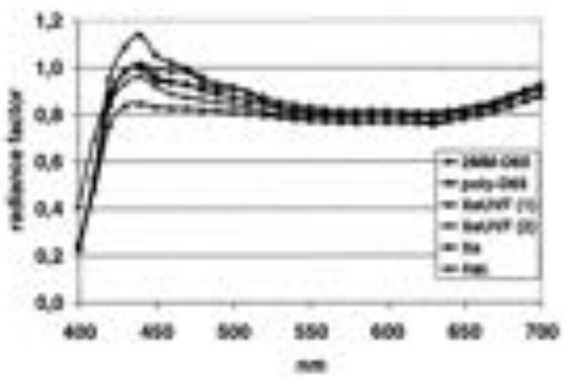


Figure 1: Total spectral radiance factors of photographic paper for 6 spectrophotometers (evaluation for standard illuminant D65 in 2MM-instrument).

Xenon overexcites luminescence, Tungsten halogen underexcites, however, all the other results fall closely together. In the concentration series of the photographic dyes divergent effects of Xenon and Tungsten halogen irradiation diminish with the concentration of the dye as the dyes absorb part of the luminescent emission of the paper without being itself luminescent. Fig. 2 shows the effect for selected samples from a Cyan series.

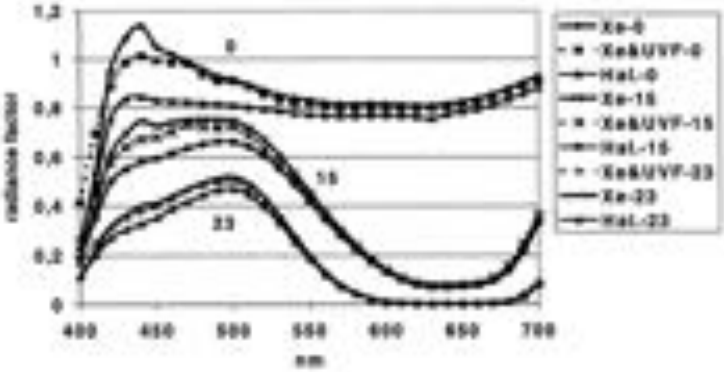


Figure 2: Total spectral radiance factors of the photographic paper (0) and of two concentrations of the Cyan series (15, 23) measured with three different sources of irradiation (Xenon, Xenon + UV-filter, Tungsten halogen).

CIELAB colour differences between the colorimetric results from Xenon and Tungsten halogen irradiation are dominated by the component Δb^*. Therefore, in Fig. 3 this measure is given for the Cyan series using the results of UV-filtered Xenon irradiation as reference.

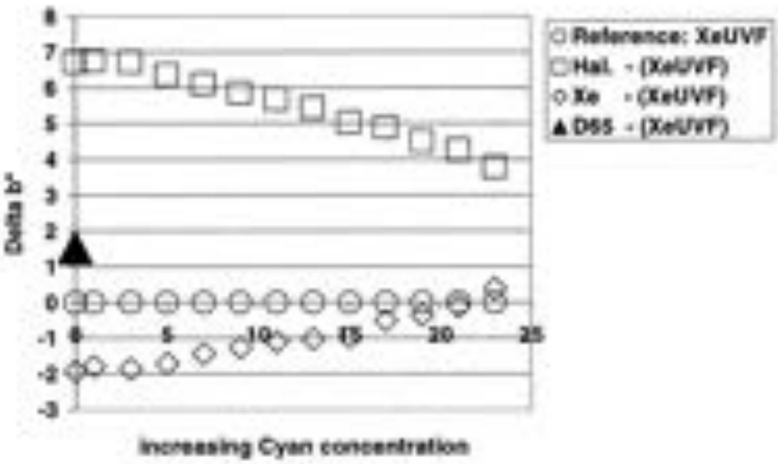


Figure 3: CIELAB component Δb^* for differences between measures with UV-filtered Xenon (XeUVF) irradiation as reference and Xenon (Xe) or Tungsten halogen (Hal.) irradiation. For the photographic paper the equivalent difference for D65 irradiation is added.

Between the extreme cases of irradiation the colour differences by far exceed the intended accuracy of 3 CIELAB units recommended in ISO/IEC 15775[5], and even in the highest concentration of the Cyan series it is larger. In the other two series of Yellow and Magenta the effect is equivalent with less pronounced colour difference at the highest concentrations. The position of the difference point for D65 irradiation indicates, that the UV-filtered Xenon irradiation did not perfectly meet the effect of D65. Further details of colorimetric inter-comparisons for the photographic paper are given in Tab. 1.

The ranking of irradiation sources with reference to the BAM-2MM-spectrophotometer gives the D65 simulator the best position as is expected. Both Xenon sources with UV-adjustment follow on the next places with a clear difference between them: Xe &UV-filter (2) is better than Xe & UV-filter (1). Eventually the UV-adjustment was not optimal in case (1). On the other hand, even in the worse case the colour difference is clearly within the accepted range. This is not the case for Xenon and Tungsten halogen irradiation which by far exceed the intended colour difference of 3 CIELAB units. However, both the extremes are at opposite positions from the reference and at nearly equal difference. If one calculates the mean of the CIELAB values of both measures one comes near the intended reference value.

sources	L*	a*	b*
2MM (BAM)	92,0	1,4	-7,9
D65 simulator	92,5	1,7	-8,4
Tungsten halogen	90,8	-0,2	-2,8
Xenon	93,8	3,3	-11,9
Xe & UV-filter (1)	92,9	1,5	-10,0
Xe & UV-filter (2)	91,2	1,4	-7,3

Ranked differences	ΔL^*	Δa^*	Δb^*	ΔE^*_{ab}
D65 simulator - 2MM	0,5	0,3	0,5	**0,8**
Xe & UV-filter (2) - 2MM	-0,8	0,0	0,6	**1,0**
Xe & UV-filter (1) - 2MM	0,9	0,1	-2,1	**2,3**
Xe - 2MM	1,8	1,9	-4,0	**4,8**
Tungsten halogen - 2MM	-1,2	-1,6	5,1	**5,5**

Table 1: CIELAB values of the photographic paper for 6 types of sources and colour differences with reference to BAM-2MM-spectrophotometer.

4. CONCLUSIONS

Ordinary spectrophotometry in most cases uses sources of the types unfiltered Xenon lamp or Tungsten halogen lamp. Both types are not suited to measure photographic prints with the intended accuracy. Moreover, customers may use different types of spectrophotometers with opposite irradiation sources, and may find colour differences of the same specimen extending up to 10 CIELAB units. Very clearly, this is a typical source of great debate !

The correct measure with a 2MM-spectrophotometer for many laboratories may be not applicable because of high cost. Also, a good D65 simulator is not available in the market. Insofar, the message may be welcome that Xenon lamps with adjustable UV-filter are good solutions for the intended colorimetric use. However, the correct adjustment of the UV-filter needs the reference of a luminescent specimen with known emittance. Who calibrates them and how long are specimens of this type stable after calibration ? If such an instrument is not at hand, two measures may be done, one with a Tungsten halogen source and a second with a Xenon source, and both measures averaged.

ACKNOWKLEDGEMENTS

Greatly acknowledged are the assistances with instruments by Datacolor, Hunterlab, Labsphere, and Minolta, the provision of photographic prints by K. Richter, the help for measurements by B. Günther and W. Hammmer and the collegial advice by W. Czepluch and K. Richter.

REFERENCES

1. DIS ISO/IEC 19839-2; 2000-04, "Information technology – Office machines – Colour image reproduction equipment, Part 2: Method fir specifying image reproduction of colour devices by digital input and analog output as hardcopy for colour image reproduction devices digital – analog (printers) – Realisation and application."
2. R. Donaldson, "Spectrophotometry of fluorescent pigments", *Brit. J. Appl. Phys.* **5**, pp. 210-214, 1954.
3. D. Gundlach, "Die Zwei-Monochromator-Methode für die Farbmessung an lumineszierenden Proben", *Die Farbe* **32/33**, pp. 81-125, 1985/1986.
4. D. Gundlach, and H. Terstiege, "Problems in Measurement of Fluorescent Materials", *Color Res. Appl.* **6**, pp. 427-436, 1994.
5. ISO/IEC 15775; 1999-12, "Information technology – Office machines – Method of specifying image reproduction of colour copying machines by analog test charts – Realisation and application."

LED Colorimetry

Schanda J[1], Muray K[2], Kránicz B[1]

[1]Laboratory for Colorimetry and Multimedia, University Veszprém, Hungary

[2] Institute for Photometry and Radiometry, CA-USA

ABSTRACT

LEDs (Light Emitting Diodes) become the most important light sources in traffic signal applications, but their use increases in other areas, e.g. indoor and outdoor signals and information boards, now also in general lighting. They become popular also as instrumental radiation sources. LEDs emit in narrow emission bands, and as every semiconductor, their optical characteristics are temperature dependent. In outdoor applications they are exposed to extreme temperatures, influencing both their absolute intensity and their chromaticity.

In the present paper we investigate the spectral power distribution of different types of real LEDs, as well as the change of their spectrum with temperature. The question of measuring these spectra will be re-visited. Instruments tested fall into three categories: high-end double spectrometer, single grating instrument and array type instruments of different quality. These instruments show very different stray light rejection, band-pass, and wavelength accuracy characteristics, leading to non-negligible errors of LED chromaticity if calibration is made with incandescent lamps. Results on the influence of these factors and of spectral bandwidth and sampling rate for measuring modern LEDs will be provided.

Chromaticity will be calculated based on above spectral measurements and colour differences will be evaluated. This becomes a hot topic with present LED cluster construction, as LEDs mounted in a panel side by side have to agree both in chromaticity and luminous intensity to an extent that is below visual acceptability levels.

Keywords: LED spectrum, LED colour, standard LEDs

1. INTRODUCTION

LEDs (Light Emitting Diodes) become the most important light sources in traffic signal applications, but their use increases in other areas, e.g. indoor and outdoor signals and information boards, now also in general lighting. They become popular also as instrumental radiation sources. LEDs emit in narrow emission bands, and as every semiconductor, their optical characteristics are temperature dependent. In outdoor applications they are exposed to extreme temperatures, influencing both their absolute intensity and their chromaticity.

During the past few years many new semiconductor compounds have been developed. Modern LEDs are based on direct bandgap III-V compounds. The four classes of LEDs used at present fall into the categories of GaAsP, AlInGaP, AlGaAs, and (In)GaN. In some cases, e.g. to produce white light, the blue light of GaN LEDs is partly transformed with phosphors into yellow (or green plus red) light. The emission spectra of LEDs available at present differ from those we had encountered ten years ago. Also the spatial dependence of the emission spectrum is an item we had not been dealing with previously.

Three classes of spectrometers have been used in our tests: High-end double monochromator instruments, single grating spectrometers and relatively low end array type spectrographs. This latter class has been included in the investigations because one often hears the claim that with the appearance of these instruments comparing quite favourably in price with tristimulus colorimeters, this type is not recommended anymore for LED colorimetry. The three classes of instruments show very different stray light rejection, band-pass, and wavelength accuracy characteristics, leading to non-negligible errors if calibration is made with incandescent lamps. Also the question of best wavelength sampling has been investigated and a spectral deconvolution is recommended if the spectrometer has bandwidth limitations not permitting realistic sampling below 5 nm.

Based on our investigations we came to the conclusion that if one wishes to calibrate the spectrometer with (primary) incandescent standard lamps, spectrometers with very good stray light characteristics (double monochromators) have to be used. Instruments with lower stray light rejection characteristics or tristimulus colorimeters can perform equally well if LED standards are used as reference calibration sources.

2. LED CHARACTERISTICS

LEDs are semiconductor p-n junction devices, and as for every semiconductor, their electrical and optical properties are temperature dependent. This temperature dependence may change with material composition. The current through a p-n junction depends on the voltage drop and the temperature of the junction:

$$I = I_0 [\exp(eV/nkT) - 1]$$

where I_0 is the saturation current, e the value of the elementary charge, V the p-n junction voltage, n a constant between 1 and 2, depending on the type of recombination taking place, k the Boltzmann constant, and T the temperature of the junction. As light is produced by the recombination of the free current carriers, the light output will also depend on the temperature. Naturally further semiconductor properties also influence the light output, as e.g. the band-gap and the recombination probability depend on the temperature too. Figure 1. shows as an example of a green LED how the spectral power distribution changes with temperature.

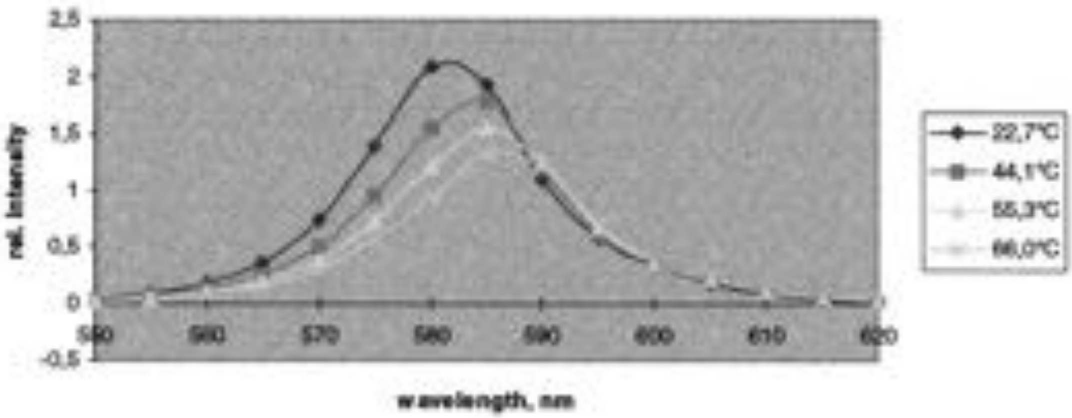


Figure 1: Spectral power distribution of a green LED at different temperatures.

Similar characteristics are found for LEDs of other colour (i.e. other composition).

Older LEDs consisted of a chip that was placed in a reflecting cup and the whole structure was encapsulated in a transparent plastic case. Modern constructions are based on the same principle, only the metal cup is more sturdy, forming a base plate that can serve as a heat sink for the chip, such an LED is seen in Figure 2. New versions of LEDs are introduced almost daily, the most modern tendency being the construction of so called surface mounted LEDs, where the chip is placed in a micro miniature reflector and most of the light guidance is left for external optics. In a restricted solid angle such an LED can be regarded as a point source.

A further version is an LED with a luminescent coating. This luminescent material serves as a wavelength converter: short wavelength (blue) light of the LED is transformed into longer wavelength radiation, enabling the construction of white light emitting diodes. The cross-section of such a white-light LED is seen in Figure 3.

As the spatial emission coming from the LED chip and the phosphor layer will be different, such white-light emitting diodes will have a direction dependent spectral power distribution. Figure 4. shows the u',v' chromaticity of a white-light LED, in the direction of the geometric axis and at 2°, 4°, 6° and 8° off the geometric axis. This shift in chromaticity has to be considered when colorimetric measurements are made on such devices. CIE has standardized two measuring geometries for Average LED Intensity (ALI) measurement[2] that prescribe the measurement in the direction of the geometric axis. No geometry has been agreed upon yet for partial luminous flux measurement, but there seems to evolve an agreement for total luminous flux measurement: measure the LED completly immersed into a photometer sphere, but exclude light coming out at the base (if the base is translucent).

Figure 2: A high output LED, built for several hundred mA drive current.

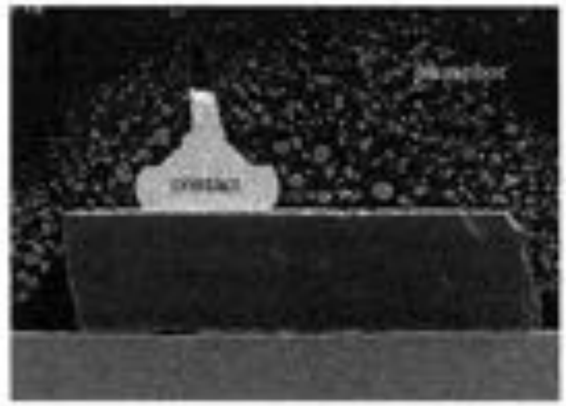


Figure 3: Cross section of a white-light emitting diode.

3. TEMPERATURE STABILIZED STANDARD LED

Based on above described characteristics of LEDs we constructed a new class of temperature stabilized LEDs, where the LED itself, the light engine, has been separated from the emitting part, by introducing between the two a fibre optic element[3](see Figure 5.). This enables to heat-sink the LED properly, but have at the same time an emitting "lamp" well suited both for ALI and total luminous flux measurement.

In these temperature stabilized LED structures, just as in our older constructions, the chip temperature sensing is made by measuring the voltage drop on the LED at constant drive current. Keeping this voltage constant excellent output intensity stability could be achieved[4].

Red, yellow, green, blue and white temperature stabilized LEDs have been used to compare the spectral and colorimetric performance of the different classes of spectral measuring instruments.

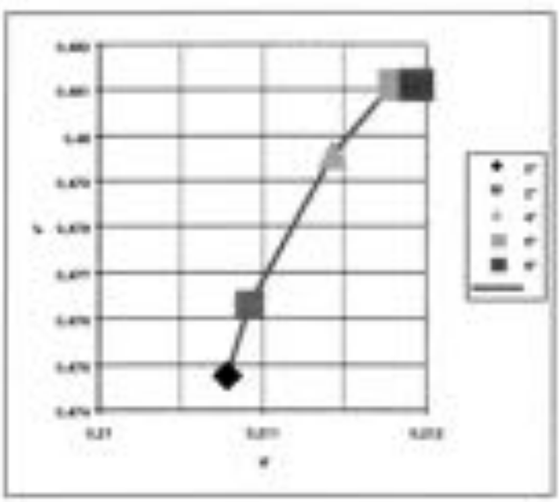


Figure 4: Change of chromaticity of a white LED by tilting the LED.

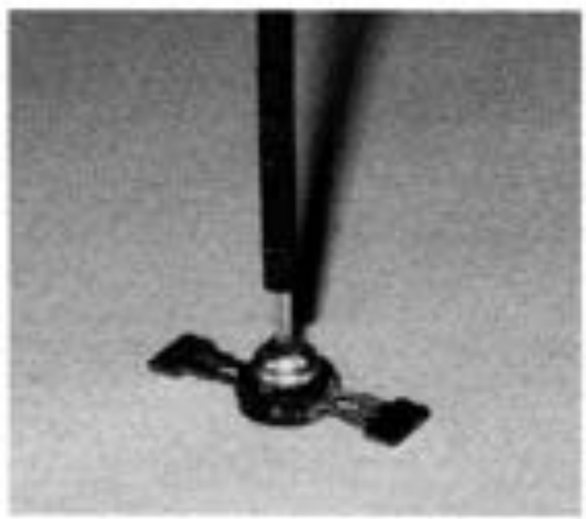


Figure 5: Light engine part of fibre optic LED construction.

4. COMPARISON OF SPECTRORADIOMETERS

A prism plus grating, a single grating and two array detector spectroradiometers have been compared with the NIST double grating spectrometer. Colorimetric characteristics of the detectors have been calculated and deviation of the single instruments from the NIST data determined[3].

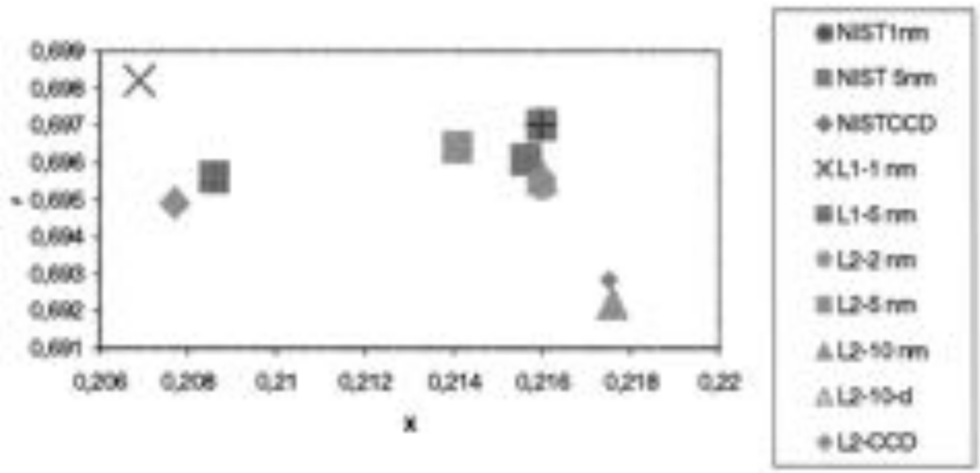


Figure 6: Chromaticity of a green emitting LED measured using the different spectroradiometers.

The NIST 1 nm values have been taken as standard, as seen from the figure the NIST 5 nm values compare excellently, the 1 nm and 5 nm measurements of Laboratory 1 show considerable differences, measurements of Laboratory 2 with 2 nm steps and 5 nm steps are also in a reasonable distance from the „standard" value. The 10 nm step size produced already a larger difference, that could be corrected, however, using a deconvolution technique. The array spectrometers delivered values farther away from the value measured in the standardizing laboratory. Analyzing results of other LEDs as well, one can assume that this is due to the larger stray light in this instrument that produces a deviation between measurement of the narrow band sample and calibration with the broad band incandescent lamp.

Using tristimulus instruments and LED standards of red, yellow, green and blue colour as reference standards, deviations from the standard value (value measured with the spectroradiometer used for calibration) was also only in the order of 0,02 in x,y chromaticity, i.e. colour corrections of tristimulus instruments could be made to a level of the uncertainty of the measurement with the standardizing high level spectroradiometer.

5. CONCLUSIONS

From above one can conclude that the colorimetry of LEDs shows unacceptable interlaboratory differences that might be caused by the higher stray light level of the spectrometers. Using temperature stabilized standard LEDs for calibrating a tristimulus colorimeter can provide measurement results comparable to high end spectrordiometric measurements and definitely more accurate results then can be achieved using low-end array spectrometers.

---

1 Commission Internationale de l'Eclairage, Measurement of LEDs, Publication CIE 127-1999.

2 Schanda J, Schanda G, Muray K, Light emitting diode standards, *2nd CIE Expert symposium on LED measurements*, Gaithersburg, 2001.

3 Muray K, Kránicz B, Ohno Y, Schanda J, Comparison measurements of LEDs: Spectral power distribution, *2nd CIE Expert symposium on LED measurements*, Gaithersburg, 2001.

Advances in color measurement

David R. Battle, Harry Oana and Colman Shannon*, Datacolor International

ABSTRACT

A high-performance, dual-beam spectral analyzer, the SP-2000, has been developed based on active-pixel complementary-metal-oxide-semiconductor (CMOS) technology. Each of the two diode arrays contain 256 pixels. The small size of the analyzer allows it to be used in portable spectrophotometers. A wavelength range from 360 to 780 nm has been achieved with a wavelength resolution of 1.8 nm and a signal-to-noise ratio of 85 dB. Wavelength calibration is done separately from the instrument using eight narrow-band spectral lines. Fiber optics are used to connect the spectral analyzer with an integrating sphere so that areas as small as 3 mm can be accurately measured.

1. INTRODUCTION

Until recently, the spectral analyzers (spectrometers) in most high-grade color measurement spectrophotometers used discrete diode arrays with separate amplifiers and processing electronics in order to get the required signal-to-noise performance. This led to large arrays, 5 mm wide by 40 mm long containing 40 diodes, that in turn led to large spectral analyzers (75 x 75 x 150 mm) and large color-measuring instruments. In addition, complex mechanical alignment techniques were required to obtain satisfactory inter-instrument agreement.

Several years ago Datacolor introduced the MC-90, a high performance, miniature, dual-channel spectrometer based on active-pixel complementary-metal-oxide-semiconductor (CMOS) technology. [1] The MC-90 was significantly smaller (40 mm diameter by 60 mm long with a 128 pixel detector) than previous spectrometers and could fit into a portable color-measuring instrument.

For the last two years, Datacolor has been developing the SP-2000. Similar in design to the MC-90, the SP-2000 replaces the MC-90's 128 pixel array with a CMOS diode array containing 256 pixels. The SP-2000's 256 pixels result in improved signal-to-noise performance, an increased wavelength range and an increased wavelength resolution. In addition, the measurement array and the reference array are both integrated into the CMOS chip eliminating the need for mechanical alignment.

2. DESCRIPTION OF THE SPECTROMETER

The SP-2000 (figure 1) consists of three main parts: the grating, the cylinder and the sensor plate. The spherical surface of the grating is attached to a stainless steel cylinder. A sensor plate is mounted at the other end of the cylinder. The slits and CMOS arrays are mounted in the same plane on the sensor plate. The zero and minus first order reflections from the grating are blocked by blackened baffles. Infrared reflections are blocked with filters in the pickup optics. Second order diffraction from the grating is corrected with the instrumental firmware. Fiber optics are used to interface the SP-2000 to an integrating sphere, providing the ability to measure an area as small as 3 mm.

3. IMPROVEMENTS FROM THE MC-90 TO THE SP-2000

The SP-2000 employs a 256 pixel CMOS array as compared to an array of 128 diodes used by its predecessor, the MC90. This increases the distribution of diodes across a particular wavelength range (see figure 3), and improves the wavelength resolution from 2.6 nm provided by the MC-90, to 1.8 nm. Each diode array in the SP-2000 is 1 mm x 7 mm, and is contained on a single integrated chip, making the mechanical alignment of the measurement array to the reference array part of the chip design. In contrast, separate measurement and reference detector arrays are used in the MC-90, and must be manually aligned during spectrometer assembly.

The SP-2000 spectrometer has excellent light collection capabilities (f/1.6) which can enhance the measurement accuracy for dark colors, and speeds the measurement time. It also improves upon the signal-to-noise ratio of the MC-90, which improves the accuracy of the spectral data. The SP-2000 has a signal-to-noise ratio of 85 dB, while the MC-90 has a ratio of 74 dB. In addition, the SP-2000 combines an aberration-corrected, concave grating with the 256 pixel diode array, which increases its wavelength range over that of the MC-90, from 360 nm – 700 nm to 360 nm – 780 nm. This matches the range recommended by the CIE[2] for most color-measuring applications, and conforms to illuminant/observer weighting tables listed in ASTM E-308[3].

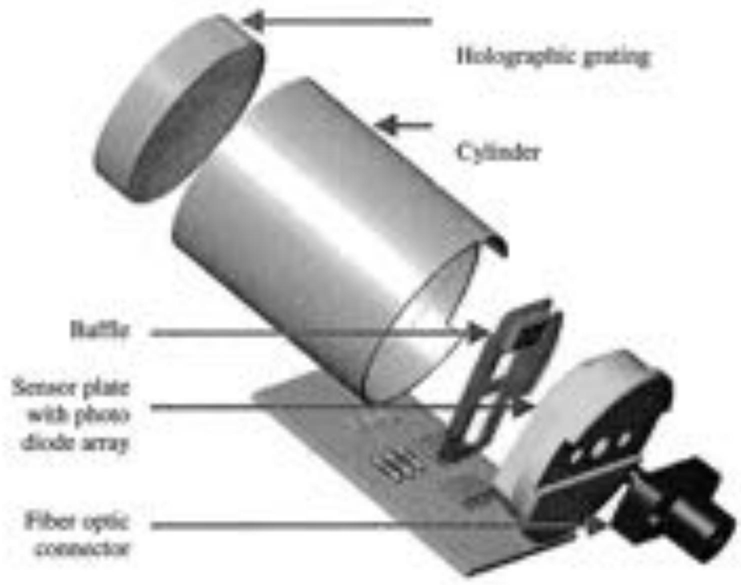


Figure 1. The SP-2000 spectral analyzer

4. ADVANTAGES OF CMOS DETECTORS

Spectrometers based upon detector arrays are preferred for portable instruments since they do not require any moving parts and are quite small. One type of detector array commonly found in commercial and industrial applications (cameras, imaging devices, etc.) uses charge-coupled device (CCD) technology. After the pixels are exposed to light in a CCD array, the CCD transfers each pixel's charge packet sequentially to an output structure, which converts the charge to a voltage, buffers it and then sends it off-chip for further processing. The CMOS detectors chosen for the MC-90 and SP-2000 have three major advantages over the CCD detectors: 1) the ability to integrate the photo diodes with other capabilities such as amplification; 2) a CMOS detector also has the charge-to-voltage conversion built into each pixel, reducing the noise of the 'read out' process; and 3) CMOS detectors require less power to operate than CCD arrays, reducing the operational problems associated with heat build up near the active area of the detector, which is very thermally sensitive. Finally, CMOS detectors do not require the specialized manufacturing processes of CCD array, which reduces the cost.

5. WAVELENGTH CALIBRATION

Errors in wavelength as small as 0.1 nm can lead to color differences in the order of 0.1 CIELAB color difference units. Because of this, the wavelength calibration is a critical step in the manufacture of a spectrophotometer. As with the MC-90, wavelength calibration of the SP-2000 is done after the spectrometer is assembled. It is based on measuring a number of narrow spectral lines across the spectrum and is not dependent on the use of material standards. Two high power spectral lamps are used in the calibration – a mercury-cadmium lamp and a helium lamp. The lines that the lamps emit have a high signal-to-noise ratio and are clean, that is they do not have interfering lines present within the bandpass range. Eight lines from the lamps are spread uniformly across the spectral range of the analyzer. Table 1 lists the centroid wavelengths for the spectral lines, and figure 2 illustrates their spacing across the spectrum. For each line, the data from each pixel in the array is recorded as a set of digitized diode photocurrents (counts). The centroid of the instrument bandpass function for each spectral line can be determined by fitting the line in pixel space. Thus pixel numbers can be associated with each of the eight lines. Increasing the number of pixels used to define the spectral peak results in a more accurate centroid value. Figure 3 illustrates the improvement in pixel density of the SP-2000 compared to the MC-90.

Line number	Line source	Centroid wavelength (nm)	Line number	Line source	Centroid wavelength (nm)
1	Mercury	404.656	5	Helium	587.562
2	Mercury	435.833	6	Cadmium	643.847
3	Cadmium	508.582	7	Helium	667.815
4	Mercury	546.074	8	Helium	706.519

Table 1. Centroid wavelengths of the spectral calibration lines

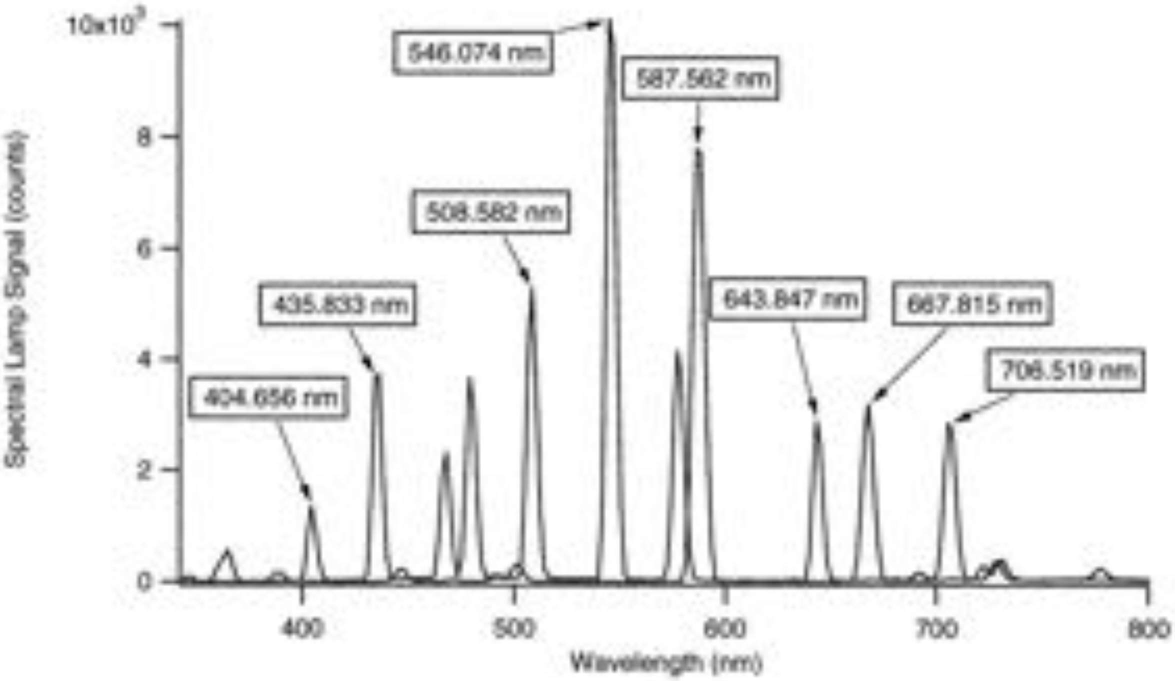


Figure 2.. The spacing of the eight wavelength calibration spectral lines across the spectrum

During the calibration procedure the grating dispersion equation is fitted to the centroids in order to assign each diode a corresponding wavelength. The fitted dispersion equation is then used to calculate the wavelengths that correspond to the center of each pixel to create a wavelength table for the array. The result is a spectrophotometer that achieves an inter-instrument agreement of 0.1 CIELAB units with a wavelength resolution of 1.8 nm.

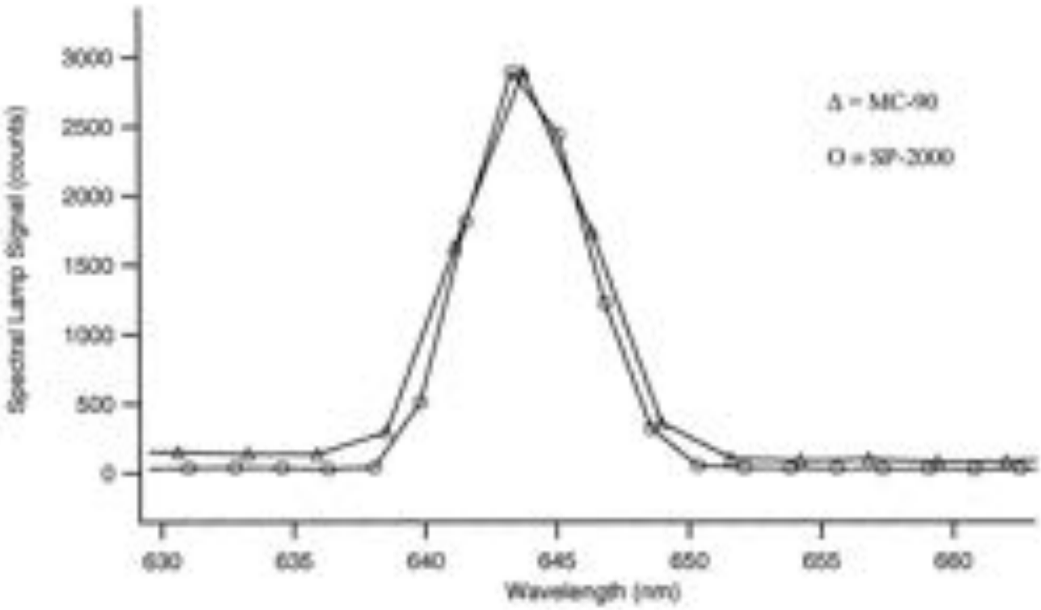


Figure 3. The lamp signal per pixel for the 643.847 nm cadmium peak

SUMMARY

The SP-2000 is a high-performance, dual-beam spectral analyzer based on active-pixel complementary-metal-oxide-semiconductor (CMOS) technology. It represents a significant improvement over the charge-coupled device (CCD) technology used in many instruments and expands upon the CMOS technology first introduced by Datacolor in the MC-90 spectral analyzer. Both the measurement photo diode array and the reference photo diode array are integrated onto a single chip. By integrating both arrays onto one chip, the need for a mechanical alignment during assembly is eliminated. A holographic grating combined with the 256 pixel photo diode arrays allows a wavelength range of from 360 to 780 nm with a wavelength resolution of 1.8 nm and a signal-to-noise performance of 85 dB. The excellent light collection capabilities (f/1.6) of the spectral analyzer used with a fiber optic interface to the sphere allows areas as small as 3 mm to be measured accurately. Wavelength calibration is done separately from the instrument using eight narrow-band spectral lines. This calibration technique using a 256 pixel photo diode array is highly accurate, achieving an inter-instrument agreement of 0.1 CIELAB units.

REFERENCES

1. H. Oana, L. Jahreiss, D. Rich, and S. Trost, "Development and characterization of a miniature dual-channel spectrometer for spectrocolorimetry", *SPIE* **1681 Optically Based Methods for Process Analysis**, pp. 12-28, 1992.

2. Commission Internationale de l'Éclairage, Publication CIE No. 15.2, *Colorimetry*, 2nd ed., Central Bureau of the CIE, Vienna, 1986.

3. "ASTM E 308-99 Standard practice for computing the colors of objects by using the CIE system", *Annual Book of ASTM Standards*, Vol. 6.01, American Society for Testing and Materials, West Conshohocken, PA. 2001.

---

* Correspondence: cshannon@datacolor.com; phone 609-895-7492; fax 609-895-7461; Datacolor International, 5 Princess Road, Lawrenceville, NJ 08648.

Comprehensive Comparison Between Different Mathematical Models for Inter-instrument Agreement of Reflectance Spectrophotometers

Sidney Y. S. Chung*, John H. Xin* and K. M. Sin*

ABSTRACT

In color-related industry, reflectance spectrophotometers are one of the most popular equipment for evaluating the color quality and color difference. Currently, manufacturers claim that the measurement difference between different models of spectrophotometer was lower than 0.1 CIELAB ΔE units. But in our investigation, the color difference values range from 0.5 to 0.8 CIELAB ΔE units, which implies that the correction models must be applied to correct such errors. In our investigation, two models were also developed, so call "Lab Model" and "R-Model". These two models only involve simple regression calculation and the results also showed significant improvement. A comprehensive comparison between those models and the previously reported models is made. The comparison involves the use of BCRA-NPL Series II tiles as the calibration data and the testing is based on the Color Curve Paper Samples.

1. INTRODUCTION

Currently, color-related industries, such as textile coloration, painting or printing, etc., are very much dependent on the color measurement results in order to evaluate color quality of their products. Thus, the spectrophotometer measurement becomes far more important comparatively. According to our previous study, it was found that the reproducibility of the two top-end dual beam spectrophotometers varied from 0.164 to 1.292 CIELAB ΔE units. This showed that even for the machines with the same measurement mode, there is still variation between them. In this paper, the reproducibility of the measurement of the MATT type of BCRA CCS II tiles and the testing of the different mathematical model using ColorCurve Paper Samples were reported.

2. REPRODUCIBILITY OF THE SPECTROPHOTOMETERS

In this study, two different spectrophotometers for the color measurement were selected.

- COLOR-EYE® 7000A (CE-7000A) from GretagMacbeth®
- Spectraflash® 600 PLUS-CT (SF-600) from Datacolor International®

According to our continuous assessment between the above two spectrophotometers, the variations of reproducibility between the two dual beam spectrophotometer are listed in the table below:

Table 1. The average CIELAB color difference between the two spectrophotometers CE-7000A and SF-600.

	CE-7000A vs SF-600			
Tiles	GE[1]	GI[2]	ME[3]	MI[4]
Average	0.828	0.707	0.671	0.574

Note:

[1]The GLOSSY CCS-II tiles measured under the condition of the specular component excluded

[2]The GLOSSY CCS-II tiles measured under the condition of the specular component included

[3]The MATT CCS-II tiles measured under the condition of the specular component excluded

[4]The MATT CCS-II tiles measured under the condition of the specular component included

3. EXPERIMENTAL

According to the above table, it was found that the reproducibility between the about two top end spectrophotometer was unacceptable. Thus different mathematical models were developed in order to improve this poor result. The most popular one was "Berns and Petersen's Model" [1]. And in our study, two new models were also developed, one is "Lab Model" [2] and the other one is "R-Model" [3]. Based on these three models, the reproducibility between the tiles were significantly improved.

3.1 Instrument Settings

The instrument settings should be set according to the following.

- large area of view;
- wavelength range: 400nm to 700nm at 10nm intervals

Since all the spectrophotometers are sphere type. In this paper only the specular component excluded (SCE) were discussed.

3.2 Experimental Samples

MATT BCRA CCSII tiles were treated as the calibration samples and also the ColorCurve Paper Samples were treated as the testing samples

3.3 Sample Conditioning

Because of the thermo-sensitivity of the CCS II tiles and the ColorCurve Paper Samples, all the those samples and reflectance spectrophotometer were well conditioned in our control laboratory to avoid the temperature and the humidity change which may affect the measurement result.

3.4 Instrument Calibration

Before measurement of the tiles, all color measuring instruments should be allowed to warm up for the period recommended by the instrument supplier. In addition follow the instrument set-up in section 3.1, the instrument should be well calibrated according to the manufacturer's guide by using the black and white standards provided by the manufacturers.

3.5 Measurement Procedure

Each tile and paper Samples should be measured once at the center position for spectral reflectance factor from 400nm to 700nm at 10nm intervals. Average CIE ΔE^*_{ab} were reported (Illuminant D_{65}, 10° standard observer).

3.6 R-Model Development

Concerning "R-Model", it was developed based on the "Basspass Correction" method and the using of the linear regression method also. And the foundation equations for "R-Model" were summarized below:

At 400nm

$$\text{Corrected } R_{(400)} = n \times R_{(400)} + o \times R_{(410)} + q \text{ —— EQ.1}$$

At 410nm – 690nm

$$\text{Corrected } R_{(\lambda)} = m \times R_{(\lambda-1)} + n \times R_{(\lambda)} + o \times R_{(\lambda+1)} + q \text{ —— EQ.2}$$

At 700nm

$$\text{Corrected } R_{(700)} = m \times R_{(690)} + n \times R_{(700)} + q \text{ —— EQ.3}$$

where m, n, o and q are constant.

4. RESULTS AND DISCUSSIONS

After applying the measurement data to the above three mentioned models, the inter-instrument agreement (Reproducibility) between the two spectrophotometers was summarized in the table below:

Table 2: Inter-instrument agreement in terms of ΔE using the 12 MATT BCRA-NPL series II tiles in SCE Mode

		Berns and Petersen's Model		Lab Model		R Model	
Tiles	Un-corrected ΔE	Corrected ΔE	% Improvement	Corrected ΔE	% Improvement	Corrected ΔE	% Improvement
Pale Grey	0.577	0.478	17.226	1.005	-40.311	0.094	83.709
Middle Grey	0.434	0.393	9.450	0. 299	31.152	0.066	84.793
Diff. Grey	0.419	0.375	10.564	0. 243	41.934	0.069	83.532
Deep Grey	0.209	0.173	17.048	0.209	0.027	0.092	55.981
Deep Pink	0.649	0.056	91.373	0.068	89.510	0.086	86.749
Red	0.711	0.115	85.251	0.138	82.288	0.067	90.577
Orange	0.909	0.022	94.669	0.049	88.262	0.076	91.639
Bright Yellow	0.716	0.092	89.185	0.111	86.988	0.242	66.201
Green	0.854	0.110	74.561	0.166	61.753	0.159	81.382
Diff. Green	0.78	0.374	58.906	0.492	45.919	0.234	70.000
Cyan	0.923	0.201	65.126	0.286	50.413	0.169	81.690
Deep Blue	0.871	0.421	40.840	0.499	29.824	0.241	72.331
Average ΔE	**0.671**	**0.314**	**54.517**	**0.347**	**47.313**	**0.133**	**79.049**

From table 2, we can conclude that the "R Model" shows a better performance in inter-instrument agreement, the average % improvement shows about 79% which is better that "Berns and Petersen's Model" and also "Lab Model".

In addition to the MATT tiles, 400 ColorCurve Paper samples were also selected to evaluate the performance of the three models, and the distribution of the color difference before and after correction are shown below

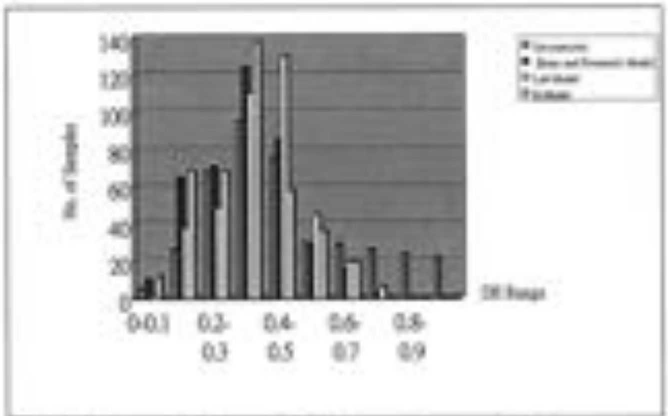


Fig 1. The distribution of the color difference before and after inter-instrument of the paper samples by using the MATT tiles as calibration data

From Figure 1, it is seen that the color difference are improved after applying the correction models and the distribution of the ΔE shift to lower values. Concerning the "R-Model", it can see that the color difference mainly distribute at the range of 0.1 – 0.4 and for the "Berns and Petersen's Model", the color difference were mainly distribute at the range of 0.1-0.5. Thus it showed that the "R-model" shows better correction result when compare with "Berns and Petersen's Model". For the "Lab Model", as it was developed based on the colorimetric data, L*, a* and b*, thus the correction results were not so good compare with the rest two models.

5. CONCLUSION

In general, after applying the three models, the color different was shift to the lower values and "R-Model" shows better improvement compare with the rest two models. In addition, as discuss before, the "R-Model" were developed based on the "Basspass Correction", it showed that "Basspass Correction" was one of the correction method to correct the reflectance data. And also "R-Model" involved just only the sample linear regression, it was better than the other models involved many multiple regression calculations.

ACKNOWLEDGE

The authors wish to acknowledge a studentship received from The Hong Kong Polytechnic University Postgraduate Research Grant.

REFERENCES

1. Berns R. et al., An Abridged Technique to Diagnose Spectrophotometric Errors, Color Research and Application, Vol. 22, No. 1, P.51-60, Feb. 1997

2. Chung S.Y.S., New Regression Models for The Measurement of Textiles by Spectrophotometer, Proceedings ATC'99, The 5th Asian Textile Conference, Vol. 1, P. 289-292
3. Chung S.Y.S., Study of New Regression Model for Inter-Instrument Agreement, COLOR 2000, P.31 – 33

*Correspondence: tcrachys@inet.polyu.edu.hk; phone: 852-2766-6520; fax: 852-2773-1432; Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

Harmonisation of scales of colour measurement

Peter J. Clarke* and Andrew R. Hanson, National Physical Laboratory, London, UK

ABSTRACT

Surface colour measurements are important in a large range of industries (e.g. printing, textiles, paints and foodstuffs), and a reduction in associated uncertainties is needed to improve competitiveness in the trading of coloured goods. One of the major uncertainties is due to the difference between measurement scales of national laboratories. A harmonisation process co-ordinated by the National Physical Laboratory (NPL) was set up to reduce errors in colour measurements with a target such that 95% of the results should agree to within 0.5 CIELAB colour difference units (ΔE^*_{ab}). Nine laboratories took part in the harmonisation process. A wide range of instrumentation was used ranging from commercially available instruments to specially developed facilities. Three of the laboratories also looked at fluorescent colour measurement using the two-monochromator technique. The co-ordinator had developed techniques for determining and correcting errors in colour measurements as well as a range of transfer standards for colour as part of a national research programme. Although not all the possible errors for the measurement of colour have been addressed 93% of the measurements agreed to within 0.5 ΔE^*_{ab}.

Keywords: colour measurement, colour scales, reflectance, radiance factor, fluorescence, harmonisation

1. INTRODUCTION

1.1 Background

Industry needs to be able to measure colour within the colour discrimination limits of the human eye, about 0.5 ΔE^*_{ab} units. An earlier European intercomparison[1] of surface colour measurements showed that 50% of colour measurements made by national standards laboratories did not agree within this limit. This is not adequate for industrial requirements. One of the major uncertainties is due to the difference between measurement scales of national laboratories. This could contribute 0.2 ΔE^*_{ab}. In this harmonisation process measurements were normalised to the same scale. A harmonisation process was set up to reduce errors in colour measurements with a target such that 95% of the results should agree to within 0.5 ΔE^*_{ab}. Nine laboratories, some national laboratories and the rest commercial laboratories, took part in the harmonisation process. Commercially available instruments to specially developed instrumentation facilities were used. Three laboratories also used the two-monochromator technique to look at fluorescent colour measurement.

This paper is one of three presented at this conference using information from the same project. The other two describe the sources of error and the correction process[2], and a method for the determination of uncertainty in surface colour measurement[3].

1.2 Review of objectives and strategic aspects

The main objective of the project was to harmonise colour measurements, to achieve a target of 95% agreement within 0.5 ΔE^*_{ab} units for non-fluorescent colours. This was to be achieved through the use of a common agreed methodology for determining and correcting errors in colour measurement and tested through an intercomparison. A second objective was to extend the capability for measurement of fluorescent safety colours using the two-monochromator method to three countries within the European Union, and carry out an intercomparison of fluorescent coloured materials to meet the metrological requirements of EN471, Specification of High Visibility Warning Clothing. This standard specifies performance tolerances for the colour of fluorescent safety clothing.

Three years ago a survey of industrial needs for colour measurements in the United Kingdom highlighted the problem of disagreements over the results of colour measurements. 30% of respondents stated disagreement between measurements made in different laboratories and instruments was their biggest problem in colour measurement. In June 1998 the CIE published a model for specifying colour appearance to be used in industries where design work is carried out on a computer controlled visual display unit and printed subsequently on paper or textiles[4]. This will increase the demands for accurate measurement of both visual display colour and surface colour.

2. WORK PROGRAMME

NPL has developed techniques for determining and correcting errors in colour measurements as well as a range of transfer standards for colour measurement as part of a national research programme. The procedures to be used to achieve harmonisation of measurements to the required level were discussed during a meeting of all the partners and a methodology for determining and reducing colorimetric errors was established. Thirteen steps in the harmonisation and correction process were agreed between the laboratories:- errors in absolute scales of diffuse reflectance and 0°/45° radiance factor, errors due to differing properties of white reference standards, non linearity of the photodetector, incorrect zero level, wavelength scale error, specular beam exclusion error (gloss trap error), specular beam weighting error, errors due to non-uniformity of collection of integrating spheres, polarisation errors in the 0°/45° geometry, differences in methods for calculating colour data from spectral data, geometry differences between illumination and collection optics within the specified limits, errors due to thermochromism in samples and errors due to the dependence of spectral resolution on bandwidth, scan speed and integration time. These stages are summarised elsewhere[1]. Corrections were applied in the case of ten of these steps. For the remaining three, the effects were investigated and uncertainties ascertained, but no corrections were made.

Following the determination and correction of errors, each partner made measurements on 16 non-fluorescent ceramic tiles: 8 glossy and 8 matt. The colours were red, green, bright yellow, cyan, deep blue, pale grey, mid grey and black. Measurements were made in three CIE defined geometries:- specular included, specular excluded and 0°/45°, over as much of the spectral range 380 to 780 nm as possible. All tiles were measured at NPL prior to dispatch to the other laboratories. Due to the large amount of data collected during the intercomparison, it was necessary to reduce this in some way for the purposes of analysis. It was therefore decided that the intercomparison should be primarily concerned with colorimetric data. Comparison of colorimetric data was made using CIE Standard Illuminant D_{65} and the CIE 10° Standard Observer. For most partners the ambient temperature of measurement was 23 ± 1°C.

For the fluorescent measurements, sets of 5 fluorescent samples, white, red, orange, yellow, green and one non fluorescent sample, grey, were produced by Bundesanstalt für Materialforschung und-Prüfung (BAM). Three laboratories made measurements on the samples. A set of samples was also measured by NRC Canada. Some of the measuring instruments are described elsewhere[5,6,7]. The two-monochromator method (as opposed to a spectrophotometric method) was used as the spectral power distribution of daylight D_{65} is included at the calculation stage and does not need to be simulated An earlier European intercomparison of fluorescent demonstrated the superiority of the two monochromator method over spectrophotometric methods[8]. With the spectrophotometric measurement of fluorescent colours the spectral power distribution of D_{65} must be simulated by a practical source.

3. PROJECT ACHIEVEMENTS AND CONCLUSIONS

3.1 Non-fluorescent colours

Partners supplied four sets of results data:- 1 data corrected for zero error and normalised to the common scale, 2 data corrected for previous errors and wavelength errors, 3 corrected for previous errors and sphere errors and 4 corrected for previous errors and linearity errors. At each stage of correction the colorimetric difference between the partners' ($_{pa}$) values for the samples and NPL's values ($_{NPL}$) for the samples were calculated using:-

$$\Delta E^*_{ab\,pa} = [(L^*_{NPL} - L^*_{pa})^2 + (a^*_{NPL} - a^*_{pa})^2 + (b^*_{NPL} - b^*_{pa})^2]^{1/2} \quad (1)$$

The average ΔE^*_{ab} for all laboratories was found, and then the differences ($D\Delta E^*_{ab\,pa}$) between each partner's tile $\Delta E^*_{ab\,pa}$ and the average ΔE^*_{ab} were found. This method generates a range of values about a mean. The range gives a good indication of the degree of agreement between partners.

The percentage of $D\Delta E^*_{ab\,pa}$ values <= 0.5 for each stage of correction are given in Figure 1. This shows how, in most cases, agreement increases as each correction is applied. There is some drop after the wavelength corrections are applied due to small increases (<0.05 $D\Delta E^*_{ab\,pa}$) on a couple of tiles taking the values just over the 0.5 ΔE^*_{ab} limit. The spread of agreement after full corrections have been made is shown in Table 1.

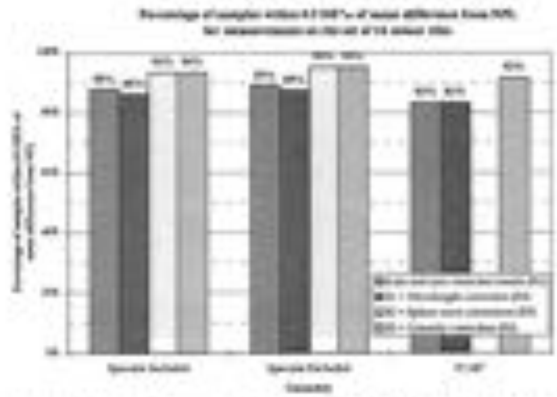


Figure 1. Percentage of samples within 0.5 ΔE^*_{ab} of mean difference from NPL.

Agreement	Geometry		
	Specular Included	Specular Excluded	0°/45°
< 0.75 ΔE*ab	100%	100%	100%
< 0.5 ΔE*ab	94%	95%	92%
< 0.2 ΔE*ab	69%	63%	65%

Table 1 Percentage of fully corrected samples within specified agreement.

To understand which factors influence ΔE^*_{ab} the differences in ΔL^*_{ab} and ΔC^*_{ab} were also compared in a similar way. It was found that for neutral tiles ΔL^*_{ab} dominates. For chromatic tiles there is no significant difference between the spreads of DL* and DC*. This is because the most significant source of error (i.e. linearity) for neutrals will not affect chroma. The same linearity errors will be present for chromatic tiles but additional wavelength errors will also contribute. These will not always be in the same direction as the linearity errors.

3.2 Fluorescent colours

The results from the 3 laboratories, including NPL, making fluorescent measurements give the differences in Table 2.

Sample	Colorimetric difference from NPL ΔE^*_{ab}	
	Laboratory A	Laboratory B
White	0.93	1.69
Red	6.08	3.96
Orange	4.33	3.63
Yellow	3.40	3.72
Green	4.27	2.04
Grey	0.42	0.47

Table 2 Colorimetric differences from NPL for 5 fluorescent colours and 1 non-fluorescent colour (grey).

The accumulated colour difference ΔE^*_{ab} between the different sets of samples used is negligible compared to the difference between the partners. The uncertainties (coverage factor k=2) of the results estimated by the partners are between 1 to 2 units to 1 to 20 units depending on the sample.

To minimise the differences in colour measurement it is recommended that the following are standardised: the optical parameters of the instrument; the wavelength range and the wavelength step used; the definition of a special non-fluorescent sample for calibration at 0% reflection and 0% fluorescence; the definition of a special sample for calibration at 100% reflection and with calibrated high fluorescence for several combinations of exciting and measuring wavelengths; the definition of the method for mathematical evaluation of the data, e.g. taking into consideration the differences in the bandwidth effect between one-monochromator and two-monochromator instruments or separating reflection and fluorescence by calculation.

4. CONCLUSIONS

Although not all possible errors for the measurement of colour have been addressed, the error correction method employed has considerably improved the agreement between the measurements carried out by the partners for the 16 tiles. Overall, 93% of the measurements made by all the partners for all the non-fluorescent samples agreed within 0.5 ΔE^*_{ab} following the correction process. This result fell slightly short of the target set at the outset of the project but is considerably better than the agreement achieved in previous intercomparisons.

Comparing ΔL^*_{ab} and ΔC^*_{ab} for neutral and chromatic tiles shows that ΔL^*_{ab} dominates for neutral tiles and that there is no significant difference between the spreads of ΔL^*_{ab} and ΔC^*_{ab} for chromatic tiles.

There is still some further work required to investigate some of the outstanding errors that were not addressed within this project. In particular more work will be required to gain a better agreement for the 0°/45° geometry. Partners are agreed that additional research is needed to further reduce colorimetric uncertainties and that the results of spectral measurements will be required to get a full understanding of all the errors involved.

The derivation and specification of uncertainty in measurement is an important aspect of the harmonisation process. It became clear throughout the project that a standard means of determination of uncertainty was of great importance. The magnitude of uncertainty is of similar size to the agreement. Future work on the improvement of the agreement must go hand in hand with work on the reduction and standard methods for determining uncertainties.

Differences between laboratories for fluorescent sample measurements were at least a factor of 10 greater than for non-fluorescent colours. This has direct consequences on the European Standard CEN 471 "Specification of High Visibility Warning Clothing" and other specification standards and should be taken into account when the standards are revised.

ACKNOWLEDGEMENTS

The authors were in the co-ordinator team for this work and are indebted to others who were involved in the project from: Consejo Superior de Investigaciones Cientificas, Portugal; Bundesanstalt für Materialforschung und-Prüfung, Germany; University of Joensuu, Finland; Laboratoire Nationale d'Essais, France; Centro de Ciencias e Technologias Opticas, Spain; Swedish National Testing Research Institute Ltd; British Ceramic Research Ltd and DELTA - Danish Electronic Light and Acoustics.

REFERENCES

1 J. F. Verrill, *Intercomparison of colour measurements, Synthesis Report* European Commission, Report EUR 14982 EN, 1993.

2 P. J. Clarke and A. R. Hanson, "The determination and correction of errors in surface colour measurement", AIC Color 2001 proceedings.

3 A. R. Hanson and P. J. Clarke, "The determination of uncertainty in spectrophotometric surface colour measurement", AIC Color 2001 proceedings.

4 The CIE 1997 Interim Colour Appearance Model (Simple Version), CIECAM97s, CIE Publication 131, Vienna, Austria, 1998.

5 D. C. Williams, "Fluorescent Standards for Surface Colour", *NPL Report QU 111*, National Physical Laboratory, Teddington UK, 1995.

6 D. Gundlach, "Die Zwei-Monochromatoren-Methode für die Farbmessung an Lumineszierenden Proben", Die Farbe **32/33** 1985/86.

7 J. C. Zwinkels, F. Gauthier, "Instrumentation, standards, and procedures used at the National Research Council of Canada for high-accuracy fluorescence measurements", *Analytica Chimica acta* **380**, pp 193-209, 1999.

8 D. Gundlach;G. Döring and K Mäder, *Intercomparison of measurements of the total spectral reflectance factor of luminescent colours for standard illuminant D65 BCR project MTR-60*, European Commission, Report EUR 12378 EN, 1989.

*Correspondence: peter.clarke@npl.co.uk; telephone +44 20 8943 6406, fax. +44 20 8943 6458; http://www.npl.co.uk; National Physical Laboratory, Queens Road, Teddington, Middlesex, TW11 0LW, United Kingdom.

Goniochromatic color measurement systems – the past 20 years

P.W. Gabel, Merck KGaA

ABSTRACT

During the past 20 years, many changes have occurred in the color measurement systems, due to new effect pigments. Both effect pigment suppliers including the paint industry and manufacturers of color measurement systems have been affected by these changes. MERCK, as the leading manufactor of effect pigments, has in recent years played a significant part in promoting the development of color measurement equipment. This paper reviews the development of goniochromatic color measurement systems from 1980 to state of the art. Furthermore, MERCK improvements in instrument performance and a new color measurement system will be presented.

Keywords: color measurement, effect pigments, goniospectrophotometer, quality control

1. INTRODUCTION

Many industries, notably the automotive, printing, plastics and cosmetics industries, would not be what they are today if it were not for special effect pigments. Looking at the past, stylists started with conventional metal pigments, like aluminum or bronze pigments, followed by pearlescent pigments, also know as mica pigments, pearl pigments or mineral effect pigments. In the last two years a new generation of effect pigments has become more and more popular. They are based on innovative substrates, like silika flakes or alumina flakes, ultra-thin multilayer interference film flakes and crosslinkable liquid crystal silicones Table1. They are used to make an object distinctively appealing. Effect pigments fulfill this requirement admirably because of their gonioapparent nature, e.g., the change in their appearance with the change in angle of illumination or view.

1. Generation		
metal pigments	METALURE	ECKART, SILBERLINE
pearlescent (mica) pigments	IRIODIN, AFFLAIR	MERCK
	MEARLIN	ENGELHARD
2. Generation		
silika flake pigments	COLORSTREAM	MERCK
alumina flake pigments	XIRALLIC	MERCK
multilayer film pigments	CHROMAFLAIR	FLEX,
	VARIOCROM	BASF
liquid crystal silicones	HELICONE	WACKER

Table 1: Trademark and manufacturers of effect pigments [1 – 5]

2. COLOR MEASUREMENT

Color measurement and color measurement management will play key role in quality control in the paint industry in the next years.The reason for this is twofold:

- First, paint accepted by instrumental color data of the suppliers is becoming an increasingly important cost factor for company's competitiveness.
- Second, the exchange and transfer of data between suppliers and clients is not only a question of information, but just as much a question of corporate culture, trust, and mutual respect.

Furtherone national and international standard organisations like DIN or ASTM have now finished to specify conditions for the uniform characterization of special effect pigments. However, the development of new effect pigments of the second generation requires new color measurement concepts.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

2.1. Color measurement systems – from the historical point of view

„Colorimetry is currently undergoing a rapid change". GERLINGER chose this headline for his editorial in 1992 [6]. A headline which is present also in 2001. However, what has happened on the market since this time? Manufacturers of color measurement systems has developed new equipements. But are these developments realy helpfull? Until 1992 there has been so far no recommendation for a standard under which and how many angles metallic finishes have to be determined in order to ascertain the effect as well as the color. This long delay may have beem the reason why the development of goniospectrophotometers proceeded in different directions, although the way was shown already in 1974 with the „Trilac" by CERES [7]. This way was realized by HOFMEISTER [8] with a modified three filter instrument made by „Hunterlab".This tilt concept was adapted by RÖSLER [9] with the „Macbeth Color-Eye5010", formerly the „Johne and Reilhofer ER10". Mobile spectrocolorimetry was possible for the first time to establish the colorimetric characteristics of large samples, such as car bodies. A first comparison study of other color measurement systems from manufacturers like „Datacolor MMK 111/GK 111", „Zeiss MCS 333/GK 311M", „Optronik Multiflash M45", „Minolta" and „Phyma Codec Wi5", was done by GABEL in 1992 [10,11]. Based on this investigation the main objections were :

- from the physical point of view ,the special characteristics of mica pigments require special measuring geometries and methods of evaluation,
- experts agree that classical colorimertic determination with standard geometries (d/8° (sphere) or 45° / 0° (directional)) do not provide reliable results for a complete colorimetric description of interference pigments and their applications.
- at least two measuring geometry groups are necessary in order to be able to characterize pearlescent pigments
- colorimetric results are in agreement with visual assessment.

The studies show the measuring geometries of the day to have been generally only adequate for the first-generation of effect pigments; nevertheless, there were a small number of problem pigments that were not amenable to spectrophotometric testing [12]. For the new modern, second-generation of effect pigments, extensive angle-dependent spectrophotometric testing is an absolute necessity.

2.2. Goniospectrophotometer, state of the art - an angle-dependent overview

Various companies produce angle-dependent spectrophotometers. The "GretagMacbeth Auto-Eye 642" illuminates the surface from an angle of 45° and offers viewing angles of 25°, 45°, 75° and 110° (aspecular angles). The "X-Rite MA68II", too, illuminates at 45°; in this instrument the viewing angles are 15°, 25°, 45°, 75° and 110° from gloss. With their fixed angle of illumination and their optional viewing angles, the two instruments are very similar. The "Minolta" and "Optronik" spectrophotometers, on the other hand, illuminate at various angles and measure at a single, fixed angle. With an observer of 0°, the "Minolta CM-512m3" measures under 25°, 45° and 75° circular illumination; the "Optronik MultiFlash" measures at 45° under illumination in eight geometries ranging from 25° to 115°. The effect angle in the latter case changes from the trans to the cis position within the geometric series. Fig. 1. The same effect angle can thus be based on various measuring geometries and thus describe different color sites.

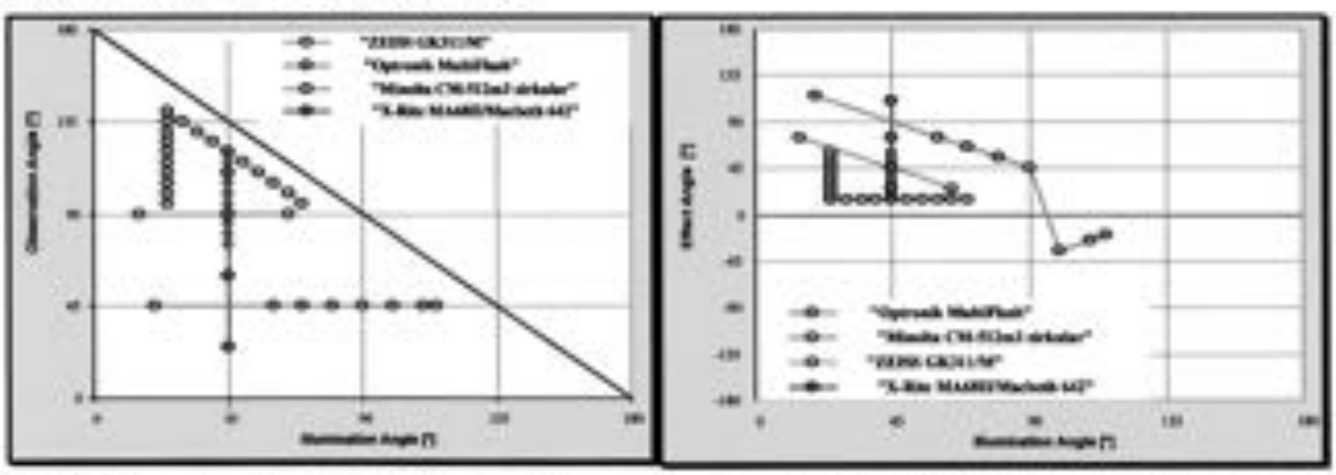


Figure 1: Schematic comparison of the geometries of various measuring systems: The "Zeiss GK 311/M" measures under constant illumination or a constant aspecular angle. The "X-Rite" and "GretagMacbeth" instruments measure under constant illumination; the "Optronik MultiFlash" measures from a constant viewing angle under various illumination angles, the effect angle being cis or trans to the specular angle.

The "Phyma WICO 5&5" System measures under 22.5° and 45° illumination, offering 67.5°, 0°, -22.5°, -45° and -67.5° viewing and a large measuring spot. The five pre-sets between 0° and 180° (relative to the horizontal) provide virtually ideal pigment definition. The "Murakami GCMS-3" provides complete definition in 1° steps. The instrument features illumination from 16° to 180° and observation up to 196° (transmission). Totally variable reflectance and transmittance measurements from 0° to 360° can be achieved with the "GON 360" from "Instrument Systems". For comparison of results, the "Zeiss GK 311/M" multi-angle instrument was used, though this is no longer manufactured. In it, it is possible to set both the angle of illumination and the viewing angle independently of one another in 5° steps. However, the limit of the minimum illumination angle is 25° (horizontal) and the maximum viewing angle 155°.

2.3. Comparison results of goniospectrophotometer

2.3.1.Colorstream Ti-Pigment

This pigment is one of the second-generation innovative types based on thin flakes of silica (SiO_2). The color changes from violet to green at a constant effect angle of 15°.[13] The effect lines (aspecular shift) under 25° and 45° illumination are tending towards the same point. It can be clearly seen that the aspecular shift at 45° shows good agreement in both instruments Fig.2a. However, it also becomes clear that the instrument with the fixed illumination angle of 45° cannot adequately display the broad color bandwidth of the pigment.

2.3.2 ChromaFlair 190

This pigment changes from yellow to green via red, violet and blue when the angle of illumination is changed while the aspecular angle is kept constant[13,14]. When the illumination angle is kept constant, the color changes to dull. Fig.2b.
The area that is described by the color changes can be well presented in the a*b* diagram. Although the CIELAB system, strictly speaking, is only applicable for showing color differences , it is nevertheless useful for demonstrating color effects. The Zeiss GK 311/M cannot clearly register visual impressions of color. Since its design does not permit illumination angles flatter than 25°, the visual impression of yellow at < 25° can no longer be measured.
While all of the measuring instruments register the color change at 45° illumination or observation in more or less the same way, the positions of the data points with the Minolta are much more conspicuous here. The reason is,this instrument changes the angle of illumination and the aspecular angle simultaneously.

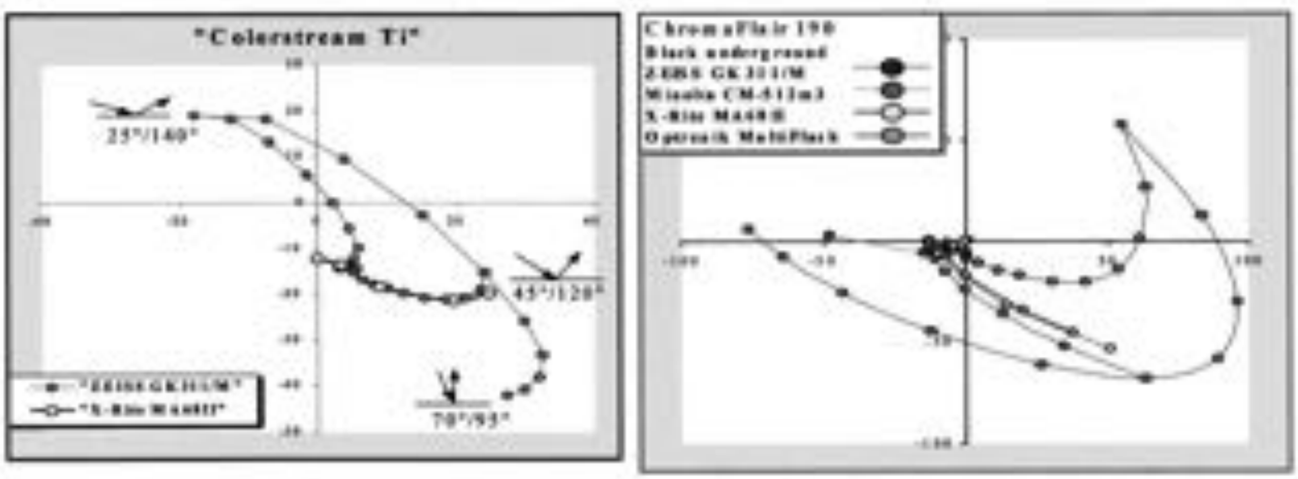


Figure 2a, b: Interference and aspecular shift for multi-layer effect pigments in the a*b* diagram of various measuring geometrie

2.4. Interim solution

The measurement data show that the visual behavior of the second-generation of effect pigments cannot, or can only barely, be measured using the spectrophotometers presently available. The new DIN 6157-2 standard goes as far as to exclude these pigments. Only two manufacturers offer flexible goniospectrometers that are suitable for R & D. On the production floor there is a need for portable instruments having more measuring geometries than the instruments presently available. As an interim step in the existing systems with 45° illumination, it might be possible to introduce a measuring angle behind the gloss or trans angle. Extensive experimental measurements add support to this notion Fig. 3 [13].

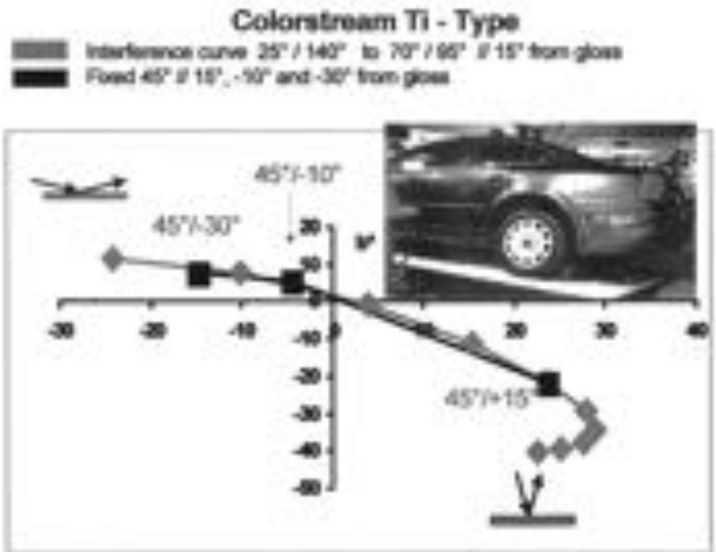


Figure 3: Comparison of interference shift under various illumination angles and a constant 15° aspecular angle and under constant 45° illumination and various cis-trans effect angles.

2.5. New MERCK color measurement system

As mentioned above for the modern, second-generation effect of pigments extensive angle-dependent spectrophotometric testing is an absolute necessity. Illumination and observation angles should therefore be introduced as close as possible to the horizontal, so as to better mimic the actual visual impression through the measurement data. The immediate question is: what features must the spectrophotometer have to enable this type of testing to be carried out? The answer to this question can be derived from points already made above:

- Firstly, there must be a variable light source. In a spectrophotometer this is achieved through pre-set angles.
- Secondly, the observation point must also be variable. This is again achieved through pre-set angles.

This is the most efficient way of measuring the color dynamics that result from the combination of geometries and pigments. With the new equipment developed by "MERCK" and "ETA-Optic" these requirements are fulfilled. From the instrumental data point of view the system provides L*-,a*-,b*- values from 20° to 80° of illumination and (90°), 110° to 170° of observation Fig.4. The visual interference shift agrees very well with the instrumental data.

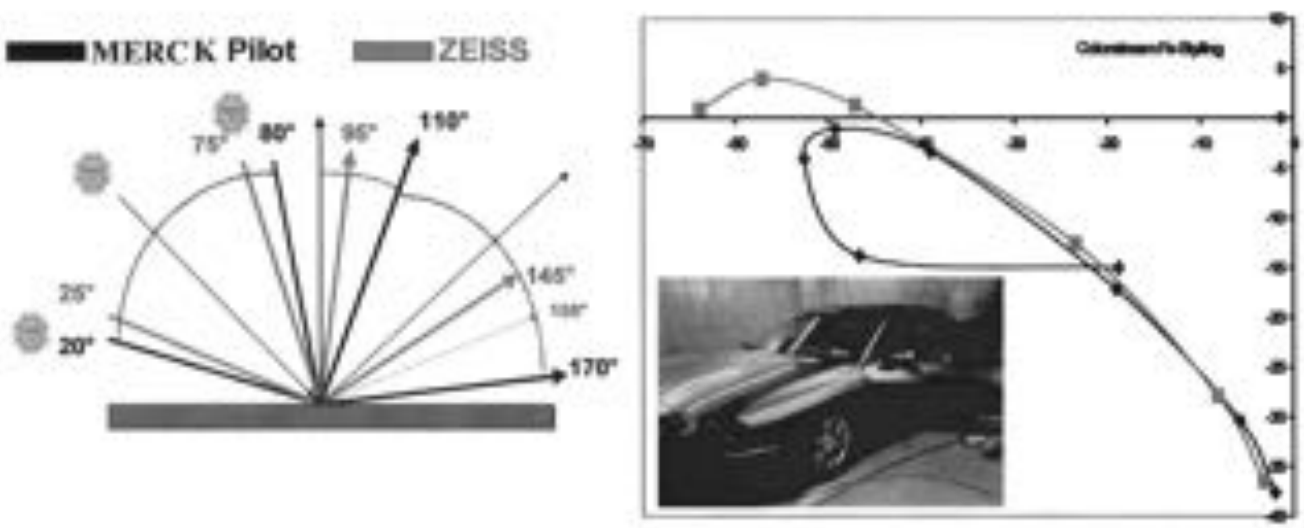


Fig. 4: Additional instrumental information in the a*- b*- diagrams from the new MERCK system comparing to ZEISS

SUMMERY

This paper shows the following points. The importance of precise color quality control for our customers and the complex, difficult nature presented by effect pigments in achieving precise color measurements. The specific techniques MERCK has instituted to make sure color measurement is as meaningful and reproducible as we can make it. The need for continuing improvements in instrument performance to allow color measurement techniques to continue to keep up with the increasing demands of our customers

REFERENCES

1. RODRIGUES, A., B., J., Color and Appearance Measurement of Metallic and Pearlescent Finishes, ASTM Standardization News, October 1995
2. TEANEY, S., PFAFF, G., NITTA, K., New Effect Pigments using Innovative Substrates, ECJ (1999) 4, 434
3. SHARROCK, S.R., SCHUEL, N., New Effect Pigments based on SiO_2 and Al_2O_3 Flakes, ECJ (2000) 1-2, 105
4. SCHMIDT, R. et al., Optisch variable Glanzpigmente, Farbe & Lack 104 (1998) 5, 44
5. HEINLEIN, J., KASCH, M., LC-Pigmente – Feuerwerk der Farben, Phänomen Farbe 7+8 / 2000, 18
6. GERLINGER, H.: Industrielle Farbmessung im Umbruch, Technisches Messen 59 (1992), 5, S. 189
7. SADOWSKI, F. Farbton, Effekt und Flop von Metalliczweischichtlackierungen Farbe+Lack, 8 (1985)
8. HOFMEISTER, F.: Koloristische Bewertung von Perlglanzpigmenten, Farbe+Lack 93 (1987) 10 S.799-802
9. RÖSLER, G. Colorimetric characterization and comparison of metallic paints ,PPCJ Vol.181, 1991
10. GABEL, P.W., PIEPER, H., A Comparison of different Colorimeters, EuroCoat 6, (1992), 356
11. GABEL, P.W. und PIEPER, H.: Farbmessung an Interferenzpigmenten, Technisches Messen 59 (1992), 5, S. 226-228
12. GABEL, P.W., HOFMEISTER, F., PIEPER, H, Interference Pigments as Focal Point of Color Measurement, Kontakte (1992) 2, 25
13. GABEL, P.W.,et al ,Goniochromatic Quality Control of Effect Pigments, Conference Papers, PRA, The Colour Delivery Challenge, Leeds 2000
14. CRAMER, W.R., GABEL, P.W.,Effektvolles messen, Farbe+Lack 107 (2001) 1 S.42-49

The determination and correction of errors in surface colour measurement

Peter J. Clarke* and Andrew R. Hanson, National Physical Laboratory, London, UK

ABSTRACT

A harmonisation process co-ordinated by the National Physical Laboratory (NPL) was set up to reduce errors in colour measurements with a target such that 95% of the results should agree to within 0.5 CIELAB colour difference units (ΔE^*_{ab}). Nine laboratories took part in the harmonisation; some were national laboratories and the rest commercial organisations. The techniques for determining and correcting errors in colour measurements are described. Thirteen sources of error were identified, ten of which were corrected for. Although not all the possible errors for the measurement of colour have been addressed 93% of the measurements agreed to within 0.5 ΔE^*_{ab}.

Keywords: colour measurement, colour scales, reflectance, radiance factor, fluorescence, uncertainty, error correction

1. INTRODUCTION

The methodology for determining and reducing colorimetric errors was discussed during a meeting of all the partners and the procedures to be used to achieve harmonisation of measurements to the required level were established. This paper is one of three presented at this conference using information from the same project. The other two describe the harmonisation results[1], and a method for the determination of uncertainty in surface colour measurements[2].

2. ERRORS AND CORRECTIONS

2.1 Errors in absolute scales of diffuse reflectance and 0°/45° radiance factor

The method used for this harmonisation process relies on the stability of reference white tiles to transfer accurately common absolute scales to all participants, with a high degree of accuracy. The results from partners were with reference to these white standards, which were all calibrated by NPL to provide common scales for the partners' measurements. These scales contain an inherent uncertainty associated with the NPL calibration. Deterioration in the tiles over the time-scale of the project should be negligible, and the white tiles are unlikely to be affected by environmental issues, (with the possible exception of dirt on the matt white tile). The methods used within this project have been designed to minimise the error in the absolute scales.

2.2 Errors due to differing properties of white reference standards

When making measurements of matt samples using spectrophotometers, which include an integrating sphere accessory, errors may be introduced if the instrument is calibrated using a glossy standard. The same is true for measurements of glossy samples against matt reference standards. The reasons for these errors are accounted for in the literature[3]. To reduce these effects in this intercomparison, two reference standards were used - a glossy white tile for glossy measurements and a matt white tile for matt samples. These errors should not affect measurements made in the 0°/45° geometry unless the collection angles of instruments vary significantly.

As previously mentioned (2.1), whilst the white glossy tile is easy to clean, the matt one is not. This means that dirt on the surface may become a problem in time.

2.3 Non-linearity of the photodetector

The response of a spectrophotometer detector is not always linear throughout its entire working range. Towards the higher end of the signal range, saturation of the detector or electronics may occur. Additional effects such as inter-reflection between glass surfaces within the instrument, and the reduction in sphere response with dark samples, will also manifest themselves as a non-linearity. The degree of non-linearity was investigated in this programme of work by measuring grey tiles and expressing the results in terms of a simple quadratic function:-

$$R = bR_m + cR_m^2 \qquad (1)$$

where R is the true reflectance, R_m is the measured reflectance and b and c are the determined coefficients. The model used to describe non-linearity was found to change the results for the reflectance of a 50% grey tile by an absolute amount in reflectance between -0.88% and +0.24%.

The determination of linearity in sphere instruments using neutral tiles gave results significantly different to those found by an additional investigation using neutral transmittance filters in the incident beam. This confirms the presence of several factors generating a non-linear response. These factors may limit the accuracy of absolute measurements. A more effective method would be to use grey tiles calibrated on a gonioreflectometer, and to this end a diffuse reflectance scale evaluated using a gonioreflectometer is being developed at NPL[4]. With the existing method, the improvement in agreement following linearity correction using grey tiles was minimal.

2.4 Incorrect zero level

Stray light and detector noise will lead to a non-zero signal for zero reflectance. It is important to correctly determine the magnitude of the 'dark signal', and subtract this from subsequent readings. The dark signal may vary with wavelength. Simply performing a scan with the sample port open is not a satisfactory method for determining the dark signal. Commercial gloss traps provided with instruments can be inadequate for evaluating dark signal. This project recommended the dark level scan should be made by placing a black glass wedge, which does not reflect any of the incident light, at the sample port for specular included and specular excluded geometries and a black glass plate for 0°/45° geometry. Participants measured the dark signal as a function of wavelength. On the whole the dark readings were found to be independent of wavelength. Most participants' dark readings were in the range ±0.1%. One participant had a dark reading that varied in the range 0.22% to 0.48%.

2.5 Wavelength scale error

It was agreed that wavelength could not be calibrated to an uncertainty of less that 0.3 nm using the holmium reflectance tile whereas 0.1 nm was possible using spectral emission line sources or transmission filters such as a holmium oxide filter or a McCrone crystal wavelength standard. Errors in wavelength will give the greatest errors on tiles with steep spectral slopes. Partners were instructed to use whichever means of wavelength error determination was most convenient and effective. A variety of methods were used including the use of Holmium tiles, a McCrone crystal, and spectral emission lines. In most cases the wavelength error was estimated to be less than 0.1 nm. One partner reported a wavelength error of 1 nm.

2.6 Specular beam exclusion error (gloss trap error)

Gloss traps which do not fully trap all light specularly reflected from samples can lead to an error when measuring glossy samples in the specular excluded geometry. Partners evaluated the gloss trap error using a calibrated mirror and a matt white tile[5]. The results are an index of the amount of specularly reflected light which will not fall into the gloss trap but be included in the measurement. (Ideally the value should be zero). Values were found to vary with wavelength and ranged between 0.001 and 0.13. These values were subsequently used to apply a correction to the results.

2.7 Specular beam weighting error

For a glossy sample measured in the specular included mode, non-uniformity of the integrating sphere may mean that the specular component is not collected with the same efficiency as the diffusely reflected light. Partners measured a calibrated mirror and matt white reflectance standard in the specular included geometry to determine the magnitude of this effect[5]. The results are an index of the efficiency of collection for diffuse light compared with that for the specular beam. (Ideally the value should be zero). The values were found to vary with wavelength and ranged between 0.001 and 0.68. These values were subsequently used to apply a correction to the results.

2.8 Errors due to non-uniformity of collection of integrating spheres

The internal reflectance of an integrating sphere will usually vary over its surface. In addition, baffles included within the sphere lead to a variation in response with angle of reflectance. The reflectance of samples, particularly materials such as metals and paper, varies considerably with direction of view, and this, linked with the non-uniform angular response of the sphere may lead to errors. Whilst there is some variation in angular reflectance profiles of the tiles used in this project, it is small compared with the variations encountered when measuring other samples. There have been no attempts to ascertain the magnitude of this effect in this project, though work is taking place elsewhere[6,7].

2.9 Polarisation errors in the 0°/45° geometry

For the 0°/45° geometry, several partners have carried out studies on the effects of polarisation. The light incident on the samples was polarised and measurements of the polarisation components of the reflected light were made. No one reported any detected polarisation effects.

2.10 Differences in methods of calculating colour data from spectral data

Errors may be introduced in the conversion of spectral data to colorimetric values. The CIE standard observer data are available at 5 nm intervals and are given as 'point values'. However, measurements can occur at different intervals and the effects of bandwidth may be significant. The literature[8,9] also stresses how so-called 'weighting' errors can occur when performing colorimetric calculations and recommends methods which were adopted by this project to ensure consistency. Using the ASTM weighting method, CIELAB values agreed to the number of quoted significant figures.

The partners supplied the co-ordinator with spectral reflectance results in addition to their own calculated colour values. The co-ordinator performed additional calculations to independently evaluate colour values as a check. This process found some errors in the data. In some cases the results from the different measurement geometries had been swapped, in another the wrong data were supplied and elsewhere there were typing mistakes. This demonstrates the importance of checking.

It is also possible that in data processing with several stages, rounding errors will occur. The correct rounding procedure is to round only at the final stage[10].

2.11 Geometry differences between illumination and collection optics within the specified limits

This factor relates to comments made in 2.8. The tolerances given in the CIE geometry specification[11] are sufficiently large to result in a wide range of implementation in instrumental design. Participants provided information on their exact instrumental geometries. The partner's instruments used a wide range of instrumental parameters: e.g. the sample port area to illumination patch area ratio varied from 0.08 to 1.00. There is some variation in the instrumental angle of incident illumination, between 7° and 10°, , though these all lie within the 10° CIE tolerance.

Additional geometric factors, such as the distance between the sample plane and the tangent to the integrating sphere wall, and the thickness of the inevitable recess between interior wall and sample, will also have a bearing on results. Chamfering of the sample port wall will reduce errors but some of the light reflected from the sample may still be blocked and not enter the sphere[1].

The relationship between illumination patch size and sample port size is an important factor[12]. In samples which exhibit a degree of translucency this can result in significant errors as light scattered laterally may be collected by some instruments but not others. None of the tiles used in this project suffer from this problem.

2.12 Errors due to thermochromism in samples

In common with all materials, the tiles used in the intercomparison will change colour with temperature. For this reason the participants agreed to perform measurements within the temperature range (23 ± 1) °C which should not introduce a significant thermochromic effect. One partner measured tiles outside this range and performed a correction according to published correction methods[13,14].

2.13 Errors due to the dependence of spectral resolution on bandwidth, scan speed and integration time

A fast speed scan with a slow integration time will generate a different result to a slow speed fast integration time scan, particularly in the resolution of slopes. In some instruments some of these are interlinked or the bandwidth is controlled automatically and will vary with wavelength. The difference between the two resulting spectra might appear as a wavelength shift and particularly affect results for the more chromatic tiles. The same is true for instruments with differently shaped spectral band-pass functions. The partners attempted to measure with instrumental parameters similar to those recommended by the co-ordinator. Some of this effect will be accounted for in the wavelength calibration. This effect can be investigated using a tile with a steep spectral slope, such as an orange tile. In an investigation on an orange tile using different combinations of response time and scanning speed typical differences of 0.3 ΔE^*_{ab} were obtained and in extreme cases differences as large as 1.4 ΔE^*_{ab} resulted.

2.14 Other issues

Some of these have been touched upon already, such as human error in data transcription. Effects that have not been considered are humidity. This may have an effect on the tiles, especially the matt ones. Work in this area is currently being done at NPL. Others have looked at the stability of ceramic tiles[15].

Fluorescence is another problem for a reference material. The ideal surface colour reference material should not fluoresce unless it is specifically a fluorescent standard. The ceramic tiles used in the harmonisation process did not have any significant fluorescence.

The uniformity of the tiles has been previously examined at NPL[16] and, although the areas measured ranged from 4 mm x 8 mm to 30 mm diameter, should not affect results.

The most significant corrections were for zero, linearity and wavelength errors. The resulting agreement after these were applied is detailed elsewhere[1]. The other corrections were usually found to be small or negligible, and were not corrected for but added in as terms in the uncertainty evaluation of the results. Uncertainties were estimated by the partners for their results, after applying the appropriate corrections.

4. CONCLUSIONS

Errors in surface colour measurement have been identified, determined and corrected for. The main errors to correct for are the zero, scale, linearity and wavelength. Using the method described it is possible to get good inter-instrument agreement. For the harmonisation process 93% of the measurements agreed to within 0.5 ΔE^*_{ab}.

There is still some further work required to investigate some of the outstanding errors that were not addressed within this project. In particular more work will be required to gain a better agreement for the 0°/45° geometry.

ACKNOWLEDGEMENTS

The authors were in the co-ordinator team for this work and are indebted to others who were involved in the project from: Consejo Superior de Investigaciones Cientificas, Portugal; Bundesanstalt für Materialforschung und-Prüfung, Germany; University of Joensuu, Finland; Laboratoire Nationale d'Essais, France; Centro de Ciencias e Technologias Opticas, Spain; Swedish National Testing Research Institute Ltd; British Ceramic Research Ltd and DELTA - Danish Electronic Light and Acoustics.

REFERENCES

1 A. R. Hanson and P. J. Clarke, "Harmonisation of scales of colour measurement", AIC Color 2001 proceedings.

2 P. J. Clarke and A. R. Hanson, "The determination of uncertainty in spectrophotometric surface colour measurement", AIC Color 2001 proceedings.

3 F.J.J Clarke, J. A. Compton, "Correction Methods for Integrating-Sphere Measurement of Hemispherical Reflectance", *Color Res. Appl.* **11**, pp 253 - 262, 1986.

4 D. C. Williams, "Establishment of absolute diffuse reflectance scales using the NPL Reference Reflectometer", *Anal Chim Acta*, **380**, pp 165-172, 1999.

5 J. F. Verrill, P. J. Clarke and J. O'Halloran, *Study of improved methods for absolute colorimetry, fifth report, study of colorimetric errors on industrial instruments*, NPL Report COEM 2, October 1997.

6 A. R. Hanson, J. F. Verrill, "Study of the dependency of spectral radiance factor and colorimetric values on geometric tolerances", *Anal Chim Acta*, **380**, pp 363-367, 1999.

7 P.C. Knee, Investigation of the uniformity and stability of integrating spheres, Anal Chim Acta, **380**, 390-399, 1999.

8 ASTM, "Standard practice for computing the colors of objects by the CIE system", *ASTM E308-95*, 1995.
9 K.J. Smith, "Recommended weightings for colorimetric calculations", *J. Soc. Dyers Colorists*, 114, pp 375, 1998.
10 Guide to the expression of the uncertainty of measurement, ISO 1993.
11 Colorimetry, CIE Publication 15.2, Vienna, 1986.
12 J. F. Verrill, "Advances in spectrophotometric transfer standards at the National Physical Laboratory", *Spectrophotometry, Luminescence and Colour; Science and Compliance*, Ed. C Burgess and D G Jones, pp 49 - 63 Elsevier Science, Amsterdam, 1995.
13 F. Malkin, J. A. Larkin J. F. Verrill and R. H. Wardman, "The BCRA-NPL Ceramic Colour Standards, Series II - Master spectral reflectance and thermochromism data", *J. Soc. Dyers Colorists*, **113**, pp 84-94, 1997.
14 J. F. Verrill, J. A. Compton and F. Malkin, "Thermochromism of ceramic colour standards", *Appl. Opt.*, **25(18)**, p 3011, 1987.
15 H. S. Fairman, H. Hemmendinger, "Stability of ceramic color reflectance standards", *Color Res. Appl.*, **23**, pp 408-415 1998.
16 J. F. Verrill, P. C. Knee and J. O'Halloran, "A study of the uniformity and thermochromism of surface colour standards", *Special volume 23rd Session of the CIE, New Delhi, November 1-8,1995, Late papers*, CIE Publication x011, Vienna, 1996.

*Correspondence: peter.clarke@npl.co.uk; telephone +44 20 8943 6406, fax. +44 20 8943 6458; http://www.npl.co.uk; National Physical Laboratory, Queens Road, Teddington, Middlesex, TW11 0LW, United Kingdom.

The determination of uncertainty in spectrophotometric surface colour measurement.

Andrew R. Hanson and Peter J. Clarke*, National Physical Laboratory, London, UK

ABSTRACT

This paper reports on work undertaken by nine European laboratories as part of a European Commission funded research project. The project's goal was to improve harmonisation of international colorimetric scales. One objective of the exercise was to devise a means of expressing total uncertainty in colour measurement. When measuring colour (or indeed any physical quantity), an assessment of the uncertainty of the result is as important as the value itself. This fact, long recognised in physics, is increasingly important to any quality assured organisation that relies on measurements. The approach described first determines values of the sources of spectrophotometric uncertainty, and uses a simple model to combine these into total colorimetric uncertainties. The model has been used to determine uncertainties for the following colour data: x, y, Y, u', v', L*, a* and b* for the CIE 10° Standard Observer and the CIE Standard Illuminant D_{65} for three geometries: specular included, specular excluded and 0°/45°. The method is used routinely at NPL in its UKAS accredited calibration services.

Keywords: uncertainty, colour measurement, colour scales, reflectance, radiance factor, spectrophotometry.

1. INTRODUCTION

Too frequently, NPL is reminded that industry is not fully cognizant with the terms error, uncertainty and accuracy. Users of colorimeters and spectrophotometers often quote measurement capability figures which transpire to be the instrument to instrument agreement quoted in the manufacturer's specification. This figure is likely to be much more complementary to the instrument's abilities than the absolute accuracy determined by rigorous methods.

Error is the difference between the measured value, and the 'true value'. Measurements contain several independent sources of error (such as temperature). Errors may only ever be partially corrected for, since their determination will contain a degree of *uncertainty*. If the error cannot be simply corrected for, it may be added to the total uncertainty of the measurement. *Accuracy* is the closeness of agreement between measured result and true value – it is a qualitative term only.

A recent European harmonization project required several laboratories to investigate the sources of error in an effort to reducing total uncertainty in colour measurement by error correction. A product of this exercise was a series of tests, which will be of benefit to any laboratory attempting spectrophotometric or colorimetric measurement. The overall findings of the harmonization project form the basis of two further papers at this conference. One deals with the reduction of error, and the other reports the overall success of the exercise.

The course of action for good metrology should be to minimize uncertainty. This can be achieved by traceable calibration using high quality measuring instruments or transfer standards, correcting for errors, and by additional independent checking of measurements by an alternate method (this might be by a second person).

It is of value to distinguish between Type A and Type B uncertainty evaluation methods. *Type A* uncertainties will have been evaluated by statistical methods (such as repeatability); while *Type B* uncertainties are found using non-statistical methods. For reflectance and 0°/45° radiance factor measurements made at NPL, the only Type A uncertainty is the repeatability.

2. SOURCES OF UNCERTAINTY

The procedure for evaluating sources of error in measurements has been addressed in the adjunct paper: "The determination and correction of errors in surface colour measurement". In the event of practical use of these papers, the user will have corrected for several sources of error and a set of uncertainties will now remain. These will now be commented upon in turn.

2.1 Uncertainty in the level of the absolute scales of diffuse reflectance and radiance factor

Correction of scale error will usually be by method of direct comparison of result for a calibrated transfer standard (such as a white opal or tile) with the value given by the instrument. Following scale correction, the residual uncertainty will be the uncertainty in calibration of the transfer standard itself, plus an estimation of any degradation which may have occurred to the transfer standard since its original calibration. This aspect introduces an important feature of the traceability chain – additional uncertainty is added with each measurement with increasing distance from the highest-level measurement at the National Measurement Institute (NMI). As the lowest uncertainties quoted by NMIs are in the region of 0.5 CIELAB ΔE^*_{ab} units, it is impossible for a laboratory farther down the traceability chain to achieve an absolute uncertainty lower than that value. The uncertainty in absolute scale is treated as a 'level' offset to the data (R becomes R $\pm$a at all wavelengths) as shown in the 'level' chart of figure 1.

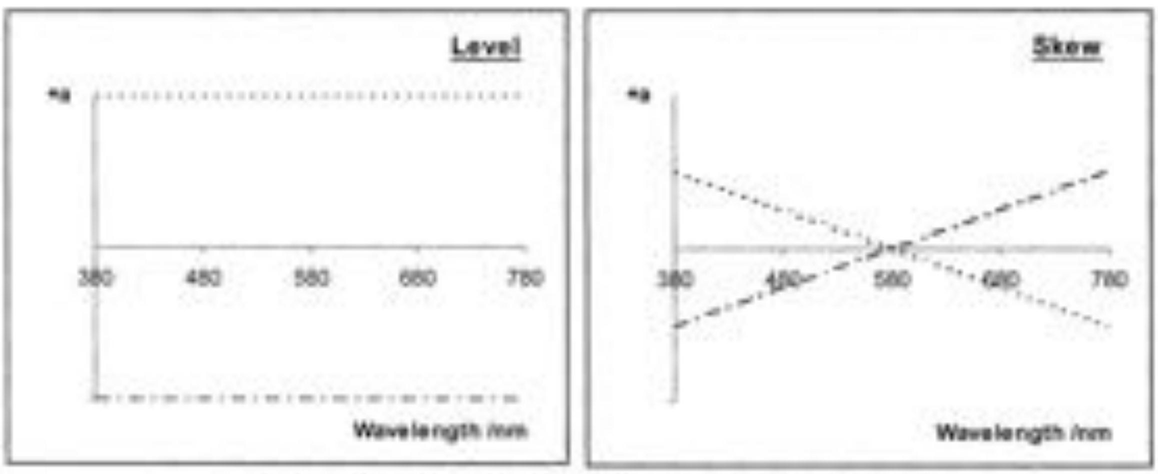


Figure 1: Level and skew uncertainties as a function of wavelength.

2.2 Uncertainty in the spectral slope of the scales (skew uncertainty)

The uncertainty in absolute scale may change with wavelength. This is modeled by skewing the data by half the uncertainty at the 100% level. Both negative and positive slopes are considered as shown in the 'skew' chart of figure 1. This is important in evaluating colorimetric uncertainties.

2.3 Dark uncertainty

Instrumental electronic zero offset, and (for diffuse reflectance) internally scattered light combine to give a dark uncertainty. This error can be examined by placing a black glass wedge at the sample port of an integrating sphere instrument[5] or a single black glass plate at the sample port for a 0/45 instrument. Merely blocking the beam will not account for internal scattering effects within the integrating sphere.

2.4 Linearity uncertainty

System non-linearity may be assessed by examining results for a series of calibrated neutral tiles. This project revealed that calibrated neutral filters placed in the incident beam would provide a different result. Non linearity is modeled by a polynomial which is set to zero at 0% and 100%.

2.5 Wavelength scale uncertainty

Wavelength errors are assessed by measurements of the spectral emission lines of discharge sources, (such as a deuterium lamp). If the error is uncorrected, the uncertainty will be equivalent to the error. Otherwise, it will be the uncertainty in the determination of the wavelength error. This will be the quadratic sum of: the uncertainty in the spectral feature, and uncertainty in the process of calibration. The latter will relate to instrumental drift and varies with time after the instrument has been switched on.

2.6 Thermochromism uncertainty

The spectral reflectance and colour of ceramic colour standards with changes in temperature has been investigated[2]. Colourful samples (ie those with steep aspects to reflectance curves) are most prone to thermochromism. Temperature may affect both sample and instrument. Evaluation of the effect is by measurement at two temperatures.

2.7 Glossy to matt ratio uncertainty

Recent work at NPL is strengthening the view that integrating spheres can introduce an error in measurement, which is particularly evident when measuring glossy samples with an instrument calibrated using a matt standard (and vice versa). This can be evaluated using both matt and glossy calibrated standards.

2.8 Specular beam uncertainty (specular included geometry only)

The specular beam (glossy reflection) may not be collected with the same efficiency as the diffusely reflected light. The error can be determined using a mirror and a calibrated matt white[3,4].

2.9 Gloss trap uncertainty (specular excluded geometry only)

Incomplete absorption of the specular beam can lead to errors in specular excluded measurements. The error can be determined using a mirror and a calibrated matt white[3,4].

2.10 Uncertainty in bandwidth

Bandwidth, and other factors such as step interval, scanning type (which may be stop-and-measure or continuous), integration time and noise level can be interdependent in some automatic instruments. It is possible that these settings will have some effect on the results of steeply sloped spectral curves (i.e. those of chromatic samples).The European project agreed on a set of standard parameters for measurements.

2.11 Measurement repeatability

'Repeatability' investigates several aspects of measurement such as sample placement, operator reliability and instrumental noise. A set of n measurements is taken, and s, the standard deviation from the mean, can be calculated. The estimated standard uncertainty u is calculated as $u = s/\sqrt{n}$ This quantity has also been known historically as the standard error of the mean or the standard deviation of the mean[3,4].

3. COMBINING UNCERTAINTIES

To assist in calculation of total uncertainty, an 'uncertainty budget' as shown in figure 2 is often of use.

Uncertainty budget for percentage reflectance specular excluded measurements on Spectrophotometer X when used to measure matt white tiles against glossy masters				
Source of uncertainty	Value +/- %R	Probability distribution	Divisor	Standard Uncertainty
Absolute scale	0.40	normal	2	0.20
Spectral slope	N/a	N/a		
Dark level	0.01	Rectangular	$\sqrt{3}$	0.01
Linearity	0.02	Rectangular	$\sqrt{3}$	0.01
Wavelength scale	N/a	Rectangular	$\sqrt{3}$	
Temperature (thermochromism)	0.00	N/a		
Glossy to matt ratio	0.10	Normal	2	0.05
Specular beam (specular included geometry only)	N/a	N/a		
Gloss trap (specular excluded geometry only)	0.01	Normal	2	0.01
Bandwidth	0.00	N/a		
Repeatability (standard uncertainty of 10 repeated readings)	0.02	Normal	1	0.02
Combined standard uncertainty		Assumed normal		0.29
Expanded uncertainty		Assumed normal (k=2)		0.58

Figure 2: Uncertainty budget

Each uncertainty component is described in terms of a probability distribution. For example, if the true value definitely lies within y-x and y+x, the distribution is described as a rectangular distribution with a 100% confidence level. Uncertainties are converted to a confidence level equivalent to that of ±1 sigma of a normal distribution (about 65%) using a divisor appropriate to the distribution function. Contributions are all summed in quadrature and then multiplied by 2 to give a value at the 2 sigma (approximately 95% confidence) level according to standard practice[5,6].

4. CONCLUSIONS

This paper shows how it is not possible to correct for all errors in colorimetry or spectrophotometry. Whilst many errors can be accounted for, some can neither be determined, nor corrected for. These then become uncertainties. The resultant total uncertainty is likely to be specific to each measurement made.

ACKNOWLEDGEMENTS

The authors were in the co-ordinator team for this work and are indebted to others who were involved in the project from: Consejo Superior de Investigaciones Cientificas, Portugal; Bundesanstalt für Materialforschung und-Prüfung, Germany; University of Joensuu, Finland; Laboratoire Nationale d'Essais, France; Centro de Ciencias e Technologias Opticas, Spain; Swedish National Testing Research Institute Ltd; British Ceramic Research Ltd and DELTA - Danish Electronic Light and Acoustics.

REFERENCES

1 F. J. J. Clarke, J. A. Compton, Color Res. Appl. 11 (1986) 347.
2 F. Malkin, J. A. Larkin, J. F. Verrill, R. H. Wardman, J Soc. Dyers Colorists 113 (1997) 84.
3 F. J. J. Clarke, J. A. Compton, Color Res. Appl. 11 (1986) 253.
4 J. F. Verrill, P. J. Clarke, J O'Halloran, NPL Report COEM 2, ISSN 1369-7807, NPL Teddington, 1997.
5. BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML. Guide to the Expression of Uncertainty in Measurement. ISO, Geneva. ISBN 92-67-10188-9, First edition 1993, corrected and reprinted 1995.
6. S Bell, NPL Good Practice Guide 'A Beginner's Guide to Uncertainty of Measurement, ISSN 1368-6550, 1999.

*Correspondence: peter.clarke@npl.co.uk; telephone +44 20 8943 6406, fax. +44 20 8943 6458; http://www.npl.co.uk; National Physical Laboratory, Queens Road, Teddington, Middlesex, TW11 0LW, United Kingdom.

Thermochromism in color measurement

J. Hiltunen[a], J. Mutanen[a], T. Jaaskelainen[a], J.P.S. Parkkinen[b]
University of Joensuu, [a]Department of Physics
[b]Department of Computer Science
P.O. Box 111, FIN-80101 Joensuu, Finland

ABSTRACT

Accurate color measurements have become more and more important during the past few decades. This is valid not only in physical research, but also in industrial production, where the importance of accurate measurements is mainly due to increased quality requirements set by the customers of various goods. The development of technology enables more and more accurate measuring systems. While the accuracy has improved one has noticed, that many unexpected factors affect the color of an object. One of these factors is the temperature of the sample. It is known that for example the reflectance of the ceramic reference tiles used for calibration of colorimeters and spectrophotometers is temperature dependent. This phenomenon is called thermochromism, which is a reversible change of color of the sample as a function of temperature. It may be noticed already at room temperature if the temperature varies few centigrades. Red and orange samples are especially sensitive to temperature variation and may cause difficulties in precise color measurements. We show, how the phenomenon is based on physical processes and not only reflects the instability of red color pigments. We derive simple formulas, which are shown to explain the experimental data. We also discuss the meaning of thermochromism for color measurements, measure the magnitude of it and propose the experimental conditions to avoid this effect.

Keywords: color, thermochromism

1. INTRODUCTION

There is quite a few of articles of thermochromism in literature. Some general principles of thermochromism in a case of transmitting filters is that the spectral transmittance at a given wavelength that increases with increasing wavelength usually decreases with increasing temperature[1]. The greater the slope of the spectral transmittance curve, the greater the temperature effects as a rule. Spectral transmittance that decreases with increasing wavelength is, in general, of minor importance, but if it becomes important it often causes transmittance increase with increasing temperature. Spectral transmittance curves varying only slightly with wavelength are usually not sensitive to temperature variations. The data sheets for colored glass filters give the shift of the half value of maximum transmittance of the rising edge with increasing wavelength towards longer wavelengths in the units of nm/K. This value increases gradually with increasing wavelength from 0.07 nm at 400 nm to 0.17 nm/K at 700 nm[2]. Reflectance spectra of ceramic color standards as a function of temperature is also studied[3]. Results shows that increasing the temperature of a sample caused a fall in reflectance, which was concentrated in the steeply rising or falling parts of the spectral reflectance. The part of the spectral curve rising with increasing wavelengths was displaced towards longer wavelengths, while the part falling with increasing wavelengths was displaced towards shorter wavelengths on heating. The slope moves typically 0.1 nm /K. It is worth to point out that the reflectance usually decreases as the temperature increases. The long wavelengths reflecting i.e. yellow, orange and red samples are found to be affected most, leading to largest color differences in the CIELAB color difference values, whereas grey samples usually do not show any clear thermochromism[4,5]. Instead of the wavelength shift per nanometer or the color difference per centigrade a third measure also exists: relative change of the optical density of the sample as a function of wavelength[6]. However, independent on the measure one likes to use, the main point is how much the observed color depends on temperature.

2. THERMAL EFFECTS

The aim of this study is to derive a simple mathematical model for thermochromism, and to investigate the magnitude of the effect. One knows from the standard literature that color of an object under a given illumination depends on the reflectance or transmittance spectrum of the sample. Reflectance and transmittance are the only quantities, which, through absorbance depend on temperature. When light reaches a surface of a nonfluorescent material, where neither nonlinear nor abnormal polarization effects appear, it holds that the sum of reflectance, transmittance and absorption equals to one.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) · 0277-786X/02/$15.00

The depth where from the reflected light is coming is not probably affected by small changes in temperature, but if the absorption coefficient changes as a function of temperature, it affects also the reflected light distribution. The absorption in the visible range is caused by low level electron transitions, where an absorbed photon excites an electron from one energy level to another having higher energy. The general case of an undisturbed absorbing unit leads to two general solutions, which are of Lorentzian and Gaussian shape of absorption coefficient and hence also of the absorption band. Lorentzian band appears at low temperatures and Gaussian at high temperatures. The absorption peak is homogeneously broadened if the absorbing units are indistinguishable. This means that the absorption peak is symmetric in the energy scale, and in the frequency scale, but not in the wavelength scale. Because the photon energy is frequency multiplied by the Planck's constant, we will get very simple relation between energy and wavelength, the photon energy in electron volts is 1240 divided by the wavelength in nanometers. Properties of the absorption band are usually given in electron volts. The Gaussian shape of the absorption coefficient and hence the absorption band is[7]

$$\mu(\varepsilon)=\mu_{max}\exp\left(-\frac{4\ln 2(\varepsilon-\varepsilon_0)^2}{(\Delta\varepsilon)^2}\right)$$

where ε_0 is the energy of the absorption peak maximum and $\Delta\varepsilon$ is the full width at half-maximum absorption (called half width). If thermal changes appear in the absorption band, they appear so that the integrated absorption, which is the area of the absorption band, remains constant. Gebhardt and Kuhnert first reported the change of the absorption band as a function of temperature[8]. The general behavior of $\Delta\varepsilon$ at low temperatures (near room temperature) was found to be proportional to $T^{1/2}$, where T is the absolute temperature in Kelvins.

The discussion above is valid only to a single absorption line. Generally a color spectrum in the energy-absorbance scale is a linear combination of Gaussian peaks Note, that single absorption lines are not symmetric in the wavelength scale. The rising and falling edges of a spectrum may be thought to consist of a single Gaussian peak. Thus to understand the general principles of thermochromism it is enough to study the properties of a single Gaussian absorbance peak instead of a linear combination of them. The peaks forming the edges have the major influence to the thermal properties of a spectrum whereas the other peaks have a minor or no effect.

In the visible range (1.59 eV –3.3 eV) one can integrate the absorption peaks, and get as a result an area A

$$A=ABS_{max}\sqrt{\frac{\pi}{4\ln 2}}\Delta\varepsilon$$

where $ABS_{max}=\mu_{max}d/\ln 10$. Let $\Delta\varepsilon_0$ be the halfwidth of the peak at a temperature T_0, then at another temperature T the left and right halfwidth points $\varepsilon_{\pm 1/2}$ as a function of temperature are

$$\varepsilon_{\pm 1/2}(T)=\varepsilon_0\pm\frac{1}{2}\Delta\varepsilon_0\sqrt{\frac{T}{T_0}}$$

Thus the shift of the halfwidth points is

$$\delta\varepsilon_{\pm 1/2}(T)=\varepsilon_{\pm 1/2}(T)-\varepsilon_{\pm 1/2}(T_0)=\pm\frac{1}{2}\Delta\varepsilon\left(\sqrt{\frac{T}{T_0}}-1\right)\approx\pm\frac{1}{4}\Delta\varepsilon_0\frac{\Delta T}{T_0}$$

where $T=T_0+\Delta T$. The approximation in the last term holds if the temperature change is small. Let us next derive the shift formula in wavelength scale where the absorption bands are not symmetric. We get the wavelength shift

$$\delta\lambda_{\pm 1/2}(T)=\lambda_{\pm 1/2}(T)-\lambda_{\pm 1/2}(T_0)=\frac{k(\lambda_{\pm 1/2}(T_0))^2}{1-k\lambda_{\pm 1/2}}$$

where

$$k=\pm\frac{1}{2}\frac{\Delta\varepsilon_0}{hc}\left(1-\sqrt{\frac{T}{T_0}}\right)$$

In many practical situations k is small and one gets as an first approximation

$$\delta\lambda_{\pm 1/2}(T)\approx\mp\frac{1}{4}\frac{\Delta T}{T_0}\frac{\Delta\varepsilon_0}{hc}(\lambda_{\pm 1/2}(T_0))^2$$

3. EXPERIMENTAL RESULTS

A few ceramic samples were heated with the thermal resistor system. Temperature of the setup were adjusted with the voltage controller and detected by the thermoelectric couple. Measurements were made with double beam scanning spectrophotometer with integrating sphere accessory. In figure 1 an example of the thermal effect is shown for the yellow sample. Spectral curves were measured in different temperatures from left to right 28°C, 40°C, 50°C, 60°C, 70°C and 80°C, respectively.

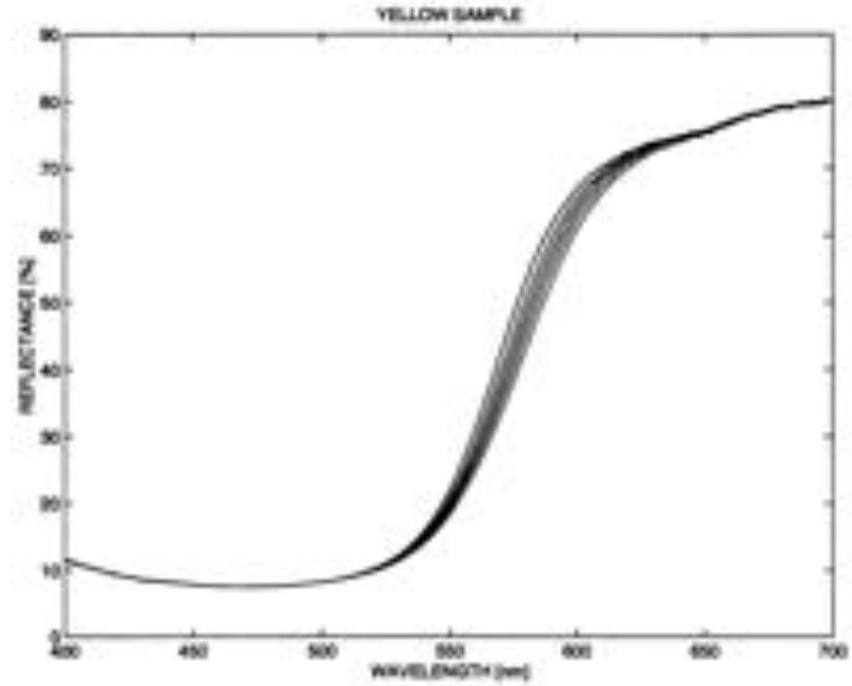


Figure 1: Spectral reflectance of a yellow sample in different temperatures.

In table 1 color difference values ΔE are shown for 4 ceramic color samples. Color differences are calculated so that those higher temperature curves are compared to lowest temperature CIELab values.

Table 1: CIELab color differences for four ceramic tiles in different temperatures.

CYAN		GREEN		YELLOW		RED	
T[°C]	ΔE	T[°C]	ΔE	T[°C]	ΔE	T[°C]	ΔE
27	0,00	28	0,00	28	0,00	27	0,00
38	0,45	40	0,95	40	1,73	39	1,26
48	0,83	50	1,47	50	2,95	52	3,14
62	1,39	60	2,17	60	4,03	60	3,90
72	1,67	70	2,77	70	5,06	68	4,80
82	1,99	83	4,24	80	6,41	80	6,17
94	2,40	92	5,14				

One can see from the table 1 that ΔE values changes quite dramatically when temperature changes. Depending on color less than 5°C is enough to change the color more than a human can perceive.

4. CONCLUSIONS

We have calculated the thermochromic effects of transmitting and reflecting materials. If we consider only the change of half width of the absorption curve as a function of temperature, we will get the result that the rising edge with increasing wavelength shifts towards longer wavelengths and the falling edge towards shorter wavelengths. The greater is the slope (high absorbance), the bigger is the change. If we take into account the shift of peak position this enhances the shift of rising edge and diminishes the change of falling edge. In some cases the effect of peak position change towards longer wavelengths can be greater than shift of falling edge towards longer wavelengths. This can happen if the slope of the falling edge is small (low absorption) and total shift can be even towards long wavelengths.

In practical filters or reflective materials there are usually several different types of absorbing units which cause several absorption bands, and the total absorption is the superposition of the different bands (algebraic sum). This does not change our result if the rising or falling edge is formed by one kind of absorbing unit. As the absorbance is logarithmic the change in absorbance height maximum does not much change transmittance or reflectance. For example if absorbance changes from 4 to 3 the transmittance changes from 0.01% to 0.1 %. This has very small effect to the value of Y, but change of the edge position either rising edge to longer wavelengths or falling edge to shorter wavelength decreases the value of Y. Thus the reflectance tends to decrease as the temperature increases. In case of grey samples the absorbance must cover all the visible range and rising and falling edges of must be out of visible range. That is why grey samples usually do not show any significant thermochromism.

In case of rising edge the shift is always towards longer wavelengths. The changes become bigger as the wavelength increases. This means biggest color differences for yellow orange and red samples as found in other studies. From the experimental data we can get the wavelength shift for the half width point of a rising edge for colors cyan, green, yellow and red approximately 0.05 nm/K, 0.12 nm/K, 0.18 nm/K and 0.15 nm/K, respectively. These results are in good agreement with our thermal model. Because of thermochromism, new recommendations for color measurements require the temperature during the measurement to be set to a predefined temperature e.g. (25 ± 1) °C.

REFERENCES

1. G. Wyszecki and W.S. Stiles, *Color Science: Concepts and Methods, Quantitative Data and Formulae, 2nd Edition*, John Wiley & Sons, New York, 1982.
2. http://www.besbtics.com/html/schott_color_filters.html
3. F. Malkin, J.A. Larkin, J.F. Verrill, and R.H. Wardman, J.S.D.C. **113**, 84, 1997.
4. M.D. Fairchild and F.Grum, Appl. Opt. **24**, 3432, 1985.
5. J.F. Verrill, J.A. Compton, and F. Malkin, Appl. Opt. **25**, 3011, 1986.
6. J.F. Verrill, *Advances in spectrophotometric transfer standards at NPL*, In: Spectrophotometry, Luminescence and Colour; Science and Compliance, C.Burgess and D.G. Jones (eds.), Elsevier Science B.V., pp 49-63, 1995.
7. W. Hayes and A.M. Stoneham, *Defects and Defect Process in Nonmetallic Solids*. John Wiley & Sons, New York, 1991.
8. W. Gebhardt and H. Kuhnert, Phys. Letters, **11**, 15, 1964.

Geometry free white standard reference plate

Chang-Soon, Kim.
Korea Research Institute of Standards and Science (KRISS)

ABSTRACT

To calibrate color meters, we use white reference plate. Common white reference plates are made with ceramic tile and have some specular components that cause some discrepancy between different geometry systems. We developed a new geometry free white reference plate that has no specular component. It will be helpful to increase the accuracy in measuring color or calibrating color meters. We want to show the properties of a new white reference plate. Our new white standard reference plate will be used for transferring the international standard of the absolute spectral diffused reflectance.

Keywords: diffuse reflectance, color meter, white reference, geometry free, absolute spectral reflectance, reflectance standard, color measurement.

1. INTRODUCTION

There are two types of color meter in the world. First is spectro-photometric type and the other is filter type color meter. The spectro-photometric type color meter measures the spectral reflectance of the color samples with the spectrophotometer which has a integrating sphere accessory. The spectral reflectance should be calibrated in absolute reflectance scale which is based on Perfect Reflecting Diffuser (PRD). As you imagine PRD is an ideal object that can not be realized in physical object. So we measure the reflectance of some high reflecting materials in absolute scale. The preferable materials for this purpose were high purity $BaSO_4$ or polytetrafluorethylene(PTFE). But these materials are not strong in physical property. The surfaces are easily scratched and contaminated. So these materials only used for transferring the standard to the reference spectrophotometer. The real Certified Reference Material (CRM) is made of ceramic tile. As you know ceramic tile is very stable and has a strong physical surface. But unfortunately the surface has a specular reflecting component. This specular component made some difficulties in calibrating the color meters between different geometric types. This situation is same for the filter type color meters which need the color vales of the white standard reference plates.

Our purpose is to make a geometry free white standard reference plate to decrease the discrepancy between the different geometries. (1),(2)

In this paper we have checked the some optical properties of our new white reference plate. As a conclusion we find out that this material has a very close reflecting property to PRD.

2. EXPERIMENTS

To check the reflecting property of our new white standard reference plate, we set up a goniophotometric system. This system is simple. Two rotating plates were used. The sample plate can rotate with detector or source and can be fixed when the detector or source is rotating around the sample. (Fig. 1)

To check the specular component of our new white reference plate. We fixed the sample and source in the angle of 45 degree illuminating. The detector went around of the sample from 0 to 85 degree. The source was a collimated light from tungsten halogen lamp. The detector was luminance detector. Data were obtained for each 5 degree interval. We measured the data several times and the average and the standard deviation were obtained. These data were relatively compared

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) · 0277-786X/02/$15.00

with the value of reflectance factor of the PRD.

Fig. 1. We have fixed the white tile in the center. And illuminated with a collimated halogen lamp light in the angle of 45 degree to perpendicular of the surface. Along the rail which is aligned to be an circular arc around the tile surface, we have measured the reflection factors form 0 degree to 85 degree in 5 degree interval.

3. RESULTS

Following are the results of our experiments. In Fig 2 the relative reflection factors of our new white reference plate were compared to those of the PRD.

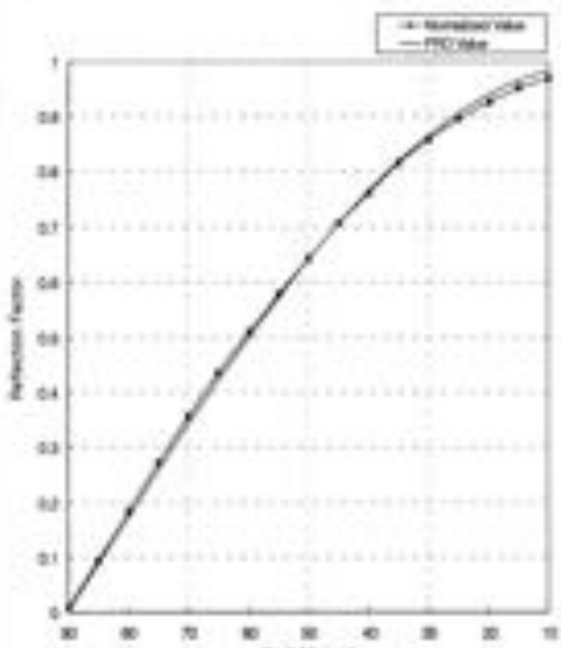


Fig 2. Spacial Distribution of the Reflection Factor of Our White Plate. (Comparing to Perfect Reflecting Diffuser)

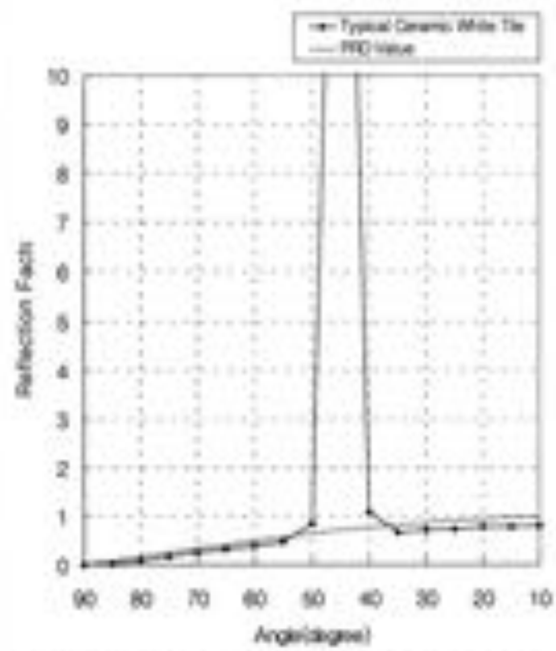


Fig 3. Spectral Distribution of the Typical Ceramic Tile White Standard Plate.

Fig 3 shows angular reflection pattern of the typical ceramic tile, which has used as white reference plate.

In these experiments we wanted to check the angular distributions of reflection of our new white plate. We used commercial radiometer with V(λ) filter and silicon photodiode detector. We have illuminated in several different angles such as 30, 40, 45, 60 degree. Our main interest is how much the specular component is reflected from our new white plate. As you see in fig 2 the specular reflecting component can not be seen. The compared measurement for the typical tile shows the great specular component. The reflection factor in 45 degree was about 23 times of that of PRD.

Nowadays Labsphere provide excellent white reference plate (Spectralon). We have tested this material in the same method. The compared result is fig 4. There were small differences in low angles. We guess that as the material has bigger transparency the reflection depth can be dipper than ours.

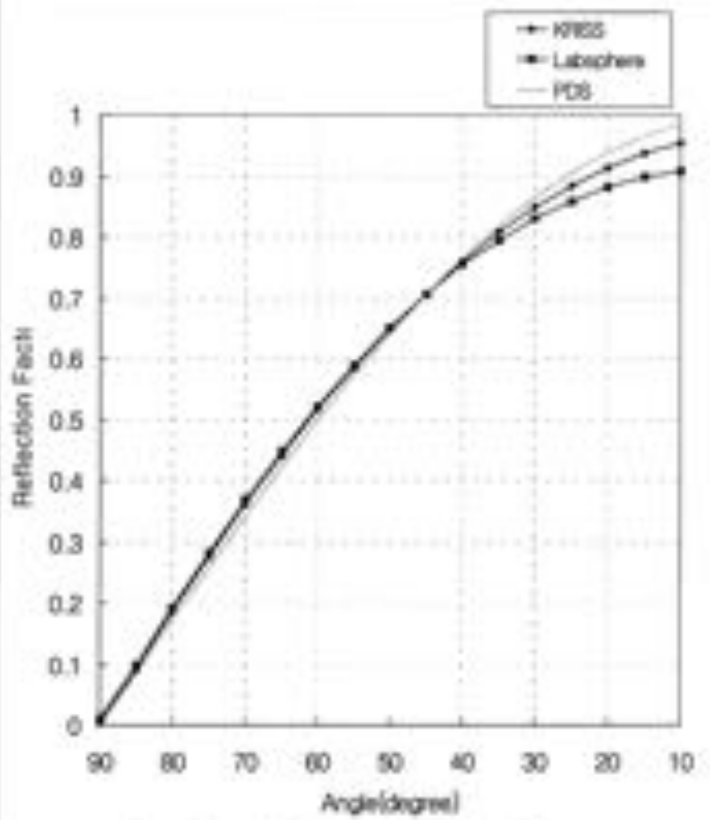


Fig 4. Spectral Distribution of Reflection Factors
(Comparing to Ladsphere's Spectralon)

4. DISCUSSION

Our results show that new white plate has excellent angular reflection property. The angular reflection factor was relatively compare to PDR. Our white plate also has a low transparency. The spectral reflectance was measured former time. (1)(2) Average spectral reflectance was more than 90 % in visible range(380 nm – 780 nm). These properties imply that our white plate can be used as a geometry free white standard reference material. Using absolute reflectance measuring system(3) more precise and accurate measurements will be continued. After the international comparison (CPPR Key comparison K-5; spectral diffuse reflectance), we will distribute these white tiles as white reference CRM.

REFERENCES

(1) Chang-Soon, Kim., "Development of the White Reference Plate for the Color Measurement Calibration", *AIC Midterm Meeting Proceedings*, pp.17-22, Central Office of Measures Optical Radiation Laboratory, Warsaw, 1999.

(2) Chang-Soon, Kim. "National Standard Traceable System for the Precise Color Measurement", *AIC 2000 Proceedings*, pp.253-256, Korean Society of Color Studies, Seoul, 2000.

(3) Chang-Soon, Kim., Hong-Jin Kong., "Rapid Absolute Diffuse Spectral Reflectance Factor Measurements Using a Silicon-Photodiode Array", *Color Research & Application*, **22**, pp.275-279,1997.

The CIE colorimetric system fails to calculate the chroma of a Nd:YAG crystal under the fluorescent illuminant F7

Yan Liu[a*], Qinghan Chen[b], Xianhui Bu[c], Pingyun Feng[d]
[a]Liu Research Laboratories, South El Monte; [b]South-West Institute of Technical Physics, China;
[c]University of California, Santa Barbara; [d]University of California, Riverside

ABSTRACT

The rare earth element neodymium doped yttrium aluminum garnet (Nd:YAG) is a laser crystal widely used for producing laser in the infrared range. Neodymium causes many characteristic absorption peaks in the transmittance spectrum of the Nd:YAG crystal in the visible range. The crystal appears pink under daylight and incandescent light, and colorless under fluorescent light. The colorimetric calculation results of chroma under the CIE standard fluorescent illuminant F7 do not agree with the color appearance under fluorescent light. The calculated chroma values should be near zero to agree with a colorless appearance, but it is actually 11.79 in the CIELAB color space. This failure of the colorimetric calculation is caused by the color matching functions of the CIE colorimetric observers. The color matching functions do not agree with the spectral sensitivity curves of the human eye, especially the $\bar{x}(\lambda)$ function does not matches the spectral sensitivity curve of the long wavelength cone photoreceptors.

Key words: Nd:YAG, CIE, chroma, F7, colorimetry, eye, illuminant, spectral sensitivity, photoreceptor, alexandrite effect

1. INTRODUCTION

Yttrium aluminum garnet is an allochromatic synthetic crystal. It belongs to the cubic system and appears colorless. Several rare earth element ions can be doped to cause colors in YAG by substituting for the yttrium. The transition elements can also be doped by substituting for the aluminum to cause different colors in the YAG crystal, such as a bluish green color of YAG for simulating that of emerald.

YAG is an important laser host crystal that can be doped by the rare earth elements for producing lasers. The rare earth element neodymium doped YAG is such a laser crystal widely used for producing laser in the infrared range. Neodymium causes many characteristic absorption peaks in the transmittance spectrum of the Nd:YAG in the visible range.

The alexandrite effect refers to the color appearance change under different light sources. It is a non-color-constancy phenomenon. This effect is classified into four categories based on the hue change caused by the different pairs of light sources [1].

A gemstone tanzanite exhibits a color change between the CIE illuminants D65 and A, but the calculated hue angles in the CIELAB color space have an abnormal change [2]. This abnormal hue-angle change can be corrected by using the spectral sensitivity curves to calculate the hue angles.

The studied Nd:YAG crystal appears pink under daylight and incandescent light, and colorless under fluorescent light. The color change of the Nd:YAG is a saturation change. The calculated chroma value of the crystal under the CIE illuminant F7 should be near zero for a colorless sample, but the calculated chroma of the Nd:YAG in the CIELAB color space under F7 is similar to the calculated chroma values under the CIE illuminants D65 and A.

2. EXPERIMENT

2.1. Sample

The Nd:YAG crystal for this study was grown using the pulling method from the melt under deductive atmosphere by the South-West Institute of Technical Physics in China. This crystal was doped with neodymium Nd for laser purpose. This crystal is the top shoulder of a Nd:YAG crystal. It is a half triangular cylinder in shape, and weighs about 140.26 ct. The Nd:YAG crystal appears pink with a purple hue under daylight and incandescent light, and colorless under fluorescent light.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

A broad absorption band centered at about 360 nm, which is associated with a crystal growth defect, can contribute a little to its color. However, this color center of crystal defect is usually eliminated by annealing at a temperature about 1300 °C. This Nd:YAG was treated by annealing , and its color center of the crystal defect was eliminated.

The saturations of the Nd:YAG crystal are fairly large under daylight and incandescent light for a YAG crystal, which usually appears colorless or near colorless. The color appearances of the crystal are very similar under daylight and incandescent light. The saturation of the crystal under fluorescent light is very low or none.

2. 2. Measurement

The spectral transmittance of the Nd:YAG crystal was measured in the wavelength range from 380 to 780 nm by a Varian Cary 500 UV-VIS-NIR spectrophotometer. Since the spectral curves of the rare earth element Nd usually has many sharp absorption lines, the measurement was taken at 1 nm wavelength interval. Figure 1 shows the spectral transmittance of the crystal in the visible wavelength range from 400 to 700 nm.

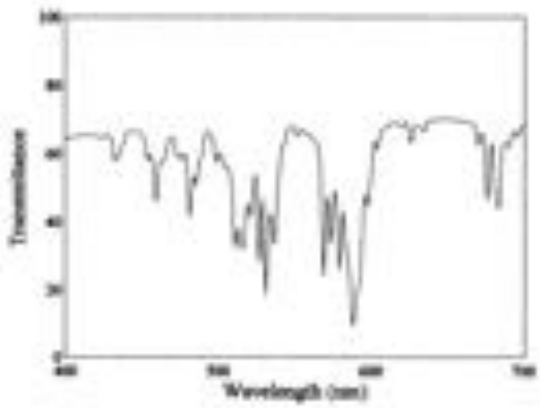


Figure 1. The spectral transmittance curve of the Nd:YAG crystal

There are six absorption bands in the visible wavelength range. The corresponding absorption peaks of the bands are at about 434 nm, 459 nm, 481 nm, 531 nm, 588, and 683 nm. Each band includes many narrow absorption pecks. The 531 nm band and the 588 band are wider and more deep than other four bands. These two bands absorb light in greenish yellow and yellowish orange ranges. Therefore, this Nd:YAG crystal appears a low saturation pink color with a purple hue due to the strong absorption bands in the middle wavelength range of the visible spectrum.

3. COLORIMETRIC CALCULATION

The spectral transmittance curve in Figure 1 was used to calculate the color of the Nd:YAG crystal in the CIELAB, CIELUV, and CIEYxy color spaces under the CIE standard illuminants A, D65, and F7. Table 1 tabulates the results of the colorimetric calculations. Figure 2 shows the (a*, b*) coordinates of the Nd:YAG crystal under the illuminants A, D65, and F7 in the CIELAB color space.

The three (a*, b*) coordinates of the Nd:YAG crystal are very close. The three hue angles are 321.8° under the illuminant A, 318.4° under the D65, and 312.3° under the F7. All the three hue angles represent the colors in purple range. The three chroma values are 12.45, 14.05, and 11.79 under the illuminants A, D65, and F7 respectively. The lightnesses of the crystal are 77.07, 76.63, and 76.98 under the three illuminants respectively.

4. DISCUSSION

The calculated colorimetric data indicate that the colors of the Nd:YAG crystal under the three CIE standard illuminants are similar. The hue angles under the three illuminants are very close, and the chroma values are also close. The three colors should appear similar pink colors. In fact, the Nd:YAG crystal appears pink colors under daylight and incident light, but colorless under fluorescent light.

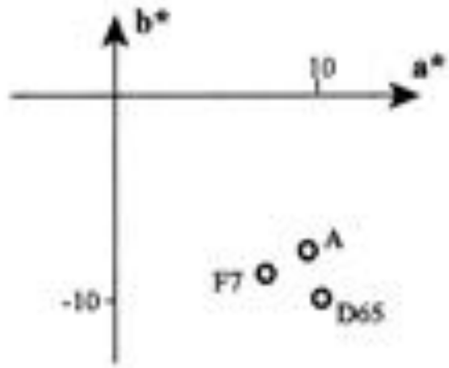


Figure 2. The (a*, b*)-coordinates of the Nd:YAG crystal under the CIE illuminants A, D65 and F7.

Table 1. Colorimetric data of the Nd:YAG crystal under the CIE illuminants A, D65, and F7.

	A	D65	F7
x	0.445	0.310	0.307
y	0.386	0.302	0.305
L*	77.07	76.63	76.98
U*	15.36	8.64	5.46
V*	-7.34	-16.01	-14.62
a*	9.79	10.50	7.94
b*	-7.69	-9.33	-8.72
C	12.45	14.05	11.79
h	321.8	318.4	312.3

Based on the calculated results, the color differences under the three illuminants cannot be distinguished by the eyes relying on the color memory. It is true that the color difference between illuminant A and D65 cannot be distinguished. However, the observed color differences between A and F7 as well as between D65 and F7 are very obvious.

The CIE colorimetry system fails to calculate the chroma of the Nd:YAG crystal under the CIE illuminant F7. The calculated chroma should be zero or near zero to represent a colorless color, but it is about 11.79 for the crystal under the illuminant F7. The calculated colorimetric results are also similar in the CIELUV and CIEYxy color spaces. These two CIE colorimetric systems also fail to calculate the chroma values of the crystal under the CIE standard illuminant F7.

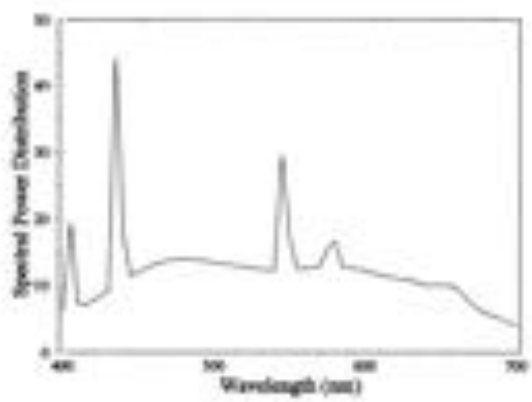


Figure 3. The spectral Power distribution of the CIE standard fluorescent illuminant F7.

The value of 11.79 of the chroma is fairly large for the color of a YAG crystal, which usually appears colorless. This large value of the chroma reveals that the error of colorimetric calculation of CIE colorimetry can be very large. The calculation error for the crystal under the CIE standard fluorescent daylight illuminant F7 is totally unacceptable.

Based on the hue-angle changes between different light sources, the alexandrite effect is classified into four categories [1]. The color change of the Nd:YAG crystal is caused by the saturation changes, therefore, this type of color change does not belong to the four categories. This type of alexandrite effect can be classified as a category of type 5. The Nd:YAG crystal is the first one so far we studied with the type 5 color change.

Figure 3 shows the spectral power distribution of the CIE standard fluorescent illuminant F7. There are four mercury emission lines superimposed on the continuous spectral power distribution. The four spectral lines are at 404.7 nm, 435.8 nm, 546.1 nm, and 577.8 nm. The mercury emission lines of fluorescent light at 435 nm, 435.8 nm and 577.8 nm overlap with the 434 nm, 531 nm, and 579 nm absorption bands of the Nd:YAG crystal. The 546.1 nm and 577.8 nm spectral lines can be totally absorbed by the 531 nm and 579 nm bands. The 435.8 nm spectral line can only be absorbed partially, since this spectral line is too strong, and the 434 nm absorption band is small. It is the total absorption of the 546.1 nm and 577.8 nm spectral lines and the partial absorption of the 435.8 nm spectral line that are the reason for reducing the saturation of this crystal under fluorescent light.

The color matching function $\bar{x}(\lambda)$ has two bands, one big band in the long wavelength range, and one small band in the short wavelength range. When calculating the colorimetric data under the CIE illuminant F7 in Table 1, the very strong mercury emission line at 435.8 nm and the weak line at 404.7 nm contribute significantly to both X and Z tristimulus values. Therefore, the calculated chroma in the CIELAB color space is significantly high. It is mainly the small band of the $\bar{x}(\lambda)$ color matching function that causes the CIE colorimetry fail to calculate the chroma of the Nd:YAG crystal under the CIE fluorescent illuminant F7.

The spectral sensitivity of the long wavelength cone photoreceptors has only one band in the long wavelength range.
The long wavelength cone photoreceptors are not sensitivity in the short wavelength range. The very strong 435.8 nm emission line causes a little response, if not none, to the long wavelength cone photoreceptors. For truly representing the color vision, the $\bar{x}(\lambda)$ should have only one band in the long wavelength range.

5. CONCLUSIONS

The rare earth element neodymium doped in YAG crystal causes many characteristic spectral absorption lines and bands. This crystal appears pink under daylight and incandescent light due to the spectral absorption of neodymium. The spectral bands of the Nd:YAG totally absorb the mercury emission lines of fluorescent light at 546.1 nm and 577.8 nm, and partially absorb the line at 435.8 nm. The absorptions of the mercury emission lines at 546.1 nm and 577.8 nm and the contributions of the emission lines at 404.7 nm and 435.8 nm make this Nd:YAG crystal appear colorless.

The colorimetric calculations reveal that the colorimetric data of the Nd:YAG crystal are correct under the CIE illuminants A and D65, but incorrect under the CIE fluorescent illuminant F7. Depending on the colorimetric data, the crystal appears similar pink colors. These colors cannot be distinguished by color memory under the three illuminants. The crystal actually appears colorless under fluorescent light, and its chroma should be near zero under illuminant F7. The large calculated chroma under F7 is caused by the small band of the $\bar{x}(\lambda)$ at the short wavelength for calculating the tristimulus value X.

The spectral sensitivity curve of the long wavelength cone photoreceptors has only one band in the long wavelength range, but the color matching function $\bar{x}(\lambda)$ has two bands, one is large in the long wavelength range, and another one is small in the short wavelength range. Usually, this small band does not contribute significantly to the X tristimulus value. When a very strong spectral line in a fluorescent illuminant near the peak wavelength 442 nm of the small band, a significant amount of value belonging to short wavelength may contribute to the X value, and makes X value incorrectly larger than what it should be. It is the incorrectly large X value that makes the chroma of the crystal incorrectly large.

The failure of calculating the chroma of the Nd:YAG under the CIE illuminant F7 by the CIE colorimetric system suggests two aspects needed to be addressed: 1. The small band of the $\bar{x}(\lambda)$ color matching function do not correlate to the spectral sensitivity curve of the long wavelength cone photoreceptors; and 2. fluorescent lamps cannot be used as a standard daylight simulator for critical colorimetric applications.

REFERENCES

1. Y. Liu et al., The "alexandrite effect in gemstones," Color Research and Application," **19**, 186-191 (1994).
2. Y. Liu et al., "Abnormal hue-angle change of the gemstone tanzanite between CIE illuminants D65 and A in CIELAB color space," Color Research and Application," **20**, 245-250 (1995).

* Correspondence: yliu@liulabs.com; phone 1 626 279 9848, fax 1 626 279 9198, http://www.liulabs.com, Liu Research Laboratories LLC, 2202 Seaman Avenue, South El Monte, CA 91733, USA.

Personal digital assistants and color measurement

Robert T. Marcus*, Peter Ruevski, David R. Battle and Kim Galloway, Datacolor International

ABSTRACT

Personal Digital Assistants (PDAs), such as the Visor Deluxe™ by Handspring™ offer a new paradigm for the design and use of computer-driven instruments. This paper concentrates on the methods of integrating a PDA into a portable color-measuring device and on the enhanced functionality it brings to the instrument. A PDA can be programmed to give these instruments the capability to obtain reflectance data from the spectral analyzer, and translate it into spectral data, color coordinates, and color differences.

Keywords: Color measurement, color instrumentation, personal digital assistants, PDA

1. INTRODUCTION

Portable colorimeters and spectrophotometers appeared in the last decade as an answer to the logistical problems posed by traditional laboratory instruments. Lighter, smaller, mobile instruments allow instrumental color evaluations to be performed on objects, both component pieces and large finished products, that cannot be moved to the lab for evaluation. Moving the instrument to the object provides for on-the-spot instrumental color evaluation, and expands the use of instrumental color evaluations. Portable instruments also offer production personnel the ability to know instantly when the current batch has satisfied the color approval tolerances, speeding the approval process and the change-over time on the production line. The moment the batch satisfies the acceptability tolerances, personnel can immediately begin preparing the for the next production batch.

For the current generation of portable instruments, the instrument development responsibilities extended beyond the design of the optics and mechanics, to the selection of a CPU, memory, and display panels, and the programming of the user interface. Although a great deal of effort was expended on the development of the interface, small memory capacity and the difficulty involved in programming these devices resulted in an interface that was cumbersome to use, and had significant limitations with respect to design, functionality, and future enhancement capabilities.

For the users of these handheld color-measuring instruments, one of the continuing challenges has been mastering the user interface. Navigation procedures often employ toggle switches that must be pushed in a precise order to customize sample names and screen selections. In order to collect the evaluation data quickly and easily, users commonly retreat to the default naming and evaluation sequences provided with the units. In the case of sample identification, users find themselves depending on the auto-numbering sequences built into the software. Customizing sample names usually involves the extra step of uploading the data to a desktop PC, and then renaming each sample. When running an evaluation procedure, users often limit themselves to cycling though a default series of evaluation screens simply because it is it easier. Although most portable instruments currently on the market today may offer a wide variety of software tools, many are never used simply because it is too difficult for the user to navigate through the program to access them.

Personal Digital Assistants (PDAs), such as the Visor Deluxe™ by Handspring™ offer a realistic alternative as the user interface for these portable instruments. Their processing power and storage capacity rivals that of larger, general purpose desktop and laptop computers designed for multi-tasking until now required for color control applications. The PDA's "ease of use" makes them a logical choice as a user interface for commercial instruments. The result is the integration of small, flexible, and powerful computers into instruments focused upon one specific task.

Datacolor International has integrated PDAs into two portable, stand-alone color measuring instruments. The recently released Mercury® portable spectrophotometer integrates a Handspring™ Visor Deluxe™ as the user interface for the instrument (figure 1a). A concept instrument, the PDA Color Reader, has been developed as a plug-in module to the Visor Deluxe™ (figure 1b). Regardless of whether the PDA is an integral part of the instrument or uses the instrument as a plug-in module, the PDA functions in the same manner.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

Figure 1a. The Mercury® Portable Spectrophotometer

Figure 1b. The PDA Color Reader concept instrument

2. PROGRAMMING ADVANTAGES

PDAs can be programmed using the high-level "C" programming language. The operating system supplied with the PDA gives the programmer easy access to the PDA's memory management functions, and the graphical user interface (GUI) includes tools such as drop down menus, radio buttons and text boxes. Since user-friendly screen forms can be quickly and easily developed, the programmer can concentrate on the functionality of the application. A PDA has a set of application buttons and special software icons that can be redirected to tasks required by a custom application. When the custom application is closed, the buttons and icons revert back to their original functionality for use with the remaining PDA applications. When a programmer writes an application program to be added to the PDA, all of the original programs and functionality remain intact and are still available to the user. A number of these pre-programmed features immediately add functionality to a portable color-measuring instrument and are available to the user at any time. For example, the user can access the memo pad and make notes about a color measurement session or use the calculator to make any necessary calculations.

3. THE TOUCH SCREEN INTERFACE

Mercury, a customized color-management application residing on the PDA, appears on the PDA desktop as another applications program. Once the Mercury program is loaded, the user can navigate through the color-management software using the standard navigation devices employed by the PDA, i.e. pressing the application buttons or tapping the screen with the stylus. One application button has been reprogrammed to initiate the measurement of a standard and another to initiate a batch measurement. While the buttons provide speedy access to frequently used functions, the remaining capabilities of the color software are available simply by tapping on-screen buttons or drop-down menus. Two of the icons on the Graffiti® pad have been reprogrammed for the color-management application. The "Home" icon automatically displays the main menu for the Mercury application, and the "Menu" icon displays the data management options.

Perhaps the most important function provided by the PDA is the ability to enter text easily. Being able to easy assign the correct name to the samples is an essential key to collecting meaningful data. This feature extends to naming standards, trials, tolerances and the folders used to contain color measurement data. There are two ways to enter text data with the PDA – the Graffiti® pad shown in figure 1a and the virtual keyboards shown in figure 2. Graffiti® is a shorthand style of writing characters recognized by the Visor Deluxe™. Once the graffiti style is learned, the user can literally use the stylus to quickly write text data on the graffiti pad. As each character is written, it appears in the active text box. For those users who prefer to type data, the Visor Deluxe™ has virtual keyboards. One keyboard contains the letters and special characters as they would appear on an English-language typewriter keyboard; a second keyboard contains numbers, mathematical operations and related special keys; and the third keyboard contains international characters. With a touch of the stylus, the user can quickly move between these keyboards, speeding the color evaluation process, and reducing errors in sample identification that can render the data useless.

Figure 2. Alphabetic, numeric and international virtual keyboards

4. THE APPLICATION SOFTWARE

Adapting the PDA to a color-management application also takes advantage of its sizeable memory and storage capacity. In the past, software offerings that have accompanied portable instruments were confined to basic quality control functions – simple color difference, pass/fail, and color indices – largely because of memory limitations. QC and color formulation systems based on PC platforms generate enormous databases of both samples and formulas, but memory limitations on the portables have restricted the availability of these databases to a handheld application. The integration of the PDA into the new portable instrument is an answer to that limitation. The memory capacity of this device makes it possible to accommodate the storage of large databases in the portable unit (up to 30,000 samples in the current Mercury PDA), and to develop more complex programs that can search, retrieve, and manipulate the color data stored in the folders.

Color application software typically has two categories of functionality – system management/maintenance and data gathering/processing. Traditionally, the data had to be uploaded to a PC in order to maintain and manipulate the data collected using the portable instrument. The PDA makes it possible to easily execute these functions on the portable. Maintenance activities include instrument set-up, and the creation, modification, deletion of samples and tolerances. Since the PDA communicates directly with the instrument, a set-up screen (figure 3) allows the user to select such features as averaging, selection of the specular port position and the number of lamp flashes to be used for measuring the sample.

Figure 3. Instrument set-up screens

Data gathering and processing activities include making measurements, calculating color differences and selecting folders in which to store the measurement data. The computing power and memory capacity of the PDA allows the user to calculate color coordinates for a large number of illuminant/observer combinations. A variety of color difference equations can be programmed into the PDA. Tolerances can also be defined so that a pass/fail message displayed along with the color difference. At the end of the day, the measurement data stored in the folder can be uploaded to a computer for preservation or additional processing.

A typical quality control color evaluation sequence using the PDA would consist of the following steps:

1. Press the standard button to initiate the standard selection.
2. Select an existing standard or enter the name of the standard using either the Graffiti® pad or the keyboards.
3. Measure the standard (when necessary). The measurement may be automatically stored.
4. Press the batch button to initiate the batch selection.
5. Select an existing batch, or enter the name of a new batch.
6. Measure the batch. The measurement may be automatically stored.
7. When the batch measurement is completed, color coordinates and color differences between the standard and batch are immediately displayed, along with a pass/fail evaluation. The data displayed is for the active illuminant/observer combination, but the tolerance can include up to six illuminant/observers combinations. Different illuminant/observer combinations can be selected without leaving the evaluation screen, and the data is instantaneously updated for the new selection. Figure 4 shows some typical quality control output screens.

Figure 4. Typical quality control output screens

5. SUMMARY

Using the PDA as a dedicated computer interface provides capabilities previously unavailable in portable color-measuring instruments. A PDA focuses a great deal of computing power on a single task. The ability to program the PDA using the C language and an operating system with ready access to the memory management functions and graphical user interface frees the programmer to concentrate on the applications programming. A user can easily enter text with either the Graffiti® pad or the virtual keyboards, which is essential to collecting meaningful data. Because of the PDA's sizeable memory and storage capabilities, large sample and formula databases can be available to the user for searching, retrieving and manipulating data.

---

* Correspondence: rmarcus@datacolor.com; phone 609-924-2189 extension 7323; fax 609-895-7438; Datacolor International, 5 Princess Road, Lawrenceville, NJ 08648

Tristimulus Weight Functions To Calculate Musts Color Coordinates From 10-nm Bandwidth Spectral Data

C. Montes [a], J. Campos [b], A. Pons [b], F.J. Heredia [a]

[a] Área de Nutrición y Bromatología. F. Farmacia. Universidad de Sevilla. 41012 Sevilla.
[b] Instituto de Física Aplicada (CSIC). 28006 Madrid.

ABSTRACT

Color measurement of red musts is affected by errors due to the instrument architecture. The influence of bandwidth in color coordinates errors is studied and a set of weighting functions for the color coordinates calculation, from 10 nm spectral data, is proposed.

Keywords: musts color, spectral bandwidth, weighting functions

1. INTRODUCTION

Must color measurement can be of great value during wine elaboration, both for evaluating grape maturation and for predicting color and chemical composition of wines. Tristimulus color results depend on measure conditions. Most of these measurements are done under different circumstances (industrial, country, laboratory environment) and, in many cases, large bandwidth instruments are used.

Although standard conditions have been defined for those parameters which influence the color measure result, such as observer, illuminant, illumination-observation geometry, bandpass and spectral measure interval, practical realizations differ from each other, so errors arise in calculating tristimulus values. These errors depend on the type of measure instrument and its characteristics of construction (Berns & Petersen, 1988; Fairchild & Reniff, 1991; Berns & Reniff, 1997; Burns & Berns, 1997). Furthermore, factors as temperature or relative humidity must be controlled to obtain single and repeatable measurements, because they may effect samples.

Color error as a function of measurement bandwidth has been studied for many sample types in several laboratories. In particular, color error in several types of food has been studied by our group, arising the conclusion that bandwidths larger than 5 nm produce a noticeable color error on many of them. Musts were one of those studied foods with a noticeable error in color coordinates for bandwidth larger than 5 nm.

Within musts, color difference between measurements of the same object, with different instruments, are mainly due to the difference in measurement geometry and instrument bandwidth, since most instruments get spectral data rather than tristimulus color measurement properly. Differences in measurement geometry are not so important in this case because transmittance is the quantity used to determine color and the must is very transparent.

2. EXPERIMENTAL PROCEDURE

Twenty seven red must samples, corresponding to different stages along the grape maturation, and belonging to four harvest (1996-1999) have been studied. From them, five representative samples were selected to test the bandpass error elimination methodology. The rest of samples were used to obtain weighting functions.

A Hewlett-Packard HP8452 UV diode array spectrophotometer was used to scan the spectra of the samples. Tristimulus values were obtained from the visible transmittance values and chromatic coordinates were calculated for the CIE 1976 (L*a*b*)-*uniform color space*, CIELAB (CIE, 1986). The method was applied over the whole visible spectrum, 380-780 nm, at 2 nm intervals, following the *weighted-ordinate* method. CIE standard illuminant A and CIE standard

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

observer 1931 (field<4°) were used in the color calculation. In order to study the bandwidth effect without influences of other experimental conditions, effective transmittance values were calculated by using the following equation:

$$T_{ab} = \frac{\int_{ab} T(\lambda)B(\lambda)d\lambda}{\int_{ab} B(\lambda)d\lambda}$$

where $T(\lambda)$ is the sample's transmittance as measured by the spectrophotometer; $B(\lambda)$ is the slit function (triangular form is assumed) and ab is the extension of the measure spectral interval. Transmittance values for a 10 nm bandpass have been calculated for all the samples and then color coordinates have been calculated using illuminant A and the CIE 1931 standard observer (2°) from 380 to 780 nm using a 10 nm summation interval.

There are mainly two approaches in the literature to avoid the bandwidth error in the calculation of color coordinates: Calculating weighting functions for the tristimulus functions or getting the 1-nm radiance values from the experimental data. In the first case, ASTM (1995) recommends weighting factors Wx, Wy, Wz, defined differently for 10 and 20 nm bandpass. These weighting factors already contain the product of illuminant A and the CIE 1931 standard observer (2°) for the respective interval and they have been prepared to correct spectral measurements errors due to bandpass effect. Color coordinates of our must samples have been calculated according to the ASTM procedure for a 10 nm bandwidth.

A method for correcting radiance data for bandpass error is proposed by Stearns and Stearns (1988). By applying this method to the samples, the calculated color coordinates should coincide with the 1-nm coordinates. The model estimates the zero bandwidth radiance data from the measured radiance, considering a 10 nm triangular and symmetrical bandpass and a measurement interval equal to the bandwidth. This method has been applied to our must samples to calculate color coordinates.

3. RESULTS AND DISCUSSION

Total color difference in (L*a*b*) as well as difference in lightness and chroma between 2-nm initial data and the coordinates calculated from the 10 nm bandpass values have been obtained, considering for the 10 nm bandwidth: uncorrected values, ASTM corrected values and values corrected by the Stearns & Stearns method.

The ASTM weighting functions results are not satisfactory, because they produce an improvement of roughly 0.1 CIELAB unit in color difference with respect to the uncorrected value, and in many cases color differences in must samples are still higher than 0.5 CIELAB units after correction.

The Stearns & Stearns method gives a better correction than the ASTM for most of the samples considered, producing a reduction of 0.2 or 0.3 CIELAB units in color difference, but the correction is still insufficient and again many differences are larger than 0.5 CIELAB units.

To get a noticeable reduction in bandpass color error, different weighting functions were calculated according to the following criterion:

$$x(\lambda, \Delta\lambda=1\ \text{nm}) = x(\lambda, \Delta\lambda\neq1\ \text{nm}) \times p(x)$$

$$y(\lambda, \Delta\lambda=1\ \text{nm}) = y(\lambda, \Delta\lambda\neq1\ \text{nm}) \times p(y)$$

$$z(\lambda, \Delta\lambda=1\ \text{nm}) = z(\lambda, \Delta\lambda\neq1\ \text{nm}) \times p(z)$$

The weighting functions are then defined as sets of values, one for every tristimulus function. The simplest expressions to calculate individual values for each are:

$$p(x) = \frac{\sum_{\Delta\lambda} x(\lambda) * T(\lambda) * E(\lambda) * \Delta\lambda}{10 * x(\lambda) * E(\lambda) * T_s(\lambda) * \Delta\lambda_{10}}$$

$$p(y) = \frac{\sum_{\Delta\lambda} y(\lambda) * T(\lambda) * E(\lambda) * \Delta\lambda}{10 * y(\lambda) * E(\lambda) * T_s(\lambda) * \Delta\lambda_{10}}$$

$$p(z) = \frac{\sum_{\Delta\lambda} z(\lambda) * T(\lambda) * E(\lambda) * \Delta\lambda}{10 * z(\lambda) * E(\lambda) * T_s(\lambda) * \Delta\lambda_{10}}$$

where $\Delta\lambda$ is the spectral interval in which the slit function is defined; $x(\lambda)$, $y(\lambda)$, $z(\lambda)$ are the tristimulus functions, $E(\lambda)$ is the illuminant and $T(\lambda)$ is the sample transmittance.

These three equations were applied to the 1-nm and 10-nm spectral data of must samples, from the four harvests. For each harvest, arithmetic media was calculated, and, since no large difference was found from harvest to harvest, the arithmetic media of the four values was calculated again. The standard deviation of these averaged values was in the order of 2 parts per thousand. So, three suitable weighting functions were obtained to apply to general must samples (Fig. 1).

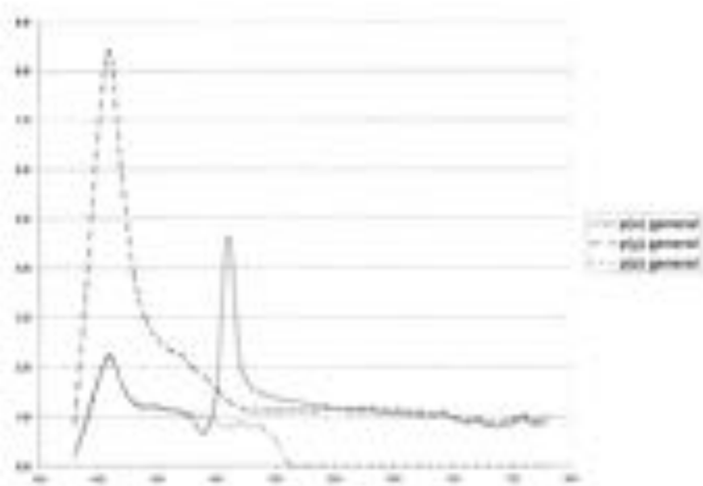


Fig 1. Weighting Functions

The three weighting functions: p(x), p(y), p(z) were analyzed, and each of them had a spectral zone where the correcting action is higher.

The function p(x) has got a maximum value in 500-600 nm (red-orange zone). This zone coincide with the $x(\lambda)$ peak. The function has got another high value in the blue zone (390-450 nm) to correct the coordinate b*.

On the other hand, function p(y) is noticeable only in the blue zone (380-480 nm). The weighting function p(z) had a maximum for correcting blue wavelengths in the same zone than p(x).

The three functions had a plane spectral zone (580-780 nm) where no corrections were necessary.

Color coordinates obtained by applying these weighting functions to a set of 5 samples of 10 nm transmittance values are much closer to the 2 nm values than those obtained by the other approximations (ASTM, Stearns). These samples, as mentioned before, were not used to derive the previous weighting functions.

4. CONCLUSIONS

When bandpass is different from 1 nm, errors arise in calculating color coordinates, although those errors are not noticeable when the bandwidth is lower than 5 nm. There are two methods in the literature to try to correct those errors. Both have been tested in this work for must samples. However, by using ASTM weighting functions or applying the Stearns & Stearns method there was no improvement in the higher bandpass values with respect to 1-nm bandpass.

To eliminate bandpass effect in tristimulus values it is necessary to calculate suitable weighting functions. A criterion for calculating these functions has been proposed. By applying these weighting function to must samples, it is possible to compare color coordinates obtained from 1-nm spectral data to those obtained from 10-nm experimental values.

REFERENCES

ASTM. *Annual book of ASTM standards*, **vol 06.01**, 1995.

R.S. Berns, L. Reniff, "An abridged technique to diagnose spectrophotometric errors", *Color Res. Appl.* **22**, pp 51-60, 1997.

R.S. Berns, K.H. Petersen, "Empirical modeling of systematic spectrophotometric errors," *Color Res. Appl.* **13**, pp 243-256, 1988.

P.D. Burns, R.S. Berns, "Error propagation analysis in color measurements and imaging", *Color Res. Appl.* **22**, pp 280-289, 1997.

CIE. Colorimetry; Pub. CIE 15.2 Viena, Austria, 1986.

M.D. Fairchild, L. Reniff "Propagation of random errors in spectrophotometric colorimetry", *Color Res. Appl.* **16**, pp 360-367, 1991.

E.I. Stearns, "Influence of spectrophotometer slits on tristimulus calculations", *Color Res. Appl.* **6**, pp 79-84, 1981.

E.I. Stearns, R.E. Stearns, "An example of a method for correcting radiance data for bandpass error", *Color Res. Appl.* **13**, pp 257-259, 1988.

W.H. Venable, "Accurate tristimulus values from spectral data", *Color Res. Appl.* **14**, pp 261-267, 1989.

Influence of the mean luminance on the detection threshold for red-green chromatic gratings

Juan L. Nieves*, E. Valero, J. Hernández-Andrés, J.A. García, J. Romero.
Departamento de Óptica, Universidad de Granada/Granada, SPAIN

ABSTRACT

The objective of the study was to examine the influence of the mean luminance level on the detection thresholds for red-green chromatic gratings of three different spatial frequencies. Data for chromatic sinusoidal gratings with higher mean luminance levels (within the photopic level) than those ones used in previous works were reported. The study analyzed the transition luminance between the DeVries-Rose law and the Weber law regions, and considered the validity of the constant-flux hypothesis for the three spatial frequencies tested. The results suggest that the "flux" would not be a critical factor in the processing of chromatic gratings in the low spatial frequency range.

Keywords: color vision, spatial vision, chromatic gratings,

1. INTRODUCTION

Several studies have been conducted about the so-called parametric experiments in the field of spatial vision (i.e. mean luminance level, orientation, spatial position, spatial extent, and temporal extent) and their influence on the sensitivity thresholds for luminance sinusoidal gratings. Regarding the influence of the mean luminance level on sensitivity thresholds[1,2], different behaviors have been reported for different luminance ranges: for lower luminances there is a linear behavior region, for mid-range luminances a DeVries-Rose law behavior is found, and for higher luminances the threshold remains constant obeying the Weber law. The luminance at which the transition from the DeVries-Rose law to the Weber law occurs has been reported to be proportional to the square of the spatial frequency of the grating[2]. This fact is explained by the use of the so-called constant flux hypothesis, which assumes that the ratio of transition luminance to the squared spatial frequency (flux) remains constant, and so it determines the transition luminance.[3] There are some, although less in number, parametric studies regarding chromatic instead of luminance gratings, but they have not entered into the question of the validity of the constant-flux hypothesis[4,5].

2. METHODS

Stimuli were horizontal stationary isoluminant red-green chromatic gratings raised-cosine enveloped along the axis of modulation in order to avoid sharp border effects. The overall phase of the stimulus was fixed at 0 deg. We defined the chromatic contrast of the gratings as:

$$C_{r-g} = \frac{RG_1 - RG_2}{K_{r-g}} \qquad (1)$$

where RG_1 and RG_2 are the responses for the red-green chromatic channel for the two colors between which the chromaticity is modulated to generate the grating, and K_{r-g} is a constant value calculated in order to make the maximum contrast value of unity.

Chromatic gratings were displayed on a SONY CPD17SF2 color monitor controlled by a VSG2/3 waveform generator with 14-bit-digital-to-analog converter. The overall phase of the stimulus was fixed at 0 deg and the visual field was 8 deg. Isoluminance for each pair of colors was evaluated by a standard Heterochromatic Flicker Photometry procedure using an equienergy stimulus of 21.50 cd/m^2 of luminance as the reference white. Six values of mean grating luminance were selected: from 10.50 to 60.50 cd/m^2 in steps of 10 cd/m^2. Thus, all the luminance values were on the photopic range, which is considered to begin at 3 cd/m^2 according to CIE recommendations. The spatial frequencies used were of 1.0, 2.0 and 3.0 cpd, which were chosen in order to minimize the influence of the chromatic aberrations, which we have not corrected for, as a cue for facilitating grating detection to the observers.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

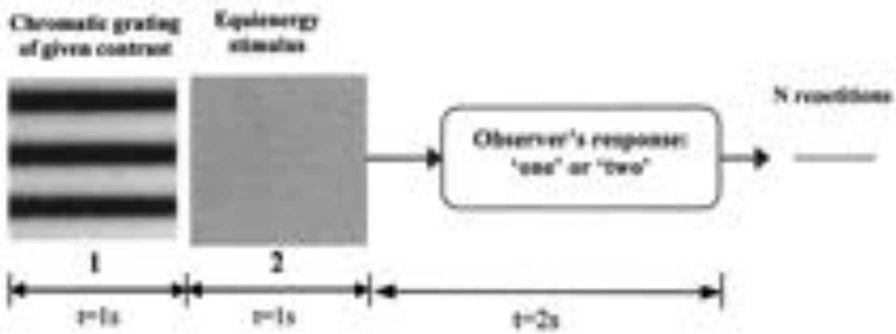


Figure 1: Temporal sequence of the 2AFC experimental procedure. Observers selected in which interval ('1' or '2') the gratings appear. The N repetitions finished after six contrast reversals.

The detection thresholds were determined using a two-alternative forced-choice (2AFC) three interleaved staircase procedure, in which the test stimulus appeared in one of two time intervals and in the other interval appeared a uniform equienergy stimulus with the same mean luminance of the chromatic grating (figure 1). The staircase procedure finished after six contrast reversals, and the threshold was calculated as the mean of the contrasts of the last four reversals. Each threshold was obtained as the mean of at least three measurements. Three observers took part in the experiment, all corrected to normal acuity.

3. RESULTS AND DISCUSSION

Figure 2 shows an example of the averaged contrast thresholds obtained for a frequency of 3 cpd. As can be seen, contrast thresholds diminish with increasing luminance levels; this tendency is found for the three frequencies used, with contrast thresholds being the lowest for 1 cpd. Visual inspection of the figure suggests that results are far from reflecting a zero-slope behavior, which would be indicative of a Weber law-type summation process. If contrast thresholds obeyed a DeVries-Rose law, results should be described according to the following equation,

$$C \propto L^{-1/2} \qquad (2)$$

where C is the contrast threshold and L is the mean luminance of the grating. On the contrary, linear fits of the data (see Table 1) confirm that this does not occur, and show that slopes are clearly lower than −0.5 in logarithmic scale.

To evaluate the deviation from a slope of −0.5, we modeled the data with an equation of the form,

$$C = k\left(-\frac{1}{2}L\right) + m \qquad (3)$$

where k is a correction factor which reflects the deviation from the predicted −0.5 slope value, L is mean grating luminance, C is threshold contrast, and m is the ordinate of the original fit. A k-value of unity would be indicative of a DeVries-Rose behavior, while a larger k-value indicates a behavior closer to a summation process of a Weber-law type. The k-values obtained were of 1.85 for 1.0 and 2.0 cpd, and 2.0 for the highest spatial frequency used.

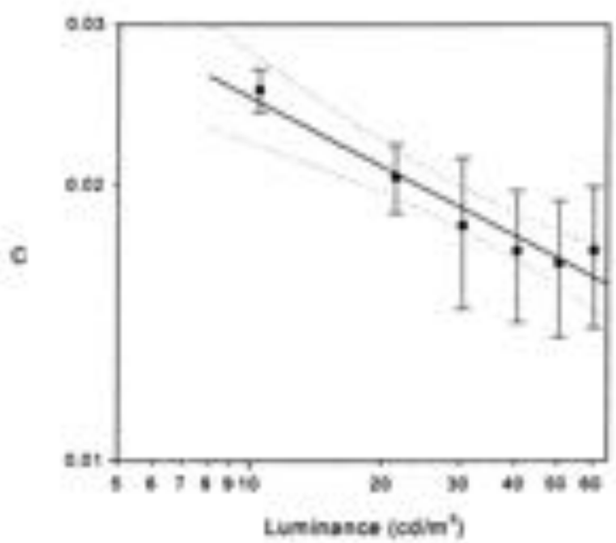


Figure 1: Averaged contrast thresholds as a function of luminance level, for a spatial frequency of 3.0 cpd. The linear fits and the upper and lower 95%-confidence bands are also shown.

The above results lead to a further study of the two regions —DeVries-Rose and Weber regions— presumably found in our data, and the transition luminance between them. Let's assume a theoretical distribution obeying the DeVries-Rose law until the transition luminance is reached and obeying the Weber law for luminance values above the transition value. If one fits linearly this distribution, one obtains slope values between -0.5 (all the points obeying the DeVries-Rose law) and zero (Weber law behavior for all the threshold points). How far this fitted slope is from each of these two extreme values depends on the transition luminance value. If the transition luminance is low, the fitted slope will be lower. So by setting different transition luminance values and iteratively repeating the fitting procedure we can obtain the transition luminance, which will give a slope very similar to our experimental fitted slopes. In our case, the transition luminance takes a fixed value of 27.5 cd/m^2. Figure 2 shows the data points and the theoretical distribution corresponding to a transition luminance of 27.5 cd/m^2. The vertical shifts, which are due to the effect of increasing spatial frequency upon detection thresholds, are derived from the three different independent terms for the DeVries-Rose fraction of the distributions. These independent terms take the values of -1.37, -1.27 and -1.05 for 1.0, 2.0 and 3.0 cpd, respectively. These theoretical distributions show a reasonable agreement with our experimental data, so we can conclude that our data are compatible with a DeVries-Rose to a Weber law transition luminance of 27.5 cd/m^2 for the three spatial frequencies used.

Table 1: Results from the linear fitting of individual and averaged sensitivity thresholds.

	Observer EV			Observer JL			Observer JH		
Freq (cpd)	Slope	Ind.	r	Slope	Ind.	r	Slope	Ind.	r
1	-0.25±0.05	-1.68±0.08	-0.92±0.03	-0.30±0.03	-1.59±0.04	-0.98±0.02	-0.27±0.02	-1.64±0.03	-0.99±0.01
2	-0.32±0.06	-1.49±0.09	-0.94±0.04	-0.23±0.03	-1.56±0.04	-0.98±0.02	-0.26±0.05	-1.56±0.07	-0.94±0.03
3	-0.36±0.05	-1.26±0.08	-0.96±0.03	-0.22±0.03	-1.39±0.04	-0.97±0.02	-0.19±0.03	-1.42±0.05	-0.94±0.02

Averaged results

Freq (cpd)	Slope	Ind.	r
1	-0.27±0.05	-1.64±0.05	-0.98±0.02
2	-0.27±0.04	-1.54±0.06	-0.96±0.03
3	-0.25±0.03	-1.35±0.05	-0.97±0.02

The results confirm basically the validity of the DeVries-Rose and Weber laws for chromatic gratings in the photopic range[3]. Our results are compatible with a fixed transition luminance of 27.5 cd/m^2 for the three spatial frequencies tested. Van der Horst and Bouman's results[4] show the same tendency for the various spatial frequencies used, while Sekiguchi et al.'s results[5] are obtained for higher spatial frequencies than those used in our work. The constant-flux hypothesis is not valid for color gratings because it predicts that the transition luminance is proportional to the square of the spatial frequency of the gratings. Nevertheless, this hypothesis has been formulated and supported by experiments[2] that use luminance but not chromatic gratings. The constant-flux hypothesis is explained usually in terms of the width of the receptive field (RF) center of the cells responding to luminance gratings[6], which has an area proportional to the inverse squared of the maximum sensitivity spatial frequency for the cell. Because the flux is proportional to this area multiplied by the transition luminance (maximum luminance for which the spatial summation phenomena holds), the transition luminance must be proportional to the squared spatial frequency if the flux remains constant for higher luminance values than the transition luminance.

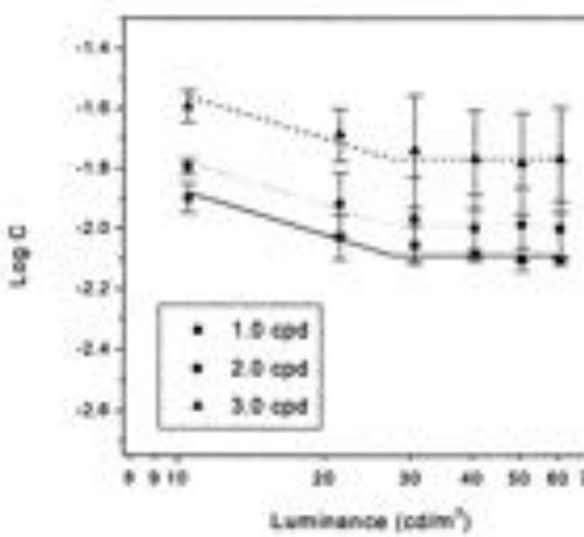


Figure 2: Averaged contrast thresholds as a function of luminance level for the three spatial frequencies used in the experiment. The theoretical behavior corresponding to a transition luminance of 27.5 cd/m^2 is also shown for each frequency.

It is a well-known fact however that there are differences in the processing of luminance and chromatic gratings by the visual system[6,7]. The main difference concerning the range of spatial frequencies used in our experiments is that there is no sensitivity decrease for low spatial frequencies for chromatic gratings. This low-pass behavior is also supported by physiological evidence at the early visual stages (retina and LGN)[8] and also somewhat less clearly at cortical levels[9]. The main reason for this low-pass character in the responses of neurons is that for those color-opponent cells, the center and periphery of the cell receive inputs from different types of cones (e.g. L-cone type to the center and M-cone type to the periphery). This fact determines that the center and periphery act sinergically for variations of color of the same sign (in our example, to shifts in chromaticity to red), so the maximum response of the cell corresponds to a spatial frequency such that a half-cycle covers both the center and the periphery, but the optimal response is maintained also for *lower* spatial frequencies. Thus, the center area (and hence the flux) is not a critical factor in the processing of chromatic gratings of different luminance levels in the low spatial frequency range. For higher spatial frequencies, which have not been involved in this work, presumable the behavior would emulate the luminance-patterns processing. In this case, the response would be in part due to complex cells, which are able to detect chromatic gratings of more than 4 cpd, although their response is not color-opponent and very similar to color and luminance patterns.

4. SUMMARY

The fixed transition-luminance value obtained between the DeVries-Rose law and the Weber law shows that a *constant-flux hypothesis* is not valid to describe the variations of chromatic contrast thresholds at photopic levels. The results derived from our experiment reveal the differences in the processing of luminance and chromatic gratings by the visual system. Our results suggest that the center area (and hence the flux) of those cells which respond to color is not a critical factor in the processing of chromatic gratings of different luminance levels in the low spatial frequency range. For higher spatial frequencies, which have not been involved in this work, presumably the behavior would emulate the pattern observed for luminance-modulated gratings processing, though this is a matter for further studies.

ACKNOWLEDGEMENTS

This research was supported by Spain's Comisión Interministerial de Ciencia y Tecnologia (CICYT) under research grant PB96-1454 and by the CICYT-European Commission FEDER grant R-IFD97-1534-CO
2-01.

REFERENCES

1. A.S. Patel, "Spatial resolution by the human visual system: the effect of mean retinal luminance", *J. Opt. Soc. Am.* **56**, 689-694, 1966.
2. F.L. van Nes, J.J. Koederink, H. Nas & M.A. Bouman, "Spatiotemporal modulation transfer in the human eye" *J. Opt. Soc. Am.* **57**, pp. 1082-1088, 1967.
3. R.M. Shapley & C. Enroth-Cugel, *Progress in Retinal Research Vol. 3* (N.N. Osborne & G.J. Chader Eds.). Oxford, Pergammon, pp. 263-343, 1984.
4. G.J.C. van der Horst & M.A. Bouman, "Spatiotemporal chromaticity discrimination" *J. Opt. Soc. Am.* **59**, pp. 1482-1488, 1969.
5. N. Sekiguchi, D.R. Williams & D.H. Brainard, "Efficiency in detection of isoluminant and isochromatic interference fringes", *J. Opt. Soc. Am. A* **10**, 2118-2133, 1993.
6. N.V.S. Graham, Visual pattern analyzers, Oxford University, New York, p.532, 1989.
7. K.T. Mullen, "The contrast sensitivity of Human colour vision to red-green and yellow-blue chromatic gratings" *J. Physiol.* **359**, pp. 381-400, 1985.
8. R.L. DeValois & K.K. DeValois, Spatial Vision. Oxford University, New York, pp. 212-235, 1990.
9. L.G. Thorell, R.L. De Valois & D.G. Albrecht, "Spatial mapping of monkey V1 cells with pure color and luminance stimuli", *Vision Res.* **24**, 751-769, 1984.

* jmicros@ugr.es; phone 34 958 246367; fax 34 958 248533; http://www.ugr.es/~geoptica/. Departamento de Óptica, Facultad de Ciencias, Campus Fuente Nueva, s/n, Univ. Granada, 18071-Granada SPAIN

Colour Characterisation of Cine Film

Leonardo Noriega[a], Jan Morovic[a], Lindsay MacDonald[a], and Wolfgang Lempp[b].

[a]Colour and Imaging Institute, Kingsway House, Derby, UK.
[b]Computer Film Company, 19-23 Wells Street, London W1, UK.

ABSTRACT

This paper describes the characterisation of cine film, by identifying the relationship between the Status A density values of positive print film and the XYZ values of conventional colorimetry. Several approaches are tried including least-squares modeling, tetrahedral interpolation, and distance weighted interpolation. The distance weighted technique has been improved by the use of the Mahalanobis distance metric in order to perform the interpolation, and this is presented as an innovation.

Keywords: Cine Film, Device Characterisation, Least-Squares Fitting, Tetrahedral Interpolation, Distance-Weighted Interpolation

1. INTRODUCTION

Digital technology is assuming an ever-increasing importance in many aspects of modern life. In particular there is a growing usage of digital technology in the production of films. Although the industry remains predominantly celluloid-based, digital special effects have enhanced the cinematic experience in no small degree. The technology for digital image capture, storage, and projection is already in existence, and will shortly be in a position to compete with conventional film in terms of the spectator experience.

A collaborative research project in the UK is investigating the digitisation of film via a high-resolution digital scanner. The prototype device is currently being developed at the Computer Film Company (CFC) in London, and the University of Derby is researching the foundations of colour management for the scanning, previewing and printing of cine film.[1] A key aspect of the project is colour characterisation of the film stock, specifically the relationship between positive film density and its colorimetry.

2. CHARACTERISING PRINT FILM

The colour characterisation problem involves finding a suitable transformation from the film density values (measured using Status A densitometry), to the corresponding colorimetric values. Other studies[2345] have examined the issue of the characterisation of scanners and input devices using a variety of techniques. The issue of the relationship between film density and colorimetry remains highly problematical, and hence the need for continued investigation. Given a point in Status A RGB density space, located by a triplet of values, we seek to determine its equivalent point in XYZ tristimulus space. This requires Status A density information, for which the measured colorimetry has already been obtained. This data enables a mathematical relationship to be established, which should hold for all colours throughout the gamut.

To identify this relationship three different approaches were pursued in this study, listed as follows.

- *Least Squares Modeling*[2]. The relationship between density and colorimetry was modelled quadratically. Pre-processing was used to prelinearise the data.
- *Look-Up Table (LUT) using Tetrahedral Interpolation*[34]. Tetrahedral interpolation was used in order to predict the colorimetry of a film. This technique requires that the data used to develop the relationship be regularly arranged, so that the geometric shapes into which the space is divided is exhaustive (covers all of the space) and exclusive (the shapes do not overlap). If the coverage is not exhaustive then strategies are required to interpolate data outside of the interpolation shapes.

For further information Contact Leonardo Noriega: E-mail: l.noriega@derby.ac.uk

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

- *Distance Weighted Interpolation*[3]. This technique consists of interpolating the film colours from the measured data, so that the measurements nearest the unknown sample have greatest effect. The fall-off of the distance weighted algorithm is dependent on a tunable parameter μ, which can be determined by minimising a suitable cost function.

3. EXPERIMENTAL APPROACH

For effective development of a transformation model, data is required both to produce the model (the *training set*) and to test the model (the *test set*). A data set consisting of a thousand single-colour frames of positive cine film was acquired, with the Status A density values measured by an X-rite 310 densitometer and the XYZ values measured by an X-rite Colortron (2°, 0-diffuse geometry) using a D65 backlight for transmission measurements. The median of the error of the Colortron measurements (tested using an ISO IT8.7/1 image) was within $2\Delta E_{ab}$ of the measurements given with the image.

The data set was subsequently partitioned in order to provide independent test and training sets for each of the modelling techniques described above. Each technique was tested several times using different training and test sets. The test set consisted of samples chosen so that no region of colour space was particularly favoured. In order to improve the performance of the modelling techniques, several data preprocessing strategies were pursued. The aim was to reduce the complexity of the relationship between the density and colorimetry, and thus to facilitate the modelling process.

- *Linearising the Status A RGB values.* The Status A density measurements are (base 10) logarithmic values. The linearisation strategy consisted of exponentiation (raising 10 to the power of minus the status A value).
- *Cube Root XYZ.* The XYZ values were converted to a more physiologically plausible representation, along the lines of $CIEL*$.
- *Logarithmic XYZ.* The XYZ values were converted to colorimtric density ($-log(X/X_0$ etc), in the hope that this would bear a closer relationship to Status A density.

Each of these linearisation strategies was pursued with each of the characterisation techniques described in the previous section. Models were also generated with the unpreprocessed data.

4. RESULTS

The results for the least squares fit modelling process proved disappointing, regardless of preprocessing (which only sabotaged the performance of the model on the raw data), with exceptionally large mean ΔE^*_{ab} values (about 20).

A look-up table with tetrahedral interpolation proved ineffective, since it was not possible to obtain a training set that represented a uniform sampling of Status A density space. Tetrahedral interpolation requires that samples submitted to the model for interpolation should fall within a regular cube in density space, and a suitable strategy is required when this is not the case. In practice it is almost impossible, given the nature of the film development process, to obtain regular sampling of density space. There were considerable distortions of the cubes, and this may explain the failure of the technique to perform adequately.

In order to compensate for the considerable distortions in the geometry, a different strategy is required for tetrahedral interpolation to deal with samples that do not fall on uniformly-spaced grid points. To this end distance-weighted interpolation was incorporated into the look-up table. This led to a model that produced results considerably better than those obtained from simple Least-Squares modelling. Initial results indicated that this modified interpolation provided a better solution, with median ΔE^*_{ab} values down to 6.5, although the maximum ΔE^*_{ab} values were still unacceptably high (at around 25).

Instead of a look-up table, all of the data in the training set were then used to interpolate the XYZ values, and this led to a dramatic improvement in the results obtained. The distance-weighted interpolation technique incorporates an exponent parameter (μ) that determines the linearity (if the exponent is unity) or the extent of the non-linearity of the effect of distance (d) between points in the training set, and the point whose colour is to be interpolated. This relationship is captured in a set of coefficients (σ_i) defined

$$\sigma_i = \frac{1}{d^{\mu}}. \tag{1}$$

Varying the values of the parameter (μ)led to different results, however for the optimum value (around 6) the mean ΔE^*_{ab} values were consistently below 3, and the maximum values were well below 20. While these results were better, there was still room for further improvement, and adjustments to the technique were sought.

As an alternative to the Euclidean distance-weighted metric in the interpolation algorithm, we experimented with an alternative distance metric. The Mahalanobis distance metric[8] is used extensively in multivariate analysis, and effectively scales the Euclidean metric for a set of samples by the standard deviation of each sample (in other words along each spatial axis), effectively giving an ellipsoidal distance measure shown in Equation 2, where x and y are vectors in the set α.

$$d^2(x, y) = (x - y)\Sigma_{\alpha}^{-1}(x - y) \tag{2}$$

Introducing the Mahalanobis distance metric led to further improvement in the characterisation process, bringing the maximum ΔE^*_{ab} between measured and predicted values down to below 10, while the mean error is consistently below 2.5. The results for all of these experiments are summarised in Table 1.

Table 1. Comparison of Interpolation Results

Interpolation Technique	Median ΔE^*_{ab}	Maximum ΔE^*_{ab}
Tetrahedral	6.5	25.39
DW(Euclidean)	2.99	15.73
DW(Mahalanobis)	2.23	9.67

Table 2. Effects of Data Preprocessing on Median ΔE^*_{ab}.

Interpolation Technique	Normal Status A Col. Dens	Normal Status A $\sqrt[3]{XYZ}$	Linear Status A Raw XYZ	Linear Status A Col. Dens.	Linear Status A $\sqrt[3]{XYZ}$
Tetrahedral	15.24	15.36	5.52	3.8	5.04
DW(Euclidean)	6.04	4.59	6.45	4.73	4.59
DW(Mahalanobis)	5.64	4.52	5.97	4.81	4.52

The cumulative ΔE^*_{ab} errors for the test samples are shown in Figure 1. This gives further evidence of the evidence of the success of the technique, showing that over seventy percent of predictions were within 2 ΔE^*_{ab} of the measured result. This compares with the error of the measurement device.

Generally speaking the preprocessing strategies did not lead to any significant improvements in any of the techniques tried as can be seen from Table 2. The interpolation techniques employed make assumptions about the nature of the relationship between density and colorimetry, which seemed to be most closely modelled using distance weighted interpolation in combination with the Mahalanobis metric on the raw density and colorimetry data. Preprocessing had the effect of changing the basic assumptions, and thus adversely affected the results.

5. CONCLUSION

The distance-weighted interpolation method, based on a large training data set appears to provide the best solution to the characterisation problem, however the results obtained so far could be improved even further. It is expected

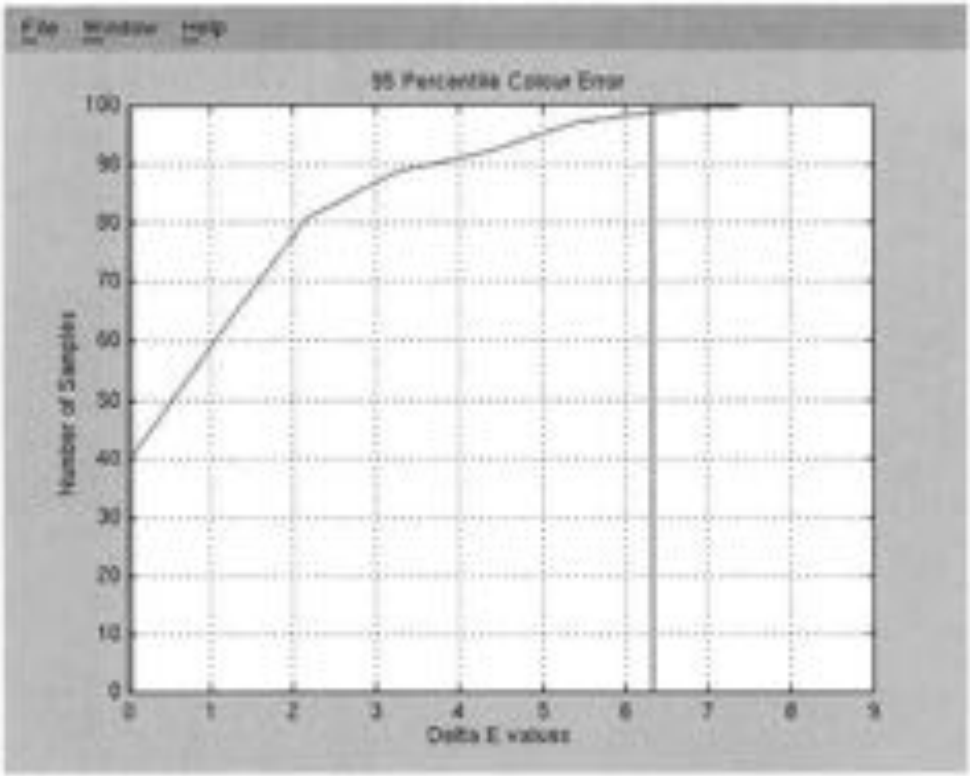


Figure 1. Cumulative ΔEs for Status A $\rightarrow XYZ$ Transform

that with a larger data set it will be possible to improve the quality of the predictions and there is evidence to suggest this from the experimentation carried out in this report. By steadily increasing the size of the training set, from 750 to 800 to 900 samples, the accuracy of the predictions improved considerably. To this end another data set is currently being acquired, consisting of 1500-2000 samples.

In the meantime this technique has been incorporated into a strategy for the colour characterisation of a scanner for negative film. Since negatives are colorimetrically meaningless, they can only be judged in terms of the positives printed from them. The solution adopted for this problem has been to model the printing process by identifying the relationship between negative (Status M) and print(Status A) density. This work will be reported in due course.

6. ACKNOWLEDGEMENTS

The work reported here was supported by DTI/EPSRC Link funding, and the film samples were provided by the Computer Film Company in London.

REFERENCES

1. Noriega, LA., MacDonald, LW., "Accentuate the Positive: Characterising a Film Scanner", Digital Futures 2000 Conference, University of Westminster, Harrow, UK, 11-13th September 2000.
2. Johnson, T., "Methods for characterising colour scanners and digital cameras", DisPlays, Vol. 16, No. 4, May 1996.
3. Hung, P.C., "Colorimetric Calibration in electronic imaging devices using a look-up-table model and interpolation", Journal of Electronic Imaging, January 1993, Vol.2, No. 1.
4. Kang, HR, "Colour Technology for Electronic Imaging Devices", SPIE 1997.
5. Morovic J. and Luo M. R. (1996), "Characterising Desktop Colour Printers Without Full Control Over All Colorants", *Proceedings of 4th IS&T/SID Color Imaging Conference*, pp.70-74.
6. Schalkov, R., "Pattern Recognition: Statistical Structural and Neural Approaches", Wiley, 1992.

Leonardo 2000: The Softcopy Screen Book

Michael H. Brill[*a], Hugh S. Fairman[b], Henry Hemmendinger[c], Jack A. Ladson[d]
[a]Sarnoff Corporation, [b]Resource III, Inc., [c]Hemmendinger Color Labs, [d]Color Innovation, LLC

ABSTRACT

As part of a larger project that is intended for self-taught color science, we developed a software tool to provide a softcopy simulation of the Munsell Book of Color under varied illuminants and for various observers. This simulation avoids setting up as ideal a particular set of pigments from which to derive spectral reflectances. The color-order database contains a reflectance function for each Munsell aim point. The aim points are the usual ones for Illuminant C and 2° Observer function. For a new illuminant and observer, each reflectance function is weighted by appropriate color-matching function and illuminant spectral power distribution, and integrated to produce new X, Y, and Z values. From these values, CIELAB and chromaticity coordinates are computed. Having specified atlas colors in a variety of coordinates, the program next renders them on screen as a color-navigation tool. To illustrate good practice in constructing an atlas of reflectances, the reflectance spectra from a linear series of aim points in Munsell space can be co-plotted to show the requirements for consistency of the series under illuminant and observer change.

Keywords: color order system, software, color education

1. INTRODUCTION

The Munsell color-order system is one of many that have proven valuable over the past century. The authoritative definition of the Munsell system was presented in a 1943 O.S.A. article[1], and is now codified in ASTM D-1535 as a national standard and an international reference document. The 1943 definition was rendered obsolete by recent CIE recommendations. Furthermore, there has been no way to extend the notation of the Munsell system to an observer function other than the CIE 2° Observer; or to illuminants other than CIE Standard Illuminant C. This is because the Munsell system does not incorporate, at its level of definition, an atlas of samples of known spectral reflectance factors. Such an atlas would implicitly remove ambiguities incurred by illuminant and observer metamerism. The work reported here is a modernization of the definition of the Munsell color-order system, an extension of its scope, making it accessible to modern data handling and colorimetric practice.

What Munsell notation corresponds to a customer-provided set of tristimulus values that refer to other than CIE Standard Illuminant C and the CIE 2° Observer? This question has a historical and a modern answer. In the 1950's and 1960's, H. Davidson and H. Hemmendinger created the forerunner of today's Munsell renotation samples by methods described in their articles in *J. Opt. Soc. Am.* [2,3,4] In the decade after 1975, Hemmendinger measured the spectral reflectance factors of these samples and created a database of them (at 10-nm increments from 380 to 700 nm). This database was corrected to modern Munsell notation and may be the first database ever published outside the Munsell Book of Color itself. To each Munsell specification was attached a reflectance spectrum that produces the specified notation. To ensure consistency of the Munsell system with respect to illuminant change, the representative reflectances were examined in series of constant Munsell hue and value, but varying Munsell chroma. Consistency was evaluated graphically as the monotonicity of reflectance at any wavelength as that scale is traversed. The consistency was in most cases quite good.

[*] mbrill@sarnoff.com; phone 609-734-3037; Sarnoff Corporation, 201 Washington Road., Princeton, NJ, USA 08540

2. SOFTWARE OVERVIEW

Because different colorants are used today than a quarter century ago, the authors designed and produced a software tool to provide a standard simulation of the Munsell Book of Color under varied illuminants, without setting up as ideal a particular set of pigments. The database contains a reflectance function for each Munsell aim point, the aim points having been established for Illuminant C and 2° Observer. For a new illuminant and observer, each reflectance function is weighted by the desired color-matching functions and illuminant spectral power distribution, and integrated to produce new X, Y, and Z values. From these values, CIELAB and chromaticity coordinates are computed in the usual way.[3] The user can obtain tristimulus values for up to ten spectral curves simultaneously using CIE 2-degree or 10-degree standard observers, and CIE Sources A, D65, D50, F2, F7, or F11 (computed with ASTM weight sets). The program provides XYZ, Yxy, CIELAB, OSA-UCS, and Munsell values. It can also co-plot the reflectance spectra of a sequence of data, and thereby illustrate fundamental principles of atlas construction. For example, if the hue and value (lightness) are held constant, then a color sequence in monotonically increasing chroma illustrates the above-noted rule for atlas consistency.[*]

Having specified the atlas colors in any of a variety of coordinates, the program next renders them on the screen as a color-navigation tool. The rendition is not intended to be exact colorimetrically, but to be sufficient for navigation through a color atlas (as a geographical map is functional even when the scales are not precise). For this purpose, the default monitor profile implied by sRGB [4] is used to approximate desired tristimulus outputs on a screen. Color differences are displayed on screen in a format that allows comparisons of color differences from a selected color.

3. SOFTWARE OPERATION

3.1 Program philosophy and operation

The program allows interactive display and data generation on colors a user chooses from provided data files. The program accepts user's numerical values for manipulation and presentation. Up to ten colors at a time may be brought into the working registers of the program, and thereafter manipulated through pull-down menus.

The user fills as many data registers as desired from a data file. The data files are listed in a list-box on the right side of the screen. Clicking on any line in the list-box fills the next available data register with that file. The files may be assembled in any order. A 'Clear All' button clears the registers to start over, or the user overwrites a file currently in the register. Having conditioned the registers with chosen files, the user may perform all operations of the program.

3.2 Setup Options

3.2.1 Change display background: Produces a list-box containing the names of ten Munsell neutrals that may be chosen as the display background. Generally Munsell N7 is a good default background color unless you wish to see the effects of other backgrounds on selected colors.

3.2.2 Select illuminant-observers: Produces a list-box containing the names of the illuminant-observer combinations available. The user may select up to three illuminant-observer conditions. Subsequent colorimetric calculations will default to these illuminant-observer combinations.

---

[*] The following rationale for the chroma-series rule may be helpful. If all the reflectance spectra in a chroma series are linear combinations of two basis functions, the rule is satisfied, and the chroma series is a straight line in tristimulus space. This linear-combination condition would be true if all the reflectance spectra in the atlas were linear combinations of three basis functions, for then every line of aim-points in the space would have two limiting reflectance spectra, and linear combinations of these would satisfy the rule. Of course, a color-order system whose reflectance spectra form a three-dimensional basis set is cooperative under illuminant transformation: cyclic chromaticity ordering and tristimulus volume ratios are strictly invariant under most illuminant changes[7]. Though this basis-function rationale does not distinguish the chroma dimension or involve a colorant-mixture rule (as might be desired), it is a starting point for further analysis.

3.2.3 Save a job file: Saves the conditions and the files that are selected, for future retrieval.

3.2.4 Retrieve a job file: Produces a list-box with the names of all saved job-files in the currently selected path for retrieval.

3.3 Importing Data

The user can import spectral reflectance data from a CSV (comma separated value) file.

3.4 Representations of Data

3.4.1 Display up to ten colors in line: Having chosen up to ten files and brought them into the program registers, the program renders the files as colors across the top of the screen with their descriptions below them.

3.4.2 Display three by three: Causes a display of up to nine selected colors in a three by three array with their descriptions below them.

3.4.3 Display lighter and darker: This display renders only the first chosen color - the one in the first color register - along with a sample of color which is one step lighter and another which is one step darker. Text-boxes on the left side of the screen give the approximate color difference values of the lighter and darker samples relative to the central sample. Up-down buttons on the right allow manipulation of the color difference values over wide ranges while viewing the color representations and their colorimetric values.

3.4.4 Display three axes of difference: This display renders only the first chosen color - the one in the first color register - along with samples of color that are one step different in an important colorimetric direction. Text-boxes give the approximate color difference of the difference samples to the central sample. Up-down buttons on the right allow the user to manipulate the color difference, axis by axis, over wide ranges while viewing the color representations and their colorimetric values.

3.4.5 Display colorimetric data: Causes colorimetric data of up to the ten selected colors to appear in six columns. The first column, headed *Sample Description*, gives the Munsell notation or the sample's description. If the sample is a Munsell sample, then the second column gives Munsell 100-hue notation. The third column of colorimetric notation is the target notation of Munsell samples always in terms of Illuminant C and the 1931 2° Observer per the definitions of the 1943 Munsell Renotation and the 1964 CIE recommendation that the reference standard for colorimetry is the perfect reflecting diffuser.

The subsequent three columns of colorimetric data contain colorimetric values for the colors in the user's chosen primary, secondary, and tertiary illuminant-observer combinations. Returning to the front screen and choosing different illuminant-observer combinations can develop other colorimetry. Those colorimetric values will be displayed here upon return. These data are by default displayed in CIELAB L* a* b* notation, but additional notations are available as follows:

XYZ: displays the four colorimetric columns of data in XYZ notation.

Yxy: displays the four colorimetric columns of data in Yxy notation.

OSA-UCS: displays the data in OSA-UCS notation. Since the OSA-UCS system is defined only for Illuminant D65 and the 1964 10° Observer, only one column of colorimetric notation appears.

L* a* b*: returns the default state with all data displayed in CIELAB L* a* b* notation.

3.4.6 Plot reflectance data: Displays the spectrophotometric curves of the colors chosen on a single 2 dimensional plot with wavelength as its abscissa and percent reflectance as its ordinate.

3.4.7 Plot reflectance data in 3-D: Renders the above plot in three dimensions rather than two.

3.4.8 Plot colors in CIELAB a*, b* diagram: Plots the chosen files in a CIELAB a* b* chroma diagram. The display is self-scaling

3.4.9 Order a scale of nine colors—The first of two drag-and-drop displays generates a display of nine random colors that one may order by dragging and dropping samples about the screen.

3.4.10 Order a page of colors—A page selected from the Munsell book of color is randomly arranged on the screen. The screen has a background grid that facilitates sorting of the colors. The task is to drag and drop the chips to the correct position by assessing the color attributes of the chips and arranging them accordingly, by hue, value, and chroma.

4. LARGER EDUCATIONAL PROJECT

Leonardo 2000 is an ongoing project whose mission is to enable color education for people with a broad variety of backgrounds and interests. A softcopy tutorial, in preparation for inclusion, will contain nine chapters: Human Eye & Vision, The Standard Observers, Illuminants, The Interaction of Light and Materials, Tristimulus Values, Colorimetric Spaces, Color Order Systems, Metamerism, and Color Vision Phenomena. Each chapter of this tutorial contains an objective, introduction, history, illustrations of each principle, experiments, imponderables to ponder, a summary of important points, and questions. The tutorial is a multimedia presentation and uses 21st Century technology. In the future, the Screen Book will be extended to other color-order systems, and also will be augmented to show users how colorant mixture affects both the perception and the spectrum of a produced color.

5. CONCLUSION

Even within the present co-authorship (all of whom had similar backgrounds) a variety of approaches appeared during the preparation of the program. The resolution of these approaches into a single tool is a continuing process as more materials are incorporated. Students and color explorers are welcome to try out the atlas and see how it guides them faithfully to their destination.

6. REFERENCES

1. S. M. Newhall, D. Nickerson, and D. B. Judd, Final Report of the OSA Subcommittee on the Spacing of the Munsell Colors, *J. Opt. Soc. Am.* **33**, 385-418 (1943).
2. H. R. Davidson and H. Hemmendinger, Color Space Based On Color-Difference Perception, *J. Opt. Soc. Am.* **46**, 383(A) (1956).
3. H. R. Davidson, M. N. Godlove, and H. Hemmendinger, A Munsell Book In High Gloss, *J. Opt. Soc. Am.* **47**, 336(A) (1957).
4. H. R. Davidson and H. Hemmendinger, Comparison Of Munsell And Macadam Color Spaces, *J. Opt. Soc. Am.* **48**, 606 (1958).
5. ASTM, American Society of Testing and Materials, E-308 – *Practice for Computing the Colors of Objects Using the CIE System*, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959
6. Michael Stokes, Matthew Anderson, Srinivasan Chandrasekar, and Ricardo Motta, *A Standard Default Color Space for the Internet - sRGB*, www.color.org/contrib/sRGB.html.
7. M. H. Brill and H. Hemmendinger, Illuminant dependence of object-color ordering, *Die Farbe* **32/33** (1985/6), 35-42.

Uniformities in OSA-UCS and in NCS tested by color difference prediction based on principal hue components

Tarow Indow*
Department of Cognitive Sciences, University of California Irvine

ABSTRACT

The OSA uniform color system is a 3-D collection of color samples according to the regular rhombohedral structure in which each color is surrounded by its 12 nearest neighbors, all perceptually equally different (local uniformity). The Swedish NCS system is a 3-D collection of color samples that vary gradually in each of the three perceptual attributes. It is not clear that this arrangement implies all neighboring pairs along the respective coordinates being perceptually equally different (local uniformity). Of pairs (j, k) of interest, predicted color differences $\tilde{d}_{jk}$ were calculated that have the following property. Suppose an observer selects a pair of Munsell grays (V_a, V_b) that matches in size with the color difference between (j, k), then $d_{jk} = | V_a - V_b |$ is predicted by $\tilde{d}_{jk}$, on the average, with error of 0.34 in Munsell V-unit. Variation of $\tilde{d}_{jk}$ in this unit was in the order of 0.22V for nearest neighboring pairs (j, k) in various cleavage planes of OSA-UCS and in the order of 0.11V for neighboring pairs (j, k) along s-coordinate and c-coordinate in sheets with fixed hue of NCS. Both were well within the prediction error range, but some systematic trends in values of $\tilde{d}_{jk}$ were found.

Keywords: OSA-UCS, NCS, color-order system, color difference

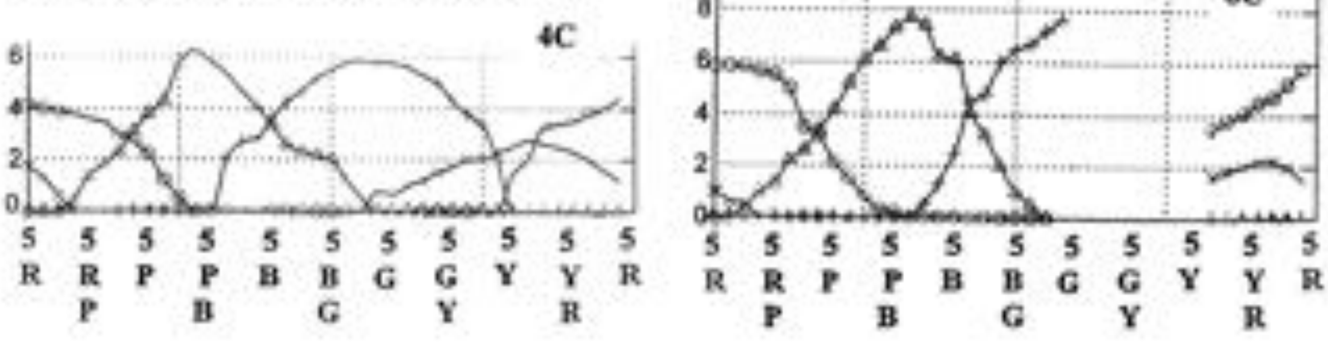
1. SCALED COLOR DIFFERENCE $\tilde{d}_{jk}$

To directly examine the local uniformities defined in the abstract, we need a large-scale experiment. Hence, for all pairs of interest, estimated color differences $\tilde{d}_{jk}$ were calculated by the following formula[1]. This study is a test of the prediction formula $\tilde{d}_{jk}$ also. For a given pair (j, k), $\tilde{d}_{jk}$ gives a Munsell V-difference that observers would select on the average when asked to match the color difference with a lightness difference. Hence, $\tilde{d}_{jk}$ is given in the Munsell V-unit, $0 \le \tilde{d}_{jk} \le 10$. The standard curves $\bar{\xi}_{\gamma\alpha}$ (H,V/C), representing the perceptual degrees of principal hue components α in color (H, V/C), were given on respective Munsell H-circles for V = 4 - 7 and C = 2 - 10, where α = R(red), Y(yellow), G(green), and B(blue). An example is shown in Fig.1. In the present study, some additional curves were defined for colors 8V and 12C. Using these curves and by interpolation, we can define $\bar{\xi}_{\gamma\alpha}$ for any color (H, V/C) in the range of $\bar{\xi}_{\gamma\alpha}$ (H, V/C). Then,

$$\tilde{d}_{jk} = 0.459\Delta V + (0.610 + \textstyle\sum_{\alpha} a_{\alpha}\Delta\bar{\xi}_{\gamma\alpha}),\quad a_R = 0.199,\ a_Y = 0.031,\ a_G = 0.098,\ a_B = 0.136,$$

$$\Delta V = |V_j - V_k|,\quad \Delta\bar{\xi}_{\gamma\alpha} = |\bar{\xi}_{\gamma\alpha}(H_j\ V_j/C_j) - \bar{\xi}_{\gamma\alpha}(H_k, V_k/C_k)|.$$

Fig. 1. Principal hue component curves $\bar{\xi}_{\gamma\alpha}$ (H, 4/C)



9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

When matched lightness difference data d_{jk} are available, d_{jk} and $\tilde{d}_{jk}$ are expected to coincide with the accuracy that the RMS (root-mean-squares) of $(d_{jk} - \tilde{d}_{jk})$ is 0.338V. This is only three times larger than the just-noticeable-difference (jnd) of lightness discrimination. The OSA samples were converted to (H, V/C) by the use of the Table by Nickerson[7]. To have (H V/C) for the NCS samples, the Tables by Benouya[2] were used.

2. OSA-UNIFORM COLOR SCALE (UCS)

In each horizontal cleavage plane with fixed L (luminance), samples form a rectangular lattice with orthogonal coordinates j and g, with the step of 2. All neighboring pairs, (j, g) and (j+2, g) along j-axis as well as (j, g) and (j, g+2) along g-axis, are expected to have the same perceptual difference. Unless we assume the color space being locally Euclidean, we cannot say anything about the perceptual difference between oblique neighbors, (j, g) and (j+2, g+2). In multidimensional studies of OSA-UCS[8,3], color differences in oblique directions, as well as differences along s-and c-axes, were taken into account. The present study focused upon color differences of legitimate nearest neighboring pairs in the logic of rhombohedral structure. Two examples of results, a horizontal cleavage (L = 0) and a slant cleavage (L = j), are given in Figs. 2 and 3, where × means a sample for which $\bar{\xi}_{jk}$ is not definable. The whole results are shown in Table 1.

Fig. 2. Horizontal cleavage (L = 0)

Fig. 3. Slant cleavage (L = j)

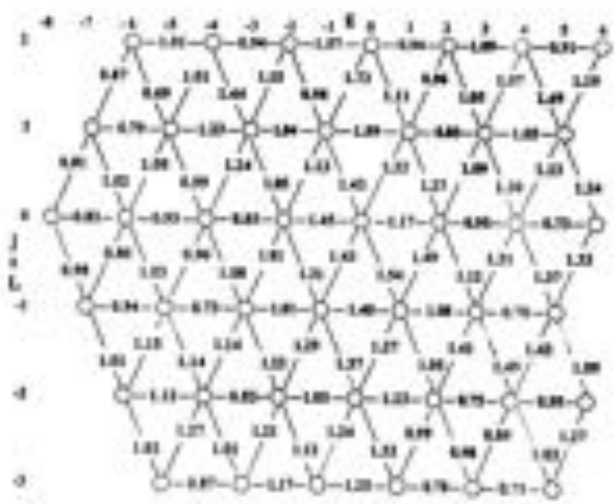


Table 1. Mean and SD of $\tilde{d}_{jk}$ of N neighboring pairs (j, k) along the respective directions

	Horizontal cleavage (L const)					
	along j-axis			along g-axis		
L	N	M	SD	N	M	SD
−3	28	.958	.215	29	1.007	.211
−2	33	.915	.230	35	.978	.239
−1	35	.932	.219	35	.973	.194
0	39	.937	.182	39	.986	.236
+1	37	.938	.227	36	.997	.218
+2	37	.897	.204	36	.985	.234
mean		.930	.213		.985	.222
SD		.021	.018		.012	.018

	Slant cleavage (j varies with L)								
	along g-axis			right-left			left to right		
	N	M	SD	N	M	SD	N	M	SD
L = j	36	1.011	.230	33	1.166	.205	33	1.159	.193
L = j+2	24	1.009	.227	23	1.207	.211	22	1.201	.260
L = j−2	38	.997	.226	34	1.117	.200	34	1.170	.209
mean		1.006	.228		1.163	.205,		1.177	.221
SD		.008	.002		.045	.006		.022	.035
	Vertical cleavage (j + g = const)								
j + g = 0				24	1.131	.256	24	1.096	.277

3. SWEDISH NATURAL COLOR SYSTEM (NCS)

This is a 3-D collection of color samples, each being specified in terms of s(blackness), c(chromaticness), and ϕ(hue), where $0 \leq s \leq 100$ and $10 \leq c \leq 90$, with the step of 10 in each. Hue ϕ is denoted such as R10B, which means that 90% of R and 10% of B are involved. Samples have been selected so as to vary gradually in each of these perceptual attributes. It is not clear, however, how to understand color differences between two neighboring samples along the respective coordinates, e.g., pairs (ϕ, s, c) and (ϕ, s+10, c) along s-axis in the ϕ plane. In 8 planes (s, c | ϕ) in which ϕ is kept constant and 2 Hue circles (ϕ | s, c) in which s and c are kept constant, $\bar{d}_{jk}$ were calculated for all neighboring pairs. Two examples of results are shown in Figs. 4 and 5, and the whole results are given in Table 2. In "Hues" diagram in SIS Colour Atlas (1978), 40 directions of ϕ are exhibited with most saturated color samples, and hence (s, c) change according to ϕ. On the other hand, Fig. 4 exhibits hue circles in which s and c are kept constant. In this Atlas, samples do not cover the whole gamut in sheets of purest hue. Hence, ϕ = R10B was chosen instead of ϕ = R, and so on.

Fig. 4. A plane (s, c | Y50R)

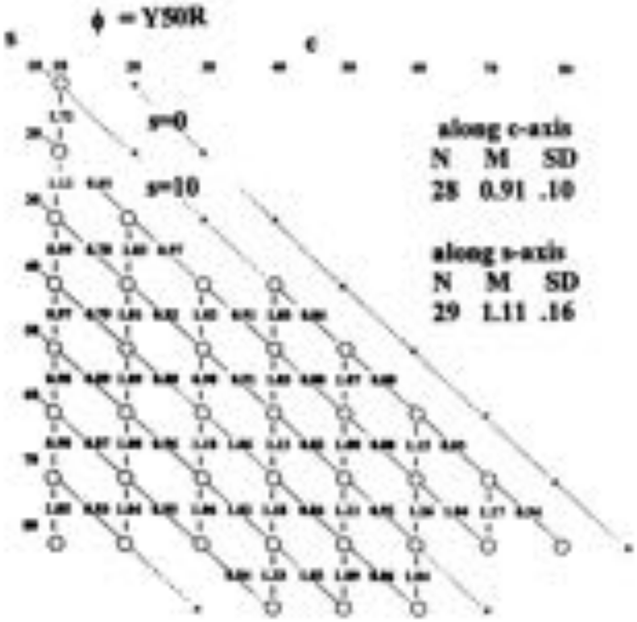


Fig. 5. NCS hue circles where s and c constant

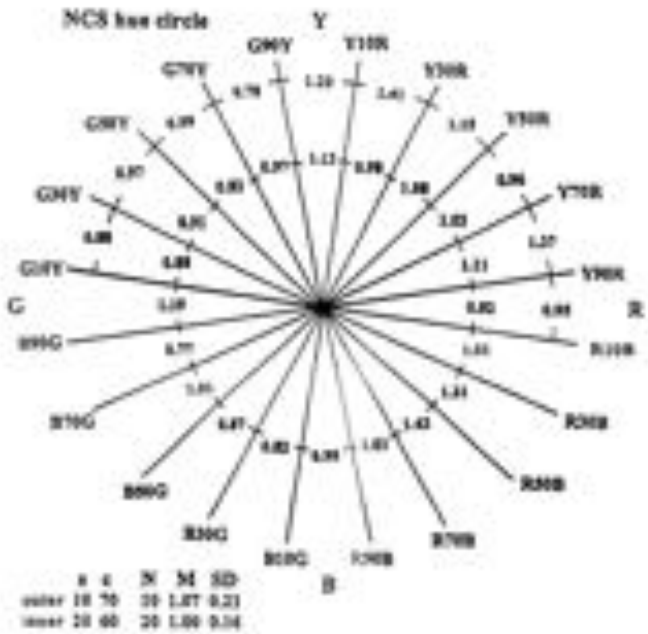


Table 2. Mean and SD of $\bar{d}_{jk}$ of N neighboring pairs (j, k) along the respective coordinates

hue	ϕ	along c-axis N	M	SD	along s-axis N	M	SD
R:	R10B	20	1.023	.092	21	1.118	.090
RY:	Y50R	28	0.911	.102	29	1.108	.156
Y:	Y10R	35	0.877	.126	35	1.183	.153
YG:	G50Y	35	0.814	.072	35	1.083	.085
G:	B90G	17	0.973	.119	19	1.240	.134
GB:	B50G	24	0.947	.105	24	1.188	.108
B:	R90B	25	1.028	.088	25	1.116	.109
BR:	R50B	20	1.121	.130	21	1.158	.151
	mean		0.962	.104		1.149	.123
	SD		0.097	.020		0.052	.029

s c	(20 hue steps) N	M	SD
10 70	10	1.065	.209
20 60	19	1.000	.163

4. RESULTS

4.1 OSA-UCS

1. In each cleavage, $\bar{d}_{jk}$ for neighboring pairs (j, k) in legitimate directions are fairly constant. As shown in Table 1, the overall SD of their variations is in the order of 0.22V in the unit of Munsell V, which is well within the accuracy range of this formula (0.33V).
2. The mean value (M) of $\bar{d}_{jk}$ is close to 1.0V, which means that the unit length of the OSA-UCS array represents color differences almost equivalent to the lightness difference between 4V and 5V or that between 6V and 7V, etc.
3. In horizontal cleavages (j, g | L), on the average, $\bar{d}_{jk}$ is slightly less than 1.0V, and $\bar{d}_{jk}$ tends to be slightly larger along g-axis than along j-axis (0.985V vs. 0.930V).
4. If horizontal cleavages are locally Euclidean within the square grid around a central sample (j, g), $\bar{d}_{oas}$ for oblique neighbors, (j, g) and (j+2, g+2), etc., can be predicted from $\bar{d}_{jk}$ along j- and g-axes. This was tested in each of 4 cleavage planes (L= –2 to +1). Values of $\bar{d}$ by the formula for these neighbors in oblique directions are smaller than the expected $\bar{d}_{oas}$ (grandmeans are 1.12V and 1.35V). It is not clear whether this result is due to non-Euclidean character of this space even within these squares or to non-linearity between $\bar{d}$ and distance in this space. The matching lacks addivitivy and $\bar{d}_{ik} < \bar{d}_{ij} + \bar{d}_{jk}$ for collinear (i, j, k).
5. In slant and vertical cleavages, $\bar{d}_{jk}$ for (j, k) along legitimate oblique directions, left to right or right to left in Table 1 where j and k differ in L, are larger than $\bar{d}_{jk}$ for (j, k) in which the two are of the same L. According to the rhombohedral structure, these are expected to be the same.
6. In many cleavages, $\bar{d}_{jk}$ for (j, k) in region around the achromatic color tends to be larger than remaining $\bar{d}_{jk}$ for more saturated colors j and k.

4.2 NCS

1. In each plane of constant ϕ, samples have been selected so that colors along s-axis, (s, c | ϕ), (s + 20, c | ϕ), and so on, appear gradually darker and those along c-axis, (s, c | ϕ), (s, c +20 | ϕ), and so on, appear gradually more saturated. Table 2 shows that the variations of $\bar{d}_{jk}$ for these neighboring pairs in the respective axes are small (the overall SD is in the order of 0.11V).
2. Clearly, $\bar{d}_{jk}$ along s-axis tend to be larger than $\bar{d}_{jk}$ along c-axis (grandmeans are 1.149V and 0.962V).
3. The variations (SD) of $\bar{d}_{jk}$ for neighboring samples (ϕ | s, c) and (ϕ+20 | s, c) in the two hue-circles are larger than SD of $\bar{d}_{jk}$ along s- or c-axis. The situation is the same even if compared in terms SD/M also.

4.3 Conclusion

In OSA-UCS, $\bar{d}_{jk}$ for neighbors in respective directions along which color differences of a constant size are expected exhibit only small variations. However, there are systematic, though slight, changes in value of $\bar{d}_{jk}$ according to direction; j-axis, g-axis, and axis in which change of L is involved. In NCS that based upon gradual change of perceptual attributes only, color differences between neighboring pairs in the respective coordinates are represented by $\bar{d}$ with even smaller variations.

REFERENCES

1. Indow, T. "Principal hue curves and color differenoe", *Color, Research and Application*, **24**, pp. 266 - 279, 1999.
2. Nicherson, D. "Munsell renotations for samples of OSA uniform color scales, *J. of Opt. Soc. Am.*, **68**, pp. 1343-1347, 1978.
3. Bencuya, A.K. "Relation between the natural color system and the Munsell color order system". Ph.D. Thesis, Rensselaer Polytechnic Institute, 1984.
4. Taylor, J.M., and Billmeyer, F.W. Jr. "Multidimensional scaling of selected samples from the Optical Society of America uniform color scales", *Color, Research and Application*, **13**, pp. 85- 98, 1988
5. Mann, T.M., and MacAdam, D.L. "Three-dimensional scaling of the uniform color scales of the Optical Society of America", *J. of Opt. Soc Am*, **6**, pp. 129-138, 1989.

* Correspondence: tindow@uci.edu (949) 824-6218, fax: (949) 824-3733, UCI Irvine CA 92697, USA

An Effective Conversion Algorithm from OSA-UCS to CIEXYZ

KOBAYASI, Mituo* and YOSIKI, Kayoko*

The University of Electro-Communications

ABSTRACT

The OSA-UCS is a color order system developed by the Optical Society of America's Committee on Uniform Color Scales. The color specification value (L, j, g) of the OSA-UCS is derived from the CIE 1964 tristimulus value (X_{10}, Y_{10}, Z_{10}). However, no direct conversion algorithm from OSA-UCS to CIEXYZ has been reported. In this paper, an analytic conversion algorithm from OSA-UCS to CIEXYZ has been developed, and its effectiveness is justified.

Keywords: color conversion, color specification system, OSA-UCS, CIEXYZ, uniform color space, analytic algorithm

1. INTRODUCTION

In 1974, after 27 years of extensive research and experiments, the Optical Society of America's Committee on Uniform Color Scales announced a color order system, the OSA-UCS,[1] which has the following characteristics:

1. Its uniformity is guaranteed for moderate or large color differences (roughly 20 times of jnd).
2. It is based on the 10 deg. visual field of CIE 1964 Standard Observer for practical use.
3. It adopts two phenomena on color appearance, crispening effect and Helmholtz-Kohlrausch effect.

Because of these characteristics, the OSA-UCS is often used in the field of categorical colors[2] and for evaluation of color appearance models.[3]

The color specification value (L, j, g) of the OSA-UCS is derived from tristimulus value (X_{10}, Y_{10}, Z_{10}) of CIEXYZ according to several mathematical expressions defined by MacAdam.[4] However, inverse conversion from OSA-UCS to CIEXYZ is not easy because of the complexity of the expressions. A conventional algorithm for OSA-XYZ conversion was achieved by means of looking up table with interpolation. Though MacAdam[4] and Smith[5] referred to an iterative algorithm provided by MacAdam, it has not been reported. An efficient conversion algorithm from OSA-UCS to CIEXYZ will extend the application of OSA.

In this paper, an analytic conversion algorithm from OSA-UCS to CIEXYZ will be introduced and its effectiveness is verified.

2. DERIVATION OF OSA-UCS FROM CIEXYZ

In order to consider an analytic conversion from OSA-UCS to CIEXYZ, it is required to state the flow of conversion from CIEXYZ to OSA-UCS. In the following steps of the flow, the subscript '10' of (X_{10}, Y_{10}, Z_{10}) is omitted for simplicity of notation.

1. First, calculate K, the factor representing Helmholtz-Kohlrausch effect, as a quadratic function of the chromaticity coordinates (x, y):

$$K = 4.4934x^2 + 4.3034y^2 - 4.276xy - 1.3744x - 2.5643y + 1.8103. \quad (1)$$

Then, the modified luminous reflectance Y_0 is obtained by the product of K and Y;

$$Y_0 = K \cdot Y. \quad (2)$$

* phone 81 424 43-5324; fax 81 424 43-5334; The University of Electro-Communications, 1-5-1 Chofugaoka, Chofu-shi, Tokyo 182-8585, JAPAN

2. Using Y_0, calculate L, the lightness, and C, the modification factor of chroma as follows:

$$L = \frac{1}{\sqrt{2}}\{5.9[(Y_0^{\frac{1}{3}} - \frac{2}{3}) + 0.042(Y_0 - 30)^{\frac{1}{3}}] - 14.3993\}, \tag{3}$$

$$C = 1 + 0.042(Y_0 - 30)^{\frac{1}{3}}/(Y_0^{\frac{1}{3}} - \frac{2}{3}). \tag{4}$$

3. Derive (R, G, B) by a linear transformation from (X, Y, Z) :

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 0.7990 & 0.4194 & -0.1648 \\ -0.4493 & 1.3265 & 0.0927 \\ -0.1149 & 0.3394 & 0.7170 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}. \tag{5}$$

4. Finally, calculate a and b as

$$\begin{aligned} a &= -13.7R^{\frac{1}{3}} + 17.7G^{\frac{1}{3}} - 4B^{\frac{1}{3}}, \\ b &= 1.7R^{\frac{1}{3}} + 8G^{\frac{1}{3}} - 9.7B^{\frac{1}{3}} \end{aligned} \tag{6}$$

and multiply them by C to obtain g and j :

$$g = C \cdot a, \quad j = C \cdot b. \tag{7}$$

3. CONVERSION ALGORITHM FROM OSA-UCS TO CIEXYZ

For a given L, Y_0 satisfies the equation (3). Since its right-hand side is a monotone continuous function of Y_0, it will be solved by means of a numerical method.

Once Y_0 is obtained, C is easily calculated by the expression (4), and for given j and g, a and b are then calculated by the expression (7).

Consider to obtain (R, G, B) or (X, Y, Z) from a, b, and Y_0. The expression (6) means two non-linear equations for three unknowns R, G, and B. Another expression (2) consists of a product of Y and K, a quadratic function of x, y. This expression is interpreted as a complex non-linear equation for three unknowns X, Y, and Z. Since (R, G, B) and (X, Y, Z) are linearly related by the transformation (5), the expression (2) becomes an equation of R, G, and B. Thus we have three equations ((2) and (6)) for three unknowns R, G, and B. Therefore R, G, and B will be obtained in principle as a solution of these simultaneous equations.

Let w be $R^{\frac{1}{3}}$, and rewrite the equation (6) as

$$G^{\frac{1}{3}} = w + a' \quad \text{and} \quad B^{\frac{1}{3}} = w + b' \tag{8}$$

where

$$a' = (9.7a - 4b)/139.69 \quad \text{and} \quad b' = (8a - 17.7b)/139.69. \tag{9}$$

Then R,G, and B are represented by cubic functions of w, so that X, Y, and Z, the linear combinations of R, G,and B, are represented by cubic functions of w :

$$\begin{aligned} X &= 1.0626w^3 - 0.4121(w + a')^3 + 0.2975(w + b')^3, \\ Y &= 0.3599w^3 + 0.6401(w + a')^3 + 0.0000(w + b')^3, \\ Z &= -0.0001w^3 + 0.3690(w + a')^3 + 1.4424(w + b')^3. \end{aligned} \tag{10}$$

Further more K, represented by a function of X, Y, Z, is also represented by a function of w. Therefore Y_0, defined by $K \cdot Y$, can be represented by a function of one variable w , which will be denoted by

$$Y_0 = \varphi(w). \tag{11}$$

The solution w of the equation (11) brings the required values of X, Y, Z through the expressions (10).

Examining the property of $\varphi(w)$ for many (L, j, g)'s, it is found that the function $\varphi(w)$ is monotone increasing, convex downward, and smooth. To solve the equation (11) to find a unique solution w, Newton-Raphson method is applicable because the derivative $\varphi'(w)$ of $\varphi(w)$ is computable.

As a result of the above analysis, the conversion algorithm from OSA-UCS to CIEXYZ is summarized as follows:

1. For given L, solve the equation (3) to find a solution Y_0 by means of a numerical method (cf. Note 1 and Note 2 below).
2. Calculate C from Y_0 using the expression (4).
3. For given j and g, calculate $a = g/C$ and $b = j/C$, and then calculate a' and b' using the expression (9).
4. Solve the equation (11) to find a unique solution w using Newton-Raphson method (cf. Note 2 below).
5. Finally, obtain X, Y, Z from w using expressions (10).

Note 1: From the point of numerical accuracy and speed of computation, it is ineffective to solve eq.(3) directly. Set $t = Y_0^{\frac{1}{3}}$, eq.(3) is transformed into a simple cubic equation of t :

$$[t - (\frac{\sqrt{2}}{5.9}L + 30^{\frac{1}{3}})]^3 + 0.042^3(t^3 - 30) = 0. \quad (12)$$

Solve this equation using Newton-Raphson method to get $Y_0 = t^3$.

Note 2: When Newton-Raphson method is applied to solve the equation (11) or (12), it is important to find a good estimation of an initial approximation of the solution. We utilize the analytical characteristics of the equation (e.g. smoothness, monotony, and convexity of a function) to find a good approximation for the exact solution, and to garantee the global convergence of the iteration. (Details are omitted.)

4. EVALUATION

4.1. Accuracy of Conversion

The accuracy of the algorithm was examined in the following way (Fig.1):

For 558 color samples of OSA-UCS,[8] the value (L, j, g) are first converted to (X, Y, Z) according to our conversion algorithm, and then (X, Y, Z) are re-converted to (L', j', g') according to the definition of OSA-UCS. The original (L, j, g) and the computed (L', j', g') are compared by the color difference ΔE on OSA-UCS :

$$\Delta E = \sqrt{2(L' - L)^2 + (j' - j)^2 + (g' - g)^2}. \quad (13)$$

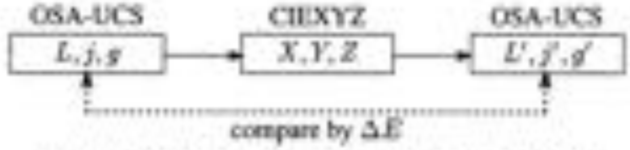


Figure 1. Evaluation of the accuracy of the algorithm

As a result, the average value of ΔE was 0.0012, the maximum was 0.0021, and the minimum was 0.0001, which shows our algorithm is sufficient for practical use. (The iteration of Newton-Raphson method both in step 1 and step 4 was terminated when the difference between two successive approximated values is less than a small constant $\epsilon = 1.0 \times 10^{-7}$.)

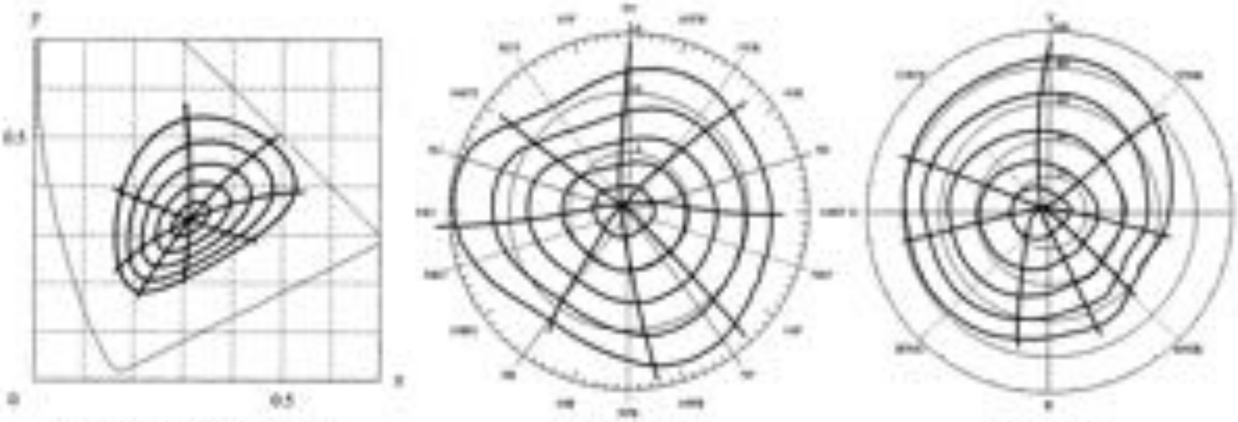
4.2. Speed of Conversion

In order to measure the speed of conversion, each of the OSA-UCS to CIEXYZ conversion and the CIEXYZ to OSA-UCS conversion for the above 558 data was repeated 20 times (11160 times in total). The program was implemented in language C and ran on the computer with PentiumIII (500MHz) CPU. The time of OSA-UCS to CIEXYZ conversion was 0.19 sec. while the time of CIEXYZ to OSA-UCS conversion was 0.09 sec, without input and output time. Practically speaking, conversion of an image with 1000 × 1000 pixels, for example, will take 17 sec. for OSA-UCS to CIEXYZ, and 8.1 sec. for CIEXYZ to OSA-UCS.

The number of iterations in Newton-Raphson method was roughly 2-4 for the step 4, and 7-11 for the step 1 (except $L = 0$, in this case it was only 1).

5. APPLICATION

As an application of the algorithm, the constant chroma circles and constant hue radii in the OSA-UCS space are transformed into other color spaces, e.g. Yxy, Munsell, NCS, etc. Some of the results are shown in Fig.2. (In this experiment, the difference of viewing enviroement is neglected.)



(a)xy chromaticity diagram (b) Munsell (c) NCS

Figure 2. Constant chroma circles and constant hue radii in (a) xy chromaticity plane, (b) Munsell hue circle, and (c) NCS hue circle.($L = 0$, the chroma step is 2, and the hue step is 45°.)

6. CONCLUSION

An algorithm for analytic conversion from OSA-UCS to CIEXYZ has been developed. It was proved by numerical experiments that our algorithm is sufficient for practical use in accuracy and speed, which enables extensive applications.

REFERENCES

1. D. Nickerson, "History of the OSA committee on Uniform Color Scales," *Optics News/Winter 1977*, pp. 8–17 (1977).
2. R. M. Boynton and C. X. Olson, "Locating basic colors in the OSA space," *Color Res. Appl.* **12**(2), pp. 94–105 (1987).
3. R. G. Kuehni, "Uniform color space modeled with cone responses," *Color Res. Appl.* **25**(1), pp. 55–63 (2000).
4. D. L. MacAdam, "Uniform color scales," *J. Opt. Soc. Am.* **64**(12), pp. 1691–1702 (1974).
5. N. S. Smith, "A colour notation conversion program revisited," *Color Res. Appl.* **17**(6), pp. 405–409 (1992).
6. D. L. MacAdam, "Colorimetric data for samples of OSA uniform color scales," *J. Opt. Soc. Am.* **68**(1), pp. 121–130 (1978).

Color Opponency and scale uniformity in the OSA-UCS system: the geometrical structure

Claudio Oleari*
Università degli Studi di Parma, Dipartimento di Fisica, Istituto Nazionale di Fisica della Materia

ABSTRACT

Two different transformations between the (X_{10}, Y_{10}, Z_{10}) coordinates and the (L_{OSA}, g, j) ones of the Uniform Color System of the Optical Society of America (OSA-UCS) are given related to two possible different geometrical structures. Both transformations are logarithmic functions obtained by integration of Weber fractions of ratios of suitable color stimuli. The first structure is related to the color opponency proper of the (g, j) coordinates of the OSA-UCS system and the second one to a mixing of the (g, j) coordinates. The second transformation has a simpler and highly symmetrical structure, and the regularity of the OSA-UCS lattice is higher.

Keywords: uniform color scale, color opponency, color atlas, Weber fraction.

1. INTRODUCTION

The analysis of the chromaticity scales for the 2° visual field given in a previous work [3] has shown that the chromatic response-functions with uniform scale of the visual process are well described by logarithms of proper cone activation ratios. In the present paper the same problem is faced for the large visual field and it is based on the data of the OSA-UCS system [1, 2]. Two different geometrical structures appear: one is very evident, is closely related to the (g, j) coordinates and shows a pair of neutral lines that separate the two parts of the color opponencies; the second is related to a mixing of (g, j) coordinates and has higher symmetry and simplicity.

(The color stimuli are denoted by bold letters, for instance **Q**, their chromaticities by italic bold letters, ***Q***, and their lengths by italic letters, *Q*.)

2. GEOMETRICAL STRUCTURE FOR COLOR OPPONENCY ACCORDING TO (g, j) AXES

The constant lightness lattices of the OSA-UCS system reveal a color-opponency process. The starting point of the analysis is given in figure 1, where the zero-lightness lattice is subdivided into four parts, whose grids are defined by the intersections of straight lines radiating from proper pairs of points $\boldsymbol{D_R}$ and $\boldsymbol{T_Y}$, $\boldsymbol{D_G}$ and $\boldsymbol{T_Y}$, $\boldsymbol{D_G}$ and $\boldsymbol{T_B}$ and $\boldsymbol{D_R}$ and $\boldsymbol{T_B}$: $\boldsymbol{D_R}$ = (1.0000, 0.1157), $\boldsymbol{D_G}$ = (0.9289, 0.0907), $\boldsymbol{T_Y}$ = (0.0538, 0.0977), $\boldsymbol{T_B}$ = (0.0935, 0.0400) (the coordinates are (x_{10}, y_{10})).

The four parts are separated by two crossing straight lines (line G and line J in figure 1**a**)), each of which is the separation line between the two parts of an opponency mechanism. Therefore these two lines are the *neutral lines of the color-opponency mechanisms* and their crossing point is the *neutral point N*. The position of this point is in agreement with the experience for daylight adaptation [4].

It can be shown that in any part, the chromatic discrimination is described by a couple of independent angular variables centered in the points $\boldsymbol{D_R}$, $\boldsymbol{D_G}$, $\boldsymbol{T_B}$ and $\boldsymbol{T_Y}$ or, equivalently, by a couple of ratios of color stimuli (*R*/*G*) and (*Y*/*B*), which belong to a set of three stimuli defining a three component diagram (Figure 1**b**) for triangles $\boldsymbol{BD_RY}$ and $\boldsymbol{BD_GY}$). The four different parts of the lattice must have continuity in the common border lines, represented by the line G and J, and it is satisfied if the three-component diagrams related to two contiguous parts have one common side that belongs to the separation line.

The points $\boldsymbol{G}$ and $\boldsymbol{R}$, and $\boldsymbol{B}$ and $\boldsymbol{Y}$ of the three-component diagrams (Figure 1**b**) for $\boldsymbol{R}$ and $\boldsymbol{Y}$) are derived from the required symmetry of the Weber fractions related to the ratios of the corresponding color stimuli: i.e. these points are obtained by

* Contact oleari@fis.unipr.it , fax +39-(0)521-905223, Claudio Oleari, Università di Parma, Dipartimento di Fisica, Parco Area delle Scienze 7/A, I-43100 Parma (Italy)

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

considering the just noticeable differences of the g and j coordinates of the OSA-UCS lattice as uncertainties of the stimuli ratios $\Delta(\underline{R}/\underline{G})$ and $\Delta(\underline{Y}/\underline{B})$, respectively, and satisfying the following Weber fractions

$$\frac{\Delta(\underline{R}/\underline{G})}{(\underline{R}/\underline{G})} = k_{RG} \;,\; \frac{\Delta(\underline{Y}/\underline{B})}{(\underline{Y}/\underline{B})} = k_{YB} \text{ and the reciprocal ratios } \frac{\Delta(\underline{G}/\underline{R})}{(\underline{G}/\underline{R})} = -k_{RG} \;,\; \frac{\Delta(\underline{B}/\underline{Y})}{(\underline{B}/\underline{Y})} = -k_{YB}$$

where $k_{RG} = 0.0061$ and $k_{YB} = 0.0193$ for $L_{OSA} = 0$ (Figure 2 for $(\underline{Y}/\underline{B})$). We have $\underline{R} = \underline{D}_R$, $\underline{B} = \underline{T}_B$ and the coordinates of the other points on the (x_{10}, y_{10}) diagram are, $\underline{G} = (-1.7307, 1.2501)$, and $\underline{Y} = (0.6940, 0.7146)$.

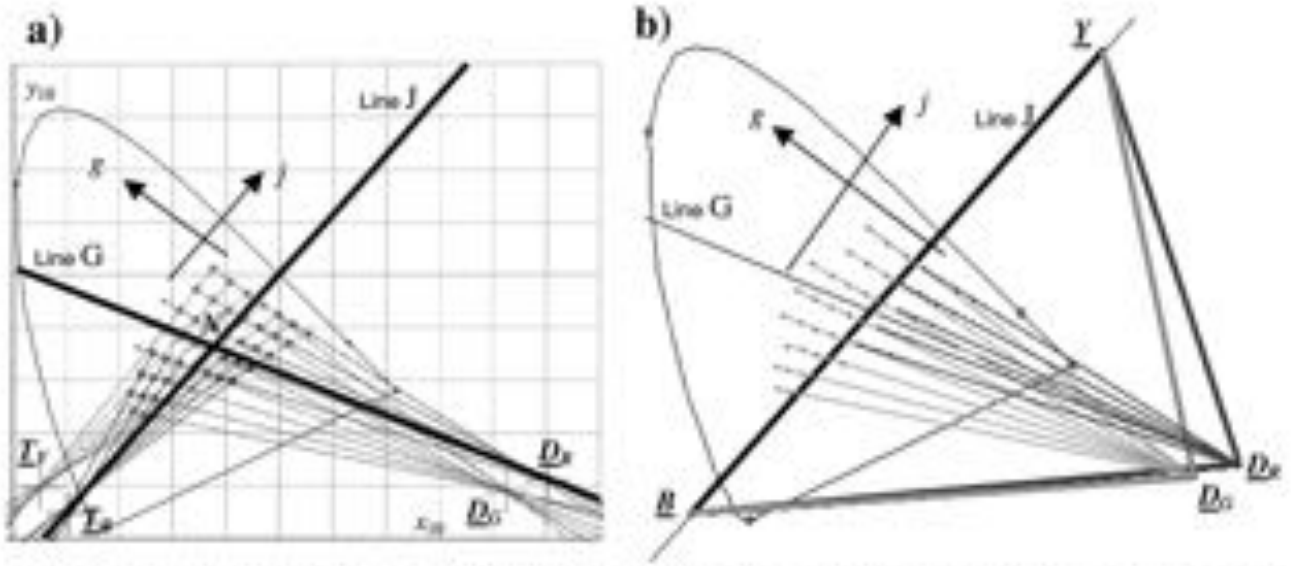


Figure 1a): CIE 64 chromaticity diagram with the zero lightness OSA-UCS lattice and the straight lines, that, fitting the points of the lattice, define four intersection points $\underline{D}_R$, $\underline{D}_G$, $\underline{T}_B$ and $\underline{T}_Y$ and define the grid. 1b): CIE 64 chromaticity diagram with the zero lightness OSA-UCS lattice and the neutral line $\underline{BY}$ separating the red and the green part of the red-green opponency. The chromatic discrimination of the green part of the lattice is represented by lines radiating from the point $\underline{D}_G$, which are in correspondence one to one with the ratios of the $\underline{B}$ and $\underline{Y}$ stimuli in the three component diagram $\underline{BD_GY}$. The chromatic discrimination of the red part of the lattice is represented by lines radiating from the point $\underline{D}_R$, which are in correspondence one to one with the ratios of the $\underline{B}$ and $\underline{Y}$ stimuli in the three component diagram $\underline{BD_RY}$. For continuity, the side $\underline{BY}$ is common to both the three-component diagrams $\underline{BD_GY}$ and $\underline{BD_RY}$. The green part is external to the $\underline{BD_GY}$ diagram and the red part is internal to the $\underline{BD_RY}$.

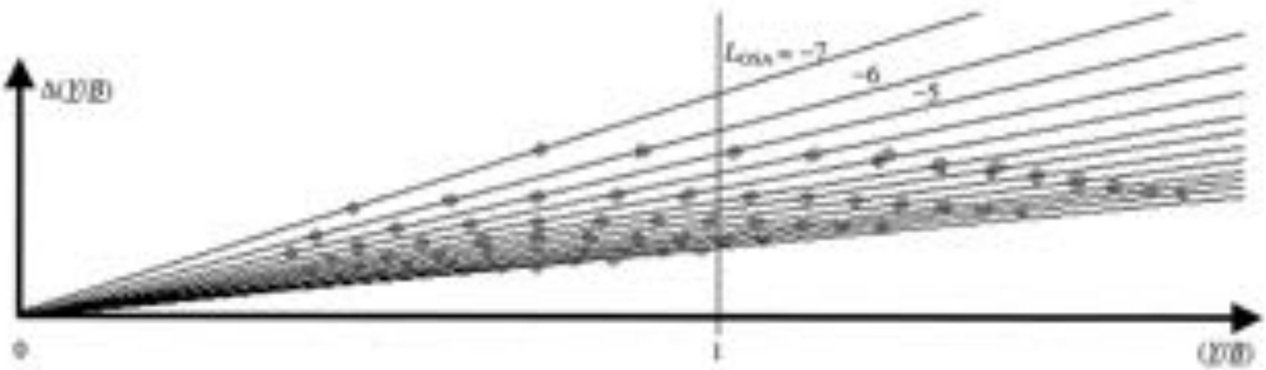


Figure 2. The lines associated with the Weber fraction related to the color samples of the OSA-UCS system: the points represent the values corresponding to the samples.

By integration of the Weber fractions two logarithmic quantities are obtained up to an additional constant, which are two coordinates with uniform scale corresponding to (g, j) of the OSA-UCS system that we call (g', j') (Figure 3).

$$g' = \frac{1}{k_{RG}} \ln\left(\underline{R}/\underline{G}\right) \text{ and } j' = \frac{1}{k_{YB}} \ln\left(\underline{Y}/\underline{B}\right),$$

where the ratios ($\underline{R}/\underline{G}$) and ($\underline{Y}/\underline{B}$) must be evaluated differently using the three-component triangles $\underline{BD_RY}$, $\underline{BD_GY}$, $\underline{GT_YR}$ and $\underline{GT_BR}$ typical of the four regions of the constant lightness lattice.

The investigation of the other constant lightness lattices of the OSA-UCS system reveals that $\underline{D_R}$, $\underline{D_G}$, $\underline{T_Y}$, $\underline{T_B}$, $\underline{R}$, $\underline{G}$, $\underline{B}$ and $\underline{Y}$ have equal coordinates for all the lightnesses, while the constants k_{RG} and k_{YB} are functions of the lightness.

Figure 3. OSA-UCS lattice with zero lightness after the logarithmic transformation on the (g', j') coordinates.

The OSA-UCS grids represented in the coordinates (g', j') are generally very square grids, but in the region with $j' < 0$ the lines with $g' = constant$ are a little bent and in the region close to $j' = 0$ the grids present a shifting, particularly evident in the planes with samples at $j' = 0$, that appears as a crispening.

3. GEOMETRICAL STRUCTURE FOR COLOR OPPONENCY WITH (g, j) MIXING

The starting hypothesis is that two three-component diagrams $A_iB_iC_i$ ($i = 1, 2$) exist such that

a. Weber fractions $\frac{\Delta(A_i/B_i)}{(A_i/B_i)} = k_{AB_i}$ hold, with $\Delta(A_i/B_i)$ evaluated between contiguous samples belonging to a line of the OSA-UCS grid at constant lightness,

b. the constant lightness lattices of OSA-UCS system represented by the integrals of the Weber fractions $q_i = \frac{1}{k_{AB_i}} \ln(A_i/B_i)$, considered as orthogonal coordinates, appear with a grid of equispaced parallel straight lines.

Such an hypothesis is verified and particularly a three-component diagram $\boldsymbol{ABC}$ exists, $\boldsymbol{A} = (0.9057, 0.2391)$, $\boldsymbol{B} = (1.1134, -1.3384)$, $\boldsymbol{C} = (0.1604, -0.0258)$ (Figure 4**a**)), and it holds:

(1) the Weber fractions are satisfied

$$\frac{\Delta(A/B)}{(A/B)} = k_{AB}, \ \frac{\Delta(B/C)}{(B/C)} = k_{BC}, \ \frac{\Delta(C/A)}{(C/A)} = k_{CA} \text{ as well } \frac{\Delta(B/A)}{(B/A)} = -k_{AB}, \ \frac{\Delta(C/B)}{(C/B)} = -k_{BC}, \ \frac{\Delta(A/C)}{(A/C)} = -k_{CA};$$

(2) any pair of the three integrals $q_{AB} = \frac{1}{k_{AB}} \ln(A/B)$, $q_{BC} = \frac{1}{k_{BC}} \ln(B/C)$ and $q_{CA} = \frac{1}{k_{CA}} \ln(C/A)$ represents perfectly in equivalent ways the OSA lattices at constant lightness by grids of equispaced parallel straight lines; such an equivalence means that the three coordinates are mutually dependent, in fact the product of the three ratios holds $(A/B)(B/C)(C/A) = 1$, and hence $k_{CA} = -(k_{AB}\, k_{BC})$ (this equation is exactly verified);

(3) the grid at constant lightness of OSA-UCS system represented by two of the three coordinates q_{AB}, q_{BC} and q_{CA} has parallel straight lines and is equispaced; in order to transform such a grid into a square grid, a proper mixing of the q's coordinates and two normalization-scale factors are needed: for example for the pair of coordinates q_{AB} and q_{BC} the mixing and scaling is

$$g'' = s_G\left(q_{AB} \sin\beta - q_{BC} \cos\beta\right), \ j'' = s_J\left(-q_{AB} \sin\alpha + q_{BC} \cos\alpha\right)$$

where s_G and s_J are suitable scale factors and α and β are the angles between the reference axes q_{AB} and q_{BC} and the parallel lines with constant g and constant j, respectively.

The coordinates (g'', j'') are very close to the corresponding coordinates (g, j) of the OSA-UCS system at any lightness and

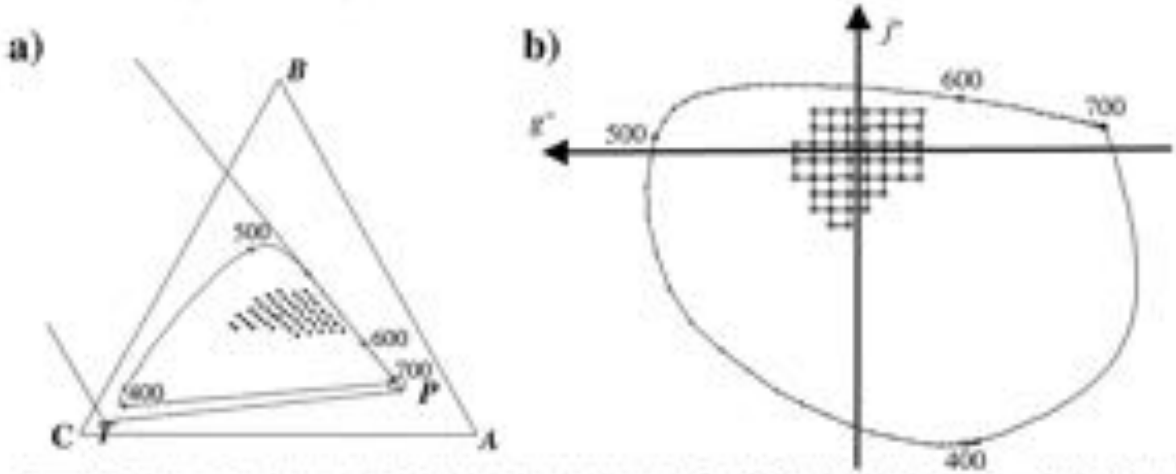


Figure 4a). Chromaticity diagram referred to the primaries **A**, **B** and **C** with OSA-UCS lattice at $L_{OSA} = 0$. **4b**). Chromaticity diagram referred to (g'', j'') coordinates with OSA-UCS lattice at $L_{OSA} = 0$ and spectrum locus.

the grids are very close to square grids without the bending and the crispening present in the (g', j') coordinates (Figure **4b**)). The spectrum locus can be represented in these coordinates and presents very high regularity. The diagram ***ABC*** is the same for any lightness.

4. CONCLUSIONS

This work puts forword two different geometrical structures to describe the color opponency and to obtain color coordinates with uniform scale: the first structure is evident and associates the color opponency to the original (g, j) coordinates of the OSA-UCS system; the second one is hidden and associates the color opponency to directions obtained by a mixing of the OSA-UCS (g, j) coordinates. This mixing must be explained for a better understanding of the process in color vision.

The transformation of both geometrical structures is based on logarithms of ratios of suitable color stimuli, in agreement with an investigation into the uniformity of scale for foveal vision [3]. The Weber fractions, that by integration generate the logarithmic functions, are very well satisfied and this leads us to prefer then to a power law.

The higher regularity of the OSA-UCS grids in the coordinates (g'', j'') of the second geometric structure combined with its simplicity, its symmetry and the mutual dependency existing among the reference stimuli **A**, **B**, **C** induce us to give great value to this geometrical structure.

ACKNOWLEDGEMENTS

This work has been supported by the National Scientific Research Program "Cofinanziamento del MURST 2000" titled "Psychophysics and colorimetry in the color of natural surfaces".

REFERENCES

1. MacAdam D L, Uniform Color Scales. *J Opt Soc Am* **64**,1691-1702 (1974).
2. MacAdam D L, Colorimetric data for samples of OSA uniform color scales. *J Opt Soc Am* **68**, 121-130 (1978).
3. Oleari C. Uniform-scale chromaticity diagrams: opponent-chromatic responses as logarithms of the cone-activation ratios. *Color Research and Application* **23**, 27-38 (1998).
4. Werner J. S. and Walraven J., Effect of chromatic adaptation on the achromatic locus: the role of the contrast, luminance and background color, *Vision Res.* **22**, 929-943 (1982).

A verification Study of NCS (Natural color system) Notation

Proposal of NCS Notation by use of the NCS Three Attribute Diagram

Jungyi Choi*

ABSTRACT

The NCS (Natural color system) is a color order system, which has been further developed by Hård and his collaborators. NCS Notation is being discussed in the international standardization. This color notation is based entirely on the perception of color as a visual and qualitative phenomena. The ISO/TC187 domestic committee in Japan is continuing experiment on the validity of this NCS notation.

I studied the NCS Three Attributes Diagram and used the NCS attributes (whiteness, blackness, and chromaticity). These three NCS attributes can be seen in the bar-graph scale, which measures the percentage of each attribute. The subjects in the experiment were requested to report their visual perception: how each color appeared in their perspective. The results of the experiments were based on the reported and calculated tests using the diagram of NCS notation.

Keywords: NCS Notation, NCS Three Attribute Diagram, Tonal Color 65, Color appearance

1. INTRODUCTION

NCS is exclusively based on the possibilities and restrictions of human color vision, and its use does not require any knowledge of physical or physiological attributes of color stimuli. NCS notation is a symbolic language and therefore easily recognized and acceptable where color discrimination is considered.According to the Swedish Scandinavian Color Institute, the NCS Notation appearance of color should be easily comprehensible. Therefore, I tried this technique in an experiment, using 3 subjects who had normal color perception.

2. THE NCS THREE ATTRIBUTE DIAGRAM

NCS color notation provides direct information such as blackness(s), chromaticity(c), and hue(ϕ). The numerical values of whiteness (w) are derived from the statement that w=100-s-c; since the sum of these three attributes being blackness, chromaticity, and whiteness is always 100. And hue(ϕ) is expressed as the percentage of one chromatic elementary attribute in the sum of chromaticness(c).

For example, notice that mizuiro (19, aqua green) of Tonal Color 65 and 1040-B60G had the same color notation in the experimental setting. In this case the blackness is s=10, the chromaticness is c=40, therefore the whiteness will be w=100-10-40=50. The hue(ϕ) is B60G, and taken into consideration the c=40, implies the greenness is g=40*60/100=24, the blueness is b=40*40/100=16, and the yellowness and the redness are y=r=0. In respect of each numerical values of the attributes, this NCS color notation of mizuiro (19) can be expressed on the Accumulation bar graph as shown in Figure 1. These three attributes of blackness(s), chromaticness(c), and whiteness (w) are being seen as the NCS Three Attributes, and the graph as the NCS Three Attribute Diagram.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

Figure 1. NCS Three Attribute Diagram 1040-B60G(mizuiro)

3. EXPERIMENTAL

3.1. Process

1) Subjects: The subjects are three normal color vision graduate students.

2) Sample: Tonal Color 65 and NCS INDEX

The Tonal Color 65 is provided by use of colored papers, which a Japanese Color Research Institute supervised, and the Japan Color Enterprise Co., Ltd. issued. These colored papers are manufactured for educational purposes, classified color: light, shade and tone based on Practical Color Coordinate System (PCCS) designed by the foundation. NCS INDEX is NCS Edition 2, that contained a total of 1750 colors, which the Scandinavian Color Institute AB manufactured.

3) Observation method: Under Macbeth Judge II light, the subjects had a juxtaposition to compare each color of Tonal Color 65 and NCS INDEX 2 and then recorded the score that approximated most closely the NCS Notation.

3.2. Results

C was executed twice although there were only 3 subjects. The individual observation data is called C1, C2, I, and S as follows, and the results are shown in Table 1.

The colors to which the four data corresponded are 13 colors (20%) in the observation results of the NCS Notation to each color of Tonal Color 65, and the colors not corresponding were 52 colors (80%). The colors to which the three data were corresponding were 20 colors (58.9%).

When these 13 colors are seen according to the tone and considering their chromaticity, two colors of five were corresponding, the agreement rate was the highest (40.0%), and the following bright tone 4 of 12 (33.3%), deep tone 2 of 8 (20.0%). However, when dark and light grayish tones were considerate, no corresponding colors were found. The analogue colors and their rates between data, according to the tone group, are shown in the following Table 2.

4. DATA ANALYSIS

In the actual experiment of NCS Notation for each color of Tonal Color 65, four data were obtained. The results are completely equivalent in the 13 colors, and differed in the 52 remaining colors. Here, each color of Tonal Color 65 can be shown by the NCS Three Attribute Diagram.

First of all, 4 elementary colors of NCS are included in the vivid tone: being aka (1, red), kiiro (5, yellow), midori (7, green), and ao (10, blue). These 4 colors are shown in the NCS Three Attribute Diagrams as shown in Figure 2. The perception of whiteness became the same amount though ao showed a different respectively amount of color perception.

The results of controlling the amount of blackness are shown. As for midori, the amount of color perception was the same for each 4 data. Kiiro had a data that perceived the one of greenness. There were two kinds of ao of with one worn a yellowness: though it was judged as a color which worn whiteness.

Table 1. NCS Notation in Tonal Color 65

No.	Color Name	Corresponding English name	C 1	C 2	1	5
1	aka	red	1080-R	1080-R	1090-Y90R	1080-R
2	syuiro	vermilion	0080-Y80R	0080-Y80R	1080-Y80R	0080-Y80R
3	daidai	orange	0080-Y40R	0080-Y40R	0080-Y40R	0080-Y40R
4	yamabukiiro	marigold orange	1080-Y20R	1080-Y20R	0080-Y20R	0080-Y20R
5	kiiro	yellow	0080-G90Y	0070-G90Y	0080-Y	0080-G90Y
6	kimidori	lime green	0080-G40Y	0080-G40Y	1080-G50Y	0080-G40Y
7	midori	green	2070-G	2070-G	2070-G	2070-G
8	aomidori	sea green	3060-B90G	3060-B90G	3060-B90G	3060-B90G
9	asagiiro	cyan blue	2060-B10G	2060-B10G	2060-B20G	2060-B10G
10	ao	blue	4050-B	4050-R90B	3060-B	3070-R90B
11	ruriiro	lapis lazuli	4050-R80B	4050-R80B	3070-R80B	4050-R80B
12	aomurasaki	bellflower	3070-R70B	3050-R70B	4050-R70B	4050-R70B
13	murasaki	purple	3060-R50B	3060-R50B	3060-R50B	3060-R50B
14	akamurasaki	raspberry	1080-R10B	1080-R10B	1080-R10B	1080-R10B
15	pinku	pink	0050-R	0060-R	0060-R	0050-R
16	hadairo	flesh	1040-Y50R	1040-Y50R	0040-Y50R	1040-Y50R
17	kuriimu	cream	0040-G80Y	0040-G80Y	0050-G90Y	0040-G80Y
18	usumidori	mint green	1040-G30Y	1040-G30Y	0040-G20Y	0040-G30Y
19	mizuiro	aqua green	1040-B80G	1040-B80G	1040-B80G	1040-B80G
20	fujiiro	wisteria	1020-R70B	1010-R50B	2010-R50B	2010-R50B
21	akoroiiro	poppy red	1070-R	1070-R	0080-Y90R	1070-R
22	ninjiniro	carrot	0070-Y70R	0070-Y70R	0070-Y70R	0070-Y70R
23	tamagoiro	apricot	1050-Y30R	1060-Y20R	0070-Y20R	1060-Y20R
24	remoniro	lemon yellow	0050-G80Y	0060-G80Y	0060-G80Y	0060-G80Y
25	wakakusairo	pistachio green	0070-G60Y	0080-G60Y	0070-G60Y	0070-G60Y
26	wakatakeiro	nile green	1050-G10Y	1050-G10Y	1050-G	1050-G
27	takeiro	turquoise	1060-B90G	1060-B90G	1060-B90G	1060-B90G
28	akoroomagi	turquoise blue	1050-B20G	1050-B20G	1050-B40G	1050-B40G
29	akoruiro	azure blue	3040-B10G	3040-B10G	3040-B10G	3040-B10G
30	fujimurasaki	heliotrope	3040-R80B	3040-R80B	3040-R80B	2040-R80B
31	botanbujiiro	amethyst	3040-R40B	3040-R40B	3040-R40B	3040-R40B
32	botaniro	peony purple	1060-R10B	1060-R20B	1070-R10B	1060-R20B
33	ebicya	terra cotta	2060-Y90R	2060-Y90R	2070-Y90R	2060-Y90R
34	kakiiro	brick red	2070-Y70R	2070-Y70R	2070-Y70R	2060-Y70R
35	oudoiro	yellow ochre	2070-Y10R	2070-Y10R	2070-Y10R	2070-Y10R
36	kusairo	grass green	3060-G40Y	3060-G40Y	3060-G40Y	3060-G40Y
37	fukamidori	billiard green	4060-G	4060-G	5050-G	4050-B90G
38	konjoiro	prussia blue	4060-B	4050-R90B	4050-R90B	4050-R90B
39	kikyoiro	pansy	5040-R80B	5040-R80B	4050-R70B	4050-R70B
40	wain	wine red	3060-R20B	2060-R20B	4050-R20B	2060-R20B
41	cyairo	brown	7020-Y90R	7020-Y90R	7020-Y70R	7020-Y80R
42	kuriiro	chestnut brown	7030-Y30R	7030-Y30R	7020-Y80R	7030-Y30R
43	oribuiro	olive green	4050-G90Y	4050-G40Y	5040-G40Y	4050-G40Y
44	tokiwairo	spruce	6040-G	5040-G	7020-B90G	6020-B90G
45	tetsuiro	fir green	6040-B10G	8020-B80G	7030-B10G	6030-B30G
46	koniro	navy blue	7030-R70B	7030-R70B	6030-R70B	6030-R70B
47	uradomeiro	old rose	2060-Y90R	2060-R	2060-R	2060-R
48	tobiiro	tabacco brown	5030-Y30R	5030-Y30R	5030-Y50R	6020-Y50R
49	kawairo	camel	4040-Y20R	4040-Y20R	4040-Y20R	4040-Y20R
50	matsubairo	elm green	3060-G40Y	3550-G40Y	3050-G40Y	3050-G40Y
51	hanadairo	oriental blue	3050-B	3050-B	4040-B10G	3040-B10G
52	aiiro	sea blue	5050-B	5050-B	5050-R90B	5040-R90B
53	usucyairo	sun brown	2010-Y70R	2010-Y70R	2010-Y70R	2010-Y60R
54	usukiiroyo	honey	1020-Y30R	1020-Y30R	1020-Y20R	1020-Y20R
55	usuiya	biscuit	2020-Y30R	3020-Y20R	3020-Y20R	2020-Y20R
56	karekusairo	bamboo	3030-Y10R	2020-Y	2020-Y	2020-Y
57	sunairo	beige	2020-Y10R	2020-Y20R	2010-Y10R	2010-Y20R
58	unohairo	sand	3020-G70Y	3020-G70Y	2020-G70Y	2020-G80Y
59	usunezumi	mist green	4020-G30Y	4020-G30Y	4020-B20G	4020-B30G
60	sukaigurei	sky grey	3020-B50G	4020-B50G	3020-B50G	4020-B50G
61	siro	white	0502-Y	0502-Y	0502-Y	0502-Y
62	akarusihairo	gelation grey	2502-Y	2502-Y	2502-Y	2502-Y
63	haiiro	grey	4502-Y	4502-Y	4502-Y	4500-Y
64	kurohairo	dark grey	7000-	7000-	6500-	6500-
65	kuro	black	9000-	8502-Y	8502-Y	8502-Y

Table 2. Agreement rate according to the tone group

Tone	Agreed colors	Sum	Total	Rate
1. vivid tone	[illegible]	3	14	21.4
2. pale tone	[illegible]	1	6	16.7
3. bright tone	[illegible]	4	12	33.3
4. deep tone	[illegible]	2	8	25.0
5. dark tone	/	0	6	0
6. dull tone	[illegible]	1	6	16.7
7. light grayish tone	/	0	8	0
8. achromatic	[illegible]	2	5	40.0

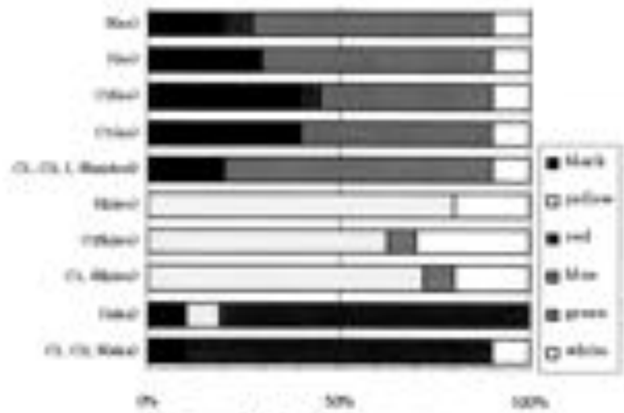


Figure 2. vivid tone group

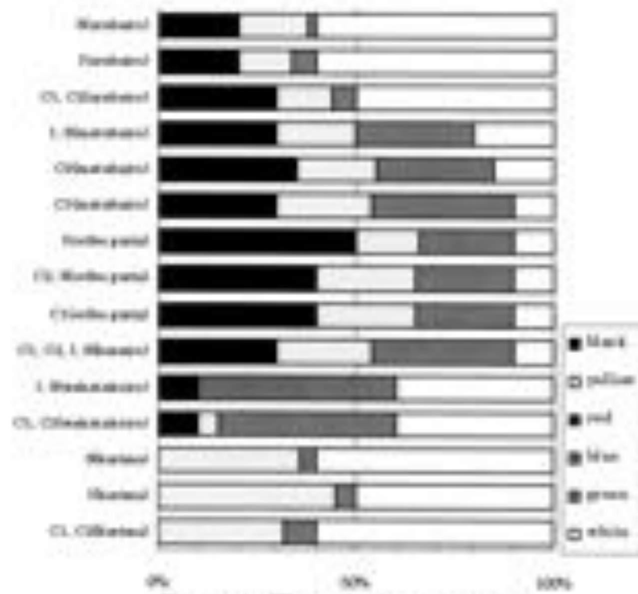


Figure3. The other tone groups

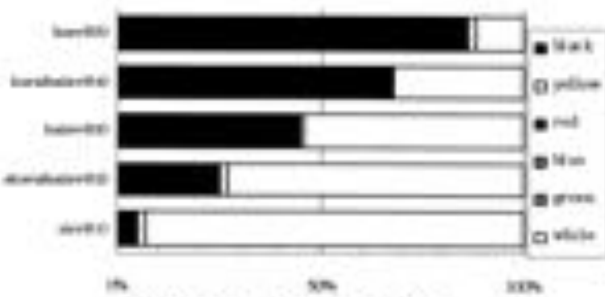


Figure 4. Achromatic colors

The NCS Three Attribute Diagrams for each one of which the colors were judged to be composed by a greenness or a yellowness hue in 6 tone groups are shown in Figure 3.

The characteristics of each tone can be seen by the differences of numerical values of whiteness and the blackness. Implementing that these groups are surveyed by the numerical values of the achromatic attributes over the chromatic attributes by comparison with the vivid tone. Especially one of 50% or more in whiteness is kurimu (17) and urabairo (57), which both belong to pale and light grayish tones. Further wakatakeiro (26) belongs to bright tone, being 40 of whiteness and 10 of blackness. A color which belongs to another deep tone, dark tone, and dull tone is a color from which the blackness is more measured than the whiteness.

Finally, the NCS Three Attribute Diagrams for 5 achromatic colors are shown in Figure 4. The color perception is clarified by the difference of the amount of whiteness and blackness. The yellowness is perceived except for kuraihaiiro (64, dark gray).

5. CONCLUSION

In result, the color perception of the comparison observation of the Tonal Color 65 and NCS INDEX, was almost viewed as common, though there was a little unstable. The difference of the numerical values of the attributes among the data did not exceed 10. Nevertheless, it might be difficult using the method of arranging NCS numerical values and hue, because of the considered floatation in psychological feelings.

The NCS Three Attribute Diagram can be shown as the integration of blackness (s), whiteness (w), and chromaticity (c). Moreover, all attributes included in one color can be understood by the use of only one graph. This is a feature in the NCS Three Attribute Diagram. Therefore, the NCS Three Attribute Diagram is believed to be a comprehensible, convenient mark.

Further examining will probably show the easy use of this NCS Three Attribute Diagram. In addition, the result to confirm the experiment by use of the NCS Notation would be highly appriciated.

ACKNOWLEDGMENTS

Proposing this NCS Three Attribute Diagram, I firstly would like to express my deep gratitude to Prof. Genro Kawakami, who gave his guidance and comments. Moreover, I wish to thank all members of the ISO/TC187 Japan domestic committee.

REFERENCES

1) Kawakami, Genro: International Standardization of Color Order System, Journal of The Illuminating Engineering Institute of Japan, 76-9 (1992) pp.478-481

2) Hård, Anders & Sivik, Lars: NCS-Natural Color System, Color Research and application 21-3, (1996)

3) Hård, Anders & Sivik, Lars: NCS-Natural Color System, Color Research and application 6-3,fall (1981)

4) NCS INDEX 2, Scandinavian Colour Institute (1995)

----

*Correspondence: seramin@pk.highway.ne.jp; 40-3, Tsurumaki 5-chome, Tama, Tokyo, 206-0034 JAPAN

Colour Zones – Explanatory diagrams, colour names, and modifying adjectives

Paul Green-Armytage, School of Design, Curtin University of Technology, Western Australia

ABSTRACT

This paper presents a flexible system for describing colours which links everyday language to colour order systems. The structure, based on that of the *Natural Colour System* (NCS)[1], has reference points which are defined and named. The structure is illustrated and an account is given of the processes used to establish the system of colour names and modifying adjectives which identify the reference points.

Keywords: Colour order systems, colour names, basic colour terms,

1. INTRODUCTION - COLOUR ZONES

Colour Zones are subdivisions of the 3-D colour solid. Each zone contains a range of similar colours with a focal colour as a reference point at the centre of the zone. All the colours in a given zone have the same identification.

1.1 Three levels of precision.

The smaller the zones, the narrower the range of different colours in each zone, the larger the number of zones needed to fill the colour solid, and the greater the precision. A primary source of inspiration, which gave impetus to this project, was the *Universal Color Language* (UCL)[2] with its six levels of precision. A simpler alternative to the first three levels of the UCL was one of the objectives of the Colour Zones project. At level one there are six zones, the focal colours of the zones being the six Elementary Colours as defined by Ewald Hering[3] which form the basis of the NCS: White, Black, Yellow, Red, Blue, and Green. Further subdivisions provide 27 zones at level two and 165 zones at level three.

1.2 Merits of imprecision – the *Post-it* advantage

Challenging assumptions is one of the strategies recommended by Edward de Bono[4] for generating new ideas. If we assume that the value of a glue is to be measured by how firmly it sticks we might not recognise the advantage of having a glue that does not stick very well. In their humble way, *Post-it* notes have changed the world. A common assumption about colour order systems is that they should be as precise as possible, but I believe that a system which is imprecise and flexible can offer what I call the *Post-it* advantage. If the hit-and-miss of everyday language can be so imprecise as to be the equivalent of no glue at all, and a colour order system is the equivalent of *Supa-Glue*, it can be useful to have something in between – the equivalent of *Post-it* – a fuzzy system with a somewhat elastic structure.

2. STRUCTURE

The colour solid of the NCS provides the structural skeleton for the Colour Zones. It can be presented in two projections – a plan view (a colour circle which shows the sequence of hues) and part cross section (a colour triangle which shows the set of nuances). Hering's Elementary Colours are the focal points of the six zones at level one. Anders Hård[5] has drawn attention to the distinctive character of colours with equal resemblance to Elementary Colours such as a grey that is equally whitish and blackish. These equal resemblance colours together with the Elementary Colours provide focal points for the 27 zones at level two. Further subdivision, with intermediate colours as additional focal points, results in the 165 zones at level three.

3. IDENTIFYING THE ZONES

Colour names are used to identify colours in the zones at levels one and two. Colour names, used singly or in pairs, and with modifying adjectives, are used for the more precise descriptions required for the smaller zones at level three. Research was undertaken to find a set of colour names and modifying adjectives which reflect current usage and can be used to describe colours in this way. A definitive study, with a large number of participants randomly selected from different populations within the English speaking world, was beyond my resources. So I can claim no more than provisional status for my findings. My objective was a set of words that people would accept and that I could defend.

4. COLOUR NAMES

Colour is a sophisticated concept which requires the ability to make connections between things that are otherwise quite different from one another. Most, if not all words that are used as colour names in English were first used for something else, 'orange' being a clear example. In some cases the original meaning has got lost in history. Philologist Anna Partington[6] has traced the word 'red' through its migrations from one language to another to an ancient word for "blood". This seems a likely scenario: Someone notices a similarity in appearance between blood and a particular flower and describes the flower as 'blood-like'. With increasing use of the expression it becomes possible to describe the flower simply as 'blood' – a colour name has been born.

4.1 Basic Colour Terms – past, present, and future

Research, which began with the study by Brent Berlin and Paul Kay[7], has provided convincing arguments for a set pattern of language evolution; there are strict limitations to the order in which languages acquire 'basic colour terms'. Basic colour terms are best defined as 'the smallest subset of color terms such that any color can be named by one of them'[8]. In today's English these are white, black, red, green, yellow, blue, brown, grey, purple, orange, and pink. But today's smallest subset was once smaller. In 1721 Nathaniel Bailey's dictionary[9] did not recognise orange or pink as colour names with today's meanings; what is 'pink' today would then have been just another kind of red. If the smallest subset was once smaller, presumably it may also get bigger. The Colour Zones project is an attempt to establish a kind of ideal subset for the future. The level two subdivision offers a manageable range of 27 colour zones in a coherent structure with well defined focal points. The idea is to boost the number of basic terms from eleven to 27. Today's eleven terms are spread unevenly over those 27 zones, with eight zones that would be 'green' and only one 'pink'. If these terms are now restricted to the zones which suit them best, new names can be provided for the remaining 16 zones. The most suitable names will be those which come most readily to people's minds and which are commonly applied to the colours in question. Several studies were conducted.

4.2 Salience test

Responses from 247 people to the request that they write down as many colour names as they could think of in five minutes produced 216 names that were listed by more than one person. Of these, 183 are recognised as colour names in more than one of the six current dictionaries consulted. A rank order of salience for the names was established by the number of people who listed each one.

4.3 Preference test

The 27 focal colours were shown to a group of eleven people who were asked to propose names for the colours. This exercise confirmed earlier ideas about which colours should become the limited domains of the existing eleven basic terms. From the names proposed for the other 16 colours, 32 names were chosen as potentially most suitable. Colours and candidate names were then shown to several groups. Responses from 148 people established orders of preference where there was more than one candidate name for a given colour zone.

4.4 Correspondence test

An indication of the range of colours to which each name might be applied was established by asking people to choose the best example for each candidate name from all the colours in the NCS atlas. Responses from 54 people established the extent to which each name was on target, the ideal situation being that all colours chosen would fall within the zone to be named.

4.5 Conversation test

To test the credibility of the names as colour names, people were asked to imagine this fragment of overheard conversation: "We saw it on television, it was .....". Responses from 35 people established the extent to which candidate names might be used to complete that sentence and be recognised as names for colours as opposed to names for other things.

4.6 Decisions – strong claims, conflicting claims, and problem colours

Decisions were made. The key consideration was the correspondence test. A name could only be accepted if the majority of colours chosen for it were within the zone to be named. For some colours the choice was easy: lemon, khaki, lime, olive, aqua, turquoise and navy were generally well supported by the data and scored better than any rival names in the tests. For other colours there were two names with competing claims. In such cases the first appeal was to the correspondence test. So apricot was chosen ahead of peach, and teal ahead of jade. But there was nothing in that test to separate maroon from burgundy, mauve from lilac, or azure from sky. Although burgundy and lilac were preferred by more people, maroon and mauve were more salient and scored better in the conversation test. Although less appealing on aesthetic grounds, maroon and mauve are clearly better established as colour names and so were chosen. Azure was chosen ahead of sky because it is a complete colour name. Unlike navy, sky cannot yet stand alone, it still has to be sky blue. Four problem colours remained. Mint and forest came out of nowhere as names for light and deep green. They are barely established as colour names, but were clear winners in the preference and correspondence tests. Chartreuse, though unfamiliar to many, is an established colour name and the best option for light yellow-green. For deep purple the best option seemed to be grape, but with green grapes and purple grapes there was ambiguity which was born out by two clusters in the correspondence test. At the last minute I came across aubergine and chose it although it has not been subjected to all the tests.

5. MODIFYING ADJECTIVES

For the greater precision at level three the 27 zones of level two contract around their focal points and new zones are formed in the gaps. It might be possible to find or invent 165 colour names but their use would be neither practical nor in line with normal use of language. We combine names, e.g. yellow-orange, to add precision in terms of hue. And we introduce modifying adjectives like pale and deep to add precision in terms of nuance. Further studies were conducted to find a useable set of modifying adjectives to identify differences in nuance.

5.1 Salience test for adjectives

As with colour names, people were asked to list as many modifying adjectives as they could think of in five minutes. In responses from 106 people, 161 words were listed by more than one person and a rank order of salience for these words was established. Of these words, the 32 most salient and most potentially useful were selected for further testing.

5.2 Correspondence test for adjectives

An indication of how modifying adjectives might be used to describe colours according to their variations in nuance was established by asking people to use a seven point scale to rank the appropriateness of each adjective as a description for each of a given set of colours. Ten colours of similar hue were presented together. Four sets were used, one for each of the elementary hues. Responses from 30 people made it possible to derive patterns which can be used to justify the choice of specific adjectives for specific nuances.

5.3 Preference test. Adjectives for describing colours in general and colours that are also named

The four sets of ten colours were arranged in random order in a square grid of 40 colours. From the list of candidate adjectives people were asked to select the most appropriate as a description for each colour. While a preference order could then be established, responses from 41 people made it clear that the choice of adjective could depend on whether or not the colour was also named – in a comparative situation a 'light blue' might or might not also be a 'light colour'. It is possible to refer to a group of unnamed colours as, e.g. 'pale colours' or 'deep colours', but when a specific colour is also named, the role of modifying adjectives is somewhat different. An adjective indicates relative appearance. E.g. focal pink belongs in the 'light' zone. In relation to focal pink a given pink might be judged to be pale, dull, deep or strong.

5.4 'Road test'. Adjectives and names combined

To test whether a finite set of names and adjectives could be used by different people to describe colours consistently and with some degree of precision in normal conversation, the grid of 40 colours was presented to another group. This time the choice of names and adjectives was limited to lists which were now all but finalised. Responses from 32 people using this system for the first time (some under protest!) did result in some degree of consensus.

6. CONCLUSION

The three levels of Colour Zones, with the reference points identified by names and adjectives, are shown in figures 1 – 3. While the underlying structure of Colour Zones is quite regular, it clearly needs to be able to bend and stretch if it is to accommodate everyday language. And it has to admit alternate descriptions for the same colour. The colour names themselves are not all entirely satisfactory and there are complications in the way people use modifying adjectives which threaten to undermine the simplicity of Colour Zones as a system. However, the degree of consensus shown in the way people used names and adjectives when their choice was restricted suggests that the system could serve its intended purpose. It could be like *Post-it*, a glue that does stick although it does not stick very well. I hope it may also ease the transition from use of unstructured language to use of a colour order system and make it easier for people to describe colours in a way that can be related to the NCS without needing to master that system's letter/number notation code.

Fig 1 Colour Zones - Level 1

Colour circle and colour triangle showing the elementary colours as reference points

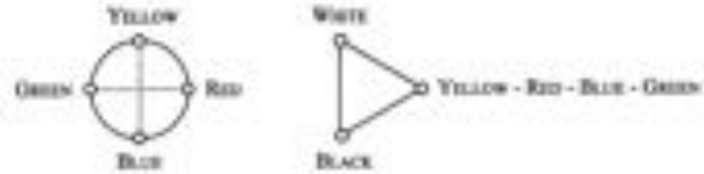


Fig 2 Colour Zones - Level 2

Colour circle and eight colour triangles showing the elementary colours and equal resemblance colours as reference points

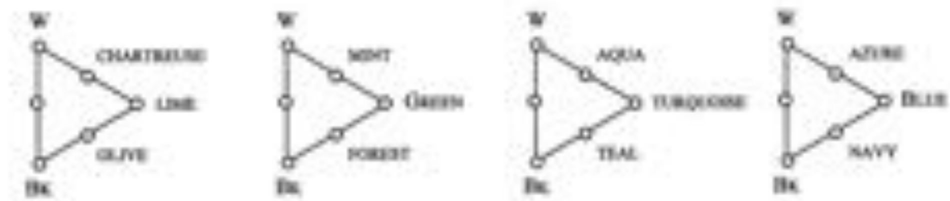
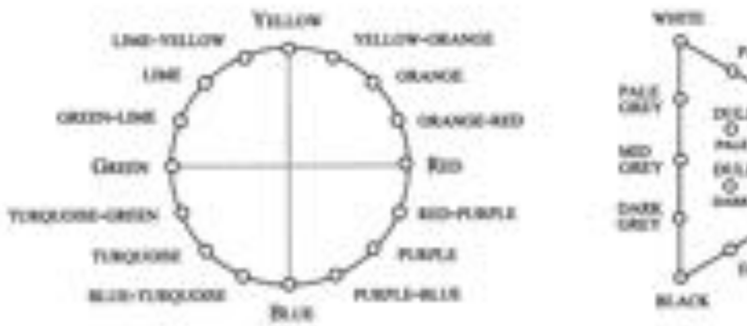


Fig 3 Colour Zones - Level 3

Colour circle with intermediate colours added as reference points between elementary and equal resemblance colours. Reference points in the colour triangle are identified by modifying adjectives



REFERENCES

1. Hård, Anders and Sivik, Lars, 'NCS - Natural Colour System: A Swedish Standard for Colour Notation', *Color Research and Application.* **6** (3), pp. 129 - 138. 1981.
2. Kelly, Kenneth, 'The Universal Color Language', in Kelly, Kenneth and Judd, Deane, *Color - Universal Language and Dictionary of Names*, U.S. Department of Commerce, Washington, 1976.
3. Hering, E. *Outlines of a Theory of the Light Sense.* Harvard University Press, Cambridge, Massachusetts,1964.
4. de Bono, Edward, *The Use of Lateral Thinking*, Penguin Books, Harmondsworth, Middlesex, 1971.
5. Hård, Anders, Sivik, Lars and Tonnquist, Gunnar, 'NCS, Natural Color System – from Concept to Research and Applications', *Color Research and Application.* **21** (3), pp. 180 – 205, 1996.
6. Partington, Anna, *Red and Blue: Some Philological Comments*, Unpublished notes, 1998.
7. Berlin, Brent, and Kay, Paul, *Basic Colour Terms*, University of California Press, Berkeley and Los Angeles, 1969.
8. Definition proposed by Kay, Berlin, and Merrifield, quoted in Hardin, C.L. and Maffi, Luisa, eds. *Color Categories in Thought and Language.* Cambridge University Press, Cambridge, 1997.
9. Bailey, Nathaniel, *An Universal Etymological English Dictionary*, 1721.

Recent experiments investigating the harmony interval based colour space of the Coloroid Colour System

Nemcsics, Antal•

ABSTRACT

Coloroid Colour System has been created for people dealing with colours constructively, first of all architects and artists. Its colour space is being based on experiments measuring harmony threshold, being perceptively uniform. This uniformity is the uniformity of big colour differences rather than that of small colour differences, it is being based on human judgement capability rather than colour differentiating capability of human eye. During its elaboration we have investigated aesthetic uniformity of hues along colour circles of colours with different saturation and lightness, and – in different hue planes - that of saturation and lightness sequences.
During mathematical formulation of the establishment of harmony relations in Coloroid colour space it has been necessary to refine aesthetic uniformity of Coloroid colour space. In the interest of it we have started a new, large scale series of experiments. Within the framework of experiments we produced aesthetically uniform changing scales between distant points of Coloroid colour space, possessing different lightness – partly by painting, partly by selection from a considerable number of colour samples. We then investigated, which path those colour scales in the colour space describe.

1. INTODUCTION

Coloroid Colour System has been planned mainly for architects, artists and other creative specialists composing with colours. Its colour space is perceptively uniform but this uniformity keeps its validity rather for non-adapted eyes than for adapted eyes. The attempts to form its colour space do not relate to the definition of small colour differences (ds units) namely to colour differentiation capability of the human eye as used for example in colour system Munsell, rather relate to the definition of large colour differences, harmony intervals (dh units) namely to the human sense.

Coloroid Colour System positions colours in a cylindrical coordinate system. The axis of the cylinder constitutes the grey scale, the hue planes start from here radially. The sheath of the cylinder has the most saturated colours, the co-axial cylinders have those of identical saturation and the perpendicular planes have the colours of identical lightness. During the development attempts we have investigated on one side the aesthetical uniformity of hue along the colour circles with different saturation and lightness, on the other side that of the sequences of saturation and lightness.

Because of its aesthetically uniform colour space Coloroid Colour System is highly applicable for the establishment of harmonic colour compositions. During its usage by practical designers there emerged the demand to further generalize the relationships of colour harmony described by its colour signals. For this purpose we have conducted experiments gaining aesthetically uniform scales between randomly chosen points of the colour space.

2. TARGET OF THE EXPERIMENTS

The demand on mathematical formulation of colour harmony relations which can be described in Coloroid – which formulation is very important for designers of colour, has made it necessary to refine colour space of Coloroid colour system and as a result, creation of EUCS (Esthetically Uniform Colour Space).

• nemcsics.antal@axelero.hu , phone: (36)-1-292-1419, fax: (36)-1-292-1419, Technical University of Budapest, 1111. Budapest, Műegyetem rkp. 3. Hungary

3. COLOROID AXIOMS

The projected EUCS colour space intends to retain the following features of Coloroid colour system based on a large number of former observations:

- Lightness of Coloroid is equal to ten times the square root of CIE luminance factor (Y) i.e. $V = 10 \cdot Y^{1/2}$
- Characteristic wavelengths of colours with identical Coloroid hue are identical.
- Coloroid saturation is a monotonous function of colour content i.e. the limit-colour contents of colours possessing the same coloroid saturation are identical.

4. EXPERIMENTS

The experiments were participated by students of a post-gradual course on colour dynamics, being graduated architects and artists. They were familiar with Coloroid colour system and had practice in creating colour scales changing with identical intervals. People creating scales with colour mixing have used two different paints representing approximately opposite points of Coloroid colour space. Scales were produced in a first step by painting several hundreds of samples, the by selection from among the painted samples. Coloroid A, T, V and CIE X,Y,Z data of scale members were defined. (It must be noted here that one of the significant features of Coloroid facilitates using its colour signals for simple calculation of the colour components X,Y,Z of CIE Colorimetric System.) Based on data obtained we have evaluated the uniform and monotonous change in saturation and lightness of scale members. Where the change has shown discontinuity or leap, the visually experienced uniform change of the scale has been revised. The experiments were conducted with D65 illumination, under registered observation circumstances.

5. SCALES OBTAINED AS EXPERIMENTAL RESULTS

The following table contains data related to members of a 30-membered scale featuring identical harmony intervals, between a saturated orange and a saturated blue colour.

Table 1

No	A	T	V	X	Y	Z
1	23.52	46.17	61.38	49.92	37.68	3.19
2	23.54	42.51	59.03	46.16	34.85	3.16
3	23.56	39.49	56.86	42.88	32.33	2.91
4	23.59	35.83	54.62	39.45	29.83	3.27
5	23.62	32.21	52.21	35.94	27.26	3.49
6	23.65	28.87	50.11	32.93	25.11	3.96
7	23.68	25.11	48.63	30.45	23.65	5.61
8	23.71	22.03	46.36	27.48	21.49	5.83
9	23.77	17.02	42.36	22.59	17.94	6.12
10	23.81	14.53	40.28	20.20	16.22	6.32
11	23.84	12.00	38.41	18.03	14.75	6.83
12	23.87	9.92	36.92	16.33	13.63	7.35
13	23.89	7.87	35.01	14.38	12.26	7.55
14	23.92	5.86	33.65	12.87	11.32	8.22
15	24.43	4.01	32.02	11.37	10.25	8.67
16	26.68	2.23	31.00	10.44	9.61	9.74
17	32.52	1.15	29.97	9.31	8.98	10.26
18	40.17	1.02	29.01	8.66	8.42	10.19
19	44.15	1.14	28.36	8.30	8.04	10.38
20	50.05	2.21	28.08	8.36	7.88	13.01
21	51.08	3.95	28.02	8.15	7.85	14.05
22	51.21	5.82	28.01	8.27	7.85	15.92

23	51.32	8.95	28.07	8.50	7.88	19.10
24	51.38	11.08	28.26	8.72	7.99	21.29
25	51.42	14.12	28.98	9.30	8.40	24.82
26	51.46	17.01	29.02	9.48	8.42	27.65
27	51.52	19.92	29.98	10.13	8.99	30.93
28	51.54	23.76	31.02	10.96	9.62	35.43
29	51.63	28.03	31.09	11.04	9.67	39.00
30	51.66	31.82	33.85	12.92	11.46	44.56

Our second table contains data on members of a scale with 23 members, which are in identical harmony intervals from one another, located between a green and a blue colour.

Table 2.

No.	A	T	V	X	Y	Z
1	70.65	7.48	41.20	11.82	16.97	10.72
2	70.38	7.22	40.02	10.86	16.02	10.12
3	66.97	6.49	39.07	10.36	15.26	10.31
4	66.72	5.38	38.15	10.38	14.55	11.01
5	66.31	4.47	37.50	10.54	14.06	11.80
6	65.78	4.42	36.81	10.31	13.55	12.00
7	65.52	5.18	36.18	9.64	13.09	11.50
8	64.82	6.49	35.57	9.21	12.65	11.68
9	64.32	8.17	34.99	8.53	12.24	11.51
10	63.92	9.92	34.58	7.99	11.96	11.52
11	63.38	11.45	34.27	7.68	11.74	11.81
12	62.89	12.63	33.86	7.43	11.46	12.11
13	62.35	13.91	33.51	7.19	11.23	12.59
14	61.75	15.09	33.28	7.11	11.08	13.31
15	61.28	16.31	33.09	6.98	10.95	13.90
16	60.71	16.43	32.84	7.09	10.78	14.49
17	56.98	18.75	32.68	6.96	10.68	15.88
18	56.67	19.99	32.61	6.94	10.63	16.76
19	55.97	21.41	32.58	7.28	10.61	18.88
20	55.43	22.68	32.47	7.50	10.54	20.64
21	54.91	23.91	32.36	7.77	10.47	22.65
22	54.02	25.21	32.31	8.29	10.44	25.52
23	53.45	26.76	32.30	8.72	10.43	28.24

Our third table contains data on members of a scale with 25 members, which are in identical harmony intervals from one another, located between a violet and a orange colour.

Table 3.

No.	A	°T	V	X	Y	Z
1.	45.11	9.24	46.50	23.81	21.62	32.42
2.	41.13	8.58	46.31	23.77	21.45	26.57
3.	33.68	7.81	45.98	23.44	21.14	22.22
4.	32.03	6.55	45.72	22.79	20.90	20.49
5.	30.69	5.72	45.49	22.62	20.69	19.23
6.	26.67	5.51	45.33	22.13	20.55	18.67
7.	25.55	6.07	44.99	21.73	20.24	17.54
8.	24.63	6.91	44.81	21.58	20.08	16.45
9.	23.89	8.09	44.52	21.44	19.82	15.01
10.	23.19	9.38	44.38	21.42	19.70	13.61
11.	22.61	10.55	44.19	21.31	19.53	12.27
12.	22.48	11.77	43.87	21.30	19.25	10.88
13.	22.17	12.96	43.82	21.38	19.20	9.70

14.	22.16	14.19	43.80	21.65	19.18	8.61
15.	22.15	15.27	43.87	21.96	19.25	7.74
16.	22.16	16.50	43.99	22.37	19.35	6.80
17.	22.19	17.60	44.21	22.84	19.55	6.07
18.	22.59	18.97	44.37	23.65	19.69	5.25
19.	22.78	20.41	44.68	24.46	19.96	4.43
20.	23.01	21.66	44.99	25.28	20.24	3.82
21.	23.54	23.53	45.45	26.81	20.66	3.10
22.	23.72	25.52	46.37	28.44	21.50	2.53
23.	23.91	27.62	47.68	30.53	22.73	2.33
24.	24.11	29.89	49.48	33.23	24.48	2.61
25.	24.72	31.97	51.72	37.11	26.75	4.18

5. SUMMARY

In the framework of our experiments we have created and investigated 21 scales intersecting Coloroid colour space transversally. From these visually equidistant sequences we started calculations of local metrics related to colour space, which results expectably the determination of refined two-dimension Euclidean sub-spaces and the determination of minimum paths or geodetic lines in three-dimensional space. In aesthetically uniform colour space we expect registrability of colour differences along these geodetic lines. Full publication of our results in scientific press, compiled commonly with my research fellows, will appear soon.

REFERENCES

1. Hunt, R. W. G. Measuring Colour. *Ellis Horwood Ltd.(1987)*
2. Indow,T._ Multidimensional Studies of the Munsell Color Solid. *Psychological Review, 95, 456-470, (1980)*
3. Judd,D.B._Wyszecki,G.: Color in Business, Science and Industry, Wiley, New York-London (1963)
4. MacAdam, D.L.: Uniform color scales. *J.Opt.Soc.Am.64. 1691-1702. (1974)*
5. MacAdam, D.L.: Colorimetric data for samples of OSA uniform color scales. *J.Opt.Soc.Am 68., 121-130. (1978).*
6. Nayatani,H.-Ihara,M.-Sobagaki,H.-Hashimoto,K.: Estimation equations for practical use on lightness-reflectance (L/Y) rations in the whole chromaticity gamut. Color Res.Appl. 17., 208-218. (1992)
7. Nemcsics, A: Coloroid Colour system. *Color Res.. Appl. 5. No.2.p.113-120.(1980)*
8. Nemcsics, A: Experimental determination of a perceptively equidistant scale in the Color Space. *Acta Chromatica, 3. No. 5.p.206-209.(1980)*
9. Nemcsics, A: The Role of Aesthetic Uniformity in Color Harmony . *Proc.XXII.Color Symp.p.24-29.(1982)*
10. Nemcsics, A: Experiments to determine aesthetically uniform psychometric scales of the Coloroid Colour System. *Hung.Pschi. Sz.38. No.1.p.40-60.(1982)*
11. Nemcsics, A: Color space of the Coloroid color system. *Color Res. Appl..12. No.3.p.135-146.(1987)*
12. Nemcsics, A: Coloroid Colour Atlas. *Innofinance. Budapest (1985)*
13. Nemcsics, A: Comparison between Coloroid, Munsell, DIN, NCS Colour. *Proc. AIC 6th Congress p. 119-122.(1989)*
14. Nemcsics, A: Colour Dynamics, Environmental Colour Design. *Ellis Horwood Ltd. New York, London, Toronto, Sydney, Tokyo, Singapore. (1993)*
15. Nemcsics, A: Spacing in the Munsell Color System Relative to the Coloroid Color System. *Color Res. Appl. 19. No. 2. P. 122-126.(1994)*
16. Nemcsics, A: Coloroid Color Atlas. *Coloroid Bt. Budapest, (2000)*
17. Newhall,S.N.: The ratio method in the review of the Munsell Colors. *Am.J.Psych.52.,394. (1939)*
18. Newhall,S.-Nickerson,D._Judd,D.J.: Final report of the OSA Subcommittee on the spacing of the Munsell colors. *J.Opt.Soc.Am.33, 385-418. (1943)*
19. Smith, N.S.: Colorcurve and Coloroid Notations for the OSA-UCS Atlas Samples. *Color Res.Appl. 18. No.2. p. 123-128.(1993)*
20. Wyszecki, G.- Stiles, W.S.: *Color Science, Concepts and Methods, Quantitative Data and Formulae, 2nd ed, Wiley, New York, (1982)*
21. Wright, W.D.: The sensitivity of the eye to small colour differences. *Proc.Phys.Soc.,53, 93 (1941)*

The quality of the NCS colour samples today and tomorrow!

Anders Nilsson, Scandinavian Colour Institute AB, Stockholm, Sweden.

Abstract

The aim of this paper is to describe the background, the methods and the resulting colour accuracy of the control process used in the production of the NCS colour samples. A study of the colour matching results for the NCS productions since the introduction of NCS edition 2 are presented.

Keywords: NCS – Natural Color System, Color control, Color samples, Color printer

Introduction

Accurate colour communication is important to almost all industries today. Designers and developers that select a colour need tools to communicate this colour accurate to producers. The consumer will notice if different copies of a product or different parts in a product do not match. The producer needs tools to control that all parts have the right colour. Bad colour matching can give customers the impression of bad quality of the product as a whole and influence them to select another manufacturer's product. The high quality colour standards are the solution to this problem.

NCS - Natural Color System

The NCS notation is based on how the human beings perceive colour, it is a user-oriented and user-friendly colour notation system. The NCS notation can be exactly obtained for any surface colour by measurements.

NCS products

The Scandinavian Colour Institute (SCI) manufactures and markets products based on the NCS system. The colour card collections contain 1750 accurately NCS notated colour samples. This covers most of the needs of colour designers. These colours are available as fandecks, as a box with A6 cards, as a Colour Atlas and as separate sheets in A4 size. All colour samples are of high colour accuracy. Calibrated standard samples are available (NCS Standard). These have a mean deviation of less than 0.27 $\Delta E_{CMC(1:1)}$ from the NCS Primary Standard and have a maximum deviation of 0.5 ΔE.

NCS quality management

History

The first NCS samples were produced in 1979. The colours were produced to have CIE XYZ-values that where calculated with NCS colour conversion software. The algorithms and boundary values used by this software was extracted from the result of all visual NCS experiments.

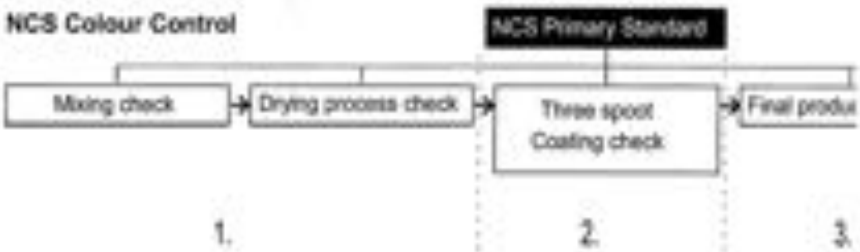
Partly due to technical limitations and partly to other factors, many of the NCS colour samples of the first productions showed large differences between the aim point XYZ-values and the colour samples XYZ-values. Lead and cadmium based pigments were used in the first edition.

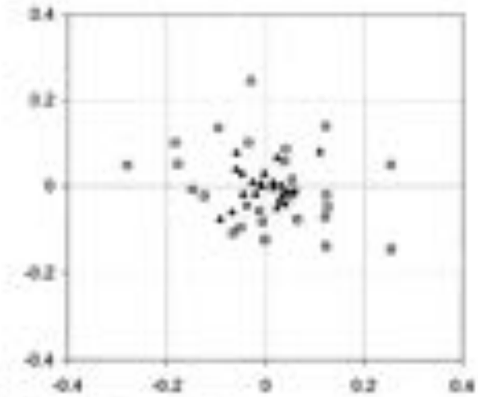
In 1995 the NCS Edition 2 was developed in cooperation with leading paint manufacturers to support the higher quality needs of the industry. The main changes were as follow:

Lead and cadmium based pigments were not used. The colour accuracy was increased, both between the colour samples and the aim points CIE-value, and more important between the successive productions of the same colour samples. The standard colour range was extended with 261 new colours. Today NCS edition 2 is among the most accurate colour samples on the market.

Colour control process

To reach the high colour accuracy a colour control system was developed by the Scandinavian Colour Institute (SCI) and the colour card manufacturers. The system depends both on the primary standard, special calibrated colour measurement instruments and on skilled personnel making extensive visual colour evaluation. The block scheme below describes the control process used for every colour card produced.





CIE a*b*-diagram showing spread between two instruments before (open squares) and after (black triangles) correlation.

The NCS Primary Standard

This is the colour standard for each NCS colour. The measurement values for these standards are kept in a database. This database is made available to the colour card manufacturers.

Mixing check (draw down)

Draw down from the manufacturer is checked. The normal demands of these matches are below 0.3 $\Delta E_{CMC(1:1)}$. The light sources used are CIE standard source D65, CIE standard source A and CIE source F11. Three draw downs are measured and at least one of these is on black and white paper for opacity check.

The drying process is important for some paints. The colour and also the gloss change some during the first day. For this reason a draw down should be at least one day old before they are accepted.

All draw downs are checked against the database with all measurement data of earlier productions of the NCS edition 2 colour samples. This is an extra check between this production and earlier produced colour cards.

Coating check

When the ready matched paint is coated on the final paper some small colour changes can occur. There is also a risk that the colour differs some between the start and the end of the production. To minimize this risk the coated colour sheets from the start, middle and end of the production are checked.

Final production check

The final production is checked to guarantee that every colour has the right notation printed on it. This is also the delivery check for the most of the produced colour cards.

Delivery check

The most colour cards produced are delivered immediately after production to the costumers. This is the NCS Trade concept, customers order the needed number of colour cards one year in advance and get the delivery in the beginning of the year after. All the colours for NCS Standard are measured, checked and labelled just before delivery.

Measurement equipment

SCI uses a Zeiss DMC26 as a reference instrument for NCS. Macbeth CE7000 is used for the day-to-day control work. Specially developed software is used. This software keeps the NCS primary values in a database together with the control status for each colour under production. To be able to use the same database with different measurement instruments it is important to correlate these instruments to maximize the inter-instrument agreement. Between different Macbeth CE7000 spectrophotometers a mean difference below 0.06 ΔE_{CIELAB} is reached under production conditions.

Visual evaluation

All the colours are visually checked for colour accuracy, opaqueness and surface quality. If the measurement value indicates a larger difference then the visual check is very important. If the check against the earlier productions indicates that there is a difference, visually checks against the reference samples of the production are done.

Colour accuracy of the NCS colour samples

Quality levels, QL

Due to the differences in production technique between different NCS colour cards, different quality demands are expected to be reached. The quality level is a statistical measure for all colours in the colour collection. All of the colours should have a ΔE less than the highest allowed difference value for the quality level. Then the certain amount of the colours must have an even lower ΔE value according to the specification.

NCS QL 1: This is the quality level for A4 sheets and all colour collections based on these (NCS Atlas, NCS Album, NCS Block and NCS Box).

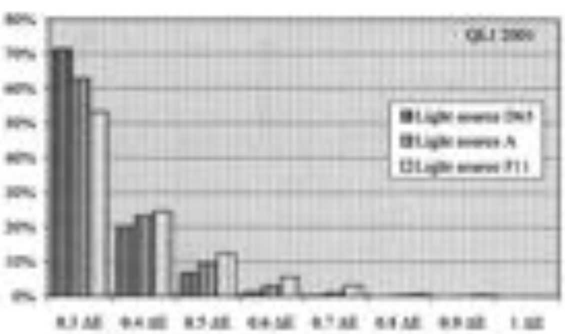
NCS QL 2: This quality level is for products containing several colours on each sheet (NCS Index, NCS selection, NCS chips). The following table shows the specified demands:

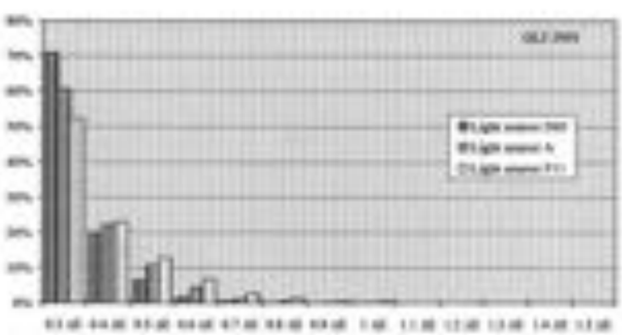
QL	<0.6 ΔE	<1.0 ΔE	<1.5ΔE
1	80%	100%	100%
2	70%	90%	100%

These are the original specifications decided on in 1995 in cooperation with some of the largest paint manufactures in Europe. As can be seen from the following, these requirements have been fulfilled.

Production results 2001

The following diagrams show the production results for NCS QL1 and QL2 for this year. The difference in $\Delta E_{CMC(1:1)}$ compared with the NCS Primary Standard is shown. The three bar types (one for each light source) show the percentage of the 1750 NCS colours that have a ΔE-value in the interval written below the bars. The first interval is 0-0.3ΔE, the following intervals are 0.1 ΔE wide each.





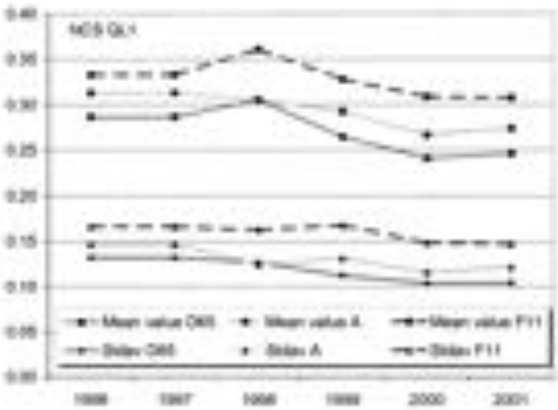
Compared with the demands of the quality level QL1 and QL2 the production outcome is as follows:

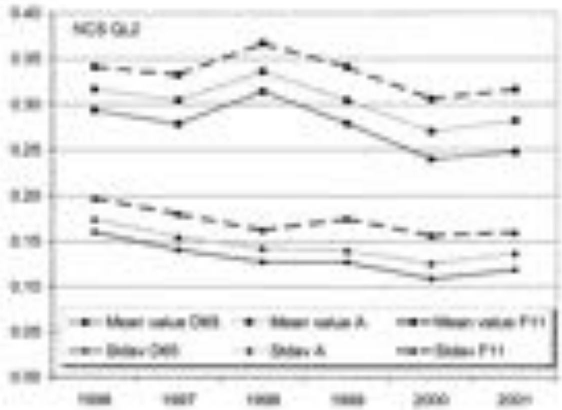
QL	<0.6 ΔE			<1.0 ΔE			<1.5ΔE		
	D65	A	F11	D65	A	F11	D65	A	F11
1	99.7%	98.6%	95.6%	100%	100%	100%	100%	100%	100%
2	99.1%	97.9%	95.0%	99.9%	99.9%	99.8%	100%	100%	100%

For example, the demands for QL1 are that 80% of the colours should have a difference less than 0.6 ΔE. As can be seen in the table, 99.7% of the colours in QL1 had this tolerance in the production this year.

Production results 1996-2001

The following diagrams show the mean value of the deviation and the standard deviation between the NCS Primary standard and NCS QL1 and QL2 for the productions in 1996-2001. The curves are shown for CIE light sources D65, A and F11.





As can be seen in the graphs above, the mean values are stable and show a tendency towards the lower tolerance. The standard deviation shows the same tendency.

Comparison of the productions 1996-2001

The productions of the NCS edition 2 colour samples from 1996 to 2001 have been compared with each other. In the table to the right, the mean ΔE values between all types of colour collections produced in these years are shown. The mean differences between different years are approximately 0.3ΔE. The difference between colour cards produced the same year are approximately 0.15ΔE (the diagonal values). The reason for the lower values here are that these colour cards are normally produced with the same paint.

	1996	1997	1998	1999	2000	2001
1996	0.16					
1997	**0.28**	0.13				
1998	**0.34**	**0.31**	0.14			
1999	**0.33**	**0.30**	**0.31**	0.11		
2000	**0.33**	**0.32**	**0.35**	**0.31**	0.13	
2001	**0.33**	**0.32**	**0.33**	**0.31**	**0.29**	0.11

Conclusions

The quality work carried out by Scandinavian Colour Institute AB has resulted in the production of NCS colour samples with high colour accuracy. The accuracy makes the NCS colour samples suitable for all kinds of colour quality work.

Products of the Coloroid Color System

Rozsevits, Ildiko[1]
Coloroid Ltd., Hungary

ABSTRACT

Coloroid Ltd. has set the aim of creating the devices of Coloroid Color System so that it could be accessible for everyone who is interested in this unique system.

1. COLOROID COLOR SYSTEM

1.1. The Coloroid Color System

The Coloroid Color System was created by Prof. Dr. Antal Nemcsics on the basis of the results of the experiments carried over by thousands of people. On the basis of their statistical evaluation he wrote certain rules about the following:

- Typically similar color groups are considered to be harmonized.
- We add similar meaning to certain colors and color groups.
- Color preference is typical of the sexes, ages and historical eras.

He built his unique model, Coloroid Color System on these discovered regulations.

Coloroid is a visual, easily treatable model, its specialty is that by its help either objectively harmonic color groups can be created, since the harmony relations between the colors can be described exactly in it. Coloroid is in mathematical relationship with the international systems of color measuring, and thanks to its continuity any existing color can be given by its parameters. For these features Coloroid is especially applicable for color design, and its computer processing.

1.2. Description of Coloroid

The uniformity of differences between colors in Coloroid, the so-called aesthetic uniformity has been determined as in true life, in a wide visual field with non adapted eyes, simultaneously by observing many color samples. The spacing of colors just noticeable under these conditions is called harmony threshold.

In the Coloroid Color System, the three-dimensional set of color senses is arranged in an upright circular cylinder.

Coloroid hue (A) varies with the angular coordinate, returning to itself. The sensibly most saturated colors such as spectrum colors and purples lie along a curve to be traced on the enclosing cylinder casing. Among these limes colors, the 48 Coloroid basic colors are aesthetically equal distances from each other. In top-view, the angles between these colors vary non equidistant, in conformity with the perceptional uniformity. Coloroid axial sections are the Coloroid color planes including colors of equal Coloroid hues.

Coloroid saturation (T) varies with the radius. In the Coloroid color space, colors of the same Coloroid saturation are at equal distances from the neutral axis, on coaxial cylindrical surfaces. Colors on the achromatic axis have a saturation of 0, that of Coloroid limes colors is 100. The definition of Coloroid saturation realizes an aesthetically uniform saturation scaling.

Coloroid lightness (V) varies along the axis' direction. Colors of equal Coloroid lightness lie in planes normal to the Coloroid achromatic axis. Absolute white has a lightness of 100. Absolute white of Coloroid is the color of a diffusely reflecting surface illuminated by CIE D65 light source. The absolute black of Cosoroid is the color of a perfectly color absorbing surface of a zero reflection.

[1] COLOROID Ltd. H-1145 Budapest, Ujvidek utca 55, Hungary – Europe
http://www.coloroid.net E-mail: coloroid@coloroid.net

The position of a color within the Coloroid color space is defined by Coloroid coordinates, the perceptional characteristics of the Coloroid Color System. Order of marking:

	HUE	-	SATURATION	-	LIGHTNESS
Letter marks:	**A**	-	**T**	-	**V**
By numbers:	13	-	22	-	56

1.3. Important harmony rules in Coloroid

The basic conditions of developing harmonious color-experience are the following on the basis of Prof. Dr. Nemcsics' experiments, in order of importance:

a) Scale-like relationship must be set up between the saturation and lightness of the color group. This requirement includes that of the contrasts too. (saturation, lightness and hue contrast)

   Scales underlined on one of Coloroid's color planes:

   - The colors lying on different lines: scales of different lightness, and/or different saturation.
   - The lines curves, or the color groups determined by curves parallel to them.

   The different types carry different meaning and atmosphere.

b) Relationship between the hues of the color system:

   - Harmony angles: the colors set in certain angles of Coloroid color circle are harmonized.
   - The number of colors is limited in harmonized compositions.

c) The preference of color group colors:

   - It depend on the sex, the age, the cultural background, the region, the mental and physical condition, the personality etc...
   - For description of preference depending on the sexes and ages Prof. Dr. Antal Nemcsics developed Color Preference Index Number System based on the statistical proceeding of his observations.

2. PRODUCTS OF THE COLOROID COLOR SYSTEM

The Coloroid Ltd. deals with development and trade of instruments supporting the use of Coloroid Color System.

The company aims to establish the additional devices of Coloroid Color System so that everyone can use this unique system. First we introduced two products, which are considered to be the most significant supporting devices of color design.

The new Coloroid Color Atlas and the Coloroid Color Harmony Designer 1.0 software is created for those experts of different professions, whose job includes color selection, color design. In this work it is necessary to orientate exactly between colors, determine the colors exactly and seek harmonic partners to the given colors. Coloroid can be used by architectures, interior designers, color environment designers, industrial designers, textile and clothes designers, graphics, printers, artists.

3.1. New Coloroid Color Atlas

Atlas is published in 2000, by Coloroid Ltd. in Hungarian and English languages containing more then three thousand one hundred color samples of high accuracy. Its task is to orientate within the color system and to support practical color selection. By its accuracy it is applicable for approximate comparing color measure.

The atlases are published with serial numbers. As part of quality control, during printing of atlas sheets the color sample of every twenty-fifth copy is checked instrumentally. These copies are available together with the measuring documentation.

The results of measuring (ΔE^*_{ab}):

	Average	Spread
For all the samples	4,01	2,05
For the best 90%	3,50	1,35

3.2. Coloroid Color Harmony Designer 1.0 software

Using the special feature of Coloroid Color System according to which the harmony relationship among colors are able to be described easily and visually, computational color harmony designer was worked out. The significance of Coloroid Color Harmony Designer 1.0 software is due to this unique function.

Features of Coloroid 1.0 Color Harmony Designer:

- The revolutionary new Computational Color Harmony support enables to generate harmonious color series using Coloroid Color Harmony Wizard.
- Display Calibration Wizard helps to calibrate the display's gamma-curve co-efficient values.
- Supports translation between Coloroid and numerous international CIE color systems.
- True color rendering and displaying are provided in the Coloroid color space.
- Color Collection Manager supports hierarchical color grouping.
- Text Export capability allows further post-processing.
- Windows bitmap format Color Collection Export lets use the designed collections in image creator and manipulator software products.

Coloroid Ltd. continues developing new instruments of color design and color/visual education using Coloroid Color System.

3. COLOR DYNAMIC DESIGN IN PRACTICE

In most planning procedures it is necessary to make decisions in relation with colors. In most cases the color designer has to make such a color design which gives pleasant experience for most of the observers. In this job the harmony relationship between colors is essential, because the visual appearance of a product, building, publication is often the key to success. In the space of Coloroid the color harmony relationships are simple to be described.

3.1. Architectural color design

Architectural color design is one of the significant applications of Coloroid. During this work a lot of factors should be taken into consideration: environmental features, lighting, the function of the building and its placements, the users' color preference, the physiological effects of the colors, etc. Color design is applicable for changing the feeling of space, warmth, lighting, and other effects too. Therefore it is reasonable to be involved in the planning procedure already at the phase of the development of the conception.

3.2. Graphic color design

Coloroid is successfully applicable at making graphic color designs. Most of the problems are considered to have different color management system of computer peripheries. Therefore the calibration of the display and printer is necessary. As Coloroid is in clear mathematical connection to the international systems of color measure, the color quality control can be solved by color measuring.

4. BIBLIOGRAPHY:

1. Nemcsics, Antal: "Coloroid Colour System". *Color Res. Appl.* **5**. No.2. p. 113-120. New York. 1980.
2. Nemcsics, Antal: "A Coloroid Szinrendszer esztetikailag egyenletes pszichometriai skalait meghatarozo kiserletek." *Magyar Pszichol. Szemle* **38**. No. 1. p. 40-60. 1982.
3. Nemcsics, Antal: "Color space of the Coloroid color system." *Color Res. Appl.* **12**. No.3. p.135-146. New York. 1987.
4. Nemcsics, Antal: *Coloroid Colour Atlas*. Innofinance. 1987.

5. Nemcsics, Antal: *Colour Dynamics. Environmental Colour Design.* Ellis Horwood Ltd. New York, London, Toronto, Sydney, Tokyo, Singapore 1993.
6. Smith, Neveille, S.: "Colorcurve and Coloroid Notation for the OSA-UCS Atlas Samples." *Color Res. Appl.* 1993.04. 18/2.
7. Nemcsics, Antal: "Spacing in the Munsell Color System Relative to the Coloroid Color System." *Color Res. Appl.* **19**. No.2. p.122-126. New York. 1994.
8. Nemcsics, Antal: "Colourland's Law." *Proc. AIC 8th Congress Kyoto*, Voll. 2. p.703-706. Kyoto. 1997.
9. Nemcsics, Antal: "Ausgestaltung eines Farbenpraferenz-Indexzahlen-Systems." *Die Farbe*, **27**. No.1-6. p.168-182. Göttingen. 1980.
10. Nemcsics, Antal: "*Farbenpraferenzindexwerte.*" Proc. Internat. Color Acad. Stuttgart. 1991.

Color spaces for discrimination and categorization in natural scenes

Richard J. Paltridge, Mitchell G. A. Thomson, Tim Yates and Steven Westland

Colour and Imaging Institute,
University of Derby, Derby, UK

ABSTRACT

Physical measurements of surfaces' color-causing properties are typically spectroradiometric, whereas color-differencing comparisons are typically colorimetric ones performed in some 3-D color space. In general, this downprojection of high-dimensional spectral data into some 3-dimensional color space incurs a loss of information, a loss that could be more critical in one color space than in another. One ecologically valid way of assessing the extent of this information loss is to determine how likely it is that a pair of surfaces which have distinctly different spectral properties would be colorimetrically indistinguishable. We describe a virtual ideal color-difference detector which uses standard color-difference metrics but has access to the absolute spectral difference in the color signals of the surface pair. Only when this ideal detector classes a surface pair as 'different' yet a standard color-difference detector classes them as 'same' is the pair said to be metameric. This paradigm is applied to a dataset of hyperspectral natural images using a wide variety of 3-D color spaces. The results show that, around thresholds which approximate human performance, the overall metamerism rate is very low, yet most pixels in an image will be metameric with at least one other image pixel. Thus, downprojecting spectral data onto a 3-D colour space may compromise colour discriminability, but is unlikely to affect colour categorization performance, a finding which is in accord with evolutionary theories regarding the function of human color vision.

Keywords: metamerism, hyperspectral images, color-difference metrics, color vision

1. INTRODUCTION

A number of researchers[1,2,3,4] have argued that efficient exploitation of the colorimetric relationships in scenes requires a color space that is well matched to the statistical properties of scene colors, a dogma that is as relevant to machine-vision color-capture systems as it is to the human visual system. The argument is particularly persuasive for the case of natural surfaces and illuminants: the corresponding spectral data have been shown to be subject to very strong statistical constraints[4,5,6] , and so when such high-dimensional spectral data are downprojected onto one of the standard 3-D color spaces, one might expect the properties of the resulting signals to depend critically on the axes of the color space. The criterion adopted in this study to analyze the performance of a given three-dimensional color space is based upon metamerism: a good color space is one which minimizes the incidence of metamerism within the target data set, since this means that little information has been lost in the downprojection from spectral space to the 3-D space.

We need to arrive at a working definition of metamerism that is acceptable from both human- and machine-vision standpoints, that is based on existing metrics, and which excludes 'trivial' metamers (surface pairs whose color signals barely differ, or differ only at wavelengths where the bases of the color space have little sensitivity). We begin by considering a fairly standard virtual color-difference detector. Given a pair of color signals a_λ and b_λ, this detector simply downprojects a_λ and b_λ into one of the 3-D color spaces to produce two points A and B, then computes the separation of A and B using some metric. For example, if the color space is CIELab and the metric is simple vector magnitude, the resulting color-difference measure is the well-known CIELab ΔE measure. Such a measure cannot be used for metamer detection per se: if the value of the difference measure falls below a given threshold t, it could be because the two points A and B are very similar whilst a_λ and b_λ are not, but it could also be simply because a_λ and b_λ are very similar.

These two possibilities may be disconfounded by designing a virtual ideal color-difference detector as shown in Fig. 1. The basic idea is that the detector has access not to the color signals a_λ and b_λ themselves, but to another

Correspondence to R.J.Paltridge@derby.ac.uk

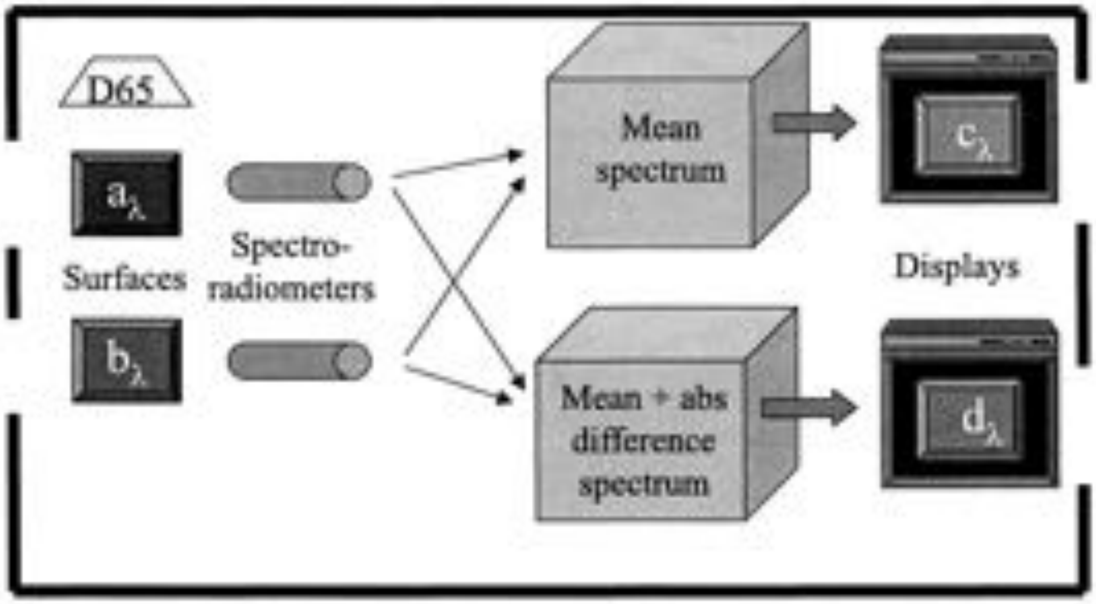


Figure 1. Diagrammatic representation of a virtual ideal color-difference detector. See text for explanation.

pair of color signals c_λ and d_λ such that the difference between c_λ and d_λ is some measure of the absolute spectral difference of a_λ and b_λ, and the mean of c_λ and d_λ is some measure of the average of a_λ and b_λ. Otherwise, this detector works exactly like the standard color-difference detector described above, using the same 3-D color space and the same metric with the same threshold level t. Both types of detector are supplied with the spectral data from a pair of surfaces: if the standard detector categorizes the pair as 'same' yet the ideal detector categorizes them as 'different' then the two surfaces are classed as metameric under that illuminant. Reasonable choices for the computation of the spectra c_λ and d_λ are as follows:

$$\begin{aligned} c_\lambda &= \frac{a_\lambda + b_\lambda - \mathrm{abs}(a_\lambda - b_\lambda)}{2}; \\ d_\lambda &= c_\lambda + \mathrm{abs}(a_\lambda - b_\lambda), \end{aligned}$$

since this means that c_λ and d_λ differ by $\mathrm{abs}(a_\lambda - b_\lambda)$ yet the mean of c_λ and d_λ is the mean of a_λ and b_λ.

This system may be used to evaluate the statistical structure of metamerism within any given data set. For example, given a large, unbiased sample of surface reflectance functions, one may compute color signals under a given illuminant for every unique pair of surfaces in order to determine the rate of metamerism. Another possibility is to take hyperspectral image data and ask: how many pixels in the image are metameric with at least one other pixel? A third possibility might involve looking at the spatial structure of metameric pairs in an image. Clearly, then, different metamerism statistics tell us different things about our chosen 3-D color space. A topic of particular interest to us is the performance of those color spaces inspired by human vision, since there would seem to be an evolutionarily basis for reducing the incidence of metamerism encountered by the visual system: primate color vision is thought to have evolved for the purpose of "fruit-leaf"[7] or "new leaf – old leaf"[8] discrimination on the grounds that color vision can eliminate many of the luminance-only surface confusions.

2. EXPERIMENTAL METHOD

We need to specify a spectral dataset; an illuminant; a set of color spaces; a metric and a threshold for the two types of detector. Results reported here are for a spectral dataset was derived from 12 hyperspectral images of natural scenes, collected by Ruderman, Cronin and Chiao.[9] The illuminant was D65. A wide variety of color spaces was investigated, including the CIELab space, the normalised Smith and Pokorny cone fundamentals, the Guth vector-based space[10] and the Buchsbaum and Gottschalk APQ factor-based space.[11] These spaces were chosen for either their linearity (CIELab space), or their ability to approximate either the the cone stage (Smith and Pokorny space) or the opponent-channel stage (Guth and Buchsbaum spaces) of the human visual system. The difference metric was vector magnitude; this means that for CIELab space, the color-difference measure is CIELab ΔE, and ΔE thresholds of 0.5 through to 5.0 were investigated, since this range encompasses threshold values reported for human observers in both simple and complex viewing environments. Thresholds were set for the other color spaces by using the spectral dataset to map this of range ΔE values into the other color spaces; for example, to determine the threshold in a space S that corresponds to a ΔE of 1.0 in CIELab space, the computer would search for all those pixel pairs which gave rise to a ΔE value within the interval $(1.0 - \epsilon, 1.0 + \epsilon)$, then find out the color differences of those pairs in the space S. The mean of these color differences would then be adjudged the threshold level in the new space S.

3. RESULTS

Since CIELab ΔE is the only standard color-difference measure used here, the results are presented in detail for this color space. The bar graphs in Figure 2 below shows the incidence of confusion and metamerism for ΔE values of 1.0 and 5.0. A 'confused' pair is simply one for which the standard color-difference detector shows a vector magnitude of less than the threshold; a 'metameric' pair is one for which not only is the above statement true, but in addition, the ideal color-difference detector shows a vector magnitude of greater than the threshold. Thus 'metameric' pairs are a strict subset of 'confused' pairs. Notice from the figures that metamerism is very rare: with a CIELab ΔE threshold of 5.0, the maximum metamerism rate is about 3%. In fact, the incidence of metamerism increases monotically with threshold until it reaches a maximum, then declines towards zero as the threshold becomes so high that the ideal color-difference detector categorizes more and more surfaces as 'same'. The bar graph shown in Figure 3 gives the answer to a quite different question: for each image, how many pixels are there which would be metameric with at least one other pixel (we call these 'nonunique' pixels)? The results may be surprising: for the 12 images analyzed at $\Delta E = 1.0$, the incidence of nonuniqueness varies from 65% to over 90%. Thus, although the CIELab space initially appears to be a very good choice for representing natural colorimetric data in the sense that the information loss incurred in downprojecting onto the CIELab basis is small, there are applications for which the high nonuniqueness rate might be a problem (although it is difficult to comment on this further without analyzing the spatial structure of the nonunique pixel pairings). The results for the space of normalised Smith and Pokorny cone fundamentals, for the Guth vector-based space and for the Buchsbaum and Gottschalk APQ factor-based space were similar to this, i.e. low overall metamerism rates yet high pixel nonuniqueness rates, although for these spaces the peak in metamerism incidence occurred at smaller values of the threshold than it did in in CIELab space.

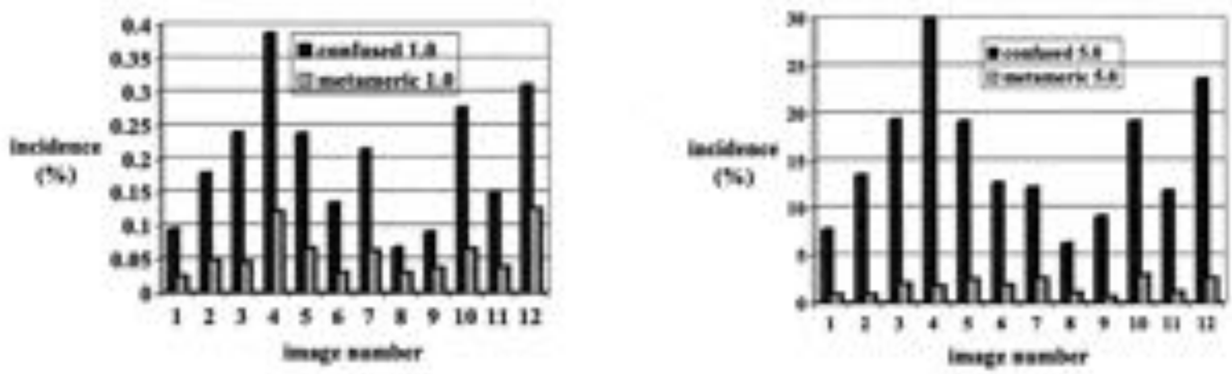


Figure 2. Confusion and metamerism rates in CIELab space at a threshold of $\Delta E = 1.0$ (left) and $\Delta E = 5.0$ (right)

4. DISCUSSION

The results show that when we search for metamers in 3-D colour spaces at thresholds which approximate human performance, the overall metamerism rate is very low, yet most pixels in an image will be metameric with at least one other image pixel. Identifying these two different findings with different tasks, one may think of the overall metamerism rate as a measure of how color categorization can fail due to the information loss, and the pixel nonuniquess rate as a measure of how two-point color discrimination can fail due to the information loss. This

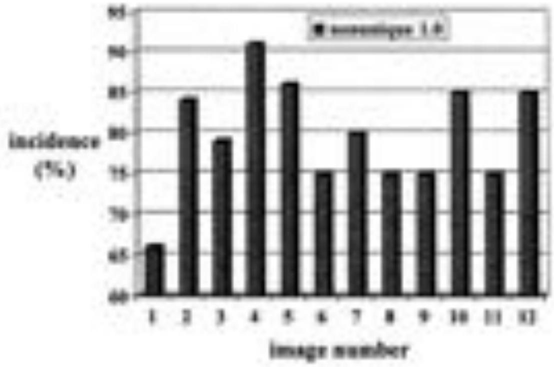


Figure 3. Incidence of pixel nonuniqueness in CIELab space at a threshold of $\Delta E = 1.0$.

interpretation implies that one must be particularly careful in assessing the suitability of a given color space in a given context, since the answer may be highly task-dependent. It has a special significance in the case of the human-vision-inspired 3-D color spaces, since good color-categorization performance at the expense of color-discrimination performance is in accord with evolutionary theories regarding the function of human color vision.

REFERENCES

1. G. Buchsbaum and A. Gottschalk, "Trichromacy, opponent colours coding and optimum colour information transmission in the retina.," *Proc. Roy. Soc. London Ser. B.* **220**, pp. 89–113, 1983.
2. L. Maloney, "Evaluation of linear models of surface spectral reflectance with small numbers of parameters," *J. Opt. Soc. Am. A* **3**, pp. 1673–1683, October 1986.
3. B. Wandell, "The synthesis and analysis of color images.," *IEEE Trans P.A.M.I.* **9**(1), pp. 2–13, 1987.
4. D. Marimont and B. Wandell, "Linear models of surface and illuminant spectra," *J. Opt. Soc. Am. A* **9**, pp. 1905–1913, November 1992.
5. D. B. Judd, D. L. MacAdam, and G. W. Wysecki, "Spectral distribution of typical daylight as a function of correlated color temperature.," *J. Opt. Soc. Am.* **54**, pp. 1031–1040, 1964.
6. S. Westland and M. G. A. Thomson, "Spectral colour statistics of surfaces: recovery and representation.," *Colour Image Science 2000 (Derby University), Proceedings* , pp. 33–40, 2000.
7. C. C. Chiao, M. Vorobyev, T. W. Cronin, and D. Osorio, "Spectral tuning of dichromats to natural scenes.," *Vision Research* **40**, pp. 3257–3271, 2000.
8. N. J. Dominy and P. W. Lucas, "Ecological importance of trichromatic vision to primates.," *Nature* **410**, pp. 363–366, March 2001.
9. D. Ruderman, T. Cronin, and C. Chiao, "Statistics of cone responses to natural images : Implications for visual coding," *J. Opt. Soc. Am. A* **15**, pp. 2036–2045, August 1998.
10. S. Guth, R. Massof, and T. Benzschawel, "Vector model for normal and dichromatic color vision.," *J. Opt. Soc. Am.* **70**, pp. 197–212, 1980.
11. G. Buchsbaum and A. Gottschalk, "Chromaticity coordinates of frequency-limited functions.," *J. Opt. Soc. Am. A* **1**, pp. 885–887, August 1984.

Colour and symbology: Symbolic systems of colour ordering

Diana Varela, Universidad de Buenos Aires

ABSTRACT

Colour has been used symbolically in various different fields, such as Heraldry, Music, Liturgy, Alchemy, Art and Literature. In this study, we shall investigate and analyse the structures of relationships that have taken shape as symbolic systems within each specific area of analysis. We shall discuss the most significant symbolic fields and their systems of colour ordering, considering each one of them as a topological model based on a logic that determines the total organization, according to the scale of reciprocities applied, and the cultural context that gives it meaning.

Keywords: Symbolism, symbolic field, meaning, relation, range of colours.

1. INTRODUCTION

If we understand colour as a visual sign and, as such give it the faculty of representation, that is to say it can stand in place of another object, we then have to consider the symbolic implications of colour. In this study, we shall investigate and analyse the structures of relationships that have taken shape as systems within each specific area of analysis, from now on referred to as *symbolic field*. These systems are based on the idea of analogy and the theory of correspondences.

We shall discuss the most significant symbolic fields and their systems of colour ordering, considering each one of them as a topological model based on a logic that determines the total organization, according to the scale of reciprocities applied, and the cultural context that gives it meaning. Firstly, however, we shall clarify a series of basic concepts that will orientate our work and will guide the reader as to the criterion of analysis used. In first place, we shall consider the word *analogy*, defined as the correlation between the components of two or more systems or orders, the relationship between two similar facts or propositions and at least, one equal component. Real symbolic analogy occurs between the level of phenomenal reality and the level of the spirit, which can be compared to Plato's world of Ideas. The influence of the psychic world over the physical world, the oneness of origin of both worlds, and the articulation of the material world over the spiritual world form the triple principle of the analogy that occurs between the external and the internal world. But the analogy not only consists of the relationship between the internal and the external, but it is also made up of the relationship between the diverse phenomena of the physical world. Material and formal similarity is only one of the cases of analogy, since analogy is also present in actions and processes.

Symbolic discourse is built up by systematizing successive identifications within common rhythms. The symbolic image cannot be understood as "example," that is, as the external and possible relationship between two objects or connections, but as an internal and structural analogy, a deep relationship, which is both necessary and constant, which underlies all symbolic construction and which, as a procedure of ordering and unification, appears in art, myth, poetry, etc.

2. SYMBOLISM

It is important here to clarify what we understand by symbolism, and from which theoretical base we analyse symbolic construction. Cirlot[1] considers that "behind the metaphor, there is something more than an ornamental substitution of reality", and defines the symbolic world as an intermediate kingdom between that of concepts and that of physical bodies. The symbolistic significance of a phenomenon tends to convey in its own language the explanation of those mysterious reasons, because it links the instrumental to the spiritual, the human to the cosmic, the casual to the causal, disorder to order, thus justifying a word as a universe, which would have no sense without that "superior integration." Mircea Eliade[2], on the other hand, points out that "symbolism *adds* a new value to an object or action and, without going against its own immediate or 'historic' values, changes it into an open fact". Jung[3] agrees with Eliade when he states that "the psychic fact 'God' is a collective archetype, a psychic existence that, as such, must not be confused with the concept of the metaphysical God". Berthelot[4] studies the process in the Near East and uses the name *astrobiology* for the religious and intellectual culture of that time. This term implied a knowledge of human biology based on astrological knowledge, in short a link between two worlds that explained themselves analogically. Later, in classical antiquity, the Greeks considered symbols to be signs of recognition that allowed parents to find their abandoned children.

Chevallier[3] states that the symbol is in its origin *an object cut into two* pieces of pottery, wood or metal; he uses a beautiful metaphor to explain how it works: "Two people each keep a part; two guests, the creditor and the debtor, two pilgrims, two people who must part for a long time. Later on, when they reunite, by joining both parts they will later recognize their bonds of hospitality, their debts, their friendship". Due to analogical procedures, the term has become extensively used for any sign of reunion or adhesion, to omens and conventions. The symbol delimits and unites, implies the two ideas of division and reunion; it evokes a community that has been divided and is able to reunite; every symbol implies a part of a *broken sign* and its meaning is found in all that is at the same time rupturing and bonding of its separate parts. Charged with affectivity and dynamism, it both represents and hides, fulfils and destroys. It plays with mental structures, the reason why it is compared to affective, functional and motor schemata, to show to what extent it mobilizes the totality of the psyche. In order to reveal its double aspect as both representative and effective, it is labelled as an "eidolo-motor", the term *eidolon* fixes it as a representation, in the plane of the image and the imaginary, instead of placing it solely in the intellectual level of the idea *(eidos)*. It is the centre around which all the psyche put into movement by this idea gravitates, distancing itself from the conventional meaning, opening the way to subjective interpretation. It is in this way that the symbol presumes a rupture of the plane, a discontinuity, a passage to another order; it introduces a new order of multiple dimensions. Symbolism is then organized as a system of very complex relationships linking the physical and metaphysical worlds.

3. SYMBOLIC FIELD AND SYSTEMS OF COLOUR ORDERING

Colour has been used symbolically in various different fields, such as Heraldry, Music, Liturgy, Alchemy, Art and Literature. The symbolism of colour is founded on one of the following: a) the expression inherent to each hue, which is perceived intuitively as a given fact; b) the relationship between a colour and a symbol to which the tradition of the specific symbolic field assigns it, and c) in elemental primitive logic, the relationship that can be observed between a colour and a given element of nature, kingdom, body or substance, in which it usually appears, or with which it is always indestructibly associated.

In our work the serial ordering of the chromatic scale is of fundamental importance; therefore we should include here the concept of system, that we define as a group of elements and/or concepts related to each other and that form an organic whole, an autonomous significant body. Each of the systems to be analysed is presented (although only because of relative abstraction) as a limited group of different defined colours, arranged according to the symbolic logic of the respective field.

3.1 The Theory of Correspondences

The theory of correspondences is one of the main elements in the symbolistic tradition. It is based on the fact that all cosmic phenomena are delimited, presented in series, and appear in specific planes, where they constitute ranges. The location and association of elements is never chaotic, whimsical, or autonomous in any range, but there are connections between the elements of each one of them, based on internal links of essence and meaning.

The primitive established correspondence is in elemental logic, and it associates a colour with an element of nature or a kingdom. Thus, a first system of relationships is born to connect the four essential elements (fire, air, water and earth) with the three primary colours, decomposing blue for water into three hues (violet-blue-green) plus, black (connected to ochre) for the element earth. The fifth element of the series is time, which as chromatic reciprocity is given an iridescent hue to reflect its everchanging quality.

Then, by using a septenary pattern, each colour of the prism is established as analogous to one of the seven faculties of the human soul; to the seven virtues and the seven vices; to the geometrical forms and to the planets. However, this correspondence is important: since the relationship is not one-to-one we cannot yet establish a precise system of reciprocities.

In 1937, a table of correspondences based on the number twelve was published in England. It incorporated a reciprocity between precious stones and colours. The table is rather obvious since it is based on the inherent colour of each gem, but it is still interesting as one more system to consider. Another important correspondence concerns the zodiac, whose twelve signs are equated with parts of the human body: Aries corresponds to the head, Taurus to the neck and throat, Gemini to the shoulders and arms, Cancer to the chest and stomach, Leo to the heart, lungs, and liver, Virgo to the belly and intestines, Libra to the spine and marrow, Scorpio to the kidneys and genitals, Sagittarius to the thighs, Capricorn to the knees, Aquarius to the legs, and Pisces to the feet. In 1934, however, Albiruni[4] points to correspondences that exist between the signs of the zodiac and different kinds of landscape: Aries corresponds to the desert, Taurus to the meadows; Gemini to the double mountain; Cancer to parks, rivers and trees; Leo to a mountain with castles and palaces; Virgo to home; Scorpio to jails and caves; Sagittarius to sandy ground and centres of magic; Capricorn to the fire square and the castles; Aquarius to caves and sewers, and Pisces to the graves. The circle is closed with the relationship with the twelve colours: Aries corresponds to white, Taurus to green, Gemini to cream, Cancer to light red, Leo to pale green, Virgo to dark blue, Libra to marble, Scorpio to yellow, Sagittarius to greenish blue, Capricorn to dark red, Aquarius to purple, and Pisces to pale blue.

As we have seen correspondences can be structured by quantitatively forcing the elements of the ranges to adapt to a common numerical law, altering the number of colours and building up the septenary pattern of hues to eight, or twelve, or even reducing it to six. For the sake of intellectual rigor, this possibility forces us to verify partial coincidences with other models, thus avoiding forcing the existing ones through theoretical constriction or expansion.

3.2 Music and Colour

In the west, all chromatic theory has always been closely associated to a knowledge of music. Due to the breadth of the subject we can only mention the key moments in the structuring of chromatic systems related to musical scales.

In ancient Greece, Arquitas of Tarento (a friend of Plato) devised a musical scale which he called "chromatic". He divided it into semitones and believed that it "coloured" the surrounding scales; these were the *diatonic scale* (divided into tones) and the *enharmonic scale* (divided into quarters of tone). According to Gage[7], "What most astonished the Greeks was the capacity of colour, as well as sound, to be articulated in a series of phases that changed at regular intervals and whose differences were perceptible in just such a regular way". From that moment on, the words *tone* and *harmony* from the musical lexicon, became part of the analytical vocabulary of colour within the visual arts. Jumping ahead in time, Newton, who had studied music in 1660, made a clear reference to the question of colour in relation to music in his conferences of 1669. Till that moment, scientific concerns had been centred on the relationship between notes and colours and not on their systematic individual and relative organization. Newton came up with a particular relationship between the colours of the spectrum and the seven musical notes understood as chords, in which he firstly considers the dimensions of analysis of each note, and then relates them on a one-to-one basis.

The idea behind these correlations was to find the basis of an audio-visual synaesthesia, the classification that takes into account the dimensions of both variables, and is based on the fact that both sounds and colours are vibrations. Regarding synaesthesia, psychology holds that in our limited vision sounds can only be compared with sounds, colours with colours, and one substance with any equivalent substance. On the other hand, in symbolic terms everything is replaceable and homogeneous, light sends forth sounds, melody makes light, colours are alive and as such have movement, objects can be simultaneously sonorous, colourful, mobile and multifaceted, and can be deciphered and reviewed at a glance.

Present symbolic studies establish that music is a key element in the level of correspondences. Correspondences of meaning and situation exist; the faster the movement, the sharper (higher) the sound, and viceversa; speed corresponds to elevation and slowness to descent; if cold colours recede, then coldness corresponds to distance, and proximity to warmth and closeness. Within a septenary system, correspondences that we consider fair occur between notes and colours: violet: sensitive; red: tonic; orange: supertonic; yellow: intervening; green: subdominant; blue: dominant; and indigo: superdominant. As we can see, here too the definition of a musical note is restricted only to those that determine a chord.

3.3 Heraldry

Heraldry[8] includes what was commonly known as the "art of the coat of arms", and studies the rules used to compose or acquire the practice of emblazoning, that is drawing and designing coats of arms in such a way that they can be used. A coat of arms means the different devices, structured according to internal laws, borne by some individuals, families or corporations as theirs by right for perpetuity. In addition to nobles, other aristocratic families outside that rank, had the right to a coat of arms, whose heraldic shields often originated from monograms, family mottoes and trademarks.

Studies in Heraldry begin in the 13th century, although coats of arms appeared during the Crusades, towards the end of the 11th century. The corporate constitution of nobility, the incorporation of the surname to the first name, the particular uses of chivalry, the celebration of competitions and tournaments, are closely related to the introduction of the heraldic shield. There are three main periods in the history of heraldry: evolution, between the 11th and the 13th centuries; the golden age, from the middle of the 13th century to the 15th; and decline, which began in the 16th century. From a stylistic point of view we can distinguish primitive Gothic, late Gothic and Renaissance shields, but examples can also be found in the baroque and the rococo periods, as well as modern art expressions.

The most iconic external components of the coat of arms are: crowns, helmets, robes, lambrequins, supporters and collars; the interior elements or arms are colours, metals, linings, partitions, honorable pieces and figures. Apart from their literal meaning, or even the anecdotes surrounding their origins, all elements have a symbolic or implicit meaning. City coats of arms can be similarly explained.

Metals and colours can be read by means of the symbolism of the elements they represent, the partitions and honorable pieces by spatial and graphic symbolism, that is the location and distribution, as well as by the implications taken from the theory of correspondences. That theory helps to structure a relationship between the seven colours used and the planets, on the basis of a septenary scale.

During the golden age of heraldry six enamels, two metals and four colours were used almost exclusively. The former, gold and silver, were frequently replaced, for practical purposes by yellow and white. The primitive colours are red (*gules*), blue (*azure*), black (*sable*) and green (*synople*), which were applied by choosing their most intense hues; for red the vermilion or

minio; for blue, cobalt or ultramarine; for green, emerald. Later on, the chromatic spectrum is enriched with the addition of purple; finally ash grey, royal purple and brown appear, as part of the overall composition, according to similarity and distribution, but not in a direct symbolic planetary relation. All the meanings of colours, metals and parts are considered as an activity generated by the active (or spiritual) principle that rules the coat of arms, over the passive quaternary material, symbolized by the surface of the shield.
The correspondence between planets established for red (gules), the planet Mars; for green (synople), the planet Venus; for blue (azure), the planet Jupiter; for purple, the planet Mercury; for black (sable), the planet Saturn; for gold, the Sun; and for silver, the Moon.

3.4 Psychology and Psychoanalysis
In the field of psychology and psychoanalysis, psychic functions are related to a particular colour and this, with a referential element which it symbolically refers to. The first palette put together is a four-chrome one of pigmentary primaries plus green, then an additional palette is added based on the derived associations.

According to the psychology of Jung[9], different cultures and human groups are seen to establish different coordinations between colours and psychic functions, but as a general rule blue –which refers to space and clear skies– is the colour of thought; yellow –a hue associated to the colour of the sun– is the colour of intuition, that is to say, the function that, in Jung's own words, instantly illuminates the origins and the trends of events; red –pulsing blood and fire– is the colour of the living fiery senses; finally green –the colour of plants– represents our perceptive functions.
Other associations along the same lines can be added to the former, and they are of the utmost importance since they broaden the variety of interrelations; red is not only blood but is also a wound, agony, and finally sublimation; orange comes to represent fire and flames; yellow, sunlight, is illumination as well as dispersion and comprehensive generalization; green is vegetation, but also the colour of death, extreme lividness, the reason why it becomes transition and bridge between black, a mineral being, and red, blood and life, but also between animal-human life and decomposition and death. Blues are divided according to their value, light blue is sky and day, a serene sea; dark blue, sky and night, the tempestuous sea; both browns and ochre is the earth, while black is manured earth. Finally gold corresponds to the mystic aspects of the sun, and silver to the moon.

4. BY WAY OF PRELIMINARY CONCLUSIONS

In this brief journey that covers only four areas (for the time being) and the analogical systems and structures that each one of them establishes, it can be seen that although there are some concordances between related colours and the elements or attributes to which they refer, it is important not to lose sight of the theoretical framework to which they belong. The analogies outlined establish different values for each chromatic scale, each one of them building a different image of the world.
The first focus (elements of nature and colour), as well as the zodiacal approach are cosmogonic outlines. In the case of the zodiacal system, it relates three large groups of variables, parts of the human body, geographical characteristics and colours according to a dodecanary range. The analogy in this case is based on the connection between human and terrestrial geography, and it is colour that establishes a bridge with the astronomical. Finally, the relationship between a sign of the zodiac and the month it rules, and the implicit "eternal" succession, incorporates the temporal variable, thus closing this cosmogonic circle that morphologically links human, terrestrial, astronomical and temporal aspects. Significant cosmoses are built and symbolically relate to a given chromatic system. This is a macroanalytical vision which seeks to understand the world from its structural generality.
The musical system begins with the physical concept of vibrations (chromatic and sonorous), including the variable of movement. This gives way to the concept of space, and ends up creating a microstructural symbolic system that attempts to explain the ways in which harmonious phenomena are established.
Heraldry brings into play other, much more human and earthly, variables such as the structures of power and social hierarchy. The articulation of variables here is twofold; in the first place the interrelation between the interior and the exterior of the emblem; in second place, the symbolic structures established in each case. The exterior refers to the composition, the icons and their associated meanings. The interior brings into play the materials of construction used and the chromatic variable inherent in the theory of correspondences. The interpretation ends with the association and interplay of this double articulation which together refers to human ambitions and desires. A clear example of this is the coat of arms of the city of Paris, which bears a ship and alludes to the myth of the Argonauts, the search for the golden fleece and alchemy.

In this study the symbolic presence of colour can be clearly perceived in three basic instances of conception of the world: macro-structural cosmogony, micro-structural cosmogony and the cosmogony referring to the human ambitions at play in social life. Colour, in all three instances and as part of a broken whole, fulfils by way of analogy the function of becoming a symbolic nexus of different and coexistent worlds, allowing passage to a multidimensional order between the physical and the metaphysical.

REFERENCIAS

[1] Juan-Eduardo Cirlot, *Diccionario de Símbolos*, Labor, Barcelona, 1992.
[2] Mircea Eliade, *Images et Symboles*. Paris, 1952.
[3] C.G. Jung, Jung, C.G. *Transformaciones y símbolos en la libido*. Buenos Aires, 1952.
[4] René Berthelot, *La pensée de L'Asie el l'astrobiologie*. Paris, 1949
[5] Jean Chevallier and Alain Gheerbrant, *Dictionnaire des symboles*. Júpiter, Paris, 1969.
[6] Albiruni, *The book of instructions in the elements of the Art of Astrology*, 1934.
[7] John Gage, *Color y Cultura*, Ed. Siruela, 1993.
[8] F.S.Meyer, *Manual de ornamentación*, 1994.
[9] C.G. Jung. *La psicología de la transferencia*. Paidós, Barcelona, 1954.

Color Management: Printing Processes-Opportunities and Limitations

Sam T. Ingram*
Department of Graphic Communications, Clemson University

ABSTRACT

Digital tools have impacted traditional methods employed to reproduce color images during the past decade. The shift from a purely photomechanical process in color reproduction to colorimetric reproduction offers tremendous opportunity in the graphic arts industry. But good things do not necessarily come to all in the same package. Printing processes possess different reproduction attributes: tone reproduction, gray balance and color correction requirements are as different as the ingredient sets selected for color reproduction. This paper will provide insight toward understanding advantages and limitations offered by the new digital technologies in printing, publishing and packaging.

For the past five years the Clemson University Graphic Communications Department has conducted numerous color projects using the new digital colorimetric tools during the previous decade. Several approaches have been used including experimental research and typical production workflows. The use of colorimetric data in color reproduction has given an opportunity to realize real gains in color use, predictability and consistency. Meeting an image's separation and reproduction requirements for a specified printing process can involve disruption of the anticipated workflow. Understanding the printing process requirements and the fit within the specifications of a colorimetric workflow are critical to the successful adoption of a color managed workflow.

The paper will also provide an insight into the issues and challenges experienced with a color managed workflow. The printing processes used include offset litho, narrow and wide-web flexography (paper, liner board, corrugated and film), screen printing (paper board and polycarbonates), and digital imaging with toner, ink and inkjet systems. A proposal for technology integration will be the focus of the presentation drawn from documented experiences in over 300 applications of color management tools. Discussion will include the structure of specifications, standards and the issues faced during the discrete steps of color image reproduction.

1. DIGITAL PROCESSING: IMPACT ON COLOR REPRODUCTION

The process of reproducing color images relied on photomechanical methods during the previous century. Computers handling color data appeared in the mainstream by the 1980's. By 1990 proprietary color systems provided the majority of color images produced for print reproduction. Several technologies arrived during the 1990's which opened the window for the graphic communications industry to reengineer color reproduction through (a) powerful desktop computing with open architecture, (b) affordable color measurement devices, (c) formatting specifications for color image data relative to manufacturing conditions. Print color reproduction gained control of color data encoding in a 'pixel by pixel' mode. Color Management System (CMS) is the descriptor typically applied to digital tools interfaced within the color reproduction process.

2. TYPES OF TOOLS

Measuring Devices

Availability of stable, portable color measuring devices has provided the printing industry with a primary source of communication. Solid state circuitry and processors offer color data which is readily communicated across production centers in a number of color languages (CIELAB, XYZ, spectrophotometric reflectance data, density…) and provides a target for color decisions. The reliability of the devices is much improved due to the standards and specifications followed for manufacturing and measurement procedures (CGATS, ANSI, and ISO Standards).

Digital Processing

Current print manufacturing practice relies heavily upon digital processing. Color input is digitized followed by various processing steps leading to color output. Color transforms have become heavily dependent on practitioners in the production

* sting@clemson.edu, 864.656.3447, G-01 Tillman Hall, Clemson, SC 29634

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

foodchain selecting the most appropriate color conversion regarding a desired production technique. Colorimetric conversions have become accessible through software applications using color management protocols. Currently color images may be processed and converted at any of several discrete points. Computer technologies have provided processing of all graphic elements and offer the potential to reduce the number of manufacturing steps leading to greater reliability, consistency, and response to client's needs.

Color Devices

Digital color proofers, increased color press capabilities, and client demands for quality and response have become top priorities in print markets. Manufacturers have given consideration to calibration and system integration elements. This has primarily been accomplished by adhering to published specifications and de facto standards.

Digital Workflows

Print manufacturing processes relative to color reproduction are very diverse. One must consider each color product to be based upon custom requirements focused on a client's needs. Digital files may be created by designers, in-house facilities, free-lance artists or other parties who are independent of the printer. Confusion over specifications and color requirements are often negotiated with a minimal interest in the system's color reproduction capabilities. A singular document, the 'contract color proof', serves as a tool for color image engineering. The content of such proofs may be less than relevant to the actual production systems. From necessity image elements must defer to device and software settings. The managers and operators of digital systems rely upon system stability and productivity.

Software Applications

The varieties of software applications found in the graphic arts falls into several classifications: page layout, illustration, and image editing software. Many of the digital color tools are integrated into each of these applications, primarily on the Apple platform via ColorSync. Versions produced in recent years permit color conversions "on-the-fly" downstream from the initial color generation. CMS tools provide a system level color conversion following the operator's procedures. This aspect of color management continues to evolve.

3. PRINTING PROCESS REQUIREMENTS

Dots, spots, lines, and solids are primarily used to reproduce color on the surface of graphic arts products. We are most familiar with color reproductions found in publications. We are more likely to take for granted the color applications found in packaging or specialty decorative color products. Observation provides insight into the printing process selection for such diverse products as flexible packaging, folding cartons, or displays (signage, decals, and point-of-purchase). Marketing techniques such as self-promotion gained popularity during the 1990's as print buyers gained expertise (sometimes misunderstood or miscommunicated) with respect to brand or product identification.

Color print production management was closely scrutinized for much of the last half of the twentieth century. As new technologies evolved a rather conservative printing industry carefully integrated tools which purported to improve productivity and response to client needs. It was expected that new technology early adopters would experience unforeseen problems and required intensive technical assistance. The more aggressive printing companies developed a technology integration plan. The foundation for technology integration rested upon a commitment to defining, measuring, and analyzing color print attributes. Process control is recognized as a beneficial strategy for technology integration. As printing technicians implemented process control techniques they quickly began to realize the opportunities of the process under consideration. The opportunities and limitations of specific printing processes were quantified and recorded.

4. CURRENT INTEGRATION

Change is disturbing. For printing operations to move to a fully digital workflow the organization must assume certain risks. Prominent among the risks faced is conforming to production capabilities, custom color reproduction requirements, and legacy work which must be digitized. Risk also occurs when new systems integration must take place with minimal disruption in production cycles. As colorimetric tools emerge in color printing the economics of ROI must also be considered. Recent developments are making these technologies affordable and much more compatible with existing digital workflows and devices. A major influence for color management systems adoption is a knowledge base among employees of color language for printing and the capabilities of digital color tools. Plans for implementation are necessary and must be introduced according to a rigorous methodology.

CMS Integration Model

The primary reason for integrating CMS is to provide a color communication link between people and the devices producing color. The rationale suggested is a better color fit between devices in an open architecture where objective computation provides the fit. The following illustration suggests how the production components are linked and fit relative to device specific color capabilities.

Figure 1: Color Management by System Integration.

Educational Perspective

The process of learning the concepts of color reproduction is approached in an 'upward spiraling curriculum' at Clemson University. Students are required to understand and practice color reproduction in a minimum of twenty projects including color continuous tone images. The first lab course requires study of the additive and subtractive color theories. During the next lab course photomechnical color separation is learned to complete the requirements for a screen printing project. Filtered separations are produced to specification complemented by lectures covering color filter technology, process requirements, and imaging. Final production requires a basic understanding of process color ink sets, proofing, and screen printing technology.

Subsequent courses cover color separation processes from a number of different perspectives. Examples of content studied in these courses are (a) process color produced by various print reproduction processes, (b) measurement of print attributes, (c) color reproduction requirements regarding tone reproduction, gray balance (neutrals), and color correction, (d) the knowledge of workflow issues which provide digital color conversions, and (d) measurement techniques with numerous devices providing color data for analysis, data display, color characterization, color conversion and archiving. Students are presented a holistic view of color reproduction in an incremental and increasingly complex manner.

A parallel set of color concepts is also being taught and practiced in laboratory projects. Text and line art are created and reproduced with color matching a focal point. Students examine the impact of color mixtures, impact of the printing process with ink and substrate interaction, the function of process control, and color lookup tables found in discrete locations within the digital workflow. A note is offered to point out the numerous software revisions that typically include color applications.

The capstone laboratory course provides the final consolidation of color reproduction concepts. For many years the course relied upon photomechnical processes: a printing process was tested by each student regarding printability characteristics such as solid ink density, trapping of overprint colors, gray balance, and tonal value increase. The objective was to provide accuracy and precision in the color images reproduced as a requirement for the selected print environment. All printing processes have been used by students, selection of the printing process is specific to the product and materials being used such as ink and substrate, and the process capabilities and limitations. Offset litho, flexography, screen printing, gravure, and digital printing (inkjet, dye sublimation, toner, and paste ink technologies) have produced products readily identified with the graphic communications industry.

Topics commonly associated with color reproduction in this course include the following:

- a. Colorant characteristics
- b. Colorant identification
- c. Color language
- d. Photomechanical color conversions
- e. Color management systems

The content of each topic has undergone continuous revision during the previous decade as the embryonic technology of colorimetric conversion was made available to graphic arts applications.

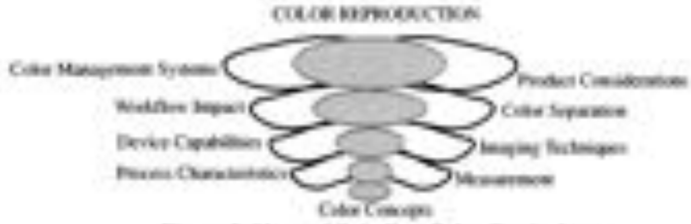


Figure 2: Upward Spiraling Color Curriculum

Manufacturing Perspective

Publishing containing color elements has been a early adopter of CMS technologies. The format of most publications is relatively standard, as are the workflows and specifications for components like inks and substrates. The focus of color reproduction has been for advertising in publication printing. Commercial printing has followed in strong suit. There is a notable amount of research involving color reproduction characteristics primarily using offset lithography. Packaging incurs a much more complex set of demands for color reproduction: processes (flexography, and gravure in addition to offset lithography), inks, and substrates show a great diversity with each possessing its unique qualities. Product performance is of as much concern as color image reproduction characteristics. CMS tools have impacted the packaging segment in a slower fashion than publication or commercial printing. A current initiative is underway by the Committee for Graphic Arts Technical Standards (CGATS) to develop a color characterization target for package printing environments. Consideration will be included for printing process, substrates (films, foils, paperboard and corrugated direct print), and the specifications for ink color requirements.

SUMMARY

The demands of color reproduction have increased dramatically. The introduction of digital technologies has provided the producers of color printing a new set of paradigms to consider. Integration of the digital color tools, color management systems, and the adoption of standards and specifications in the printing industry will depend upon a knowledgeable workforce. Employees responsible for color reproduction must have a broad–based foundation of printing processes, digital workflows, and a bank of experiences relative to the issues faced in the manufacturing process.

Continued effort by the industry will seek to better define the requirements for a transparent CMS. Issues must be addressed: better algorithms for rendering intents, access for 'special colorants', documentation of emerging technologies (i.e. direct–to–plate), digital color proofing, and real time access for clients. Teaching and training curriculums will provide the expertise needed by future employees. Technology developers will be asked to respond to the needs of the third largest manufacturing industry where custom color products are produced on a daily schedule.

References:

ANSI Standard(s): CGATS.4 &.5, IT8.7/1, 7/2, 7/3. NPES, Reston, VA.

Clemson University Graphic Communications Curriculum, http://graphics.clemson.edu.

Flexographic Image Reproduction Reproduction Specifications and Tolerances (FIRST). Flexographic Technical Association, Ronkonkoma, NY, 2nd ed., pages 55-64, 1999.

Ingram, Samuel T. "Color Management: A System for Improved Color Reproduction". *SGIA Journal*, Fairfax, VA, **vol. 5**, pages 25-29, 2001.

Ingram, Samuel T., Simon, Frederick T. "Ink Fingerprinting". *The Technical Association of the Graphic Arts Proceedings*, Rochester, NY, pages 660-671, 1998.

Johnson, Tony. "An Effective Colour Management Architecture for the Graphic Arts". *The Technical Association of the Graphic Arts Proceedings*, Rochester, NY, pages 88-111, 2000.

Evaluation of Colour Gamut Mapping Algorithms

L.W. MacDonald*, J. Morovic and K. Xiao
Colour & Imaging Institute, University of Derby, UK

ABSTRACT

Evaluation of algorithms for colour gamut compression was conducted using two different experimental methods. In the first, real prints in a viewing cabinet were compared side-by-side with the original images displayed on a CRT monitor. In the second, virtual prints were simulated on the monitor for comparison with the original images. The results showed that the new topographic algorithm achieved a good performance in both cases. Comparison of the two experiments, however, indicated rather different results for the other three algorithms applied to the same four test images, with the magnitude of differences between the algorithms being smaller in the case of simulated prints.

Keywords: Gamut mapping, gamut compression, colour image reproduction, image quality evaluation.

1. INTRODUCTION

Various methods of colour gamut compression have been proposed[1], from the basic clipping of colours to the nearest point on the gamut boundary to complex transformations of colour space in which the lightness, chroma and in some cases also hue are modified. One of the problems with many previous algorithms, is that they attempt to map all colours in the lightness-chroma (*L-C*) plane at each hue toward a single convergence point, or 'centre of gravity', based on the co-ordinates of the cusps (points of maximum chroma) of the original and reproduction gamuts.

A new topographic gamut mapping algorithm has been developed[2], which transforms values from a source colour space into a destination colour space, preserving the relationships between source and destination reversibly in a perceptually uniform colour space. Hue angle is assumed to be invariant, so that the transformation maps pixel values within the lightness-chroma plane. The algorithm is executed in four steps: (1) construct the boundary of a 'core gamut', within which no colours are altered; (2) define a distance metric along both source and core gamut boundaries; (3) construct a set of mapping chords, connecting corresponding points; and (4) perform gamut mapping along the chords, with a 'soft-clip' function.

The core gamut boundary in the new algorithm is defined by a white point L_W of the cusp with the highest lightness over all hue angles (normally yellow), and by a black point L_B of the lowest lightness cusp (normally blue). Its width is determined by the ratio of the chromas of the cusps of the destination and source gamuts, as shown in Fig. 1. Mapping chords are constructed to join corresponding points at equal intervals along the source and core gamut boundaries. Upper and lower regions are constructed above and below a horizontal chord passing through the core gamut cusp of lightness L_{SS}, as shown in Fig. 1. Points outside the core gamut boundary are mapped along the chord using a 'soft clip' mapping function.

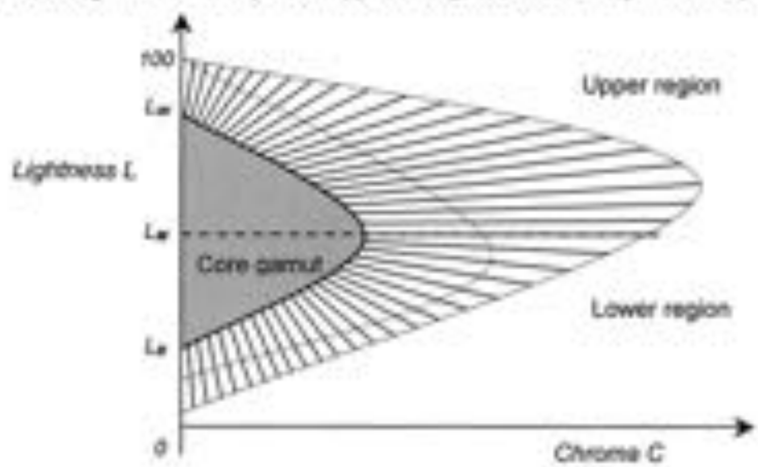


Figure 1 Construction of gamut boundaries and mapping chords.

* L.W.MacDonald@colour.derby.ac.uk; phone +44-1332-622217; fax +44-1332-622218; http://colour.derby.ac.uk; Colour & Imaging Institute, Kingsway House East, Kingsway, Derby, DE22 3HL, United Kingdom.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) · 0277-786X/02/$15.00

2. FIRST EXPERIMENT

The performance of an earlier version (v2.1) of the TOPO algorithm was evaluated[1] using the same experimental technique and test images employed previously by Morovic and Luo[7]. Three other well-known gamut mapping algorithms used in previous studies were also applied to each test image, employing a common gamut boundary dataset:

MDE	Minimum ΔE clipping to gamut boundary, preserving hue (in L-C plane).
LLIN	Linear compression of lightness and chroma.
GCUSP	Chroma-dependent lightness compression and linear compression to cusp.

The images were simultaneously viewed side-by-side, as shown in Figure 2a, with the source image displayed on the CRT and two reproduction prints in a Verivide viewing booth under a simulated D65 light source, meeting the ISO 3664 viewing condition P2. Both the white point and the grey background on the CRT were carefully matched to the corresponding colours in the booth, based on spectroradiometric measurement. The images were approximately 20 cm in width and subtended equal visual angles of approximately 14° to the observer, viewed from a distance of approximately 80 cm. The images were viewed in a darkened room (lights off). Other conditions were as described in the evaluation guidelines under development for CIE Technical Committee 8-03.[8]

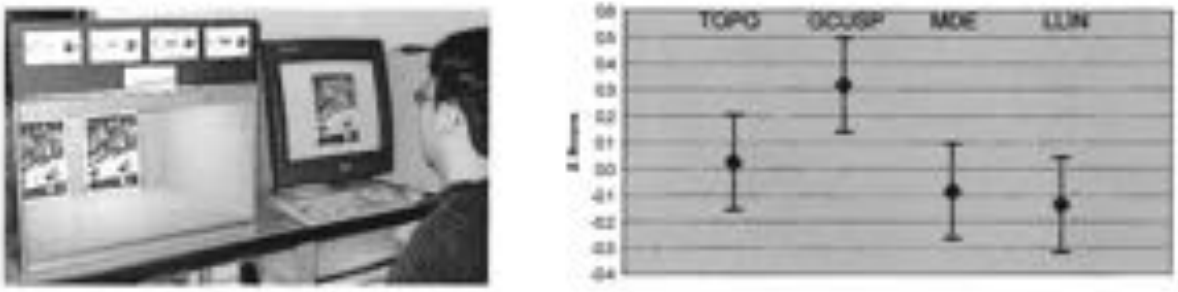


Figure 2 Viewing arrangement and overall z-scores for the four algorithms tested in first experiment (real prints).

Five test images were chosen to contain a range of different types of pictorial content and tonal and chromatic variety. Twenty prints were produced (5 images times 4 algorithms). Twelve observers, all students and staff of the Colour & Imaging Institute with normal colour vision and ages ranging from 20 to 38, took part in the experiment. Each observer was required to make ${}^4C_2$=6 pair-wise comparisons per image, a total of 30 comparisons per session. The observer's task was to decide which of the two prints in the viewing booth was the better overall match to the original (source) image displayed on the CRT. For each image, the 4x4 matrices of comparison results for each observer were averaged over the 12 observers and transformed into z-scores. The 95% confidence interval was calculated to be 0.40 for the individual images, and 0.18 overall.

3. SECOND EXPERIMENT

The TOPO algorithm was revised and an improved version (v3.3) was evaluated in a second experiment[2]. The same three gamut mapping algorithms as before were used for reference, but a different experimental technique was employed, with two simulated prints displayed alongside the original on the CRT, instead of real prints in the viewing cabinet, as shown in Fig. 3a. The white point of the simulated prints and the grey background were checked to be the same as for the real prints and the walls of the viewing cabinet respectively in the first experiment by measurement with a telespectroradiometer. The simulated prints were generated by applying the gamut mapping algorithm to each image in *JCh* (polar co-ordinate transformation of *Jab*) colour appearance space, then applying the inverse *CAM97s2* model using the display viewing conditions to obtain a colorimetric (*XYZ*) image. The GOG model[5] was used to convert the image to display *RGB* signals. Eight test images comprised four of the images used in the first experiment plus four additional images from the SHIPP set.

Thirty-two versions of the simulated prints were produced (8 images times 4 algorithms). Twenty-one observers, all students and staff of the Colour & Imaging Institute with normal colour vision and ages ranging from 21 to 50, took part in the experiment. Each observer was required to make ${}^4C_2$=6 pair-wise comparisons per image, a total of 48 judgements per session. The observer's task was to decide which of the two simulated prints displayed on the CRT was the better overall match to the displayed original image. Automatic control software presented the pairs of images in random order, recorded the observer's selections (from point-and-click on left or right test image), and computed the z-scores on completion of the session. For each image, the 4x4 matrices of comparison results for each observer were averaged over the 21 observers and transformed into z-scores. The 95% confidence interval was calculated to be 0.30 for the individual images, and 0.11 overall.

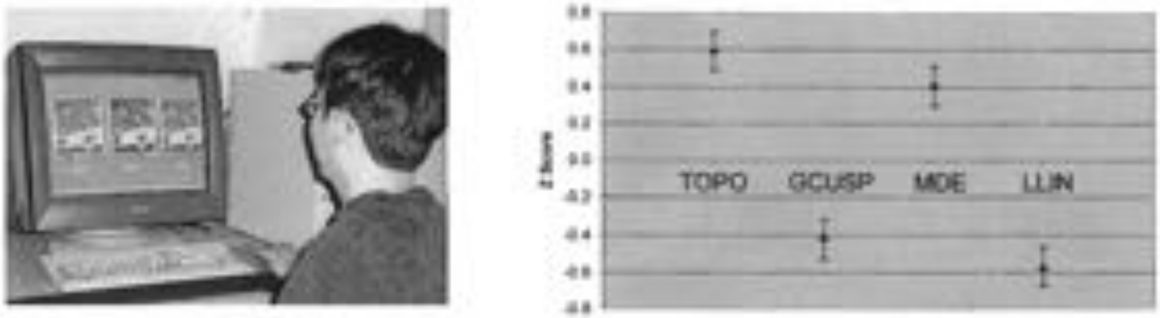


Figure 3 Viewing arrangement and overall z-scores for the four algorithms tested in second experiment (simulated prints).

4. COMPARISON OF ACTUAL AND SIMULATED MEDIA

The two experiments described above differed in a significant way. In the first experiment the gamut mapping algorithms (GMAs) were evaluated by having originals on a CRT medium and reproductions on a printed medium, whereas in the second both the originals and the reproductions were displayed on a CRT, with their gamuts restricted to the gamut of the printed medium used in the first experiment. Thus in the first experiment there was an actual (or real) difference between the two media whereas in the second experiment the difference was simulated (or virtual).

Table 1a gives the ranking of the performance of the four algorithms for the five test images in the first experiment. GCUSP was best overall and TOPO v2 second best. TOPO was ranked highest for the MUS image, in which it preserved the lightness rendering better than the other algorithms, especially in the skin colours. TOPO performed poorly for the NAT image, because observers judged the blue sky to be too dark, and also for the BUS image, because the loss in chroma was too great. Curiously, the MDE algorithm was ranked best for the GIRL image because it had little effect on the skin colours, which were largely inside the printer gamut boundary. It is clear that the relative performance of the various algorithms was very dependent on image content.

Image	TOPO2	GCUSP	MDE	LLIN
MUS	1	2	4	3
GIRL	2	3	1	4
SKI	3	1	4	2
NAT	3	1	4	2
BUS	3	1	2	4
Overall	**2**	**1**	**3**	**4**

Image	TOPO3	GCUSP	MDE	LLIN
SKI	2	3	1	4
BUS	2	1	3	4
NAT	2	4	1	3
GIRL	2	3	1	4
BRIDE	1	4	2	3
HARBOUR	1	3	2	4
TEXTILE	1	4	2	3
METAL	1	4	2	3
Overall	**1**	**3**	**2**	**4**

Table 1 Ranking of algorithm performance per image (1=best, 4=worst) for first (left) and second (right) experiments.

Table 1b gives the ranking of the performance of the four algorithms for the eight test images in the second experiment. The improved algorithm TOPO v3 was ranked highest for the four SHIPP images and second for the other four images. GCUSP and LLIN generally performed poorly, except for the BUS image, where GCUSP achieved the best compromise between maintaining chroma and rendering the surfaces of the solids. The MDE algorithm again performed surprisingly well overall, and was ranked best for the SKI, NAT and GIRL images.

5. DISCUSSION

In a survey of past literature on the experimental evaluation of GMAs one can clearly see a divide between those that use actual media and those that use simulation, as well as a corresponding divide between the kind of results reported. Studies using real media carried out by Ito and Katoh[6], Morovic and Luo[7] and Kang *et al.*[8] have tended to conclude that gamut compression and/or linear lightness mapping outperformed gamut clipping. On the other hand, studies using simulation by Gentile *et al.*[9], Pariser[10], Montag and Fairchild[11], and Braun and Fairchild[12], have reported better results for clipping and/or knee-function compression and non-linear lightness mapping. While it is conceivable that these different results could be due to other factors, such as the test images used or the magnitude of gamut differences, one should also investigate the issue of actual versus simulated media when trying to explain the divide between the respective results.

As the present study included experiments of both kinds, the data gathered could shed some light on the difference between the two approaches. The close correspondence between simulated and actual reproduction gamuts was verified by measuring the white and black points in both cases (i.e. of the print in the viewing cabinet and of the simulated print on the CRT) and it was found that they were very close. To make the comparison as fair as possible, only the observer judgements for algorithms (i.e. GCUSP, MDE, LLIN) and images (i.e. SKI, BUS, NAT, GIRL) that were used in both experiments are considered. In Figure 4, it can be seen that the overall results for the two experiments gave very different results, particularly for the GCUSP algorithm, and also that the magnitude of differences between algorithms was smaller in the simulated case.

Considering the scores for these three algorithms and four images, the correlation between the actual and simulated sets is very low (R=0.19) which shows that evaluating GMAs under either of these conditions does not lend itself to predicting what would have happened under the other. A closer look at the data also reveals that there was considerable variation between the correlation of scores for the different images, from as high as 0.99 for BUS, to as low as 0.25 for SKI and even negative (-0.82) for NAT. The correlation of scores for GMAs between the two conditions was also quite varied: 0.46 for GCUSP, 0.04 for MDE and 0.19 for LLIN. Plotting all accuracy scores from the two experiments against each other in Figure 5 further shows their weak relationship.

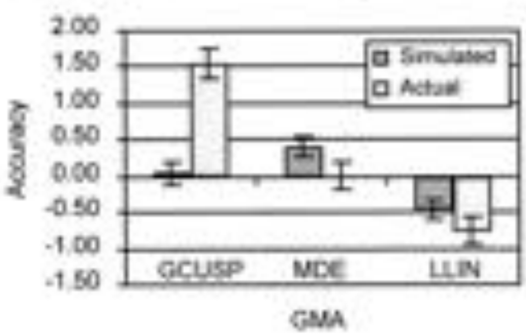


Figure 4. Overall results for actual and simulated experiments.

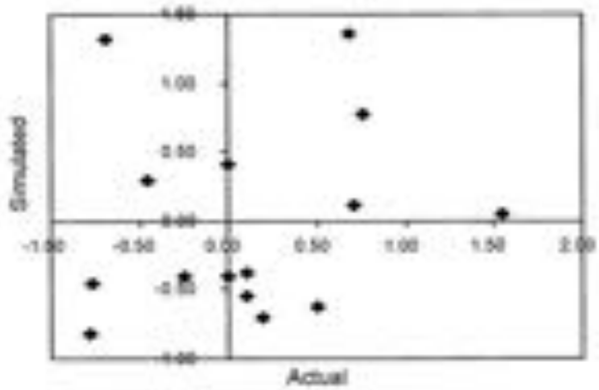


Figure 5. Accuracy scores for simulated versus actual media.

While the present data does not lend itself to gaining a deeper understanding of why these difficulties occur with simulation, it shows clearly that simulated and actual reproduction media can give rise to very different results when evaluating GMAs. A systematic investigation of these differences would therefore be a worthwhile undertaking, as it might shed light on why previous studies have differed in their findings and lead to improvements in the quality of simulation. Given the advantages of simulation, this would facilitate the study of cross-media reproduction in general and of gamut mapping in particular.

REFERENCES

1. J. Morovic and M.R. Luo, Developing Algorithms for Universal Colour Gamut Mapping, *Colour Imaging: Vision and Technology*, Ed. L.W. MacDonald and M.R. Luo, John Wiley & Sons, 253-282 (1999)
2. L.W. MacDonald, J. Morovic and K. Xiao, A Topographic Gamut Compression Algorithm, *J. Image Science & Technology* (2001)
3. L.W. MacDonald, J. Morovic and K. Xiao, A Topographic Gamut Mapping Algorithm based on Experimental Observer Data, *Proc 8th IS&T/SID Color Imaging Conf.*, 311-317 (2000)
4. http://www.colour.org/tc8-03/
5. R.S. Berns, Methods for characterizing CRT displays, *Displays*, **16** (4), 173-182 (1996)
6. M. Ito and N. Katoh, Gamut Compression for Computer Generated Images, in *Extended Abstracts of SPSTJ 70th Anniversary Symposium on Fine Imaging*, SPSTJ, Tokyo, Japan, 85–88 (1995)
7. J. Morovic and M. R. Luo, Cross-media Psychophysical Evaluation of Gamut Mapping Algorithms, *Proc. AIC Color 97 Kyoto*, Kyoto, Japan, **2**, 594–597 (1997)
8. B. H. Kang, M. S. Cho, J. Morovic and M. R. Luo, Gamut Compression Algorithm Development on the Basis of Observer Experimental Data, in *Proc. 8th IS&T/SID Color Imaging Conf.*, IS&T, Springfield, VA, 268–272 (2000)
9. R. S. Gentile, E. Walowit and J. P. Allebach, A comparison of techniques for color gamut mismatch compensation, *J. Imaging Tech.*, **16**, 176–181 (1990)
10. E. G. Pariser, An Investigation of Color Gamut Reduction Techniques, in *IS&T's 2nd Symposium on Electronic Publishing*, IS&T, Springfield, VA, 105–107 (1991)
11. E. D. Montag and M. D. Fairchild, Psychophysical Evaluation of Gamut Mapping Techniques Using Simple Rendered Images and Artificial Gamut Boundaries, *IEEE Trans. Image Proc.*, **6**, 977–989 (1997)
12. G. J. Braun and M. D. Fairchild, General-Purpose Gamut Mapping Algorithms: Evaluation of Contrast-Preserving Rescaling Functions for Color Gamut Mapping, in *Proc. 7th IS&T/SID Color Imaging Conf.*, IS&T, Springfield, VA, 167–172 (1999).

Colour Difference Thresholds for Cross-media Colour Image Reproductions

T. Song and M. R. Luo, Colour & Imaging Institute, University of Derby, Derby, UK

ABSTRACT

CRT displays and prints are the predominant media in colour reproduction. This study investigates the colour difference thresholds under the viewing conditions of cross-media colour reproduction, for which the pictorial prints presented in a viewing cabinet were compared with their reproductions displayed on a CRT monitor. The results showed that the current experimental results agree reasonably well with those found in earlier studies. Observers are more tolerant e of lightness changes and more sensitive to hue changes. The acceptability thresholds are image-dependent and also affected by the transformation functions used.

Keywords: Colour difference, thresholds, perceptibility, acceptability, cross-media colour reproduction

1. INTRODUCTION

Since the introduction of the CIELAB [1] colour difference formula in 1976, several advanced colour difference formulae have been proposed. Although they work reasonably well for large sized uniform colour patches, it is uncertain how well they perform for colour image applications. In 1991, Mike Stokes [2] investigated the perceptible and acceptable colour difference tolerances of pictorial images on a CRT monitor. Later, Uroz [3] conducted an experiment using large size prints to study the perceptibility thresholds in terms of 99% percentile in CIELAB and CIE94 ΔE units. Recently, two new experiments were conducted by Song [4] and by Gibson. [5] The former experiment investigated the colour difference thresholds based upon a CRT display. The latter experiment applied different media including a CRT display, two LCD displays and a printer. In general, there is a great consistency between different sets of results. The perceptibility thresholds found by Stokes, Uroz, Song and Gibson were 2.0, 2.3, 2.2 and 1.7 ΔE_{ab} respectively regardless of the different images used. For Gibson's LCD results, only the lightness and chroma thresholds agreed with the earlier results and large variations were found for the hue results between the two LCD displays studied. The difference between the perceptibility and acceptability thresholds is a simple scaling factor. However, the magnitudes of acceptability thresholds may vary according to different groups of observers such as different races, professions, etc. For example, the acceptability thresholds found by Stokes and Song are 6.6 and 4.4 ΔE_{ab} respectively.

Although the earlier studies provided useful information to understand human colour perception in judging colour differences between complex images, the results were based upon single media, i.e. either a self-luminous display or a printed material. There is a lack of experimental results on cross-media colour reproduction, which is an important task in the field of colour reproduction and is highly desired by the industrialists. It is also important to the CIE committee TC8-02 [6] which intents to recommend a colorimetric tool for evaluating colour differences between images. With this in mind, this work was carried out.

2. EXPERIMENT

The experiment was conducted by judging the colour differences between the hardcopy and softcopy images by a panel of observers. Three images were chosen from the ISO *12640-2* [7] (XYZ/SCID standard colour images). Figure 1 summarises the procedures for preparing the experimental images. A printer characterisation model and a CRT display characterisation model was first implemented for processing images and for calculating colour differences between an original and theirs reproductions. The hardcopies were printed using a HP DesignJet large format thermal inkjet printer on a glossy paper. The tetrahedral method [8] was used to characterise the printer by transforming the CMYK data to tristimulus values with an average error of 1.6 ΔE_{ab} and a maximum of 6.5 units. Softcopy images were displayed on a Hewlett Packard Monitor A4576A monitor. A Look-Up-Table method [9] was used for characterising the monitor with a mean error of 1.2 ΔE_{ab} and a maximum of 2.1 units. A colour appearance model is not used here. (Sueeprasan *et al* [10] found that for cross-media colour reproduction between CRT and printed images having the same colour temperature and luminance, a colorimetric match is sufficient for achieving a successful colour appearance match.) The characteristics of the three images studied are summarised in Figure 2.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

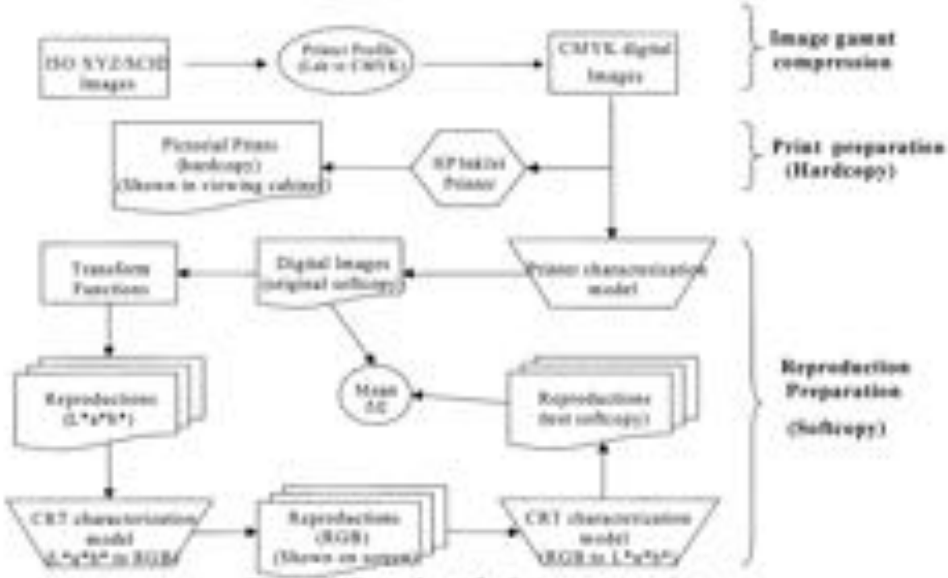


Figure 1. Procedures for image preparation

A range of transformation functions for rendering the CRT images was chosen based upon those used by the previous studies [3-5] and typically occur in practical applications. These functions are summarised in Table 1. A power function and a sigmoidal function were chosen for rendering the lightness attribute. The power and multiplicative functions were used for rendering the chroma attribute. The sigmoidal function was not chosen because the maximum chroma values at different hue angles are different. Transformation functions were also used for rendering simultaneous colour changes in both the chroma and lightness directions. Colour changes were only applied in the direction for reducing gamut, which ensured the transformed colours being within the gamut of the medium. Only a clockwise rotation was used for hue changes by adding an offset. For each function, nine parametric levels were applied.

Function	Attribute(s)	Name	Description
Power	Lightness	LP	$L^*_{out}=100\,(L^*_{in}/100)^a$ $a>1$
Sigmoidal	Lightness	LS	$L^*_{out}=50\,(L^*_{in}/50)^a$ when $L^*_{in}<50$ Otherwise $L^*_{out}=50+50\,[(L^*_{in}-50)/50]^{1/a}$
Power	Chroma	CP	$C^*_{out}=100\,(C^*_{in}/100)^a$ $a>1$
Multiplicative	Chroma	CM	$C^*_{out}=k\,C^*_{in}$ $k<1$
Power	Lightness & Chroma	LCP	$L^*_{out}=100\,(L^*_{in}/100)^a$ $C^*_{out}=100\,(C^*_{in}/100)^a$ $a>1$
Multiplicative	Lightness & Chroma	LCM	$L^*_{out}=k\,L^*_{in}$ $C^*_{out}=k\,C^*_{in}$ $k<1$
Offset	Hue angle	HO	$h_{out}=h_{in}+off$ $off<0$

Table 1. The transformation functions used for each colour attribute

In the experiment, observers were asked to compare a reproduction displayed on the monitor against a hardcopy image presented in the viewing cabinet. The white point of the monitor was set to x=0.3059, y=0.3240 with luminance of 55 cd/m^2 to match the white paper of the hardcopy. Each reproduction was presented against a grey background having the same colorimetric specification as that in the viewing cabinet. For each colour attribute, the reproductions were presented to each observer following an ascending sequence (increasing colour differences). Observers had to answer: 'can you see any colour difference between the two images presented?', and 'if you see a colour difference, can you tolerate the difference?' Twenty-one observers who passed the Ishihara vision test took part in the experiment.

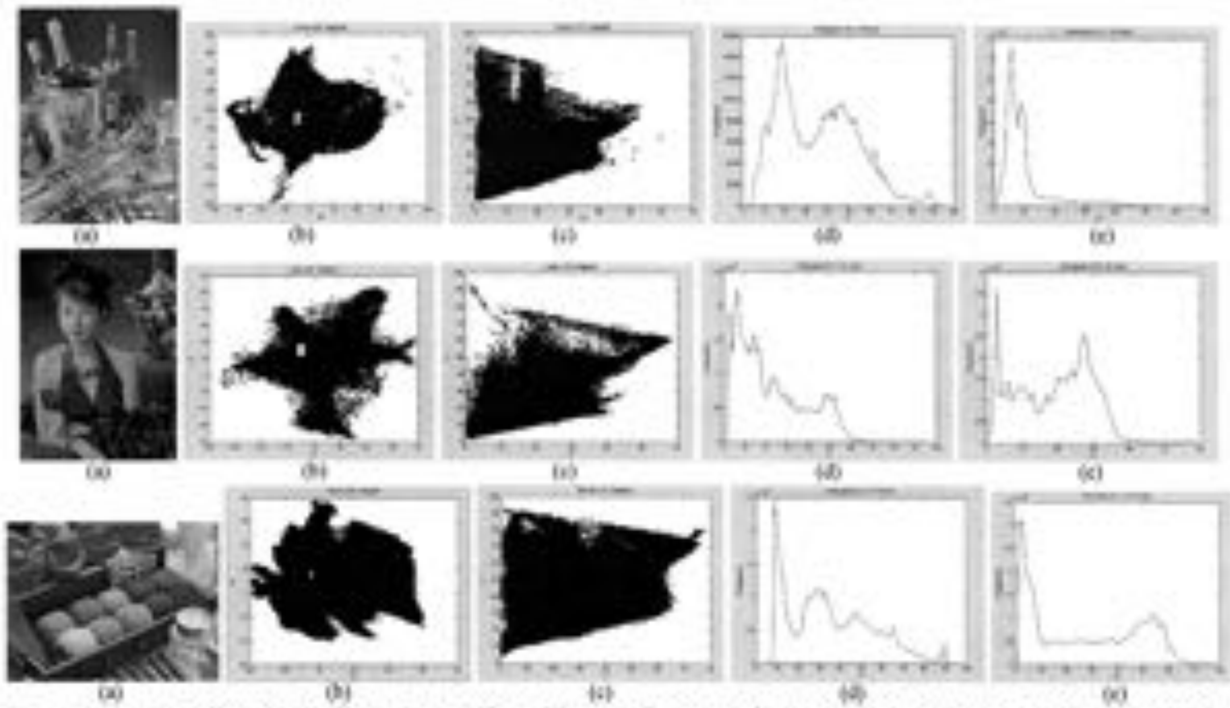


Figure 2. (a) The Silver (top left), Lady and Thread images (bottom left) used and their characteristics expressed by colour distributions in (b) a^*b^* diagram, (c) L^*C^* diagram, and (d) L^* histogram, and (e) C^* histogram.

3. RESULTS

Perceptibility threshold indicates a just noticeable colour difference. Unlike the previous studies[2-5] for assessing colour differences using a single medium, cross-media experiments require accurate characterisation models for both media and ideally, each colour in the image should be within the colour gamuts of both media. However, this was not achieved in the current study. There were always discrepancies between the hardcopy and softcopy gamuts, for which the mean colour differences were 0.30, 0.44 and 0.37 ΔE_{ab} units for the Silver, Lady and Thread images, respectively. Although according to previous studies[2-5], such errors are too small to be noticed when comparing the images presented using the same media, about four fifths of observers did perceive colour differences. In addition to the gamut difference, problems were also caused by the inaccuracy of the printer and the CRT characterisation models. As mentioned earlier, there was an accumulated mean error of about 3.0 ΔE_{ab}, which was greater than 2.2 ΔE_{ab}, the perceptibility thresholds found from the earlier studies[2-5]. Hence, only the acceptability thresholds could be investigated in this study.

Although acceptability thresholds are normally of more interest than those for perceptibility to industrialists, the criteria may vary according to the background of observers such as age, experience, profession, culture etc. This was illustrated by the results obtained by Stokes[2] with the acceptability threshold about 6.6 ΔE_{ab} and the authors' earlier study[3], about 4.4 ΔE_{ab}. Both experiments were conducted using CRT images.

Table 2 summarises the acceptability thresholds for different transformation functions. It can be seen that the thresholds for the Thread image are the largest for almost all images, functions and attributes studied. This indicates that for images having a very wide colour and lightness gamut observers are more tolerant e of colour changes in all directions. Observers were also sensitive to the flesh tone image (see Lady image), i.e. many observers stated that they rejected the trial image because the lady in the reproduction looked pale. (This was caused by the CRT rendering images with less chroma than that of the hardcopy.) The thresholds for the Silver image are even smaller than those of the Lady image except for the lightness functions. This is due to the fact that there are a large proportion of the neutral and near neutral colours in that image (see top of Figure 2(e)). Observers were very sensitive to the chromatic changes to these colours. We can conclude that the image contents does influence observers' judgements on acceptability.

It was also found that the transformation functions used affect results. In general, observers are more tolerant to lightness changes and more sensitive to hue changes. This agrees with the earlier studies.[2-5] For example, the LP function had a larger threshold than the LS function due to the fact that the latter produces a larger lightness contrast. The difference of about 1.2 ΔE_{ab} units between the LP and LS transforms for the Lady image is smaller than those of the other two images because most colours in the Lady image have lightness values less than 50 (see middle of Figure 2(d)), which reduces the contrast effect for the LS function. The differences between the CP and CM functions are much smaller than those between the LP and LS functions and quite consistent across all images i.e. they differed by about 1 ΔE_{ab} unit. For the simultaneous changes in lightness and chroma, the LCP function and LCM functions gave similar results for the Silver and Lady images, but not for the Thread image. This is caused by the much larger colour gamut for the Thread image than the other two images.

	LP	LS	CP	CM	HO	LCP	LCM
Silver	5.81	2.56	2.73	1.65	1.44	2.56	2.74
Lady	3.37	2.17	3.66	2.56	1.76	3.23	3.88
Thread	6.07	4.35	4.11	3.16	2.89	5.51	3.65

Table 2. Acceptability thresholds in terms of ΔE_{ab}

4. CONCLUSION

An experiment was conducted to assess the colorimetric thresholds for pictorial images under cross-media reproduction conditions. The results showed that the current experimental results agree reasonably well with those found in earlier studies. Observers are more tolerant of lightness changes and more sensitive to hue changes. The acceptability thresholds are image-dependent and also affected by the transformation functions used. Further work is needed to obtain high colour fidelity matches in order to study perceptibility thresholds. It is necessary to ensure all colours in images are within the gamuts of both media, and to improve the accuracy of printer and CRT characterisation models.

ACKNOWLEDGEMENTS

The authors would like to thank Professor B. Rigg for providing advice, Mr. J. Uroz and his colleagues at HP Barcelona for preparing prints, and all the observers who took part in the experiment.

REFERENCES

1. CIE., Colorimetry, 2nd Ed. CIE Pub. No. 15.2. Vienna, Austria: Central Bureau of the CIE, 1986.
2. M. Stokes, *Colorimetric tolerances of digital images*, MSc Thesis, RIT, University of Rochester, New York, USA. 1991.
3. J. Uroz, M. R. Luo, J. Morovic, "Colour Difference Perceptibility for Large-Size Printed Images", *Proceedings of Colour 2000*, pp138-151, Derby, 2000.
4. T. Song and M. R. Luo, "Testing Colour-Difference Formulae on Complex Images Using a CRT Monitor", *Proceedings of IS&T/SID 8th Colour Imaging Conference*, pp44-48, Scottsdale, 2000.
5. J. E. Gibson, M. D. Fairchild, S. L. Wright, "Colorimetric Tolerances of Various Digital Image Displays", *Proceeding of IS&T/SID 8th Colour Imaging Conference*, pp295-300, Scottsdale, 2000.
6. T. Newman, "CIE Division 8: new Directions and Dimensions to Colour Standards", *Proceedings of International Colour Management Forum*, pp7-14, Derby, 1999.
7. "Graphic technology - Prepress digital data exchange- XYZ/sRGB standard colour image data (XYZ/SCID)", *ISO 12640-2 Working draft*, 2000.
8. P. Hung, "Colorimetric Calibration in Electronic Imaging Devices Using a Look-up-table Model and Interpolations", *Journal of Electronic Imaging*, **2(1)**, pp53-61, 1993.
9. R. S. Berns, "Methods for characterizing CRT displays", *Display*, **16**, Number 4, pp173-182, 1996.
10. S. Sueeprasan, M. R. Luo, P. A. Rhodes, "Investigation of Colour Appearance models for Illumination changes across Media", *Col Res Appl*, in print, 2001.

A multiprimary display: Discounting observer metamerism

Friedhelm König[*a,b], Kenro Ohsawa[†a,c], Masahiro Yamaguchi[a,c], Nagaaki Ohyama[a,c], and Bernhard Hill[b]

[a] Akasaka Natural Vision Research Center, Tokyo, Japan; [b] Aachen University of Technology, Aachen, Germany; [c] Tokyo Institute of Technology, Tokyo, Japan

ABSTRACT

Multispectral imaging has been proposed to overcome the shortcomings of conventional three channel imaging[1,2]. This technique uses spectral data to describe the color of each pixel, allowing for a significant increase in color accuracy. While most publications on multispectral imaging deal with different aspects of image acquisition (e.g. [3,4]), the output of multispectral images becomes increasingly important. This paper describes a way to use a six-primary display[5] as a multispectral output device. Additionally to a significant increase in device gamut, the use of more than three primaries introduces additional degrees of freedom for displaying a given color. This allows to account for observer metamerism by displaying the color in such a way that the color differences are minimal for every observer. An optimization algorithm was derived that calculates optimal control values for the six channels of the projector. One important aspect of such a method is that the control values need to be constrained, because for each channel of the projector the maximum output is limited and it is also impossible to create a negative output. Using a linear programming technique such a method was found. The methods performance was evaluated using simulation. The methods dependency on the definition of the white point is discussed. Finally, it is shown that mean errors of approx. 0.5 ΔE_{ab} can be achieved.

Keywords: multispectral, display, observer metamerism

1. INTRODUCTION

1.1 Observer metamerism

It is a well known fact, that there are differences in color vision between human observers. This is most likely caused by the existence of different cone pigments and differences in the pupils transmittance. Although a number of authors measured the sensitivities of human observers, the results do not always agree and precise information on observer metamerism is not yet available. Nevertheless, a set of observer data measured by Stiles and Birch[6] has been used to define the standard deviate observer, which is the most accepted method to determine the influence of observer metamerism. In this paper we use Stiles and Birchs measurements to describe the influence of observer metamerism

Luckily the influence of observer metamerism usually is not very large. Otherwise, the metameric reproduction techniques that are widely used today, would not be possible. This metameric reproduction approach, however, is the main reason that observer metamerism usually has to be ignored. An imaging systems that use only three color signals as input (e.g. RGB values or L*a*b* values) cannot be used to produce color reproductions that are precise for all human (and/or technical) observers, because no information is available on how different observers perceive the original color.

Furthermore, the discounting of observer metamerism requires the ability to produce metameric colors. This is impossible with most color output devices, the multiprimary display being a notable exception. This display will be described in the next section.

1.2 The multiprimary display

A multiprimary display is a display where more than three primary colors are used to display a color on a screen. At the Akasaka Natural Vision Research Center and in Aachen such displays have been realized by using two commercial LCD projectors that are modified by the insertion of additional interference filters. Both projectors project their images on the same screen. Geometrical distortion due to the slightly different positions of the two projectors are corrected by software. Due to the interference filters, six spectrally different primaries are created. Fig. 1 shows these primaries.

The main advantage of the use of more than three primaries is a significant increase in the size of the color gamut of a multiprimary (e.g. 6 channel) projector compared with the color gamut of a conventional projector, allowing to display a larger variety of colors without the need of gamut mapping. This advantage has been discussed elsewhere[7].

* Contact: koenig@ite.rwth-aachen.de; Department of Technical Electronics, Aachen University of Technology, 52056 Aachen, Germany

† ohsawa@akasaka.tao.go.jp; Akasaka Natural Vision research Center, 1-8-6 Akasaka, Akasaka HKN Bldg. 3F, Minato-ku, Tokyo 107-0052 Japan

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

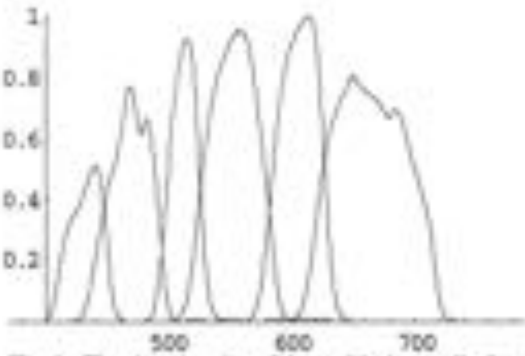


Fig. 1: The six primaries of the multiprimary display

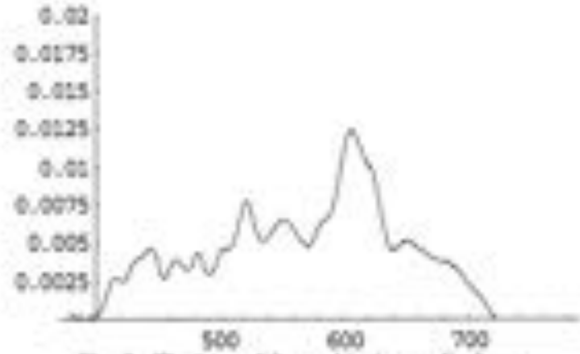


Fig. 2: The bias of the multiprimary display

In this paper a different property of the multiprimary display will be discussed. This property of the multiprimary display is the possibility to display metameric colors. At first, this does not appear to be very useful. After all, the term "metameric" implies, that an observer cannot distinguish between several displayed metameric colors.
This, however, is only partly true. As discussed in the previous section, human (and technical) observers usually are different from the standard observer. Observer metamerism can cause a considerable mismatch between two colors, that are metameric for the standard observer. Therefore, the choice which one of several possible metameric colors should be used is an important question. The answer to this question, of course, depends on the display situation.
Two different scenarios are especially important. First, if only three channel information is available, colors should be displayed in such a way that the effects of observer metamerism is minimized and the displayed image that is observed by observer A is as similar as possible to the image that is observed by observer B.
Secondly, if more information is available – for example due to the use of multispectral imaging – then the displayed color should be chosen in such a way that the displayed color is as close as possible to the original color for all observers. This is the scenario that will be discussed in this paper.
Any optimization involving a multiprimary display is -of course- dependent on an accurate display model describing the relationship between the displays input signals (control vector **C**) and its output (the spectrum $s(\lambda)$ produced by the display for a given input vector **C**). There are several possible definitions for the control vector **C**. The most obvious choice would be to use the two projectors control signals C_i ($C_i \in \{0, 1, 2, \ldots, 255\}$) directly. This approach , however, is not optimal due to the influence of nonlinearities (gamma curve) and we choose a slighly different definition:

$$\mathbf{C}=(c_1, c_2, c_3, c_4, c_5, c_6)^T,$$

where the control signals c_i ($0 \le c_i \le 1$) are a linearized version of the original control values C_i.
The model itself consists of 6 primaries $p_i(\lambda)$ and a bias $b(\lambda)$, where the bias $b(\lambda)$ is used to describe the black level of the display. The bias can be seen in Fig. 2.
Using these variables, the display output is calculated by:

$$s(\lambda) = b(\lambda) + \sum_{i=1}^{6} c_i \cdot p_i(\lambda) \tag{1}$$

2. DISCOUNTING OBSERVER METAMERISM

In this section, we will discuss a way to account for observer metamerism. The observer data of Stiles and Burch is used to represent the spread of human observers. Each of these 20 observers is represented by a set of color matching functions $x_j(\lambda)$, $y_j(\lambda)$ and $z_j(\lambda)$. Let us now consider that these 20 observers examine an object with the reflectance $r(\lambda)$ that is illuminated by a light source with the spectral power distribution $S(\lambda)$. For each observer the color values X_j, Y_j and Z_j are calculated by:

$$\begin{aligned} X_j &= k_j \int x_j(\lambda) \cdot r(\lambda) \cdot S(\lambda) d\lambda \\ Y_j &= k_j \int y_j(\lambda) \cdot r(\lambda) \cdot S(\lambda) d\lambda \\ Z_j &= k_j \int z_j(\lambda) \cdot r(\lambda) \cdot S(\lambda) d\lambda \end{aligned} \tag{2}$$

For simplicity the integration limits in equation 2 have been omitted. The integration should cover the complete visual range. The constant k_j is used to adjust the Y_j-level of the ideal reflector which is used as the white reference for observer j to Y_j=100. This is demonstrated in equation 3:

$$k_j = \frac{100}{\int y_j(\lambda) \cdot S(\lambda) d\lambda} \tag{3}$$

In the following, we will assemble the colorimetric X_j, Y_j and Z_j values of all observer into the observer vector **O**.

$$\mathbf{O} = (X_1, Y_1, Z_1, X_2, Y_2, Z_2, \ldots, X_{20}, Y_{20}, Z_{20})^T \tag{4}$$

An observer vector for each display primary $\mathbf{O}_{Pi}$ and for the display bias $\mathbf{O}_B$ can be constructed in almost the same way, only the constants k_j have to be replaced by the constants k_j' to account for the difference in luminance level between the multiprimary display and the original scene:

$$k_j' = \frac{R}{\int y_j(\lambda) \cdot \left(b(\lambda) + \sum_{i=1}^{6} p_i(\lambda) \right) d\lambda} \tag{5}$$

Equation 5 is used to map the maximum output of the display to a reference level R. The choice of a level R different from 100 can be advisable, if the white balance (x, y) of the display is different from the white balance of the original scene. Otherwise, it may be impossible to display the scene white point, because it requires an X or Z value that is larger than that of the projectors white point. To express it in another way: Adjusting the white level R results in a change of the multiprimary projector's gamut.

Using the observer vector for the primaries and bias, the observer vector $\mathbf{O}_D$ for a displayed color is calculated by:

$$\mathbf{O}_D(\mathbf{C}) = \mathbf{O}_B + \sum_{i=1}^{6} c_j \cdot \mathbf{O}_{Pi} \tag{6}$$

The effect of observer metamerism can be minimized by finding the control vector **C** that leads to a display observer vector $\mathbf{O}_D$ that is as close as possible to the observer vector **O** of the original color. This requires a constrained optimization process, because the components c_i of the control vector can only take values between 0 and 1. Probably, the best known class of constrained optimization problems is known as linear programming. Therefore, the problem of finding the optimal control vector **C** will be formulated as a linear program. Using this formulation the simplex algorithm or any of a number of other optimization algorithms can be used to find the global optimum of the problem. Due to the nature of linear programs, the global optimum is guaranteed to be found.

A linear program consists of a linear objective function and linear constraints. We use the following objective function:

$$\min(a \cdot \Delta_{max} + b \cdot \sum_{l=1}^{60} \Delta_l) \tag{7}$$

In this equation the variables a and b represent weight factors, that are chosen by trial and error. The measure Δ_l is used to calculate the difference between the l-th component of the original observer vector **O** and the respective component of the display vector $\mathbf{O}_D$. The variable Δ_{max} is used to represent the maximum deviation that is encountered for any component. The variables Δ_l and Δ_{max} are calculated using the following three types of constraints (one inequality for each value of l):

$$\begin{aligned} \Delta_l &\geq O_l - O_{D,l} = O_l - O_{B,l} - \sum_{i=1}^{6} c_i O_{P,i,l} \\ \Delta_l &\geq -O_l + O_{D,l} = -O_l + O_{B,l} + \sum_{i=1}^{6} c_i O_{P,i,l} \\ \Delta_{max} &\geq \Delta_l \end{aligned} \tag{8}$$

Combining this with the constraints for the control variables:

$$0 \leq c_i \leq 1 \tag{9}$$

we get the final linear program (Equations 7-9).

Results

The performance of the method described in the last chapter was tested using a set of 354 spectra measured by Vrhel and coworkers[7] and a display model of the multiprimary display available at the Akasaka Natural Vision Research Center. For each spectrum an observer vector was calculated. Illuminant E was assumed as scene illuminant. Then, the linear program was used to calculate a display observer vector as close as possible to the scene observer vector. For each observer and each spectrum a ΔE_{ab} error was calculated. The mean and maximum value of these errors were calculated. Additionally, it was examined how many spectra exceeded the level ΔE_{ab}=5 for at least one of the observers. This was repeated for different white levels (*R*=90, 100, 110 and 120).

Table 1 gives an overview on the results.

	R = 90	*R* = 100	*R* = 110	*R* = 120
Mean ΔE_{ab}	0.90	0.58	0.45	0.44
Max ΔE_{ab}	19.13	12.93	12.59	14.34
Number of spectra with $\Delta E_{ab} > 5$	6.5%	2.8%	2.0%	1.7%

Table 1: Simulation results for different white levels of the display

Table 1 clearly demonstrates the effectiveness of the method. Mean errors of approximately ΔE_{ab} =0.45 could be achieved. Further research showed that the relatively large maximum errors (ΔE_{ab} =12.6) are caused by spectra that cannot be reproduced due to the gamut limitations of the display (aselective spectra with high reflectance). This is the reason for the decrease in the percentage of spectra with large errors (ΔE_{ab}>5) with increasing reference level *R*. Unfortunately, *R* cannot be increased indefinitely due to a number of reasons. First an increase in *R* is equivalent to decreasing the lightness of the image. The human eye can compensate this, but only within limits. If *R* is increased to much, the image starts to appear to dark.

Another reason is caused by the quantization of the control signals. Increasing the reference level *R* reduces the effective resolution of the control signals.

The final and maybe most important reason is the influence of the bias. Obviously, no color darker than the bias can be displayed. An increase in the reference level *R* causes an increase in the perceived lightness of the bias. Therefore, the color errors for colors darker than the bias are increased. This can also be observed in table 1. For the largest choice of the reference level *R*=120, the maximum error increases compared to smaller *R* levels (*R*=100 and *R*=110). The spectrum responsible for this increase is an aselective spectrum with low reflectance.

This observations suggests that increasing the displays contrast should be a major concern, if the a multiprimary display is used for the discounting of observer metamerism.

3. CONCLUSIONS

A method to discount for observer metamerism has been proposed. This method allows to display a color that matches the original color for all observers with only a very small residual error (mean ΔE_{ab} = 0.5) as long as the color is within the gamut of the display. Therefore, the main issue for the future is to enlarge the displays gamut. Our research shows that this is done most efficiently by increasing the displays contrast ratio.

4. REFERENCES

1. Bernhard Hill, Multispectral Color Technology: A Way Toward High Definition Color Scanning and Encoding, Proc. of EICP '98 Electronic Imaging: Processing, Printing, and Publishing in Color, 1998, 2-13, Zürich, Schweiz.
2. Friedhelm König and Herzog, Patrick G., On The Limitations Of Metameric Imaging, Proc. of PICS '99, 1999, 163-168, Savanah, GA, USA.
3. Friedhelm König and Werner Praefcke, Practice of Multispectral Image Acquisition, Proc. of EICP '98 Electronic Imaging: Processing, Printing, and Publishing in Color, 1998, 34-41, Zürich, Schweiz.
4. Friedhelm König and Werner Praefcke", A Multispectral Scanner, in "Color Imaging in Multimedia", edited by Lindsay MacDonald and Ronier Luo, John Wiley & Sons, Ltd, 63-73, 1999.
5. Takeyuki Ajito, Takashi Obi, Masahiro Yamaguchi and Nagaaki Ohyama, Expanding color gamut reproduced by six-primary projection display, Proc. SPIE, Vol. 3954, pp. 130-137, 2000.
6. Günter Wyszecki and W. S. Stiles, "Color Science", John Wiley and Sons, Inc, New York, 1982.
7. M. J. Vrhel and R. Gershon, R. and L. S. Iwan, Measurement and Analysis Of Object Reflectance Spectra, Color Res. and Appl., 19, 1994.

Does Sharpness Affect the Reproduction of Colour Images?

Samira Bouzit* and Lindsay W. MacDonald
Colour & Imaging Institute, University of Derby, United Kingdom

ABSRACT

A psychophysical experiment was conducted to investigate the relationship between sharpness and preferred colour of images displayed on a CRT monitor screen. Blurred versions of each of four original images were generated by convolution with a low-pass Gaussian filter. Sharpened versions of these images were created through adjustment of the image power spectrum. Each test image was decomposed into a set of spatial frequency bands, defined as octaves of the pixel sampling frequency. The Fourier power spectrum was derived, then amplitudes of selected bands were adjusted to enhance the desired spatial frequencies. The experimental results indicated that: (1) sharpness was perceived to be increased when certain spatial frequency bands were enhanced; (2) weighting the frequency bands using the standard observer's contrast sensitivity function (CSF) gives better results for particular distances; and (3) preferred image colour is strongly related to image sharpness.

Key words: Image sharpening, colour preference, spatial frequency bands, contrast sensitivity function, psychophysics.

1. INTRODUCTION

Sharpness is defined as a perceived quality of an image associated with the abruptness of change of tone at the edge of an object or tonal area. For some applications, sharpness is argued to be a more important factor than colour[1]. Despite active research on sharpness over the past 50 years in photography, television and printing, we still cannot specify precisely the factors affecting the sharpness of images reproduced on different media. Recently Garrett and Fairchild[2] determined several rules for sharpness related to other image attributes such as contrast, noise and resolution.

The work described in this paper is part of a programme of research to investigate the perceived sharpness of displayed colour images. In order to design the optimum image-sharpening filter for a given image in a given viewing environment, we need to understand what affects the perceived image sharpness. In conjunction with our previous study[3], where we found a good correlation between image spatial frequency and preferred image sharpness, we are conducting further experiments in order to investigate the relationship between adjustment of the power spectrum of an image, perceived sharpness and preferred colour of reproduced images, as a function of viewing distance.

2. IMAGE PROCESSING

2.1 Image decomposition

Blurred versions of each original image were generated by convolution with a low-pass Gaussian filter. Enhanced versions of these colour images were processed as in Figure 1. Because the sharpness of an image depends much more on the luminance than the chrominance components, and for reasons of computational efficiency, only the luminance component is filtered, then recombined with the chrominance components as shown in Fig. 1. The original blurred *RGB* colour image was transformed to CIE-*XYZ* co-ordinates and then converted into the CIE-$L^*a^*b^*$ colour space.

The lightness (L^*) component was converted to the frequency domain by applying a Fourier Transform and then decomposed into a set of seven spatial frequency bands. Because the test images were 512x512 pixels in size, the Nyquist limit was taken to be 256 cycles per image width, i.e. 2 pixels per cycle. Octave bands were then determined by successively halving the number of cycles per image width, i.e. halving the spatial frequency. Band 7 contains all the low frequency components, including the DC (constant) term. The power spectrum of each spatial frequency band was extracted by applying an annular filter to the spectral plane, so that all phase information was preserved. The amplitudes of a group of three adjacent bands were then adjusted using weighting parameters to enhance specific frequencies (see equation (3) below). The inverse Fourier Transform was applied to obtain a lightness image in which the selected spatial frequencies were enhanced. The enhanced colour image was reconstructed by combining the original chroma components (a^*, b^*) with the enhanced lightness (L^*) component, then converted to *XYZ* using the standard colorimetric formulae and finally the image was converted to RGB signals for display.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

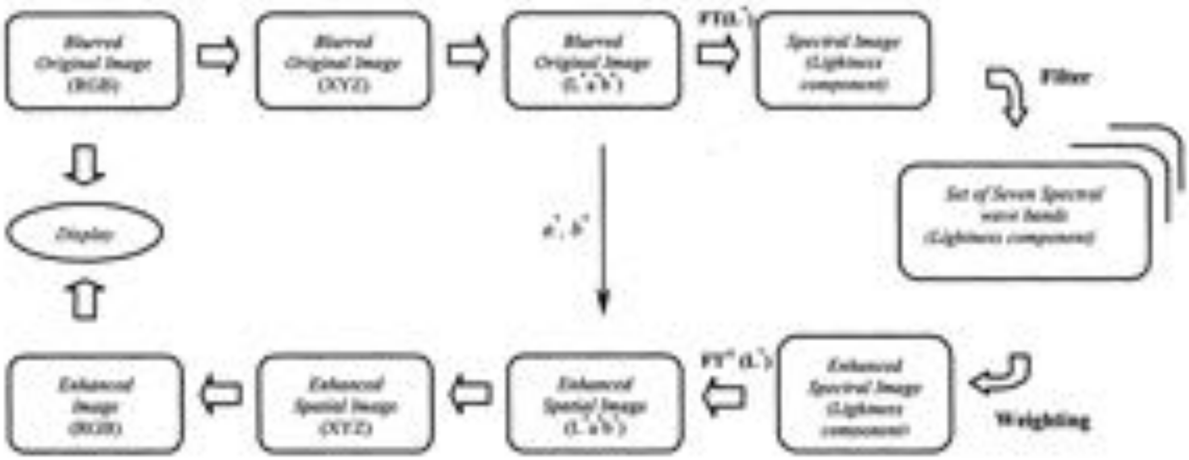


Figure1: Flow chart of the image processing procedure

2.3 Power Spectrum Weighting

Suppose that L_0^* is the lightness component of the original image; and that F_0 its Fourier Transform is given by:

$$F_0 = FT(L_0^*) \tag{1}$$

which can be expressed by:

$$F_0 = \sum_{i=1}^{7} P_i \tag{2}$$

where P_i is the power spectrum (amplitude plus phase) for one band, $i = 1..7$.

1st method

The four enhanced images were generated by weighting the amplitude of three adjacent wave bands:

$$\begin{aligned}
F_2 &= \alpha(k_1P_1 + k_2P_2 + k_1P_3 + P_4 + P_5 + P_6 + \tfrac{1}{\alpha}P_7)\\
F_3 &= \alpha(P_1 + k_1P_2 + k_2P_3 + k_1P_4 + P_5 + P_6 + \tfrac{1}{\alpha}P_7)\\
F_4 &= \alpha(P_1 + P_2 + k_1P_3 + k_2P_4 + k_1P_5 + P_6 + \tfrac{1}{\alpha}P_7)\\
F_5 &= \alpha(P_1 + P_2 + P_3 + k_1P_4 + k_2P_5 + k_1P_6 + \tfrac{1}{\alpha}P_7)
\end{aligned} \tag{3}$$

where:

F_j represents the power spectrum of the enhanced image;

$j = 2..5$ corresponds to the spatial frequency of the central band;

k_1 and k_2 are the weighting coefficients of value 1.25 and 1.5 respectively i.e. the second had double the degree of enhancement of the selected three spatial frequency components relative to the first.

α is a normalising factor, given by $\alpha = 7/(2k_1+k_2+4)$.

The lowest frequency components (Band 7) were left unchanged by the weighting procedure.

2nd method

The fifth enhanced image was generated by weighting the amplitude of the wave bands using the mean value of the contrast sensitivity function. The CSF was calculated using Barten's mathematical formula[8] for each image and at different distance. The power spectrum of the enhanced image is given by:

$$F_6 = \beta(m_1P_1 + m_2P_2 + m_3P_3 + m_4P_4 + m_5P_5 + m_6P_6 + m_7P_7) \tag{4}$$

where:

m_i represents the mean value of the contrast sensitivity function at a particular band i;

β is a normalising factor, given by $\beta = 7/\sum_{i=0}^{5} m_i$;

The adjusted lightness components were obtained by performing the inverse Fourier Transform on the weighted sums:

$$L_j = FT^{-1}(F_j) \quad (5)$$

The enhanced image was reconstructed by combining enhanced lightness component with original chroma components:

$$I_j = L_j \oplus a^* b^* \quad (6)$$

where:

L_j represents the enhanced lightness component;
a^*, b^* represent the chrominance components;
I_j represents the enhanced colour image;
j = 2,3,4,5,6 corresponds to weighting applied.

3. EXPERIMENTAL DESIGN

3.1 Test Images

Four different test images were used in this experiment. Two were selected from the standard SCID image set[5] and the others were captured using a digital camera. The first image contains fine details of a bicycle wheel, sine patterns and shapes with high chroma colours. The second shows a young woman with clear skin and contains shadow detail (in the hair) and gentle tone and colour gradations in the skin. The third represents a basket of fruit with highlights against defocused background. The fourth is a fan grille against a plain grey background, with many linear forms. Using the two methods described above, five enhanced versions of each individual image (I_2 .. I_6) were generated.

3.2 Viewing arrangement

Observers were asked to judge a pair of displayed test images of 512×512 pixels in size at five different distances. The test image dimensions on the display screen were 191(H) x 191(V) mm, corresponding to pixel dimensions of 0.37 x 0.37 mm. The horizontal angle subtended at the eye of the observer (in degrees) was calculated from the viewing geometry for the given pixel or image width D and viewing distance l:

$$w_{pixel} = \frac{D}{l} \times \frac{180}{\pi} \quad (7)$$

The values of horizontal angular subtense corresponding to the five viewing distances are summarised in Table 1. The horizontal angular spatial frequency at the observer position corresponding to the Nyquist sampling limit of the image is calculated from the dimension of 2 pixels.

Viewing distance (cm)	30	60	120	240	480
Angle subtended by image	72.96°	36.48°	18.24°	9.12°	4.56°
Nyquist limit (cycles/degree)	7	14	28	56	112

Table 1 Horizontal angular subtense and Nyquist limit of a test image viewed at different distances.

3.2 Observers' task

The images were presented on a 19" diagonal Barco *Calibrator* CRT monitor. The colour characterisation of the monitor employed the gain-offset-gamma (GOG) display model developed by Berns[6]. The monitor white point was 6500K. The peak white luminance was measured to be 128.3 cd/m^2.

Fourteen subjects, 8 females and 6 males, with normal or corrected-to-normal vision took part in the experiment. They had no deficiencies in colour vision and their ages ranged between 26 and 35. The experiment was conducted in a darkened room. Using the pair-comparison technique, each subject was successively presented with 300 pairs (original image plus five enhanced versions giving 15 combinations, times 4 images, times 5 distances) in randomised order. Pairs of images were presented side by side with a white frame of 3mm (used for the white adaptation) on a black background, separated by

10mm, and were shown with flexible timing until the subjects gave a response. For each pair, the observers were asked to make their judgements by answering the following two questions:

(1) ' Which image appears sharper?'

(2) ' According to colour, which image do you prefer?'

Subjects were forced to make a choice in this experiment (Left or Right), even when the two displayed images appeared equal in terms of sharpness and colour. The experiment was repeated five times, with the subject seated at five different viewing distances, 30, 60, 120, 240 and 480 cm, measured from the subject's forehead to the centre of the screen.

4. DATA ANALYSIS

The observers' raw numerical judgements were transformed into a subjective sharpness scale and preferred colour scale in terms of z-score, according to Thurstone's 'Law of Pair Comparison'[7]. Since the number of observers was N=14 in this experiment, the confidence interval around each scale value was 0.37. Hence if the mean scale values were within 0.37 of each other, there would be no significant difference between the mean perceived sharpness or mean preferred sharpness. The results of the experiments, averaged over all observers, are summarised in Fig. 2.

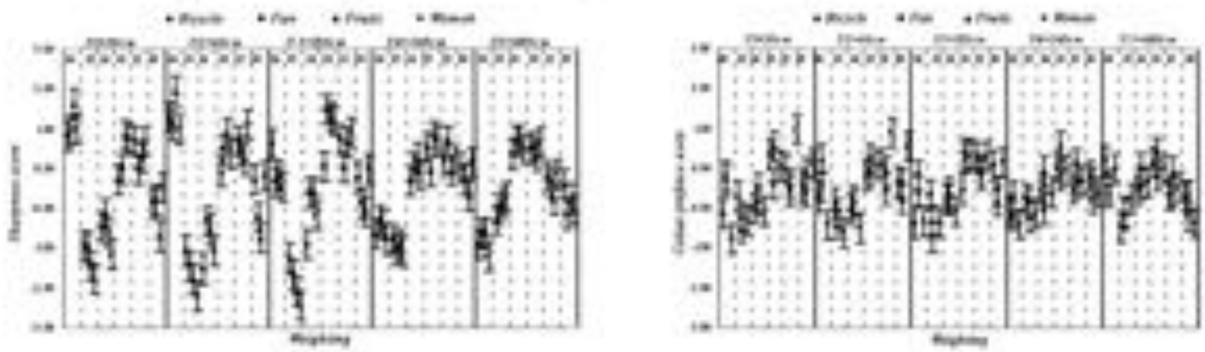


Figure2 Perceived sharpness (Left) and Preferred colour(Right) (95% confidence interval)
(I_0 = original blurred image; I2, I_3, I_4, I_5, I_6 = enhanced images).

At each distance in Fig. 2 are shown the results for the five enhanced images $I_2 .. I_6$ plus the original image I_0 for reference. The figure summarises the results of observers perceived sharpness (Left) and observers preferred sharpness (Right). Although there are small differences among the four test images, the trends are clearly defined. The images in which the highest spatial frequencies had been enhanced (I_2) were preferred in all cases to the original. The images in which the lower spatial frequencies had been enhanced were given successively lower sharpness ratings. For the first two viewing distances (30, 60 cm) the trend was monotonically upward to Band 2. At the next distances (120 and 240 cm) the preferred sharpness seems to peak at Band 3. At the longest distance (480 cm) the preferred sharpness shifted to Band 4. It appears that there is a strong relationship between image spatial frequency and preferred image sharpness. The results show a good performance of *Method 2* defined in section 2.3, with enhanced image represented as I_6. The perceived sharpness of these images was significantly higher for the shortest viewing distances (30 and 60 cm). The reasons why it didn't apply for the longer distances are still uncertain and need more investigation. The second graph shows that preferred colour follows the same trend as perceived sharpness. It would seem that observers preferred the colour reproduction of the image they judged to be sharper.

REFERENCES

1. MacDonald L.W., "Framework for an Image Sharpness Management System", *Proc. IS&T/SID Color Imaging Conf.*, pp.75-79, 1999.
2. Garrett M. J. and Fairchild M.D., "Sharpness rules" *Proc. IS&T/SID Color Imaging Conf.*, pp.24-30, 2000.
3. Bouzit S., MacDonald L.W., "Sharpness Enhancement through Spatial Frequency Decomposition", *Proc. PICS*, 377-381, 2001.
4. Barten, P.G., "Evaluation of subjective image quality with square-root integral method", *J. Opt. Soc. Am.*, 7(10), pp.2024-2031, 1990.
5. ISO Standard 12640 *Graphic Technology – Prepress Digital Data Exchange CMYK Standard Colour Image Data* (CMYK/SCID), 1997.
6. Berns R.S., "Methods for Characterising CRT Displays", *Displays*, **16**, pp.173-182, 1996.
7. Torgerson W.S., *"Theory and methods of scaling"*, John Wiley, New York, 1958.

Developing a new psychophysical experimental method to estimate image quality

Kazuhiko Takemura*[a], Keiichi Miyazaki[a], Kunihiko Kanafusa[a], Hitoshi Urabe[a],
Naoki Toyoda[b], Kazuo Ishikawa[b], Toyohiko Hatada[b]
[a]Fuji Photo Film Co., Ltd.; [b]Faculty of Engineering, Tokyo Institute of Polytechnics.

ABSTRACT

A new psychophysical experimental method is proposed for estimating image quality. The method comprises two steps; the first step is a "categorical session" and the second step is a "triplet comparison session" which is newly developed for this purpose. The triplet comparison method is developed, in order to improve the assessment accuracy and repeatability, without imposing excess observer stress during the visual assessment. Moreover, since the triplet comparison inevitably reduces the number of comparisons, experimenter can design psychophysical experiments using a higher number of samples, compared to the paired comparison method. A series of psychophysical experiments were conducted and performed. It is found that the proposed method gives reliable and stable results so far examined.

Keywords: Psychophysical experiments, Preferred color,

1. INTRODUCTION

With the advance of computer-based digital imaging technology, the opportunities to create and observe images using different types of hard copy media, as well as different types of soft copy displays, have increased significantly. As a result, there is an important need to develop requirements to obtain color-appearance matches between images produced using various media and display technologies under a variety of viewing conditions. To develop the necessary requirements, organizations including the CIE and the ICC are developing methods to compensate the effect of different viewing conditions, or to map colors optimally across disparate media having different color gamuts. Such technical activities often encounter the need to evaluate proposed methods or algorithms by visual assessment based on psychophysical experiments. K.M.Braun et al., examined five viewing techniques for cross-media image comparisons in terms of sensitivity of scaling, and mental and physical stress for the observers[1]. CIE TC1-27 "Specification of Colour Appearance for Reflective Media and Self-Luminous Display Comparisons" proposed guidelines for conducting psychophysical experiments for the evaluation of colorimetric and colour-appearance models[2]. Accordingly, for the design and evaluation of digital imaging systems, it is of great importance to develop a methodology for subjective visual assessment, so that reliable and stable results can be derived with minimum observer stress.

When performing a psychophysical experiment, it is very desirable to obtain high precision and repeatable results. In order to derive statistically reliable results, both a large number of observers and a scrupulous experimental setup are required. Multiple (repeated) assessments are also useful. Observer stress during the visual assessment process can adversely affect the results. The order of image presentation, and the types of questions or questionnaires addressed by the observers, can also affect the results. The paired comparison method is suitable especially when precise scalability is required and used widely for image quality assessment. However, a serious problem with the paired comparison method is that the number of samples to be examined must be relatively limited. As the number of the samples increases, the number of combinations becomes extensive. This causes excessive observer stress, which can affect the accuracy and repeatability of the results.

2. A NEW PSYCHOPHYSICAL EXPERIMENTAL METHOD

We propose a new psychophysical experimental method, which satisfies the following requirements.

- Enables a large number of samples to be examined
- Provides precise scalability
- Provides low observer stress

- Suitable for ordinary (non-expert) observers
- Provides high repeatability of the results

The proposed method comprises two steps as shown in Fig.1. The first step is a "category session", and the second step is a "triplet comparison session" which is newly developed for this purpose. The reason for the first session is to reduce the number of the samples to the appropriate number determined by the purpose of each experiment. Category scaling using three categories, such as "favorable", "acceptable" and "unacceptable" (or "acceptable", "just acceptable", "unacceptable") is used for the first step, and samples are selected according to the number of samples to be required for the next step. If the number of test samples to be examined is relatively small, then this first step should be omitted, and the psychophysical experiment should be started directly from the second step.

The second step is conducted to derive a precise scaling based on an interval scale. The present proposal is to use a newly developed triplet comparison method, where three samples are compared at a time, achieving high assessment accuracy while keeping the experimental scale realistic.

3. EXPERIMENTAL

To examine visual technique employed for psychophysical experiments, a project to derive preferred skin colors reproduced on photographic paper was conducted as a case study. To achieve this purpose, a standard portrait image, as shown in Fig.2, was preliminary designed. An image file encoded by sRGB[3] was also created from the standard image for the future experiments by using soft copies such as CRT or LCD. The detail of the preparation procedure to derive the standard image was described in Ref. 4 . To examine the reliability of our proposed method, the psychophysical experiments were conducted and performed for both "categorical session" and "triplet comparison session" respectively.

3.1 Part1: Categorical session

A psychophysical experiment was conducted and carried out for this session. A total of 102 reflection print samples were prepared by changing hue and chroma (17 combinations) as well as lightness (6 steps) of the facial area of the portrait image in CIELAB space. A total of 18 observers were participated in the experiment. Each observer was asked to apply category scaling using three categories such as "favorable", "acceptable" and "unacceptable". The viewing conditions were based on those specified in ISO3664 wherever possible. However, in this experiment, fluorescent lamps for color evaluation purpose were used. Illumination level was set to 1000 lx. By assigning the score simply as +1, 0, and -1 to each of categories, we can obtain the rank order as regard to the preference of the skin color.

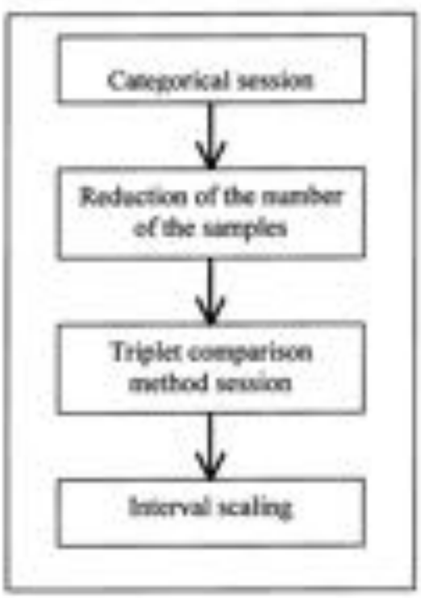


Fig.1 Flow of the proposed method.

Fig.2 Portrait image employed in the experiments.

3.2 Part2: Triplet comparison session

In order to improve the assessment accuracy and repeatability without imposing excess observer stress during the visual assessment, we develop a triplet comparison method[3]. Moreover, since the triplet comparison inevitably reduces the number of comparisons, experiments can design psychophysical experiments using a higher number of samples, compared to the paired comparison. Psychophysical experiments were carried out to examine reliability and usefulness of the proposed triplet comparison technique. The results were compared to those of the paired comparison method. The comparison considered the following points.

- Repeatability of the psychophysical scale
- Similarity of the results between the methods
- Observer stress (Evaluated in terms of the validity of the rank for each sample, and the assessment time required)

The experiments were carried out as follows. Since the triplet comparison requires observers to compare three images at a time, it is recommended to prepare a total number of the samples so that it obeys the following equations; N=6K+1 or N=6K+3, where N is a total number of samples and K is an arbitrary number. In this experiments, a total of 21 samples were selected out of 104 print samples. A total of 15 observers were joined in the experiment. All of them were requested to perform both the paired comparisons and the triplet comparisons. They were also encouraged to repeat the same experiments 5 times. The viewing conditions are same as those employed in the previous experiment. Fig. 3 illustrates examples of visual assessment results. To derive an interval scale, Scheff's method was introduced as statistical analysis. The results are shown in Fig. 4. The correlation between scale values derived by the paired comparison and the triplet comparison is examined and shown in Fig.5. It is found that there exists a good correlation between two methods. It is also found that in the triplet comparison, the scale values are distributed relatively in a wide range, suggesting that the observers can clearly distinguish the difference between samples. Fig.6 compares the assessment time required for observations.

4. CONCLUSIONS & FURTHER STUDY

A series of psychophysical experiments were performed to examine reliability of the proposed method. The followings are our conclusions so far examined.

- The scale values obtained by the triplet comparison correlate highly with those obtained by the pair comparison, suggesting a sufficiently high reliability of the triplet comparison method.
- The repeatability of the results derived by the triplet comparison is same as those derived by the paired comparison.
- The triplet comparison reduced the assessment time by almost 50% compared to the pair comparison.
- Therefore, the new psychophysical experimental method can provide a useful procedure to estimate image quality.

However, farther investigations might be required to examine the reliability of the proposal method.

- It is required to compare the scalability derived by the triplet comparison method to that derived by the paired comparison.
- In case of the triplet comparison, three samples are examined at a time. It is desirable to examine whether or not this presentation affects the perception of the samples and finally the scalability.
- When the total number of samples does not obey the equations described above, it is required to specify how to apply statistical analysis and to derive the confidence level of the sample.

It is decided that by performing rigorous psychophysical testing using both soft copy displays and hard copy prints, the reliability and the validly of the proposed method will be further examined and discussed as a new work item within the ISO/TC42/WG18. After this is completed, the practical application of the proposed method will be documented in this standard, along with guidelines for its use.

ACKNOWLEDMENT

The authors would like to thank the High-tech Visual Promotion Center, New Energy and Industrial Development Organization, and Japanese Industrial Standards Committee for their kind supports for this project. The authors also would like to thank to all who kindly participated in psychophysical experiments.

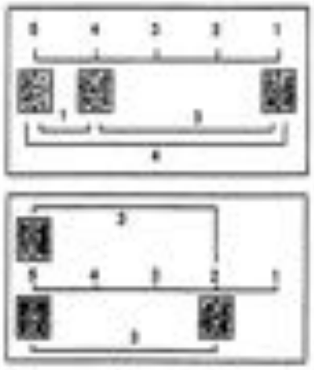


Fig.3 Examples of visual assessment results by triplet comparison

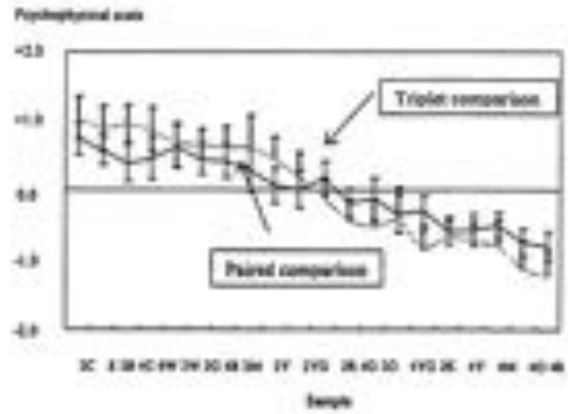


Fig.4 Comparison of the experimental results

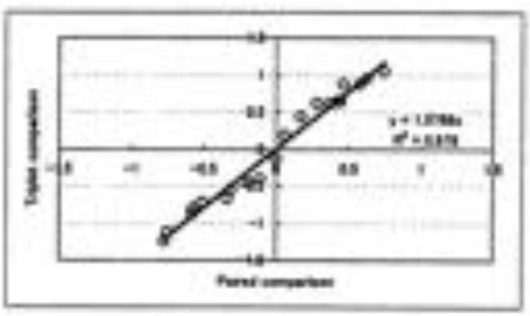


Fig.5 Correlations between two psychophysical methods

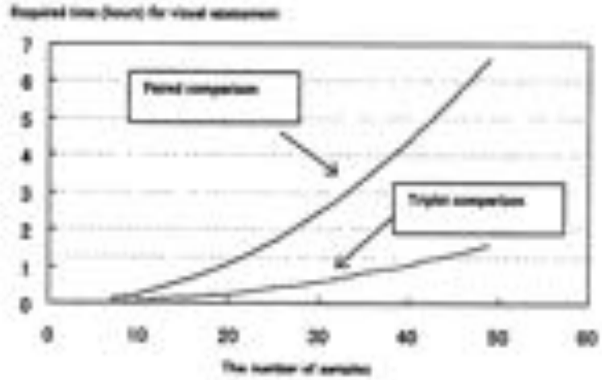


Fig.6 The estimated time required for visual assessment

REFERENCES

1) K.M.Braun, M.D.Fairchild and P.J.Alessi, Viewing techniques for cross-media image comparisons, Color Res.Appl., 21, 6, 1996

2) P.J.Alessi, CIE guidelines for coordinated research on evaluation of colour appearance models for reflection print and self-luminous display image comparisons, Color Res.Appl., 19, 48,1994

3) Multimedia Systems and Equipment –Color Measurement and Management –Part2-1: Colour Management –Default Colour Space – sRGB, IEC61966-2-1(1999)

4) K. Kanafusa, K. Miyazaki, H. Umemoto, K. Takemura and H. Urabe, A Standard Portrait Image and Image Quality Assessment , The proceedings of IS&T PICS 2000 Conference, 317 (2000).

5) K.Miyazaki, K.Kanafusa, H.Umemoto, K.Takemura, H.Urabe, K.Hirai, K.Ishikawa and T.Hatada, A standard portrait image and image quality assessment(Ⅱ) Triplet comparison, The proceedings of SPIE Vol.4300, 309(2001)

---

* Correspondence: ktakemu@den.fujifilm.co.jp; Phone +81-48-462-6856; Fax +81-48-462-6995;
Fuji Photo Film Co., Ltd. Electronic Imaging Products Div.; 3-11-46, Senzui, Asaka, Saitama, 351-8585, Japan

Color Image Segmentation Using Vector Angle-Based Region Growing

Slawo Wesolkowski and Paul Fieguth
Department of Systems Design
University of Waterloo
Waterloo, Ont. N2L 3G1
Canada
s.wesolkowski@ieee.org
pfieguth@rousseau.uwaterloo.ca

ABSTRACT

A new region growing color image segmentation algorithm is presented in this paper. This algorithm is invariant to highlights and shading. This is accomplished in two steps. First, the average pixel intensity is removed from each RGB coordinate. This transformation mitigates the effects of highlights. Next, region seeds are obtained using the Mixture of Principal Components algorithm. Each region is characterized using two parameters. The first is the distance between the region prototype and the candidate pixel. The second is the distance between the candidate pixel and its nearest neighbor in the region. The inner vector product or vector angle is used as the similarity measure which makes both of these measures shading invariant. Results on a real image illustrate the effectiveness of the method.

Keywords: color image segmentation, region growing, highlight invariance, shading invariance

1. INTRODUCTION

In recent years color constancy - the perception of objects in the real world without illumination effects - has been a major concern in the research community of image science and technology. Humans perceive object surfaces in a scene in spite of shading and highlight effects. This paper proposes an algorithm for color image segmentation which is invariant to shading and highlight effects. The Dichromatic Reflection Model [1] is a useful tool for modeling light reflection, which causes essential illumination effects, and will be used as the theoretical foundation of this paper.

Common approaches for color image segmentation are clustering algorithms such as k-means [2] or Mixture of Principal Components [3], however these algorithms do not take spatial information into account. Furthermore, clustering algorithms require prior information regarding number of clusters, which is a difficult or ambiguous task, requiring the assertion of some criterion on the very nature of the clusters being formed. Some progress has been made on this issue, however much experimentation still needs to be done [5].

An alternative set of algorithms exists which uses color similarity and a region-growing approach to spatial information [7]. Region growing is based on the following principles. The algorithm starts with a seed pixel, examines local pixels around it, determines the most similar one, which is then included in the region if it meets certain criteria. This process is followed until no more pixels can be added. The definition of similarity may be set in any number of different ways.

Region growing algorithms have been used mostly in the analysis of grayscale images; however, some significant work has been completed in the color realm by Tremeau et al. [6]. They discuss the segmentation of RGB color regions which are homogeneous in color (i.e., no illumination effects are considered) thus restricting the application domain. They use a set of thresholds when calculating whether a color pixel is part of a region or not, and the Euclidean distance is used as the measure of similarity between two color vectors. In [10], the authors describe a method where pixels are aggregated together when the distances between the candidate pixel and an adjacent pixel belonging to the region, and between the candidate pixel and the region prototype are both less than some experimentally set thresholds. The region prototype is determined by computing the vector mean of the pixels within the region. The similarity is assessed as in [6] using the Euclidean distance; on the other hand, the XYZ space together with normalized xy planes is used (for a total of 5 color planes). However, it is well established [8] that the human perception of color similarity is poorly modeled by the Euclidean distance.

This paper is organized as follows. The Dichromatic Reflection Model, as well as justification for highlight and shading invariances are introduced in Section 2. In Section 3, the region growing algorithm used for color image segmentation is explained in detail. Section 4 describes the results while Section 5 concludes the paper.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

2. COLOR THEORY

The Dichromatic Reflection Model (DRM) was introduced by Shafer [11,12]. The basic premise behind this model is that light is reflected in two distinct components: specular reflection and diffuse reflection. In this paper, the focus will be on inhomogenous dielectric materials such as plastics. The presentation of the DRM follows closely that given in [5]. Light reflected from an object surface (called the color signal) is described as a function of pixel location x and wavelength λ:

$$C^{o}(\lambda,x) = body\,reflection + interface\,reflection \tag{1}$$
$$C^{o}(\lambda,x) = \alpha(x)S^{o}(\lambda)E(\lambda) + \beta(x)E(\lambda)$$

where $E(\lambda)$ is the spectral power distribution of a light source, $S^{o}(\lambda)$ is the spectral-surface reflectance of object o, $\alpha(x)$ is the shading factor and $\beta(x)$ is a scalar factor for the specular reflection term. Sensor responses can be represented with

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \int C^{o}(\lambda,x)\begin{bmatrix} R_R(\lambda) \\ R_G(\lambda) \\ R_B(\lambda) \end{bmatrix} d\lambda \tag{2}$$

where $R_i(\lambda)$ (i=R,G,B) are the camera's spectral sensitivity functions in the visible spectrum. Substituting (1) into (2),

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \alpha(x)\int S^{o}(\lambda)E(\lambda)\begin{bmatrix} R_R(\lambda) \\ R_G(\lambda) \\ R_B(\lambda) \end{bmatrix} d\lambda + \beta(x)\int E(\lambda)\begin{bmatrix} R_R(\lambda) \\ R_G(\lambda) \\ R_B(\lambda) \end{bmatrix} d\lambda = \alpha(x)\vec{c}_b + \beta(x)\vec{c}_i \tag{3}$$

where $\vec{c}_b$ and $\vec{c}_i$ are the body and the illumination color vectors (are normalized to unit vector length). If the sensor outputs R, G, and B are balanced for a white surface, then the illumination is considered to be white light. This is satisfied as long as the spectral sensitivity functions have the same areas. Otherwise a white balancing procedure needs to be carried out [5,12].

In [5], the authors demonstrate how highlight invariance is obtained by applying the following transformation

R' = R - AVG
G' = G - AVG
B' = B - AVG

Since the algorithm described in this paper also uses the vector angle to discriminate between colors, the method is also said to be shading invariant. This has been demonstrated previously [5].

3. REGION GROWING ALGORITHM

A new region growing algorithm is proposed in this paper based on the vector angle color similarity measure and the use of the principal component of the covariance matrix as the "characteristic" color of the region, with the goal of a region-based segmentation which is perceptually-based. The algorithm is presented as follows:

1. Select seed pixels within the image.
2. From each seed pixel grow a region:
   2.1. Set the region prototype to be the seed pixel;
   2.2. Calculate the similarity between the region prototype and the candidate pixel;
   2.3. Calculate the similarity between the candidate and its nearest neighbor in the region;
   2.4. Include the candidate pixel if both similarity measures are higher than experimentally-set thresholds;
   2.5. Update the region prototype by calculating the new principal component;
   2.6. Go to the next pixel to be examined.

This algorithm presents several advantages over other color image segmentation algorithms. First, it is based on the concept of color vector angle. As was shown in the case of MPC [4], the vector angle is a shading-invariant color similarity measure, implying that intensity variations will be discounted in the region growing process, which is clearly not the case when using the Euclidean distance. Secondly, since spatial information is taken into account, regions having a slightly different color, but still spatially distinct, should appear as separate regions due to the region growing process.

Clearly a significant disadvantage of this approach to color image segmentation is the need for seed pixels, and careful consideration needs to be given to the selection of those pixels. In [10], a complex neural network-based approach is used to determine seed pixels. Ikonomakis et al. [9] give an algorithm for selecting such pixels based on the hue values in the HSI space. Alternative approaches include finding those pixels in the color image with the greatest intensity globally, finding points with maximum local intensity or to use the MPC algorithm to select the seeds based on the clustering result. In this paper, the seed points are found by determining the local intensity using the standard second derivative test from calculus.

4. RESULTS

The effectiveness of the color region growing algorithm is demonstrated on a real color scene with different illumination intensities (see Figures 1 and 2). The results of the region growing algorithm are shown in Figures 3 and 4. The seed pixel distribution is shown in Figure 5.

Figure 1: Color scene image with high illumination intensity

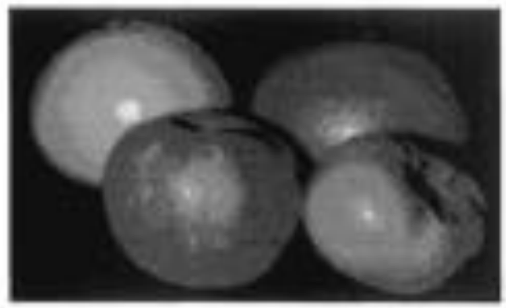


Figure 2: Color scene image with low illumination intensity

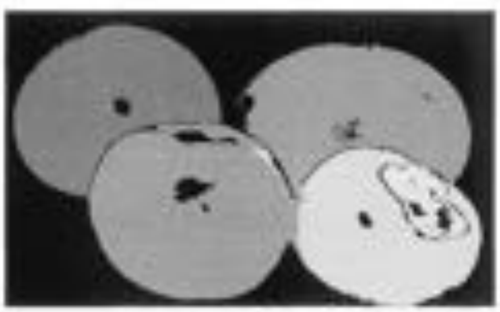


Figure 3: Region growing results for Figure 1

Figure 4: Region growing results for Figure 2

Figure 5: Seed points obtained using the second derivative test

The black area represents that lack of regions since no seed pixels existed there and no regions were able to grow into those areas. 8 regions were found in Figure 1 and 6 regions in Figure 2. The results in Figures 3 and 4 clearly show that most of the highlights have been subsumed into their respective surfaces. However, some highlights still do remain. There is two possible causes for this: (1) the parameters of the algorithm could be further adjusted and (2) the highlight areas are saturated with white light. For the first case, the algorithm was run on both images with an angle tolerance of 1°. Experimentation showed that a higher tolerance would subsume more of the highlight areas (e.g., the two fruit regions near the bottom of the image merged to a greater extent). Given the results in [5], parameter estimation seems to be the most significant factor contributing to the non-inclusion of parts of the highlight areas into their corresponding regions. In [5], the results were based on the MPC algorithm and did not depend on spatial constraints. Furthermore, the number of classes was fixed and therefore all non-black pixels had to be classified as one of the regions whereas in the region growing approach only pixels satisfying aggregation criteria were included in the final partition. A low number of the pixels in Figures 1 & 2 is fully saturated, and, therefore, in this case, this does not seem to be a significant factor in the results although it does contribute to the segmentation results.

5. CONCLUSIONS

A region growing algorithm that is invariant to shading and highlights has been presented. The preliminary results obtained with this algorithm show that a region growing framework is an alternative to global clustering-type algorithms such as MPC. Further work is necessary in setting the parameters appropriately and devising region merging algorithms to handle pixel variations due to saturated highlights. Furthermore, a comprehensive quantitative comparison with other methods is necessary.

ACKNOWLEDGMENTS

The authors would like to thank Prof. Tominaga of the Osaka Electro-Communications University in Japan for the use of the color image.

REFERENCES

1. S. Tominaga, "Dichromatic Reflection Models for a Variety of Materials," *Color Research and Application*, Vol. 19, No. 4, pp.277 - 285,1994.
2. R.J.Schalkoff, *Pattern Recognition: Statistical, Structural and Neural Approaches*. John Wiley & Sons, Inc., New York, 1992.
3. S. Wesolkowski, M.E. Jernigan, R.D. Dony, "Global Color Image Segmentation Strategies: Euclidean Distance vs. Vector Angle," in Y.-H. Hu, J. Larsen, E. Wilson and S. Douglas (eds.), *Neural Networks for Signal Processing IX*, IEEE Press, Piscataway, NJ, 1999, pp. 419-428.
4. S. Wesolkowski, Color Image Edge Detection and Segmentation: A Comparison of the Vector Angle and the Euclidean Distance Color Similarity Measures, Master's thesis, Systems Design Engineering, University of Waterloo, Canada, 1999.
5. S. Wesolkowski, S. Tominaga, and R.D. Dony, "Shading and Highlight Invariant Color Image Segmentation Using the MPC Algorithm," *SPIE Color Imaging: Device-Independent Color, Color Hardcopy, and Graphic Arts VI*, San Jose, USA, January 2001, pp. 229-240.
6. A. Tremeau, and N. Borel, "A Region Growing and Merging Algorithm to Color Segmentation," *Pattern Recognition*, vol. 30, no. 7, pp. 1191-1203, 1997.
7. Robert M. Haralick and Linda G. Shapiro. *Computer and Robot Vision*, vol. 1, Addison-Welsey: Reading, MA, 1992.
8. L. Shafarenko, M. Petrou, and J. Kittler, "Automatic watershed segmentation of randomly textured color images," *IEEE Trans. on Image Processing*, vol. 6, pp. 1530-1544, November 1997.
9. N. Ikonomakis, K. N. Plataniotis, and A. N. Venetsanopoulos, "Unsupervised Seed Determination For A Region-Based Color Image Segmentation Scheme," *IEEE International Conference on Image Processing*, Vancouver, Canada, 2000.
10. W. Wang; C. Sun; and H. Chao. "Color image segmentation and understanding through connected components," *IEEE Int'l Conference on Systems, Man, and Cybernetics*, vol. 2, pp. 1089 -1093, 1997.
11. S.A. Shafer, "Using color to separate reflection components," TR-136, Computer Sciences Dept., University of Rochester, NY, April 1984.
12. B.A. Wandell, *Foundations of Vision*, Sinauer Associates, Inc. Publishers, Sunderland, MA, 1995.

Mathematical analysis of color combination and color composition of images

KOBAYASI Mituo*, SUZUKI Takuzi**, TAKAHASHI Minori*
*The University of Electro-Communications; **National Museum of Japanese History

ABSTRACT

This study describes mathematical methods and measures valuable for revealing color features of an image, which are applied to computational analysis of several masterpieces of paintings.
Keywords: color aesthetics, painting, computational analysis, color combination, color composition, color contrast

1. INTRODUCTION

Digital images of fine art, especially images of fine art of paintings, are significant resources for computational analysis of color aesthetics. Several mathematical and computational methods were applied to extract color features of an image [1-6], which tells that the mathematical measures are effective to explain the usage of colors in painting arts. This paper introduces the following three major methods for :

1) analysis of color combination in a 3-dimensional color space,
2) analysis of color composition on a 2-dimensional picture plane,
3) analysis of color contrast of juxtaposed colors.

2. PREREQUISITE FOR COMPUTATIONAL ANALYSIS

1) Standardization of color values: Paintings selected from printed art books are scanned and stored in a computer system. The recorded device-dependent RGB values of color are transformed into device-independent values in a standard uniform color space (e.g. CIELUV). 2) Extraction of representative colors (Fig.1): A scanned image a of painting consists of a vast number ($10^4 \sim 10^5$) of colors. A small number ($10^1 \sim 10^2$) of representative colors are extracted by means of the successive *K*-means method, to obtain a macroscopic structure of the image. Source images for our analysis always consist of finite numbers of representative colors (up to 20 colors).

3. METHODS AND MEASURES FOR ANALYSIS

A software system specially designed for multiple color analysis of images have been developed, in which different kinds of color specification systems and color spaces are available (CIELUV, CIELAB, OSA-UCS, Munsell, NCS, etc.). The system is capable of mutual transformations of color values between any pairs of color spaces. Various aspects of a color image can be extracted and observed by multilateral visualization of the color distribution (Fig.2). The following computational analysis have been performed using several color spaces. Most of the results of the analysis were stable independent of color spaces chosen.

3.1 Analysis of color combination

In the present study, color combination of an image implies: what kind of colors are used, and how much? In other words, what are the constituent colors, and how much is the aerial proportion of each constituent colors to the whole image? Color combination of an image can be visualized by its color distribution in a color space. A deviation ellipsoid roughly

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

represents the size and the shape of a color distribution. The size, small or large, corresponds to the degree of contrast. The shape and the direction correspond to the structure of color combination. In this sense the deviation ellipsoid can be named as "color combination ellipsoid". Comparing the two paintings in Fig.3, it can be observed that the painting by Picasso is monochromatic (camaïeu), while Kandinsky's is polychromatic, which are clearly represented by the differences in the size, and in the shape and the direction of the deviation ellipsoids.

3.2 Analysis of color composition

Color composition of an image designates: where on the picture plane is each constituent color placed? For instance, is a constituent color clustered in one place or scattered over the picture plane? A deviation ellipse is a valuable measure to extract and visualize the characteristics of the color placement of an image. Two kinds of deviation ellipses are defined : color placement of a color and its deviation ellipse (c.p.ellipse), and centers of color placements and their deviation ellipse (color composition ellipse). Observation of the all c.p.ellipses and the color composition ellipse in Fig.4 tells that the color composition of Picasso's painting is dynamic, whereas the painting by Klee is well balanced, or symmetric.

3.3 Analysis of color contrast of justaposed colors

Large color differences in an image draws our attention. Contrast of justaposed colors of an image can be measured by computing the color differences (ΔE^* and its components ΔL^*, ΔC^*, ΔH^*) of justaposed colors. Obtained color differences can be visualized and observed by generating color difference images . In Fig.5, note that in case of Caravaggio the ΔL^*-image is most similar to the ΔE^*-image, in case of C.Monet, ΔC^*-image and R.Dufy, ΔH^*-image, which implies Caravaggio utilizes lightness contrast, Monet uses contrast in chroma, and Dufy emphasizes hue contrast in each work presented here.

4. SUMMARY

Mathematical methods and measures for analyzing color combination and color composition of images are introduced, which revealed color features of fine art of paintings. The methods and the measures introduced can be applied to other fields, such as image retrieval, digital archives, color design and color education.

REFERENCES

[1] M.Kobayasi, T.Suzuki: Quantitative analysis of color features in paintings -- classification based on distance of color distribution in color space --, Proceedings of the 8th Congress of AIC, vol.1, pp.367-370(1997-5).

[2] M.Kobayasi: Classification of color combinations based on distance between color distributions, Proceedings of IEEE International Conference on Image Processing (ICIP), Kobe, vol.III, pp.70-74 (1999-10).

[3] M.Kobayasi: Analysis of color combination in fine art paintings, Proceedings of International Symposium on Multispectral Imaging and Color Reproduction, Chiba, pp.139-142(1999-10).

[4] M.Kobayasi: Analysis of colors in art thorough distribution of color difference, Proceedings of Oslo International Colour Conference, Oslo, pp.147-148,(1998-10).

[5] M.Kobayasi: Quantitative analysis of color in fine art paintings by means of justaposed color difference, SPECTRUM, Journal of the Colour Society of Australia, vol.14, no.3 pp.3-7(2000-12).

[6] M.Kobayasi, T.Suzuki: Characterization of paintings by means of juxtaposed color difference, Color Forum JAPAN '99, pp.33-36(1999-11).

* phone 81 424 43-5324; fax 81 424 43-5334, The University of Electro-Communications, 1-5-1 Chofugaoka, Chofu-shi, Toyo 182-8585, JAPAN

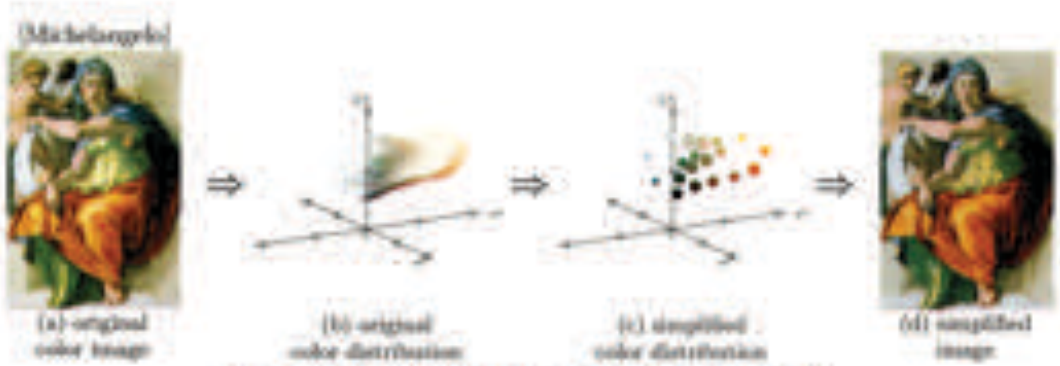


Figure 1: extraction of representative colors (CIELUV)

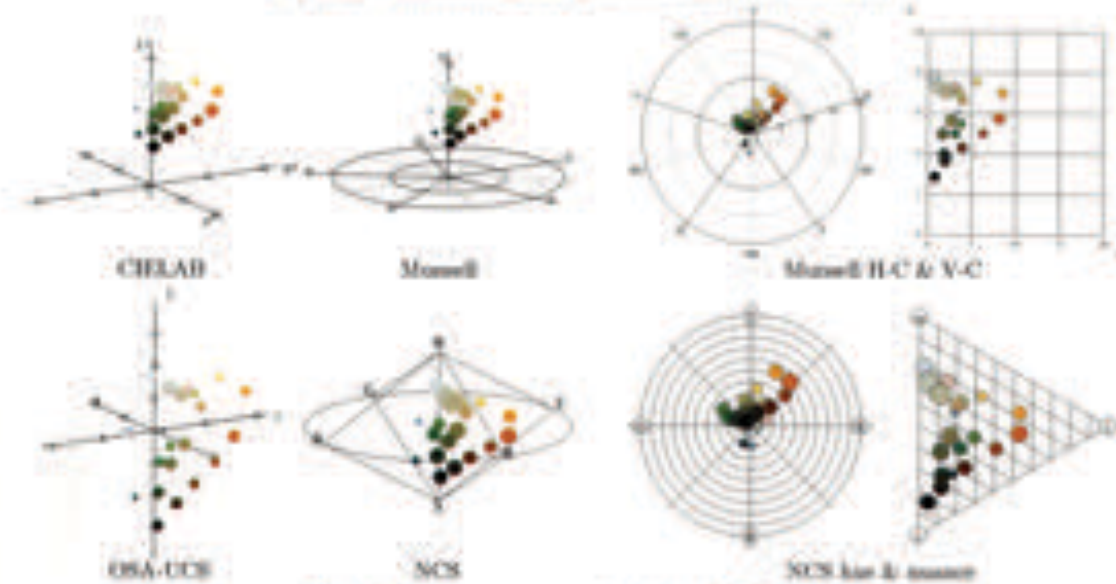


Figure 2: various presentation of color distribution

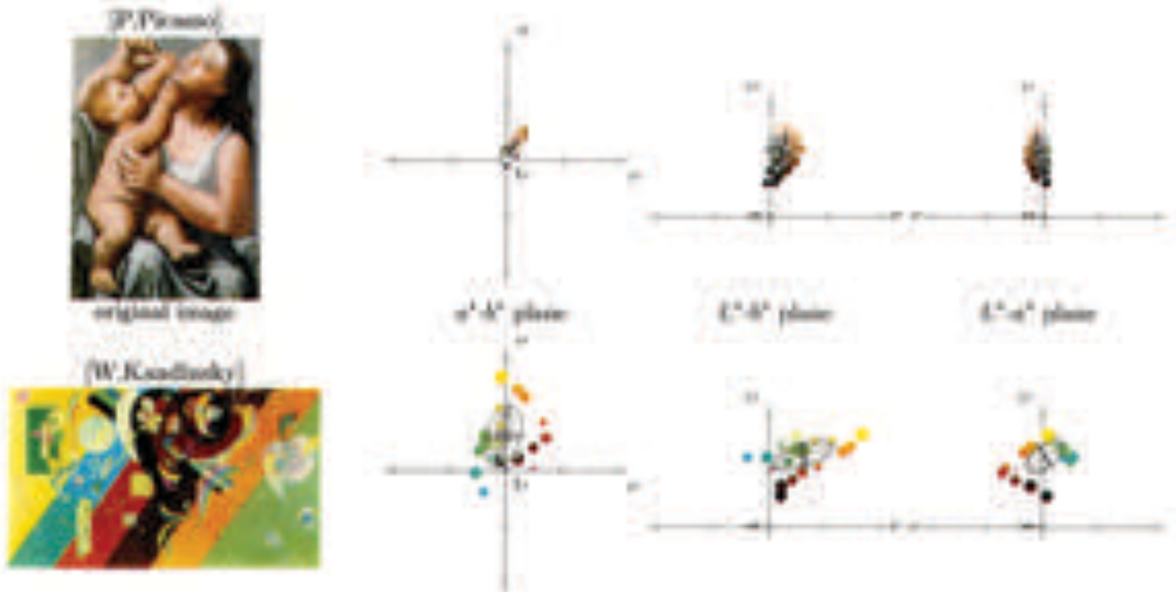


Figure 3: color combination & deviation ellipsoid

Figure 4: color composition & deviation ellipse

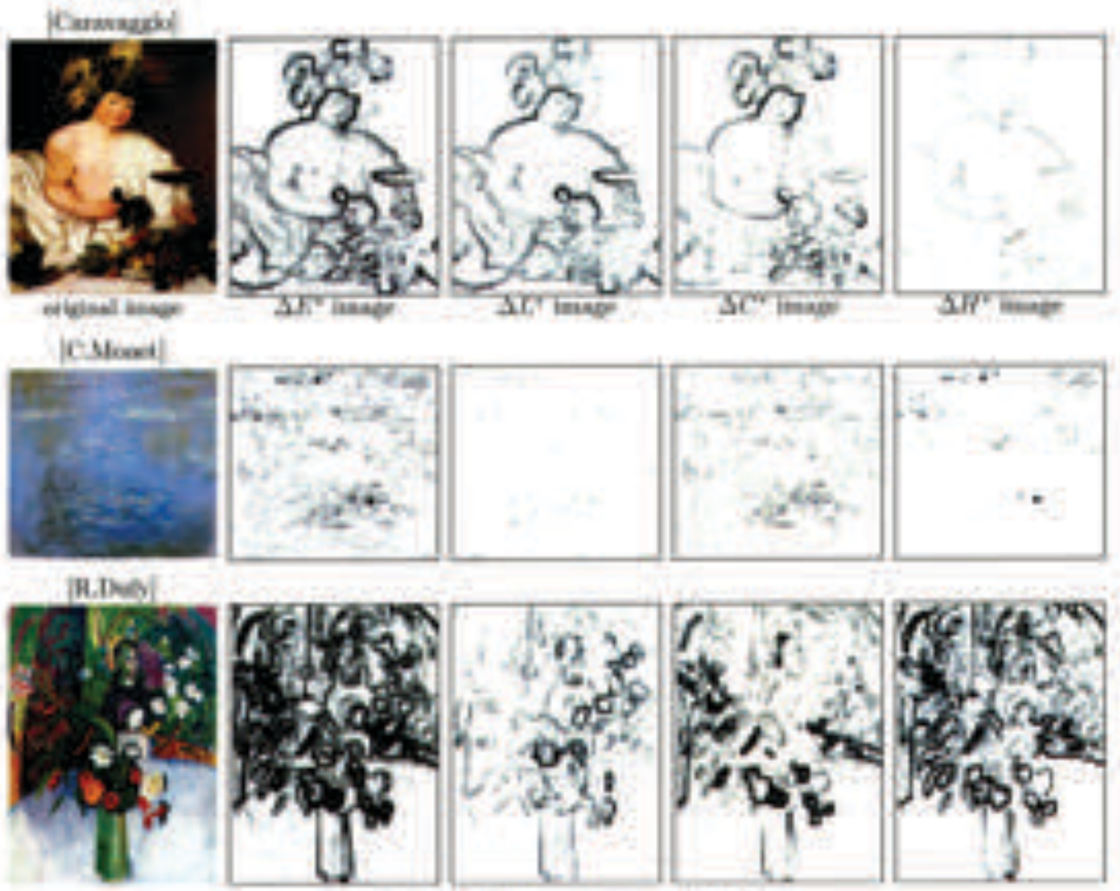


Figure 5: color difference image (CIELUV)

Illuminant Estimation of Natural Scene Using the Sensor Correlation Method

Shoji Tominaga, Atsushi Ishida, Brian A. Wandell*
Osaka Electro-Communication University
Department of Engineering Informatics, Neyagawa, Osaka 572-8530, Japan
* Stanford University, Image Systems Engineering, Stanford, CA 94305, USA

ABSTRACT

This paper describes practical algorithms and experimental results using the sensor correlation method. We improve the algorithms to increase the accuracy and applicability to a variety of scenes. First, we use the reciprocal scale of color temperature, called "mired", in order to obtain perceptually uniform illuminant classification. Second, we propose to calculate correlation values between the image color gamut and the reference illuminant gamut, rather than between the image pixels and the illuminant gamuts. Third, we introduce a new image scaling operation with an adjustable parameter to adjust overall intensity differences between images and find a good fit to the illuminant gamuts. Finally, the image processing algorithms incorporating these changes are evaluated using a real image database.

1. INTRODUCTION

The estimation of scene illumination from image data is important in many fields of color science, computer vision, image processing, color imaging, image reproduction, and image database retrieval. Given the inescapable limitation on estimating the illuminant spectral-power distribution, it is reasonable to classify the illuminant as belonging to one of several likely types. The classification approach rather than the estimation approach is simple for data processing, stable for computation, and appropriate for applications such as photography. In a previous paper [1], we built on earlier illuminant classification methods [2] to estimate the illuminant color temperature. Our illuminant classification was to restrict the estimation to a set of blackbody radiators. Color temperature classification provides simple specification of many common light sources. That , which we called sensor correlation, used a scaled version of the red and blue sensor responses to classify scene illuminant by color temperature.

The present paper describes practical algorithms and experimental results using the sensor correlation method. We improve the algorithms to increase the accuracy and applicability to a variety of scenes. The wide range of application of the improved algorithms is confirmed using a data set of natural images under different illuminants.

2. ILLUMINANT SET AND COLOR TEMPERATURE

Blackbody radiators are used frequently to approximate scene illuminants in commercial imaging, and we classify scene illuminants according to their blackbody color temperature. The color temperature of a light source is defined as the absolute temperature (in kelvin K) of the blackbody radiator. For an arbitrary illuminant, the correlated color temperature is defined as the color temperature of the blackbody radiator that is visually closest to the illuminant. The correlated color temperature of a scene illuminant can be determined from the CIE (x, y) chromaticity coordinates of the measured spectrum [3]. The spectral radiant power of the blackbody radiators as a function of temperature T (in K) is described by the formula

$$M(\lambda) = c_1 \lambda^{-5} \{\exp(c_2/\lambda T) - 1\}^{-1}, \qquad (1)$$

where $c_1 = 3.7418 \times 10^{-16}$ Watts-m^2 and $c_2 = 1.4388 \times 10^{-2}$ Watts-K and λ is wavelength (m). Differences in the scale of color temperature do not correspond to equal perceptual color differences. Judd's experimental report [4] suggested that visually equally significant differences of color temperature correspond more closely to equal differences of reciprocal color temperature. The unit on the scale of micro-reciprocal degrees ($10^6 K^{-1}$) is called "mired". The blackbody radiators are written as a function of reciprocal temperature $T^{-1} (= 10^6/T)$ as

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

$$M(\lambda) = c_1 \lambda^{-5} [\exp(c_2 T^{-1}/\lambda) - 1]^{-1}. \quad (2)$$

3. DEFINITION OF ILLUMINANT GAMUTS

The scene illuminant classification algorithms use a set of reference illuminant gamuts to define the anticipated range of sensor responses. To create the reference illuminant gamuts, we used a database of surface-spectral reflectances. The image data are obtained using a Minolta camera (RD-175) with known sensor responsivities. Hence, the sensor responses can be predicted using

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \int S(\lambda) M(\lambda) \begin{bmatrix} r(\lambda) \\ g(\lambda) \\ b(\lambda) \end{bmatrix} d\lambda, \quad (3)$$

where $S(\lambda)$ is the surface-spectral reflectance function and $r(\lambda)$, $g(\lambda)$, and $b(\lambda)$ are the spectral-sensitivity functions and $M(\lambda)$ is the scene illuminant. The Minolta camera can be operated in one of two modes. One mode is appropriate for imaging under tungsten illumination (say illuminant A), and a second mode is appropriate for imaging under daylight (D65). Operating in the high blue sensor gain improves the performance of the scene illuminant classification. Hence, all analyses throughout this paper were performed in this mode. The scene illuminants for classification are blackbody radiators spanning 118 mired (8500K) to 400 mired (2500K) in 23.5 mired increments.

The illuminant gamuts are defined on the RB plane. The (R, B) sensor plane is a reasonable choice for the blackbody radiators because their illuminant gamuts differ mainly with respect to this plane. The boundary of the illuminant gamut is obtained from the convex hull of the set of (R, B) points. Figure 1 shows the illuminant gamuts of the blackbody radiators in the (R, B) plane in two ways. In Figure 1 (left) gamuts are depicted at equal spacing in reciprocal color temperatures, while in Figure 1 (right) gamuts are depicted in equal spacing of color temperatures, spanning from 2500K to 8500K in 500K increments. The illuminant gamuts separated by equal reciprocal color temperature steps are better separated than those separated in equal color temperature steps.

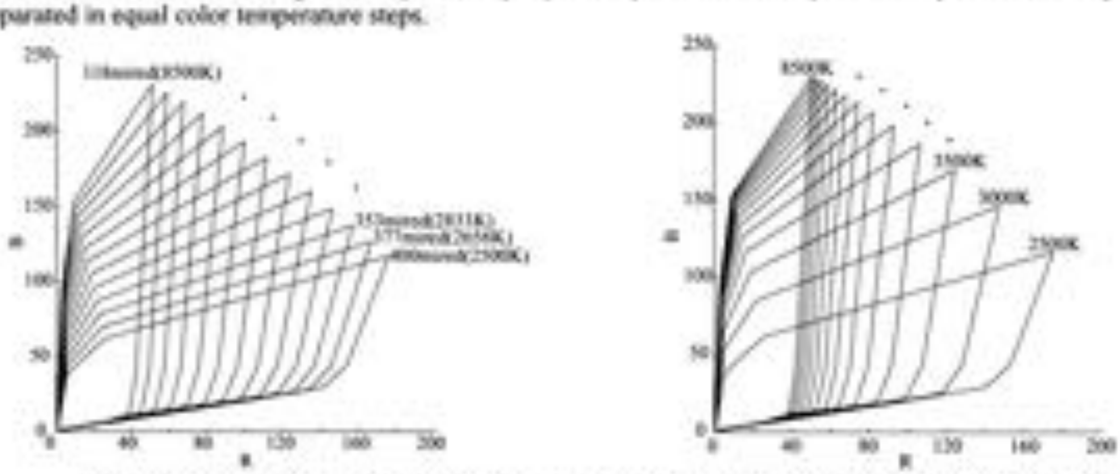


Figure 1 Illuminant gamuts for blackbody radiators in equal intervals of 23.5 mired (left) and 500K (right)

4. GAMUT-BASED ILLUMINANT CLASSIFICAITON

4.1 Image gamut

In the pixel-based classification proposed in a precious paper [1], image data are converted to the binary histogram in which holes and sparse clusters are possible. Therefore it is inevitable that the correlation function is sometimes unstable and not unimodal. To solve this problem, we propose using the convex hull of the image data to determine an image gamut in the RB plane. A correlation value is then computed between the image gamut and the illuminant gamut. The gamut-based correlation differs from the pixel-based correlation in that the calculation presumes that interior points might all have been present in the scene. A practical correlation value is computed from the area of the gamuts as

$$r_i = A_{Ii} \Big/ \sqrt{A_I A_i}\,, \qquad (i=1, 2, \ldots, 13) \tag{4}$$

where A_I is the area of an image gamut, A_i are the area of the i^{th} illuminant gamut, and A_{Ii} is the area of the overlap between the image and illuminant gamuts.

For example, Figure 2 shows the synthesized image consisting 18 chromatic patches of the Macbeth Color Checker. Figure 3 shows the plot of the (R, B) pixel values for Figure 2 and the image gamut, where the solid curve represents the convex hull of (R, B) values and the surrounded region by this curve represents the image gamut.

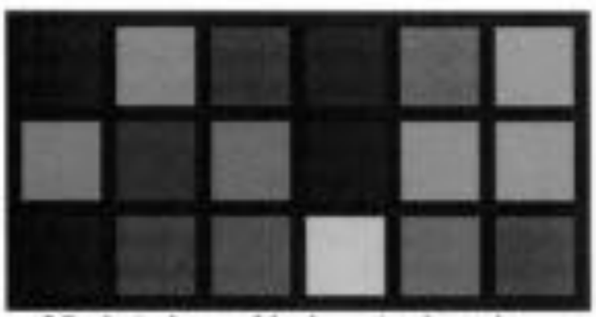


Figure 2 Synthesized image of the chromatic color patches.

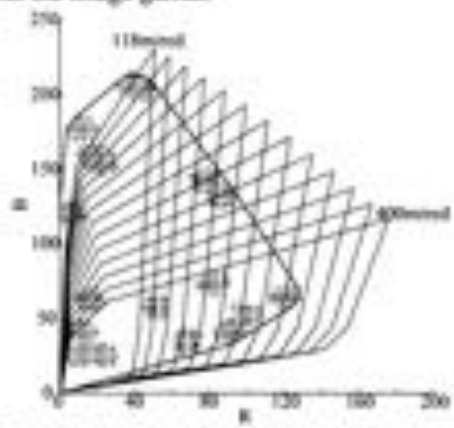


Figure 3 Plot of the (R, B) pixel values and image gamut.

4.2 Image scaling

The sensor correlation method requires a scaling operation that compensates for intensity differences between images. This scaling operation is equivalent to placing a neutral density filter in the light path or adjusting the exposure duration. Scaling preserves the shape of the image gamut and the relative intensity information within an image. To scale the data, we define I_i as the i^{th} pixel intensity,

$$I_i = \left(R_i^2 + G_i^2 + B_i^2\right)^{1/2} \tag{5}$$

and let I_{max} be the maximal value of the intensity over the image. Then to scale the intensity across different images, we divide the sensor RGB values by the maximum intensity,

$$(R, G, B) = \left(R/I_{max}, G/I_{max}, B/I_{max}\right). \tag{6}$$

Bright image regions contribute much the illuminant information. This is especially true if nearly white surfaces are present in the scene, in which case these image regions mainly determine the color temperature estimate. However, if there is no bright surface, the scaling operation converts dark surfaces into bright image regions, and the estimation accuracy decreases. Hence, the selection of a proper scaling parameter is an important element of the algorithm.

In the initial formulation of the sensor correlation algorithm, we chose the scaling parameter based on a set of properties of the brightest pixels. Since then, we have discovered a better normalization method that is illustrated in Figures 4 and 5. Figure 4 shows the convex hulls of the (R,B) pixel values of the image in Figure 2. These convex hulls are each scaled by a different normalization parameter, k. A set of these image gamuts were used to generate the correlation functions shown in Figure 5; each curve shows the function for a different parameter k. To select a value k, we compute all of these gamuts and then choose the peak correlation over all the functions. In this example, the peak correlation occurs for $k=0.8$ and a reciprocal color temperature of 212 mired (4722K). This normalization procedure can be applied to any image.

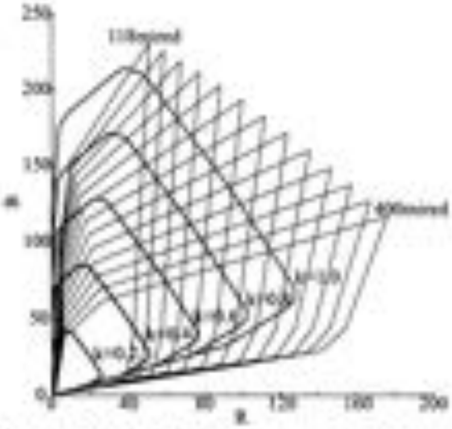


Figure 4 Convex hulls with different normalization parameter.

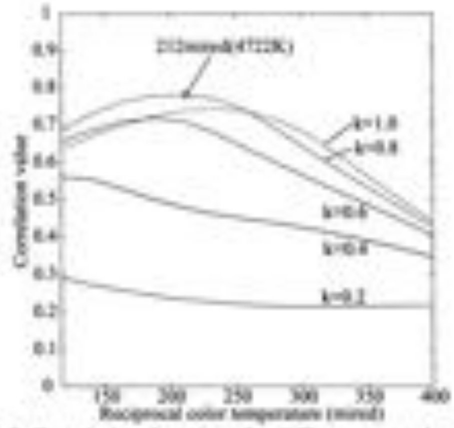


Figure 5 Correlation functions for different normal parameters.

5. EXPERIMENTAL RESULTS

We have evaluated the proposed algorithm using a database of images for indoor scenes. Figure 6 shows a set of 12 images of scenes photographed under a halogen lamp in our laboratory. This illuminant has a correlated color temperature near 3100K. The estimate of scene illuminant was obtained and the difference between the estimate by the image and the direct measurement by the spectroradiometer was calculated in the reciprocal color temperature unit (mired). The proposed modifications improve the estimates for all images except image 5, where bright texture on the shirt has random fluctuations of pixels. The difference between estimates and direct measurement is 6.3 mired on average.

Figure 6 Set of images of indoor scenes under a halogen lamp.

6. CONCLUSIONS

We have described improvements of our research on the sensor correlation method for illuminant. First, the reciprocal scale of color temperature should be used to achieve perceptually uniform illuminant classification. Second, we proposed that a gamut-based correlation value should be calculated between an image gamut and the reference illuminant gamuts. Third, we have proposed a new normalization operation that makes classification performance independent of image intensity. Finally, the applicability of the improved algorithm was shown using real images.

REFERENCES

1. S. Tominaga, S. Ebisui and B.A. Wandell, "Scene illuminant classification: Brighter is better" *J. Opt. Soc. Am A*, vol. 18, pp.55-64, 2001.
2. G.D. Finlayson, P.M. Hubel, and S. Hordley. "Color by correlation," *The 4th Color Imaging Conference*. 1997.
3. G. Wyszecki and W.S. Stiles, *Color science: concepts and methods, quantitative data and formulae*, Wiley, 1982.
4. D.B. Judd, "Sensibility to color-temperature change as a function of temperature," *J. Opt. Soc. Am.*, vo.23, pp.127-134, 1933.

A Computer Graphic System for Rendering Gonio-Apparent Colors

Gary W. Meyer, Harold B. Westlund, Peter A. Walker, and Joseph P. Wingard*

Department of Computer and Information Science
University of Oregon
Eugene, OR 97403

ABSTRACT

A computer graphic system has been developed that allows a color scientist to evaluate the appearance of gonio-apparent colors. Reflection modeling software is used to define a BRDF from existing computer graphic reflection models and standard appearance measurements for gloss and metallic travel. A visualization program allows the user to examine the BRDF that results from reflection modeling. Real-time software and hardware can be employed to adjust the BRDF and display a surface with the specified reflection properties. A high quality rendering system is available to make individual pictures that incorporate complex lighting and reflection effects.

Keywords: Color, Computer Graphics, Reflectance Modeling

1. INTRODUCTION

A system has been developed for making accurate computer graphic pictures of metallic and pearlescent automotive finishes. The system is different from other computer graphic rendering programs in that it characterizes surface reflection by using industry standard gloss and multi-angle spectral measurements of gonio-apparent surfaces. These instrumental measurements are used to construct a bi-directional reflectance distribution function (BRDF) that models both the color and the spatial distribution of the light reflected from a surface. The system includes a visualization tool that allows the analyst to see the shape of the BRDF at a variety of different incidence angles. The appearance of a dynamic object, to which the BRDF has been attached, can be seen by using recently developed real-time shading techniques. In addition, a public domain rendering program has been extended to produce static pictures of objects with metallic or pearlescent BRDF's in complex lighting environments.

2. BRDF VISUALIZATION

The spatial distribution of the light reflected from an object's surface plays a key role in determining the appearance of that object. To assist in evaluating the shape of the reflectance distribution, a BRDF visualization tool was developed as part of the system for rendering gonio-apparent colors. The BRDF to be displayed could be the result of making a surface reflection measurement with a gonio-photometer. The BRDF could also be generated by evaluating an analytically defined reflectance function. A software library of such reflection models from within the field of computer graphics is available as part of the system.

The BRDF visualization tool was created using a commercially available visualization package from Advanced Visual Systems (AVS) called AVS Express. Express utilizes a dataflow paradigm in which the user employs a network editor to route data through modules specifically created for the visualization application. Each module performs a transformation on the data which is ultimately passed to a final three dimensional viewing module. Example pictures produced by the BRDF visualization tool are shown in Figures 1 and 2. The user can select different reflection models, change the direction of the incoming light, modify parameters for the reflection models, and alter the color, transparency, and resolution of the reflectance distribution.

* Further author information:
G.W.M.: E-mail: gary@cs.uoregon.edu
H.B.W.: E-mail: westlund@cs.uoregon.edu
J.P.W.: E-mail: joseph@cs.uoregon.edu

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

3. APPEARANCE BASED REFLECTION MODELING

The most important part of the system is the construction of a BRDF from gloss and multi-angle spectral measurements.[1] A "virtual glossmeter" has been used to find the correspondence between standard gloss measurements[2,3] and the parameters of an existing computer graphic reflection model.[4] Given the source aperture for a standard glossmeter, the virtual glossmeter subdivides this aperture and evaluates the computer graphics reflection model using light incoming through one of the subdivisions. Integration across the detector aperture computes the gloss for this small portion of the source aperture. Repeating this process across the entire source aperture and summing up the component gloss values produces one data point for a function relating standard gloss to the parameters of the reflection model.

Multi-angle spectral measurement at three critical aspecular angles has been proven sufficient to characterize the "flop" of metallic and pearlescent paint.[5,6] A BRDF to model this subsurface reflection was constructed by interpolating the three aspecular measurements with second order polynomials. The cross section of the specular lobe was assumed to be symmetrical allowing these in-plane polynomials to be used to determine the out-of-plane portions of the BRDF. A BRDF produced in this manner for a blue metallic paint is shown in Figure 1. If this paint has a clear coat with gloss of 10, the first surface BRDF produced using the virtual glossmeter must be combined with the subsurface BRDF generated from the interpolating polynomial. The result is shown in Figure 2.

4. REALISTIC RENDERING

Creating a photorealistic computer graphic picture of the gonio-apparent surface is the final step in the rendering process. The reflectance properties of the surface, including both first surface gloss and subsurface flop effects, are determined by the BRDF. Recent developments in real-time shading make it possible to display objects with arbitrary BRDF's using consumer level PC graphics cards.[7,8] A program that utilizes the separable transform approach of Kautz and McCool has been integrated into the gonio-chromatic rendering system. To adjust the BRDF that is used by the real-time shading program, an interactive application has been developed that allows manipulation of the aspecular measurements that determine the flop of a metallic or pearlescent paint (Figure 3).

While gonio-chromatic objects may be rotated in real-time using the above programs, only limited global illumination phenomena can be simulated. To incorporate area light sources and complex inter-reflections a more sophisticated rendering program is required. The public domain Radiance program[9,10] has been modified so that it can make pictures of objects with complex BRDF's, including those that model gonio-apparent surfaces. Figures 4 and 5 show metallic and pearlescent colors that were produced using the modified Radiance program and BRDF's that incorporate gloss and flop effects.

5. CONCLUSIONS

Taken together, the components of this system make it easy for a color scientist to explore the appearance of new and existing gonio-apparent paints and surface coatings. Starting with a set of real or hypothetical multi-angle measurements, the analyst can interactively adjust individual data points or the entire reflectance distribution using the program shown in Figure 3. After specifying a gloss for the first surface reflection, the reflectance model in Section 3 can be employed to determine the spatial distribution of the reflected light. The shape of this BRDF can be examined using the visualization tool shown in Figures 1 and 2, and the appearance produced by the BRDF can be displayed in real-time using techniques mentioned in Section 4. After several quick iterations, a high quality final rendering can be made that includes complex lighting and inter-reflection effects.

This system illustrates that computer graphic hardware and software have now advanced to the point where computer aided color appearance design is possible.[11] In the 1960's, computer graphic terminals first demonstrated that it was feasible to display the outline of three-dimensional objects in real-time. This led to the development of computer aided geometric design techniques that are currently used by engineers, architects, and other designers. Within the last ten years the same real-time computer graphic capability has been developed for the display of complex surface reflection. As shown in this paper, these advances in computer graphic rendering can provide color scientists with computer aided color appearance design tools similar to those available in the geometric design field for over thirty years.

ACKNOWLEDGMENTS

The authors would like to thank David Alman and Allan Rodrigues of DuPont Automotive Products for providing paint samples and reflectance measurements. This work was funded by the National Institutes of Standards and Technology.

REFERENCES

1. Westlund, Harold B. and Gary W. Meyer, Applying Appearance Standards to Light Reflection Models, *to appear in Proceedings of SIGGRAPH'01*, 2001.
2. Hunter, Richard S. and Dean B. Judd, Development of a Method of Classifying Paints According to Gloss, *ASTM Bulletin*, No. 97, p. 11, March 1939.
3. ASTM D 523-89, Standard Test Method for Specular Gloss, *Annual Book of ASTM Standards*, Vol. 06.01, Philadelphia, PA, 1999.
4. Ward, Gregory J., Measuring and Modeling Anisotropic Reflection, *Computer Graphics*, Vol. 26, No. 2, pp. 265-272, July 1992.
5. Alman, David H., Directional Color Measurements of Metallic Flake Finishes, *Proceedings of the ISCC Williamsburg Conference on Appearance*, pp. 53-56, 1987.
6. Rodrigues, Allan B. J., Measurement of Metallic and Pearlescent Colors, *Die Farbe*, Vol. 37, pp 65-78, 1990.
7. Heidrich, Wolfgang and Hans-Peter Seidel, Realistic, Hardware-Accelerated Shading and Lighting, *Proceedings of SIGGRAPH'99*, pp. 171-178, 1999.
8. Kautz, Jan and Michael D. McCool, Interactive Rendering with Arbitrary BRDFs Using Separable Approximations, in *Tenth Eurographics Workshop on Rendering*, pp. 281-292, June 1999.
9. Ward, Gregory J., Francis M. Rubenstein, and Robert D. Clear, A Ray Tracing Solution for Diffuse Interreflection, *Computer Graphics*, Vol. 22, No. 4, pp. 85-92, 1988.
10. Ward Larson, Greg and Rob Shakespeare, *Rendering with Radiance: The Art and Science of Lighting Visualization*, Morgan Kaufmann, 1998.
11. Meyer, Gary W., Computer Aided Color Appearance Design, *Proceedings of CGIP 2000: First International Conference on Color in Graphics and Image Processing*, pp. 195-200, 2000.

Figure 1. BRDF for a blue metallic paint.

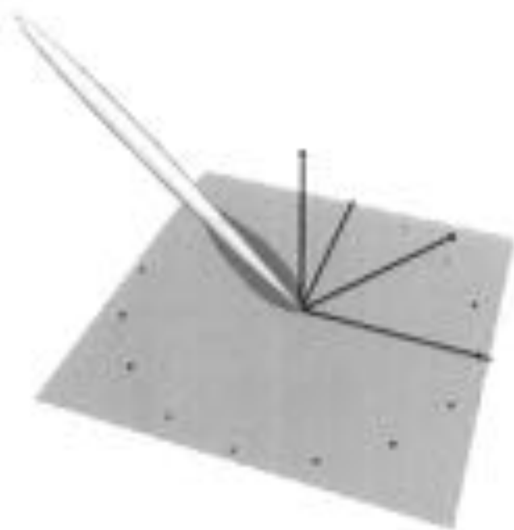


Figure 2. BRDF for a blue metallic paint with ASTM standard gloss of 10.

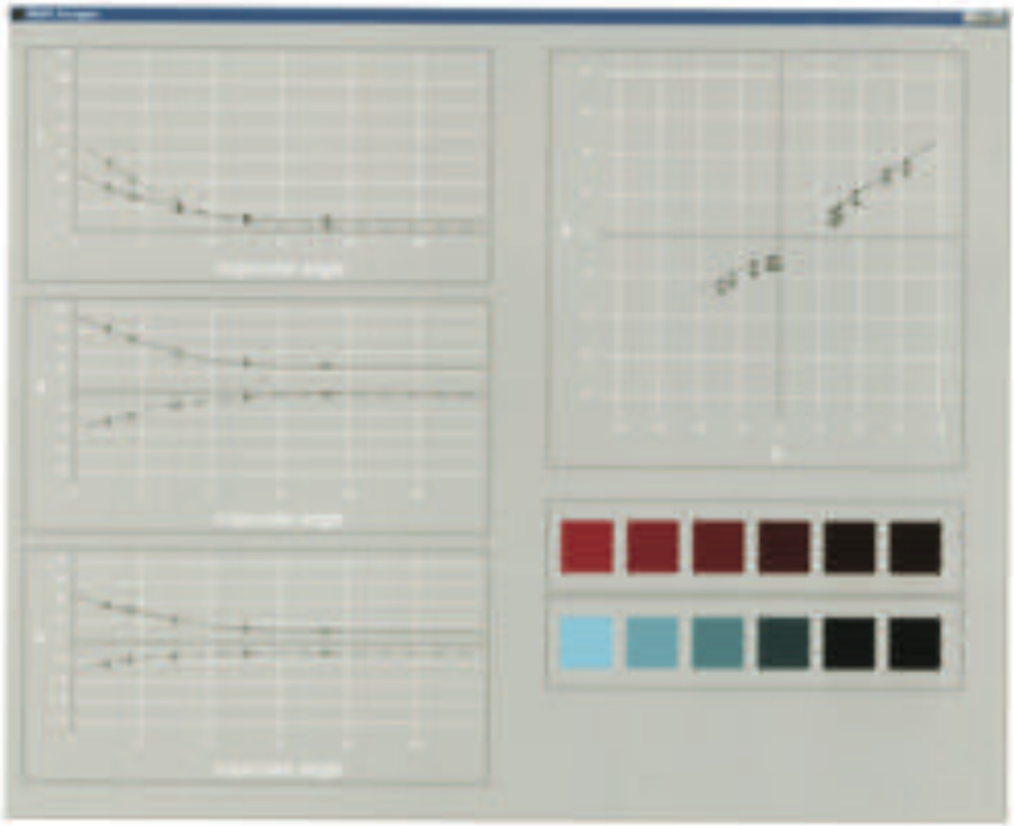


Figure 3. Interactive program used to plot and make adjustments to aspecular measurements.

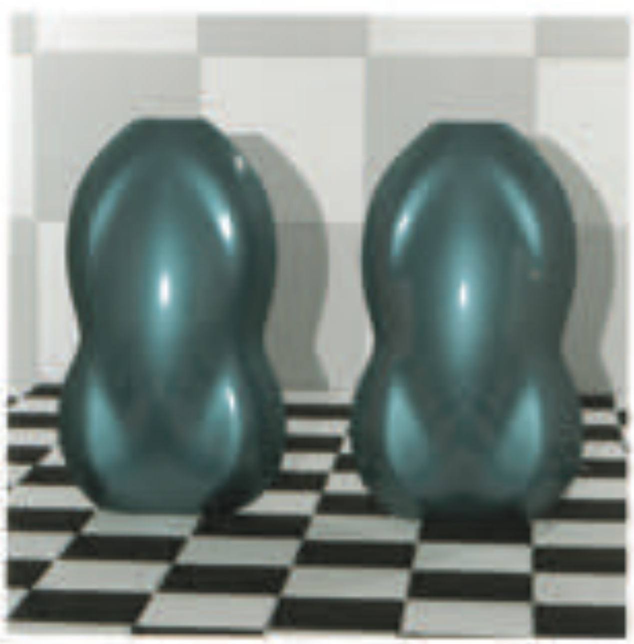


Figure 4. Gloss of 10 (left – same BRDF as Figure 2) and 60 (right).

Figure 5. Pearlescent (left) and metallic (middle an
right) colors.

Estimation of a 3D Spectral Reflection Model for Color Image Rendering

Norihiro TANAKA* and Shoji TOMINAGA*
Osaka Electro-Communication University
Department of Engineering Informatics, Neyagawa, Osaka 572-8530, Japan

ABSTRACT

This paper describes a method for estimating a reflection model from a color image of an object taken by a multi-band CCD camera. The Torrance-Sparrow model is used for modeling light reflection on an object surface. We propose algorithms for estimating model parameters from a single image by the multi-band CCD camera. To estimate the surface roughness, we propose the use of the brightness image and the reflectance map in the neighborhood of a highlight peak point. An algorithm is presented for finding a particular solution of the surface orientation. The feasibility of the method is demonstrated in an experiment using a painted object. The estimation accuracy of the whole model is confirmed based on computer graphics images.

1. INTRODUCTION

Reflection models are used in many fields including computer graphics, computer vision, image understanding, and digital archives. A three-dimensional (3D) reflection model is crucial for rendering realistic color images. We should note that (1) the reflection properties of an object surface depend on the surface material, and (2) the reflection model is described as a function including various parameters related to color (spectrum) and geometry. However, it is difficult to find suitable values for such parameters for a real object, and so far those were selected by the method of trial and error. In a previous paper [1], we proposed a method for estimating various parameters of a reflection model from a single image of an object taken by a CCD camera. The Phong model was used for modeling light reflection on an object surface composed of non-conducting materials called inhomogeneous dielectric materials. This model is too simple to produce realistic images. In fact, the Phong model has difficulty in describing the specular reflection component because the Fresnel term is neglected.

The present paper proposes a method for estimating reflection parameters using the Torrance-Sparrow model. Spectral functions such as surface-spectral reflectance, illuminant spectrum, and geometric parameters are estimated from an image by a multi-channel CCD camera system. The Torrance-Sparrow model is more precise than the Phong model. The specular reflection is described in terms of the distribution of isotopic orientation, the geometrical attenuation factor, and the Fresnel term. The proposed method has a much higher advantage of being able to estimate a 3D spectral reflection model from only a single image of a multi-band camera, compared with the other gonio-metric methods [2]-[3]. The feasibility of the proposed method is demonstrated in an experiment a painted object. The estimation accuracy is also confirmed based on computer graphics images.

2. CAMERA SYSTEM

A six-color camera is used as the multi-band camera for image measurement and reflection model estimation. Figure 1 shows six-color camera system. The system of a six-color camera is composed of a monochromatic CCD camera, a standard photographic lens, six color filters, and a personal computer. Figure 2 shows the spectral sensitivity functions for the six sensors that are a combination of the spectral-sensitivity function of the camera and the spectral transmittances of the different color filters. Use of this camera system makes it possible to estimate the reflection model parameters and the spectral information such as surface-spectral reflectance, which is difficult to be estimated in use of an ordinary RGB color system.

Figure 1 Multi-channel camera system.

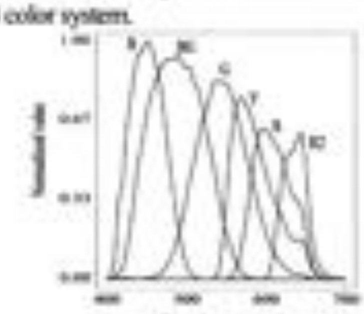


Figure 2 Spectral sensitivities of the camera.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

3. PARAMETER ESTIMATION ALGORITHMS

Figure 3 shows reflection geometry used in a reflection model. The spectral radiance distribution $Y(\lambda, x)$ from a reflective object surface is a function of the spatial location x and the wavelength λ. Torrance-Sparrow described this function as

$$Y(x,\lambda) = \alpha \cos(\theta_i) S(\lambda) E(\lambda) + \beta \frac{D(\varphi) G(\mathbf{N},\mathbf{V},\mathbf{L}) F(\theta_Q, n)}{\cos(\theta_r)} E(\lambda), \tag{1}$$

where the first and second terms represent, respectively, the body and interface reflection components. $S(\lambda)$ is spectral reflectance, $E(\lambda)$ is illuminant spectral distribution, θ_i is angle of incidence, θ_r is viewing angle. φ is angle between global surface normal and micro-facet normal, **Q** is the surface normal vector of a micro-facet. The interface reflection component consists of several terms. D is a function providing the index of surface roughness defined as $D(\varphi) = \exp(-\ln(2)\varphi^2 / \gamma^2)$, where γ is constant. G is a geometrical attenuation factor, and F is Fresnel spectral reflectance, where n is the index of refraction. We estimate various parameters of the above reflection model. These parameters are as follows: (1) surface spectral reflectance $S(\lambda)$, (2) illumination spectral distribution $E(\lambda)$, (3) ratio of body-to-interface intensity β/α (4) surface roughness γ.

In order to estimate these parameters, we analyze the pixel distribution (histogram) of an image taken by the multi-band camera. Figure 4 shows a typical histogram of image of dichromatic reflection. If an object surface has dichromatic reflection property without texture, the histogram shape exhibits some important features about reflectance, illuminant, and roughness.

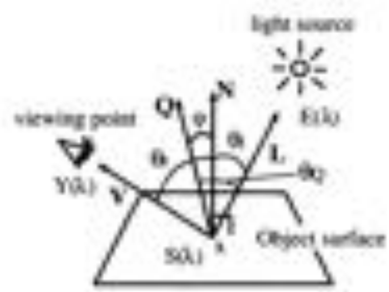


Figure 3. Reflection geometry

Figure 4. Histogram of image

3.1 Estimation of spectral functions $S(\lambda)$ and $E(\lambda)$

A linear finite-dimensional model is used to recover the spectral functions of illuminant and spectral reflectance from the multi-band sensor outputs. The spectral functions are expressed as a linear combination of basis functions

$$S(\lambda) = \sum_{i=1}^{n} \sigma_i(x) S_i(\lambda), \quad E(\lambda) = \sum_{i=1}^{m} \varepsilon_i(x) E_i(\lambda), \tag{2}$$

where $\{S_i(\lambda), i = 1, 2, \ldots, n\}$ and $\{E_i(\lambda), i = 1, 2, \ldots, m\}$ are the sets of basis functions for the reflectance and illuminant, and $\{\sigma_i(x)\}$ and $\{\varepsilon_i(x)\}$ are the sets of weights. Therefore, the spectral estimation becomes inferring the two sets of weight coefficients from the camera outputs.

3.2 Estimation of ratio of body-to-interface reflection ratio β/α

The histogram is composed to two linear clusters of matte cluster and interface cluster. The ratio of these clusters corresponds to the body-to-interface intensity ratio. The camera outputs are expressed as

$$\boldsymbol{\rho}(x) = w_b(x)\boldsymbol{\rho}_b + w_i(x)\mathbf{e}, \tag{3}$$

where $\boldsymbol{\rho}(x)$ is a column vector formed from six sensor responses $\rho_i(x)(i = 1, 2, \ldots 6)$ at special point at x. The vector $\boldsymbol{\rho}_b$ is the body reflection component of the camera output. The interface reflection component $\mathbf{e}$ corresponds to the 6D vector of the illumination color vector. w_b and w_i are the weighted coefficients of body and interface reflectance components. The histogram features suggest that P_d and H_m are, respectively, the maximal body reflection component and the maximal interface reflection component. The ratio r of the segments $\overline{OP_d}$ and $\overline{H_m P_m}$ is described as

$$r = \overline{OP_d} / \overline{H_m P_m} = \beta F_p G_p \|\mathbf{e}\| / \alpha \cos(\theta_i) \|\boldsymbol{\rho}_B\|, \qquad (4)$$

where the symbols F_p and G_p indicate the Fresnel and geometrical attenuation terms at the highlight peak points. The ratio r in the left-hand side of Eq.(4) is calculated from the shape of the histogram. On the other hand, the vectors $\boldsymbol{\rho}_B$ and $\mathbf{e}$ are estimated using the normalized vectors of $S(\lambda)$ and $E(\lambda)$. This computation is as follows: Let **S**, **E**, and **S'** be the 61-dimensional vectors with a unit length which represent $S(\lambda)$, $E(\lambda)$ and $S(\lambda)E(\lambda)$ respectively. Moreover the spectral sensitivity functions for six sensors are summarized in a 61x6 matrix **R**. Then the vectors of body reflection and interface reflection are given by $\boldsymbol{\rho}_B = \mathbf{R}^t\mathbf{S}'$, $\mathbf{e} = \mathbf{R}^t\mathbf{E}$. Calculating the norms of these vectors leads to obtaining $\|\boldsymbol{\rho}_B\| / \|\mathbf{e}\|$. The estimate of β / α is calculated as

$$\beta / \alpha = r \cos(\theta_i) \|\boldsymbol{\rho}_B\| / F_p G_p \|\mathbf{e}\|. \qquad (5)$$

3.2 Estimation of surface roughness γ

In order to estimate the roughness parameter γ in D, We use the histogram shape at half-maximum of the highlight peak. However, it is not easy to estimate the surface roughness parameter for surfaces of general shape. Because, we have to know the surface orientation at the spatial point where the intensity of the interface reflection reaches the half maximum point of the highlight peak. We try to use brightness for estimating the orientations of surface. However, brightness at a single point in the image provides only one constraint, while surface orientation has two degrees of freedom. Therefore we use the brightness image and the reflectance map in the neighborhood of the highlight peak point. An algorithm is then found for finding a particular solution of the surface orientation.

In a reflectance map, the contour map of brightness is represented as a function of the gradient of a surface. Let (p, q) be coordinate of gradient space. Then we use the gradient symbol (p_s, q_s) to specify the illumination direction in gradient space. The reflectance map $R(p,q)$ is given as

$$R(p,q) = \cos(\theta_i) = \frac{1 + pp_s + qq_s}{\sqrt{1 + p^2 + q^2}\sqrt{1 + p^2_s + q^2_s}} \qquad (6)$$

There are several properties regarding the relationship between the brightness image and the reflectance map. The solutions for symbol of spatial coordinate symbol X, Y, Z, and symbol of gradient in reflectance map (p,q) are found by solving the five differential equations

$$\frac{\partial X}{\partial \xi} = R_p, \quad \frac{\partial Y}{\partial \xi} = R_q, \quad \frac{\partial Z}{\partial \xi} = pR_p + qR_q, \quad \frac{\partial p}{\partial \xi} = E_X, \quad \frac{\partial q}{\partial \xi} = E_Y, \qquad (7)$$

where symbol (E_X, E_Y) and (R_p, R_q) are gradient of brightness image and reflectance map, respectively. We use the Runge-Kutta method for numerically solving the above system of differential equations. When this trajectory reaches one of the half-maximum points, the recursive computation is terminated. Therefore we can find normal vector at half-maximum point from the solution.

The relation at half-maximum point and highlight peak point described as $H\exp(-\ln(2)\varphi^2/\gamma^2) = P/2$, where $H = (F_h G_h)/(\cos\theta_{rh})$, $P = (F_p G_p)/(\cos\theta_{rp})$. The symbols F_h and G_h indicate the Fresnel and geometrical attenuation terms at half-maximum point. Moreover, F_p and G_p indicate the Fresnel and geometrical attenuation terms at highlight peak point. The surface normal vector **N** at the half-maximum point is obtained from the above iterative solution, so that θ_r and θ_i are estimated at the half point. Then possible solutions for γ are given as $\gamma = \varphi / \sqrt{1 + \ln(H/P)\ln(2)}$

4. EXPERIMENTAL RESULTS

We used an orange painted tray shown in Figure 5 (a). The light source of an incandescent lamp was placed at about 2m from the object. Figure 6 shows the estimation results of spectral functions of the object, where one curve represents the estimate and the other represents the direct measurement result. We estimated the ratio as β/α=3.4, and the surface roughness as γ=0.17. Figures 5(b) and 5(c) show the computer graphics images of the object, that were recovered with these estimated parameters under the illuminants of an incandescent lamp and D65, respectively. A comparison between the measured image and the reproduced images suggests a reliability of the proposed method for estimating the reflection parameters from an image.

(a) Measured image (b) Reproduced image under incandescent lamp. (c) Reproduced image under D65.

Figure 5. Comparison between the measured and reproduced images.

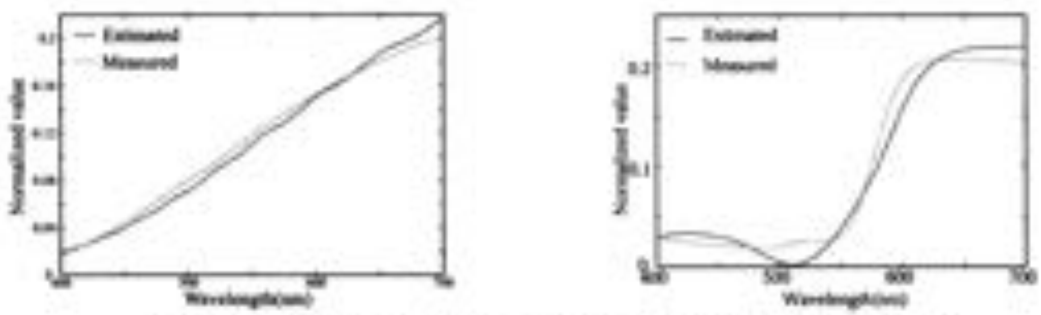


Figure 6. Estimated spectral functions: illuminant (lest), surface reflectance (right).

5. CONCLUSTIONS

A method was described for estimating a reflection model from a color image of an object taken by a multi-band CCD camera. The Torrance-Sparrow model was used for modeling light reflection on an object surface. The model parameters to be estimated were as follows: (1) surface spectral reflectance, (2) illumination spectral distribution, (3) ratio of body-to-interface intensity, (4) surface roughness. We have proposed algorithms for estimating these parameters from a single image by a multi-band CCD camera. To estimate the surface roughness, we proposed the use of the brightness image and the reflectance map in the neighborhood of the highlight peak point. The feasibility of the method was demonstrated in an experiment using a painted object. The estimation accuracy of the whole model was confirmed based on computer graphics images.

REFERENCE

[1] S. Tominaga and N. Tanaka, "Estimation of reflection parameters from a single color image", *IEEE Computer Graphics and Applications*, Vol.20, No.5, pp.58-66 (2000).

[2] Y. Sato and K. Ikeuchi, "Temporal-color space analysis of reflection", *J. of Optical Society of America A*, Vol.11, No.11, pp.2990-3002 (1994).

[3] H. Haneishi, T. Iwanami, N. Tamura, and Y. Miyake, "Goniospectral Imaging of 3D object", *Proc. of the IS&T/SID Color Imaging Conference*, pp.173-176,(1998).

* Correspondence: norihiro@tmlab.osakac.ac.jp; shoji@tmlab.osakac.ac.jp; phone +81-72-820-4562; fax +81-72-824-0014; Osaka Electro-Communication Univ. Tominaga lab. Neyagawa, Osaka 572-8530 Japan

"Color Image Processing using sRGB sub-divided space technique"

P. Cunthasaksiri[*a], A. Hansuebsai[*a], P. Pungrassamee[*a] and Y. Ando[**b]

[a]Dept of Imaging Science, Chulalongkorn Univ; [b]Canon Inc. (Japan)

ABSTRACT

A new method to improve the accuracy of color transformation, using sub-divided *sRGB* color space, is proposed. This combines tetrahedral partition technique and linear regression model. It is found that the 3^{rd} order coefficient matrices give acceptable result with average color difference, $\Delta E_{avg}=3.31$. This process is quick and simple for general use of Internet's application.

Keyword: Color transformation, sRGB, Tetrahedral, Characterization

1 INTRODUCTION

Device Characterization is a process to define a relationship between input signal and output signal of an unknown model. Figure 1 shows a schematic diagram of a typical relationship between *Input signal*(X_i) and *Output signal*(Y_i) of *Real model* (Ω). The real model performs the transformation for each pair of signals by passing the input signal through the device and measuring each of corresponding output signal. There are two directions to characterize the real model: *Forward characterization* and *Backward characterization*. The former is usually used for an input device in color management system and the latter for an output device. The characterization process, basically, gives an *Approximated model*(θ) which is the reverse approximation of *Real model*(Ω^{-1}). It composes of two major processes: sampling signal pairs of the real model and generating an algorithm based on those signals to approach the approximated model.
The results of sampling signal process is usually tabulated and called *Forward Look-up table data*(Φ) for the *Forward characterization* as well as *Backward Look-up table data*(Φ^{-1}) for the *Backward characterization*. Ideally, if the table contains all signals of the real model, it can exactly represent the real model. As a result, the *inverse of real model*(Ω^{-1}), the *backward LUT data*(Φ^{-1}) and the *approximated model*(θ) are the same. However, there are only practically selected number of signal samples since their large number are impossible to obtain. Then the generating process is applied by many methods such as 3d-interpolation, regression model and neural network etc.[1] Moreover, these methods can be applied to any geometric techniques.

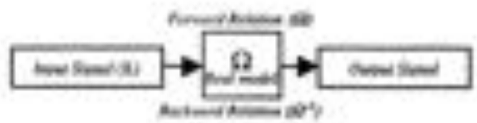


Figure 1 The schematic diagram of typical relationship.

2 THEORY AND PROPOSED METHOD

The proposed method is a combination of *Regression model* and *Tetrahedral partition* technique. There are two major alternatives to make partition: 1) to create a partition based on the knots point, 2) to apply any geometric form into the color space regardless of the knot point. The first alternative can be a simplex[2] if the partition is base on 4 knots in three dimension space which is the smallest partition it could be. This method usually gives the outstanding approximated result for the maximum error entire the space for typical algorithm. However, the search engine to find the adjacent knots of each interested point is expensive. The second alternative is just apply any geometric forms into a color space. This will geometrically divide the *LUT data* into sub-spaces. Thus, it is important to realize that each partition might consist of uncertain number of *LUT data* and, moreover, the position of each *LUT data* in the partition. The tetrahedral partition technique chosen here is the latter approach. It applies to the *sRGB* color space followed by the plane of $R+G+B=383$, whereby 12 partitions are obtained. Finally, each sub-divided color space is applied by regression model to retrieve the coefficient of transformation. Before going further to the experiment, it is necessary to categorize some kinds of partition used in this work. Followings are some terminologies that use in the proposed technique: 1.) *Coefficient Partition* is a

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

· 0277-786X/02/$15.00

portion of *LUT data*, which is geometrically grouped by a partition method. This portion of *LUT data* is used for deriving its coefficient. 2.) *Target Partition* is a boundary that locates each input signal to approximate the result by corresponded coefficient partition. Typically, this partition has the same boundary as the coefficient partition. 3.) *Overlapping Partition* is a method of dividing color space to be coefficient partition, which allows each partition to overlap each other. Basically, each coefficient partition has the same boundary as each corresponding target partition. However, it seems to be non-practical to approach by this method, because some of the input signals may be outside the boundary of *LUT data*. In Figure 2 (a), the black thick line is the *Coefficient Partition* and dash line is *LUT data boundary*, the black circle points represent *LUT data*, the white triangle is the *Input signal [Y]*, the black triangle is *Input signal [Y]* which is out of *LUT data boundary*. In this case, if the *Target Partition* has the same boundary as *Coefficient Partition*, some of the *Input signals[Y]* may be out of the *LUT data boundary*. The approximated values may be huge of error outside *LUT data boundary* due to the characteristic of regression model that it is not suitable for predicting an outer range values. Therefore, it is suggested to extract the *Coefficient Partition*, at least, to cover the *Target Partition*. Figure 2 (b) shows an extracted *Coefficient Partition*.

(a) (b)

Figure 2 The input signals, which are outside of the *LUT data* boundary (a). And a *Coefficient partition*, which is extracted to cover the corresponding target partition (b).

3 EXPERIMENT

The output device is treated as *RGB* device. The first step is to generate the *LUT data* by passing the evenly sampling signals into the *Real model* to obtain the color chart. The results of measurement are the response of color signals in *sRGB* color space which each pair of data is inverted as *Backward LUT data*(Φ^{-1}). Then the parameters to generate the approximated model are applied as following: Model of Printer: *Canon BJC8500* and *Canon CLC1120*, LUT data size: *7x7x7* and *9x9x9 levels*, Partition method: *Whole space* and *Tetrahedral divided by plane of R+G+B=383 with 25 unit overlapping*, Order of Regression Model: *1st order with 4 terms*, *2nd order with 11 terms*, *3rd order with 14 terms* and *20 terms*. The testing data$[T]_i$ are 497 uniformly sampling signals in *sRGB* color space, defined as T_{set} which theirs *approximated input signals* are obtained from each approximated models. These signals are passed through the *Real model*(Ω) to get the output signals. The same testing data, then, are passed through the *Inverse model*(Ω^{-1}) and the *Real model*(Ω), which does not affect the testing data. Hence, the testing data and the output signal are the same. The schematic diagram of the evaluation process is shown in Figure 3. The accuracy of each algorithm is evaluated by statistical methods in terms of include *Root Mean Square* (ΔE_{rms}) and *Maximum* (ΔE_{max}) of color difference between the result of the approximated model and the input signal.

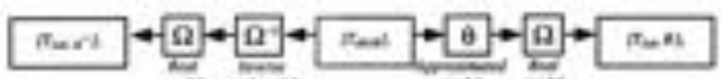


Figure 3 The schematic diagram of the evaluation process.

4 RESULTS AND DISCUSSION

According to the experimental setup, it should be noted that the apparatus stability is around ΔE_{rms} = *1 - 2* for both types of printer models. Especially the inkjet printer, which produces the printout that fades rapidly. Therefore, the measurement is done immediately after each printing. The *LUT data* shows that some parts of the *Printer gamut boundary* exceed the *sRGB gamut boundary*. These outer range colors, however, are not denied in the coefficient calculation process, because it is better to use all *LUT data* to generate the approximated model.

4.1 Effect of the LUT data size and Regression Order

The *LUT data size* of 7x7x7 and 9x9x9 levels are chosen because *Tone Curve Adjustment* is not pre-adjusted in this work. However, this is not a purpose of earning higher accuracy but for the representation of the major characteristic of the real model, because in some parts of the model are more non-linear than other, especially in the dark area of the color space. Moreover, the time and resource consumed are not worth using to rise up the accuracy as the results show in the figure 4 for *BJC8500* and *CLC1120*. When the *LUT data size* is increased, the ΔE_{avg} will be reduced. However, around 200% increasing of the *LUT data size* affects decreasing of ΔE_{avg} just a few units, while the higher degree of regression significantly affects the accuracy of the approximation. The 1st order has the worst approximated accuracy in both of ΔE_{avg} and ΔE_{max}. While the 2nd order has better accuracy and the 3rd order is the best appropriate approximated model. The difference of the approximated accuracy between the best and the worst of *BJC8500* and *CLC1120* is around 50% and 30% respectively. Only the case of *7x7x7 LUT data size* for *CLC1120*, which the results show that the ΔE_{avg} does not gradually decrease as the order of regression model increases. It is because of its highly non-linear characteristic which the *7x7x7 LUT data size* could be supposed to be too less to represent its major characteristic. However, the unexpected effect does not appear in *9x9x9 LUT data size* model which could be supposed that *LUT data size* is large enough. It should be noted about the 3rd order that there is no significant difference of ΔE_{avg} and ΔE_{max} between the 14 terms and 20 terms. This is because the extra terms are just the different combinations of the same input signal.

Figure 4 Effect of the LUT data size and Regression Order

4.2 Effect of the Partition Method

Figure 5 (a) shows that the method of partition also affects the approximated accuracy. By comparing the reduction of both partition methods, it is found that the ΔE_{avg} of *7x7x7* and *9x9x9 LUT data size* for *BJC8500* are not reduced as much as the reduction of the effect from the higher degree of regression model. It should be noted that the best-approximated accuracy is $\Delta E_{avg} = 3.31$ and $\Delta E_{max} = 12.10$, which is resulted from a combination of 3rd order and tetrahedral partition.

Figure 5 (b) shows that the approximation behaviour of *CLC1120* is not the same as the *BJC8500*. The reduction from the partition effect is not a significant meaning for both of *LUT data* models due to its highly non-linear characteristic. However, the best-obtained accuracy is *5.60* and *13.96* for ΔE_{avg} and ΔE_{max} respectively, which can be assumed to be the compensation of the tetrahedral partition method.

(a)

(b)

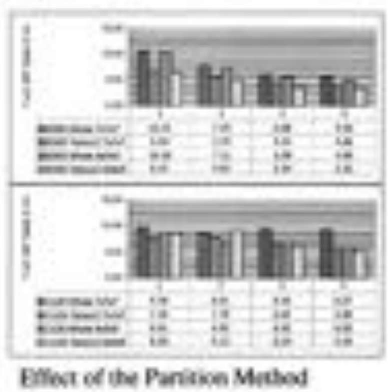


Figure 5 Effect of the Partition Method

4.3 Effect of Overlapping partition

The approximated accuracy, evaluated by ΔE_{avg} and ΔE_{max}, only represents its overall performance that is not in particular. There are some undesirable effects from the partition method. Figure 6 above shows the sample of gray steps approximated without partition method, which their reproduction steps change gradually. This is also called as *'Continuity'*. While Figure 6 below shows the sample of gray steps approximated with a partition method that is the *sRGB* color space divided by the plane of *R+G+B=383*. Then the wall of each boundary is at the middle of *Gray Axis*, where the reproduction does not gradually change across this boundary. This is called a *'Discontinuity'*. Nevertheless, the ΔE_{avg} of the latter is better than the former's. To remedy this, It is necessary to extend the *Coefficient Partition* to overlap each other. This is a balance between the approximated accuracy and the gradualness. For tetrahedral partition method, each *Coefficient Partition* has 25 units extended boundary. This value is obtained from trial and error to approximate the real model. If this value is too less, the boundary of *Coefficient Partition* will close to *Target Partition*. Consequently, some of the color may be out of the *LUT data boundary* and the approximated model at both sides will be more incongruent which have an influence on the discontinuity. While this value is too high, the ΔE_{max} will be raised up which indicates that all the advantages of the partition method could not be achieved.

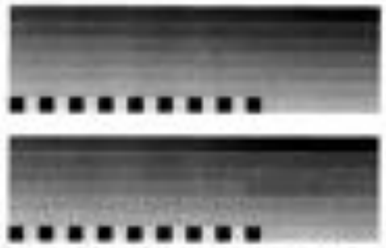


Figure 6 The sample of gray steps approximated without partition method (a) and with partition method (b)

5 CONCLUSION

We conclude that the higher accuracy of the color transformation can be achieved by the optimum *order of linear regression model* in *sub-divided color space*. As mentioned before, the proposed method divides the color space regardless of the *LUT data's knots*. Thus the accuracy of the approximating is varied upon the characteristic of each model. However, the 3[rd] order with tetrahedral partition is the best combination to approximate both printer models. The accuracy of color transformation is directly proportional to the *LUT data size*, which is a base of the regression model. The larger *LUT data size* is absolutely suitable for the obtained regression model. However, The high accuracy should not be achieved by only increasing the *LUT data size*, because it needs large processing time and resources. The *LUT data size* should be large enough to represent the major characteristic of the real model. In this work, the *7x7x7 LUT data size* is not enough for the 3[rd] order to approximate the *CLC1120* model that it shows the result of the accuracy as 1[st] order. For the *order of regression model*, it can be concluded that the higher accuracy would be obtained from the *higher order of regression model*, because the error significantly decrease not only the ΔE_{avg} but also ΔE_{max} to around 50% for the *BJC8500* model with 9x9x9 level in the whole partition. Moreover, it can be concluded that more term's number in the regression model is not useful to achieve much of higher accuracy, because it is based on the same *LUT data*. For the *sub-divided color space*, it is a method to achieve higher accuracy of color transformation, as the regression model of each sub-space represents each characteristic of its sub-boundary. In this work, the *Tetrahedral Partition* method is chosen because of its simply searching algorithm and also the appropriateness. However, the partition method can not be considered as high accuracy as the order of the regression model, because it must compromise the accuracy of each partition with the *Continuity* which is handled by *Overlapping Partition*. Moreover, the partition method does not significantly reduce the error for the model with high non-linear. Finally, the combination of the third order of *Regression Model* and *Tetrahedral Partition* seems to be effective as the results of satisfied accuracy. Both printer models are acceptable in most of the field of color applications. Note that with the maximum error, it might be unacceptable in some areas such as logo colors. In addition, if the *Tone Curve Adjustment* is pre-adjusted, it could be expected that this proposed method would be more acceptable in the practical use.

ACKNOWLEDGMENTS

The authors are thankful to the kind support of Chula-Canon Technical Research Cooperation.

REFERENCES

1. Kang, H. R. *Color Technology for Electronic Imaging Devices*, SPIE-The International Society for Optical Engineering, Washington, 1997.
2. Groff, E., Koditschek, E. and Khargonekar, P, "Representation of Color Space Transformations for Effect Calibration and Control", *International Conference on Digital Printing Technologies*, pp255-260, The Society for imaging Science and Technology, Virginia, 1998.

*cunthanaksiri@yahoo.com; phone +662-218-5568; Chulalongkorn University, 254 Phyathai Road Patumwan, Bangkok, 10330, Thailand; **Canon Aptex Inc., 5-15, Shimomaruko 2-chome, Ohta-ku, Tokyo 146-0092, Japan

Polyhedral gamut representation of natural objects based on spectral reflectance database and its application

Hideaki Haneishi*, Yasunori Sakuda and Toshio Honda
Department of Information and Image Sciences, Chiba University

ABSTRACT

Spectral reflectance of most reflective objects such as natural objects and color hardcopy is relatively smooth and can be approximated by several numbers of principal components with high accuracy. Though the subspace spanned by those principal components represents a space in which reflective objects can exist, it does not provide the bound in which the samples distribute. In this paper we propose to represent the gamut of reflective objects in more distinct form, i. e., as a polyhedron in the subspace spanned by several principal components. Concept of the polyhedral gamut representation and its application to calculation of metamer ensemble are described. Color-mismatch volume caused by different illuminant and/or observer for a metamer ensemble is also calculated and compared with theoretical one.

Keywords: spectral gamut, principal component analysis, polyhedron, spectral reflectance database, metamer

1. INTRODUCTION

It is well known that spectral reflectance of most reflective objects such as natural objects and color hardcopy are relatively smooth and can be approximated by several number of base spectral functions with high accuracy [1-4]. Those functions can be found by principal component analysis (PCA) for a set of samples collected appropriately. The subspace spanned by those obtained principal components represents a space in which spectral reflectance of reflective objects exist. However, it still has infinite extension, namely, it does not identify the gamut or the bound in which the samples distribute. In this paper, we propose to represent a spectral gamut of objects by a convex polyhedron in this subspace. If spectral reflectance is approximated by N principal components (PCs), it is represented by N coefficients for the corresponding PCs. A polyhedron representing the gamut is formed by an outer surface. The outer surface is composed of many patches that we call facets and each facet has N apexes or N samples. Thus defining a gamut is equivalent to listing the facets of polyhedron.

If such a practical gamut of reflective object in spectral domain becomes available, it can be used for calculation of metamer ensembles. Literatures have been published on finding metamer ensembles [5-7]. These works consider physically possible ensembles by introducing a constraint that the upper limit of reflectance be 1 and the lower limit 0. We consider, however, this constraint is too loose for practical use. Gamut representation using a polyhedron is more practical. When sensor responses are given, mathematical metamer ensemble is expressed by a subspace in the spectral reflectance domain. Once the object gamut is specified, the metamer ensemble is given by a cross section of the polyhedral gamut and the subspace determined by the sensor responses. In this paper, for some given illuminant and observer conditions, metamer ensembles are calculated, then the extent of the ensemble viewed under different illuminant or by different observer in a color space is calculated. Those results are compared with theoretical ones presented by Schmitt[7].

2. SEARCHING OUTER SURFACE OF GAMUT AND METAMER ENSEMBLE

2.1 Searching spectral gamut

We assume that all spectral data are sampled into P elements over a visible wavelength range. Spectral reflectance of object is represented by a column vector, $\mathbf{f} = [f_1 \ \cdots \ f_P]^T$, where $[\cdot]^T$ denotes the transposition. First, let us assume that a database including enough number of samples is given. We add an ideal black object, $\mathbf{f} = \mathbf{0}$, to the database. Because these samples surely exist, a linear combination, or an area-weighted mixture, of arbitrary n samples selected from the database should also be treated as possible color as shown below.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

$$\mathbf{f} = \sum_{i=1}^{n} w_i \mathbf{f}_i,\ 0 \le w_i,\ \sum_{i=1}^{n} w_i \le 1. \tag{1}$$

Expressing the gamut by the PC coefficients that can approximate the original spectral reflectance is equivalent to expressing the gamut in spectral reflectance domain. In this paper, as a set of samples for performing PCA, we use the original samples plus those with negative sign as Maloney did [4]. By this treatment the mean of samples moves to the origin and data handling becomes easy. The original spectral reflectance can be expressed using the PC vectors as

$$\mathbf{f} = \sum_{i=1}^{N} a_i \mathbf{k}_i = \mathbf{K}\mathbf{a}, \tag{2}$$

where $\mathbf{K} = [\mathbf{k}_1 \ \cdots \ \mathbf{k}_N]$ and $\mathbf{a} = [a_1 \ \cdots \ a_N]^T$. Here $\mathbf{k}_i, i = 1,\ldots,N$ denotes the first N orthonormal PC vectors. The coefficient vector $\mathbf{a}$ is calculated from $\mathbf{f}$ by $\mathbf{a} = \mathbf{K}^T\mathbf{f}$.

To understand the feature of convex polyhedron we shall begin with low dimensional spaces. Figure 1 shows the cases that $N = 2$ (2-D) and $N = 3$ (3-D). In the 2-D case, the outer surface of the polyhedron is formed by line segments with two apexes each. In the 3-D case, the outer surface of the polyhedron is formed by triangle patches with three apexes each. For consistent expression over all dimensions, we call an element forming the outer surface of the polyhedron a facet. In general, the outer surface of a polyhedron in N-dimensional space is formed by facets with N apexes each. We define a facet by a set of apexes and represent ith facet as

$$S^{i}_{facet} = \{\mathbf{a}^{(i,j)} \mid j = 1,\ldots,N\}.$$

Here $\mathbf{a}^{(i,j)}$ represents jth apex of ith facet.

We next consider the figure formed by all apexes except for only one apex and call it the edge of the facet. The edge of the facet is represented as

$$S^{(i,j)}_{edge} = \{\mathbf{a}^{(i,k)} \mid k = 1,\ldots,N, k \ne j\}.$$

A facet of polyhedron in N-dimensional space has N edges. In Fig. 1(a), for example, the facet AB has two edges, point A and point B. In Fig. 1(b), the facet ABC has three edges, line segments AB, BC and CA. Each facet of polyhedron in N-dimensional space is connected with N neighboring facets by sharing the edges of the facet. For example, in Fig. 1(b), the facet ABC is connected to three facets, ABD, BCG and ACF at the edges AB, BC, and CA, respectively. Based on the above-mentioned features, the apexes forming the gamut polyhedron can be found.

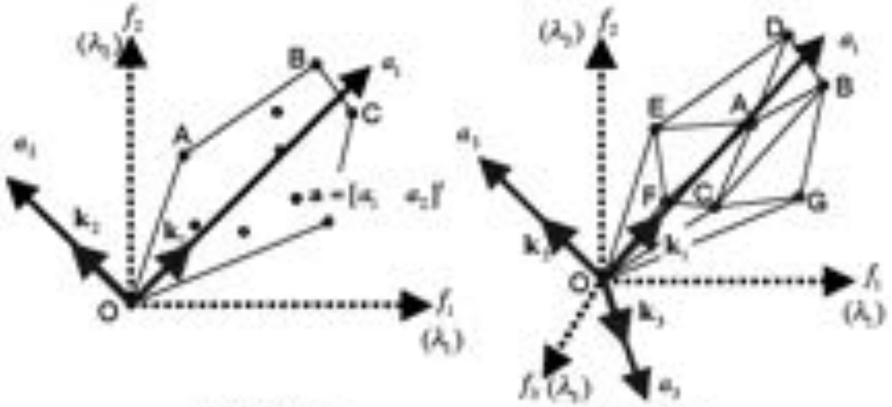


Figure 1. Schematic illustration of a convex polyhedron representing an object gamut.

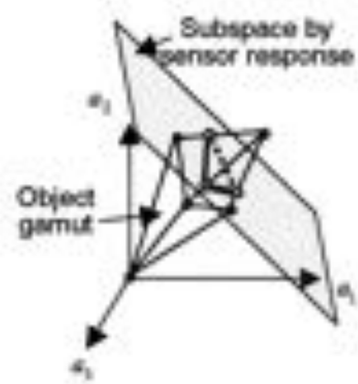


Figure 2. Cross-section of object gamut and the subspace.

2.2 Finding metamer ensemble

Let us consider the metamer ensemble based on the convex polyhedral gamut. As a general case, we assume M channel sensors and represent those spectral sensitivities by column vectors, $\mathbf{s}_i, i = 1,\ldots,M$. For instance, if colorimetric values of light are considered, the spectral sensitivities are the color matching functions of the standard observer. Sensor response $\mathbf{t} = [t_1 \ \cdots \ t_M]^T$ for the object $\mathbf{f}$ is expressed as,

$$\mathbf{t} = \mathbf{S}^T\mathbf{E}\mathbf{f} = \mathbf{S}^T\mathbf{E}\mathbf{K}\mathbf{a}, \tag{3}$$

where $\mathbf{S} = [\mathbf{s}_1 \ \cdots \ \mathbf{s}_M]$ is a sensitivity matrix with $P \times M$ elements and $\mathbf{E}$ is a diagonal matrix whose diagonal elements represent the spectral radiance of the illuminant. All objects satisfying the above equation form a metamer ensemble. Eq. (3) means a mapping of a vector **a** in *N* dimensional space to a vector **t** in *M* (<*N*) dimensional space. Clearly, there are *N*-*M* degrees of freedom for the solution or the metamer ensemble. Mathematically this subspace has infinite extension. We restrict the metamer ensemble to a practical one using a known spectral reflectance database. The metamer is then given by a cross section between the above subspace and the convex polyhedral gamut. The resulting metamer ensemble is given by an *N*-*M* dimensional polyhedron. In the case that $N = 5$ and $M = 3$, for example, the cross section is a polygon in two-dimensional subspace.

3. CALCULATION OF COLOR MISMATCH VOLUME

Let us show some calculation examples using the sample set of "silver halide type color printer" of the SOCS (Standard Object Colour Spectra database for colour reproduction evaluation)[7]. PCA for this set was first performed and the reflectance spectra were approximated by five PCs. Cumulative contribution ratio with five PCs was 99.88%. Among 512 original samples in this set plus the ideal black, 272 samples were extracted as apexes of a polyhedral gamut and 8697 facets formed the polyhedral surface.

As seen in Eq. (3), for reflective objects, both spectral sensitivity of sensor (color matching function in case of human observer) and spectral radiance of illuminant affect the sensor response. For metamer ensemble for a given observer-illuminant pair, different observer and/or difference illuminant make observers perceive a different color. Ohta and Wyszecki [5,6] and Schmitt[7] studied the extent of this color difference called color-mismatch volume (CMV) for the theoretical metamer ensemble. In this paper, we present the CMV on the basis of a spectral reflectance database instead of the theoretical limit.

CMV in the following three cases was investigated. First two are the illuminant metamerism and the third one is the observer metamerism.

(i) Reference illuminant is A, test illuminant is D65. Observer is fixed to CIE1931 standard observer.
(ii) Reference illuminant is D65, test illuminant is A. Observer is fixed to CIE1931 standard observer.
(iii) Reference observer is CIE 1931 observer, test observer is CIE 1964 observer. Illuminant is fixed to A.

In each case, gray colors with two luminance factors (Y=10, 50) were tested. Figure 3 shows apex spectral reflectances of the metamer ensemble for (x, y, Y)= (0.31273, 0.32902, 50) under the condition of the standard D65 illuminant and the CIE1931 standard observer. Figure 4 shows two basis functions spanning the metamer subspace. It can be seen that the variation of metamer ensemble shown in Fig. 3 is corresponding to these two functions.

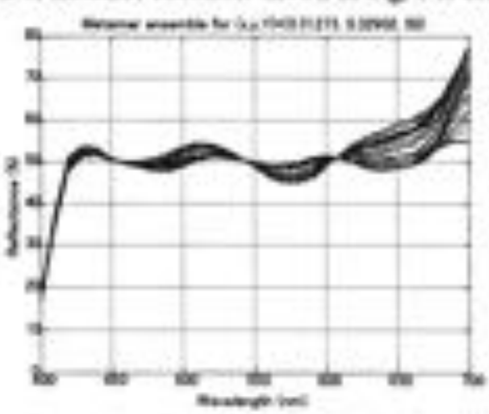


Figure 3. An example of metamer ensemble. Illuminant: D65, Observer: CIE 1931.

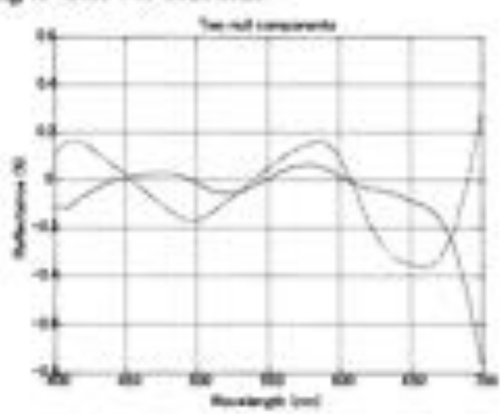


Figure 4. Two basis functions spanning metamer subspace.

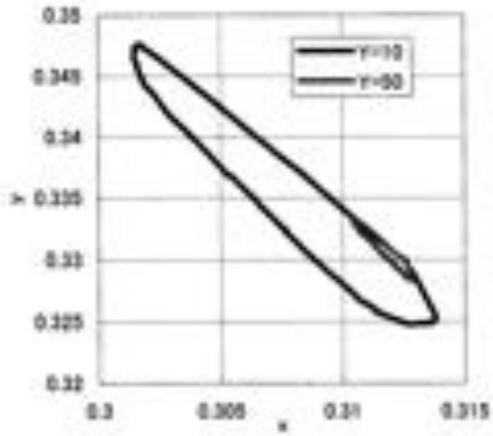


Figure 5. Color-mismatch volume projected onto x-y plane.

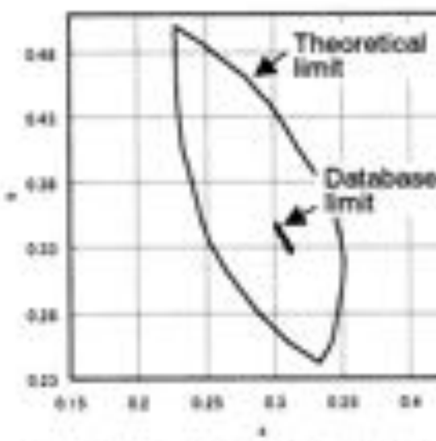


Figure 6. Comparison with theoretical limit.

Following the calculation of apexes of metamer ensemble for a given observer-illuminant pair, tristimulus values of those colors under a test observer-illuminant pair were calculated. Figure 5 shows a projection of CMV in the case (i) onto the x-y chromaticity plane. We further evaluated the CMV by the following measures: maximum and mean color difference among all combination between apexes of metamer ensemble. Color difference was calculated in the CIELAB color space. Table 1 shows the results. The numbers of apexes are also shown. Two illuminant metamerism give similar results. The calculation result that for Y=10 the maximum values are about 8 and mean values are about 3 suggests that small color difference not perceivable under a certain condition may turn to be perceivable under a different condition. Color difference of observer metamerism was smaller than illuminant metamerism presented here. CMV in Y=50 was smaller than that in Y=10 in all cases. Finally, the CMV calculated here is compared with the theoretical one presented by Schmitt[7]. Figure 6 shows the comparison result for case (i). It is clearly shown that the database limit is much smaller than theoretical one.

Table 1 Color difference of color-mismatch volume.

Luminance	Condition	Max ΔE*ab	Mean ΔE*ab	# of apexes
Y=10	(i) Ref.: A Test: D65	8.77	3.58	67
	(ii) Ref.: D65 Test: A	8.22	3.35	75
	(iii) Ref.: 1931 Test: 1964	2.56	1.08	67
Y=50	(i) Ref.: A Test: D65	3.33	1.40	45
	(ii) Ref.: D65 Test: A	3.02	1.24	46
	(iii) Ref.: 1931 Test: 1964	0.99	0.42	45

4. CONCLUSIONS

In this paper, we proposed a polyhedral representation of reflective object gamut and presented some examples of metamer calculation. It was confirmed that color-mismatch volume for illuminant metamerism and observer metamerism is much smaller than theoretical one, though, in some cases, the color differences of the metamer ensembles are large enough for human observer to perceive.

ACKNOWLEDGEMENT

This research is partially supported by the Ministry of Education, Science, Sports and Culture, Grant-in-Aid for Scientific Research (B), #13650038, 2001.

REFERENCES

1. J. P. S. Parkkinen, J. Hallikainen and T. Jaaskelainen, "Characteristic Spectra of Munsell Colors," J. Opt. Soc. Am., Vol. 6, No. 2,1989. pp. 318-322
2. J. L. Dannemiller, "Spectral reflectance of natural objects: how many basis functions are necessary?" J. Opt. Soc. Am. Vol. 9 1992, pp. 507-515
3. H. Haneishi, T. Hasegawa, A. Hosoi, Y. Yokoyama, N. Tsumura, and Y. Miyake, "System design for accurately estimating spectral reflectance of art paintings," Appl. Opt., Vol. 39, No. 35, 2000, pp. 6621-6632
4. F. H. Imai, N. Tsumura, H. Haneishi and Y. Miyake, "Principal component analysis of skin color and its application to colorimetric color reproduction on CRT display and hardcopy," J. of Imaging Sci. and Tech.,Vol. 40, No. 5, pp. 1996, pp.422-430
5. N. Ohta and G. Wyszecki, "Theoretical chromaticity-mismatch limits of metamers under difference illuminants," J. Opt. Soc. Am., **65**, 1975 pp. 327-333
6. N. Ohta and G. Wyszecki, "Theoretical chromaticity-mismatch limits of metamers due to a change from CIE illuminant D65 to C," J. Opt. Soc. Am., **65**, 1975, pp.1152-1153
7. F. J. M. Schmitt, "A method for the treatment of metamerism in colorimetry," J. Opt. Soc. Am., **66**, 1976 pp.601-608
8. L. T. Maloney, "Evaluation of linear models of surface spectral reflectance with small numbers of parameters," J. Opt. Soc. Am. **3**, 1986, 1673-1683
9. J. Tajima, et al. "Development and standardization of a spectral characteristics data base for evaluating color reproduction in image input devices," SPIE **3409**, 1998, 42-50

---

* Correspondence: haneishi@image.tp.chiba-u.ac.jp, Phone/fax:+81-43-290-3463, http://sawori.tp.chiba-u.ac.jp/~haneishi, Department of Information and Image Sciences, Chiba University, 1-33, Yayoi-cho, Inage-ku, Chiba 263-8522, Japan.

Multi-primary display optimized for CIE1931 and CIE1964 color matching functions

Kenro Ohsawa*[a,b], Friedhelm König[a,c], Masahiro Yamaguchi[a,b] and Nagaaki Ohyama[a,b]
[a] Telecommunications Advancement Organization of Japan, Tokyo, Japan;
[b] Tokyo Institute of Technology, Yokohama, Japan;
[c] Aachen University of Technology, Aachen, Germany

ABSTRACT

A novel color reproduction method that is independent of the viewing angle is proposed. In this method two sets of tristimulus values corresponding to the CIE 1931 and the CIE 1964 color matching functions are reproduced using a six-primary display. The digital counts of the six-primary display to reproduce a given set of six-stimulus values can be uniquely determined by using a 6 by 6 matrix which is calculated from the two color matching functions and the primary spectra of the six-primary display. In this paper we report the result of the simulation that examines the color reproduction accuracy using this method when a spectrum of the object is given. Comparing the color reproduction accuracy achieved by the 6-primary display using our method with that by a current RGB display it is verified that the proposed method can improve the accuracy.

Keywords: spectrum, color matching functions, multi-primary display

1. INTRODUCTION

Recent advancement of multimedia technology introduced the possibility to realize electronic art museums, electronic commerce, telemedicine and so on. In such systems reproducing accurate color is one of the most important technologies. Multispectral color reproduction system which estimate spectrum using multi-band camera as input device have been actively studied. However current RGB color display systems for this aim are based on metameric matching of tristimulus values. And the metameric color reproduction causes the error of the color matching when the color matching functions (CMF) of the actual observer are deviated from those used in the color reproduction. It is recommended that the CIE 1931 standard colorimetric system should be used for the fields of angular subtense between about 1 deg. and 4 deg. and the CIE1964 supplementary standard colorimetric system greater than about 4 deg. according to the change of the human color vision characteristics[1]. In the case of the color reproduction of an image it is uncertain which colorimetric system should be used and it is probable that the adequate colorimetric system is different from region to region on the image and depending the distance between the reproduction and the observer. The current RGB systems cannot reproduce color taking this into account exactly.

In this paper a novel color reproduction method using a multi-primary display[2,3] is proposed for the accurate color reproduction independent of the viewing angle. Using a 6-primary display 2 sets of tristimulus values (i.e. 6-stimulus values) corresponding to the CIE 1931 and the CIE 1964 CMF are reproduced. The digital counts of the 6-primary display to reproduce a given set of 6-stimulus values of the object are uniquely determined by using a 6 by 6 matrix. The simulation is conducted that examines color reproduction accuracy using this method when a spectrum of the object is given.

2. METHOD

2.1 Theory

In this section we propose the method to reproduce a variety of tristimulus values corresponding to the CMF which vary depending on the observing conditions. And then the method that is applied to the color reproduction independent of the viewing angle of the observation is described.

*ohsawa@akasaka.tao.go.jp; phone 81 3 3568 2461; fax 81 3 3568 2471; http://www.akasaka.tao.go.jp; Akasaka Natural Vision Research Center, Telecommunications Advancement Organization of JAPAN, 1-8-6 Akasaka Akasaka HKN Bldg. 3F, Minato-ku, Tokyo, JAPAN 107-0052

Usually human color vision has three kinds of color sensors, the spectral sensitivities of which are equivalent to those of the CMF. However the CMF vary depending on the observing conditions (e.g. the angle of the view in the observing field or personal difference of CMF). We model the CMF $t^{(k)}(\lambda)$ (t is x or y or z) of an observation **k** (**k** specifies all the observing conditions relative to the variations of the CMF)as a linear combination of N kinds of functions c_i (i=1~N) by

$$t^{(k)}(\lambda) = \sum_{i=1}^{N} a_{ti}^{(k)} c_i(\lambda) \tag{1}$$

where $a_{ti}^{(k)}$ is the coefficient corresponding to $c_i(\lambda)$. So the tristimulus values $T^{(k)}$ (T is X or Y or Z) of the object spectrum $S(\lambda)$ in the observation **k** are given by a linear combination of N-stimulus values C_i (i=1~N) as

$$T^{(k)} = \sum_{i=1}^{N} a_{ti}^{(k)} C_i \tag{2}$$

where

$$C_i = \int_{\lambda=380}^{780} c_i(\lambda) S(\lambda) d\lambda \tag{3}$$

When the displayed spectrum of the M-primary display $P(\lambda)$ is modeled by a linear combination of the maximum spectra of the M primaries $p_j(\lambda)$ (j=1~M), $P(\lambda)$ is expressed by

$$P(\lambda) = \sum_{j=1}^{M} q_j p_j(\lambda)$$
$$q_j = \gamma_j(d_j) \tag{4}$$

where d_j is the digital count and $\gamma_j()$ is the tone reproduction curve of j-th primary color. The relationship between q_j (the digital counts corrected by $\gamma_j()$) and the tristimulus values $T_p^{(k)}$ of the M-primary display in an observation condition **k** is represented by

$$T_p^{(k)} = \sum_{i=1}^{N} \sum_{j=1}^{M} a_{ti}^{(k)} q_j P_{ij} \tag{5}$$

where

$$P_{ij} = \int_{\lambda=380}^{780} c_i(\lambda) p_j(\lambda) d\lambda \tag{6}$$

To achieve the color matching between the object spectrum and the M-primary display spectrum for arbitrary observations **k** the tristimulus values in equation (2) have to be equal to those in equation (5) for arbitrary coefficients $a_{ti}^{(k)}$. Accordingly the condition to give the color matching reduces to

$$C_i = \sum_{j=1}^{M} q_j P_{ij} \quad (i=1\sim N) \tag{7}$$

It is necessary for the above equation to hold that the inverse of the N by M matrix **P** composed of the elements P_{ij} exists and all the digital counts satisfying equation (7) are within the range corresponding to the display gamut. The digital counts which display metameric color for arbitrary observing conditions **k** are given by

$$\begin{pmatrix} q_1 \\ q_2 \\ \vdots \\ q_M \end{pmatrix} = \begin{pmatrix} P_{11} P_{12} \cdots P_{1M} \\ P_{21} P_{22} \cdots P_{2M} \\ \vdots \\ P_{N1} P_{N2} \cdots P_{NM} \end{pmatrix}^{-1} \begin{pmatrix} C_1 \\ C_2 \\ \vdots \\ C_N \end{pmatrix}$$
$$d_j = \gamma_j^{-1}(q_j) \tag{8}$$

where −1 represents the operator of inverse. As the condition to achieve the accurate color reproduction independent of the viewing angle we assume the color reproduction of arbitrary tristimulus values corresponding to the CMF represented by linear combinations of the CIE 1931 CMF and the CIE 1964 CMF. In the case that a 6-primary display is used for the above aim (i.e. N = 6, M = 6 and **k** specifies the viewing angle) equation (8) is expressed as

$$\begin{pmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \\ q_5 \\ q_6 \end{pmatrix} = \begin{pmatrix} P_{X_2,1} P_{X_2,2} P_{X_2,3} P_{X_2,4} P_{X_2,5} P_{X_2,6} \\ P_{Y_2,1} P_{Y_2,2} P_{Y_2,3} P_{Y_2,4} P_{Y_2,5} P_{Y_2,6} \\ P_{Z_2,1} P_{Z_2,2} P_{Z_2,3} P_{Z_2,4} P_{Z_2,5} P_{Z_2,6} \\ P_{X_{10},1} P_{X_{10},2} P_{X_{10},3} P_{X_{10},4} P_{X_{10},5} P_{X_{10},6} \\ P_{Y_{10},1} P_{Y_{10},2} P_{Y_{10},3} P_{Y_{10},4} P_{Y_{10},5} P_{Y_{10},6} \\ P_{Z_{10},1} P_{Z_{10},2} P_{Z_{10},3} P_{Z_{10},4} P_{Z_{10},5} P_{Z_{10},6} \end{pmatrix}^{-1} \begin{pmatrix} X_2 \\ Y_2 \\ Z_2 \\ X_{10} \\ Y_{10} \\ Z_{10} \end{pmatrix} \quad (9)$$

$$d_j = \gamma_j^{-1}(q_j)$$

where $X_2Y_2Z_2$ are the tristimulus values calculated using the CIE 1931 CMF($x_2(\lambda)$, $y_2(\lambda)$, $z_2(\lambda)$), $X_{10}Y_{10}Z_{10}$ are the tristimulus values calculated using the CIE 1964 CMF($x_{10}(\lambda)$, $y_{10}(\lambda)$, $z_{10}(\lambda)$) and the suffices x_2, y_2, z_2, x_{10}, y_{10} and z_{10} of the elements P mean to use $x_2(\lambda)$, $y_2(\lambda)$, $z_2(\lambda)$, $x_{10}(\lambda)$, $y_{10}(\lambda)$ and $z_{10}(\lambda)$ as $c_i(\lambda)$ in equation (6) respectively. The spectral sensitivities of both the CMF are shown in Fig.1.

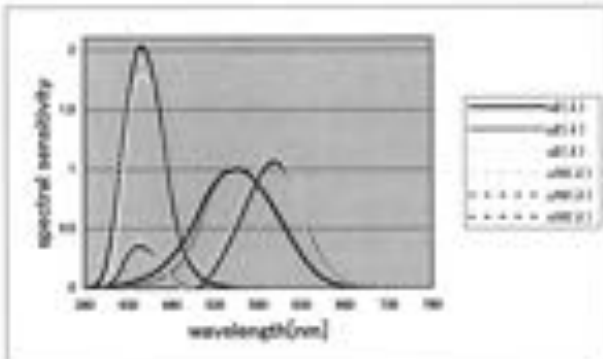


Fig.1 The CIE 1931CMF and the CIE 1964 CMF

2.2 Simulation

The accuracy of color reproduction using a 6-primary display and a RGB display for a variety of object spectra under two kinds of illuminations are simulated. The spectra of the 6-primaries used in this simulation are measured data of the 6-primary display developed in Akasaka Natural Vision Research Center. The spectral power distributions of the 6-primary display and those of the RGB display are shown in Fig.2 and the CIE 1931 xy chromaticity coordinates of each primariy of the 6-primary display and the RGB display are shown in Fig.3. The object spectra are calculated by multiplying the spectral reflectances of the objects in Standard Object Colour Spectra Database for Colour Reproduction Evaluation (SOCS) [6] by the illumination spectrum of the CIE standard illuminant C and the measured spectrum data of a fluorescent lamp TL84. The CIE ΔE error in L*a*b* space which is calculated using the CIE 1931 colorimetric system is evaluated for the color reproduction of the 6-primary display and the RGB display. In the case of the 6-primary display the color displayed using the digital counts derived from equation (9) is evaluated. In the case of the RGB display the color displayed using digital counts that display the CIE 1964 XYZ tristimulus values is evaluated.

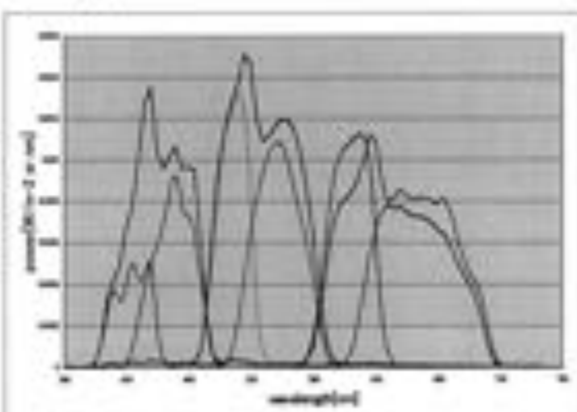


Fig.2 The spectral power distributions of the 6-primary display (——) and RGB display (----).

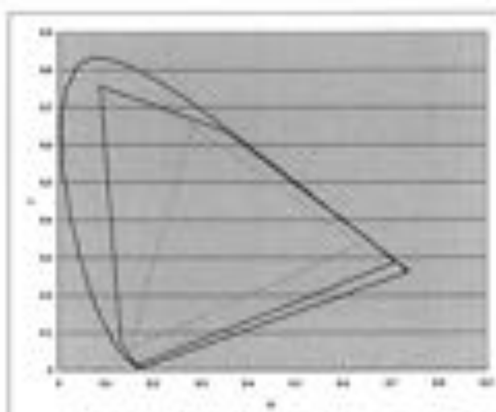


Fig.3 The CIE 1931 xy chromaticity coordinates of the 6-primary display (——) and RGB display (----).

3. RESULTS

The average and maximum color reproduction errors under two kinds of illuminants are listed in Table 1. The objects are classified into the eight categories according to the categories in the SOCS database. In the case of the CIE standard illuminant C the average error calculated taking the sample numbers into account is 0.07 and the maximum error is 3.2 by the 6-primary display. On the other hand the average error is 1.1 and the maximum error is 9.5 by the RGB display. The results of the fluorescent lamp TL84 become to be similar to those of the CIE standard illuminant C in spite of the large difference between the spectral characteristics of the illuminants.

Table 1 Color reproduction errors

Category	Sample Number	The CIE standard illuminant C				Fluorescent lamp TL84			
		Ave. (6PRI)	Ave. (RGB)	Max (6PRI)	Max (RGB)	Ave. (6PRI)	Ave. (RGB)	Max (6PRI)	Max (RGB)
Photo	2176	0.164	1.330	2.168	5.342	0.034	1.309	1.141	4.096
Graphics	27532	0.057	1.053	1.914	6.242	0.015	1.228	1.801	4.910
Printer	6436	0.154	1.951	3.245	9.464	0.047	1.328	1.822	5.532
Paints	153	0.137	1.679	2.272	7.000	0.042	1.857	1.145	6.648
Flowers	119	0.029	1.454	0.812	4.973	0.026	1.747	0.435	5.334
Leaves	92	0.000	1.342	0.000	2.716	0.000	2.640	0.000	3.939
Face	8049	0.000	0.742	0.000	1.823	0.000	1.605	0.000	2.360
Krinov data	351	0.033	0.946	0.751	3.219	0.000	2.186	0.000	4.054

4. DISCUSSION

In this simulation the inverse matrix P^{+} in equation (9) exits. So theoretically the color reproduction errors for arbitrary objects' spectra should become zero except in the case that the six-stimulus values of the objects in the six dimensional space are out of the gamut of the 6-primary display. Accordingly the residual errors in the reproduction of the 6-primary display are due to the colors exceeding the gamut of the 6-primary display. Although in this simulation the color out of the gamut are mapped on the gamut surface by clipping the digital counts of the display the gamut mapping technique can be applied in 3-D color space (e.g. the average 3-D color space) for more accurate or preferred color reproduction.

The aim of the method proposed in this paper is not restricted to the color reproduction independent of the viewing angle but for the other situations that the variations of the color matching functions exist. The variations of the CMF caused by personal deviations, the difference of the race, the age and so on are such cases. In those cases the $c_i(\lambda)$ in equation (1) can be given by the principal components of a population of CMF in the observations.

5. CONCLUSION

A novel color reproduction method that is independent of the variations of the color matching functions using a multi-primary display is proposed. This method is applied to the accurate color reproduction independent of the viewing angle. The simulation that examines the color reproduction accuracy using this method supposing that a spectrum of the object is given is conducted. Comparing the color reproduction accuracy achieved by the 6-primary display using our method with that by a current RGB display it is verified that the proposed method can improve the accuracy.

REFERENCES

1.Colorimetry 2nd ed., CIE Publication, No.15.2, Central Bureau of the CIE, Vienna, 1986.

2.T. Ajito, T.Obi, M.Yamaguchi, and N. Ohyama, "Expanding color gamut reproduced by six-primary projection display," *Proc. SPIE*, **3954**, pp.130-137, 2000.

3.T. Ajito, K. Ohsawa, T. Obi, M. Yamaguchi, and N. Ohyama, "Color conversion method for multiprimary display using matrix switching," *J. of Opt. Rev.*, **8**, No.3, 2001. (To be published)

4.TRX0012, JIS 1998.

Parametric investigation of Multispectral imaging

David Connah*, Stephen Westland and Mitchell GA Thomson
Colour & Imaging Institute, Derby University, Derby, UK

ABSTRACT

Multi-spectral imaging systems can be used to recover estimates of the spectral reflectance properties of surfaces in an image. This process can be aided by utilising *a priori* knowledge of the reflectance spectra derived from linear models of surface reflectance. We use this recovery method in a simulated camera system, and investigate the effect of varying sensor characteristics and illuminants on the accuracy of the system. We also investigate the effect of quantisation noise and random sensor noise on the process. Unlike other recovery methods, increasing the number of sensors in the system - and hence the number of basis functions used in the linear model - does not necessarily improve performance. We find that increasing the amount of noise increases reconstruction error and it does so to a greater extent for large sensor numbers and large sensor band-widths. The robustness of the process to noise is improved by using illuminants that have approximately equal power across all visible wavelengths of light.

Keywords: camera model, reflectance recovery, basis functions, linear models, multi-spectral imaging.

1. INTRODUCTION

The spectral reflectance functions of surfaces in a scene can be estimated using a trichromatic imaging system and a known light source. However, more accurate estimates can be obtained if more than three signals are captured at each spatial location in the image. This can be achieved by capturing the image under more than one known light source or by using a monochrome digital camera in conjunction with a number of coloured filters. The purpose of this study is to investigate the important imaging parameters in designing such a multi-spectral imaging system. The approach taken here is to build a simulated camera model using MATLAB software, and to systematically vary the parameters in this model to investigate their effect on the recovery of spectral reflectance functions.

The camera model is an ideal image-capture system based upon a simple mathematical model of the interactions between surfaces, light sources, filters and the camera sensitivities. The model assumes that the camera is a completely linear system. Thus

$$O_i = \int_\lambda E(\lambda)R(\lambda)S_i(\lambda)d\lambda + e \qquad (1)$$

where $S_i(\lambda)$ is the spectral sensitivity of each channel i which is given by the transmittance of each filter coupled with the spectral sensitivity of the monochromatic camera, $E(\lambda)$ and $R(\lambda)$ refer to the illuminant power and the surface reflectance functions of wavelength λ respectively, and O_i is the output of the sensor array for each sensor i. The error term e represents a small random term to simulate additive sensor noise.

* For correspondence contact d.r.connah@derby.ac.uk

A wide range of tools exist for the estimation of reflectance from digital camera data[1-4]. The method used here incorporates a linear model of surface reflectance spectra. That is, each reflectance spectrum $R(\lambda)$ is represented as the weighted sum of basis functions $B_j(\lambda)$ thus

$$R(\lambda) = \sum_j a_j B_j(\lambda) \quad (2)$$

where a_j are weighting functions and $j = 1, \ldots, N$.

If these basis functions are chosen carefully as few as 6-9 basis functions can be used to closely approximate most man-made and natural reflectance spectra[5]. Therefore, in order to estimate a reflectance function R it is sufficient to determine the coefficients a. Equation 2 can be substituted into equation 1 to give

$$O_i = \int_\lambda E(\lambda)\left(\sum_j a_j B_j(\lambda)\right) S_i(\lambda) d\lambda + e. \quad (3)$$

If we assume that $E(\lambda)$, $S(\lambda)$ and $B_j(\lambda)$ are all known, equation 3 can be recast as a matrix-algebra problem with i equations and j unknowns. This gives

$$\mathbf{o} = \mathbf{La} \quad (4)$$

where $\mathbf{a}$ is a column vector of coefficients, $\mathbf{o}$ is a column vector of digital output values and $\mathbf{L}$ is an $i \times j$ matrix obtained by multiplying together the illuminant, spectral sensitivity curves of the camera and the predetermined basis functions. Equation 4 can be solved to yield $\mathbf{a}$ by determining the inverse of $\mathbf{L}$, denoted by $\mathbf{L}^{-1}$, and multiplying through to give $\mathbf{L}^{-1}\mathbf{O} = \mathbf{a}$. Once $\mathbf{a}$ is known the estimated reflectance is then calculated using equation 2.

2. METHODOLOGY

This study makes several assumptions. Firstly, channel sensitivities $S(\lambda)$ were always assumed to be Gaussian with peaks equally spaced in wavelength. Secondly, each sensor was normalised such that the integral under the sensitivity curve was 1. Thirdly, the number of basis functions used was always equal to the number of sensor channels so that the solution matrix $\mathbf{L}$ (see equation 3) was always square. The values of $E(\lambda)$ used represented CIE illuminant A, F11, D65 and an equal-energy illuminant with a value of 1 at all wavelengths. The imaging parameters investigated were sensor number N and sensor half width σ, and the effects of changing these parameters were evaluated in the presence of random noise e, quantisation noise and without noise. The variable e was normally distributed with mean zero and a variable standard deviation that controlled the magnitude of the noise. The effect of quantisation noise was evaluated by converting the calculated values of sensor output O into discrete 8-, 10-, and 12-bit representations.

Thus, for various values of N and σ the output of the camera model O_i was computed (equation 1) and equation 4 was inverted to estimate the reflectance functions for a set of 1269 Munsell chips[6] using various noise and illuminant conditions. Solution of equation 4 requires a set of known basis functions. These were derived using a singular value decomposition of a matrix containing the Munsell reflectance data. Reconstructed spectra were compared with original spectra by computing the CIELAB ΔE differences under illuminant D65.

3. RESULTS

3.1 Effect of sensor number

Figure 1 shows the mean ΔE reconstruction error as a function of sensor number ($\sigma = 110$ nm) for various illuminants for the no-noise condition. It is evident that in general performance improves (ΔE decreases) with increasing number of sensors. Recall that the number of basis functions used to represent the reflectance functions increased with the number of sensors.

However, performance did not always improve with increasing number of sensors. For example, pronounced 'peaks' in mean ΔE are clearly evident when $N = 6$ for all illuminants.

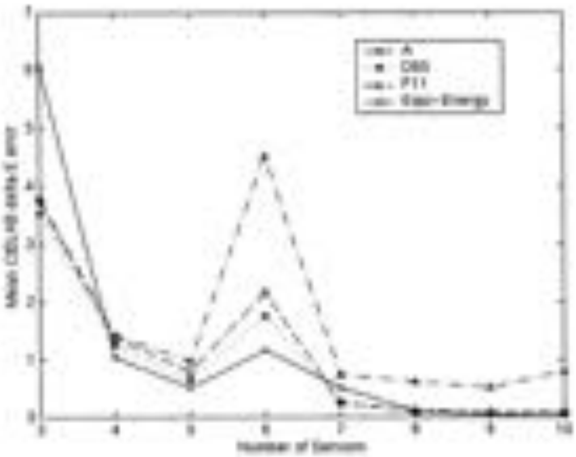


Figure 1: Mean ΔE reconstruction error vs. sensor number for 4 illuminants, $\sigma = 110$nm.

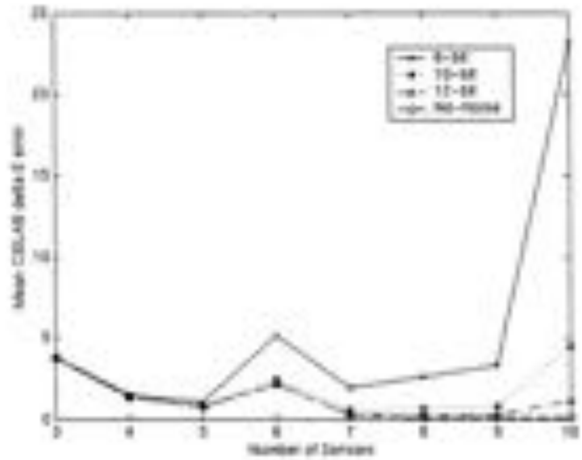


Figure 2: Mean ΔE reconstructed error vs. sensor number for four levels of quantisation noise, $\sigma = 110$nm, $E(\lambda)$ = equal energy illuminant.

3.3 Quantisation noise

Figure 2 shows the effect of increasing quantisation noise on the reconstruction error for different numbers of sensors ($\sigma = 110$ *nm* and equal energy illuminant condition). Generally the effect of quantisation noise was to increase the error as expected but was more marked for high values of N. The effect was also more marked with greater values of σ.

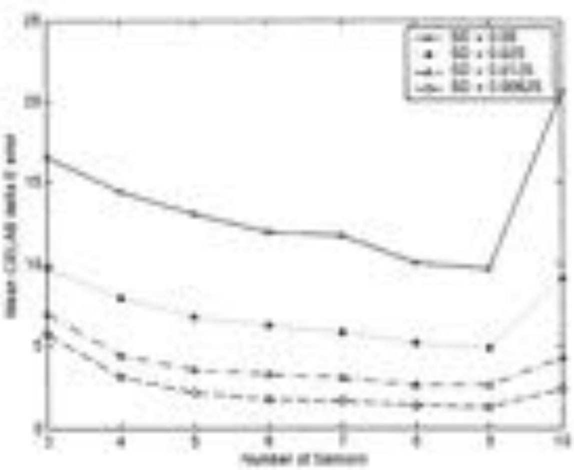


Figure 3: Mean ΔE reconstruction error vs. number of sensors, SD = standard deviation of ε, $\sigma = 10$nm, $E(\lambda)$ = equal energy illuminant.

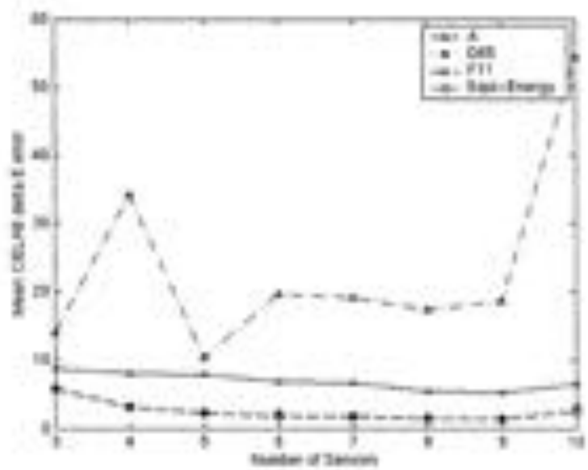


Figure 4: Mean ΔE reconstruction error vs. sensor number, $\sigma = 10$nm, SD = 0.00625.

3.4 Random sensor noise

The effect of random noise was evaluated by adding small random values e to the sensor outputs. Figure 3 shows the result of increasing the standard deviation *SD* of e and unsurprisingly, the reconstruction error increases with increasing noise. The effect of noise was more marked for large sensor half width σ. Figure 4 compares the results for the different illuminants with the same noise level. This shows a consistent difference between the different illuminants, with high errors for both illuminants A and F11. Conversely, illuminants D65 and the equal energy illuminant appear to make the reconstruction process relatively robust to sensor noise.

4. DISCUSSION

The purpose of this study was to provide some insight into the optimal imaging parameters necessary for the recovery of spectral reflectance functions using linear models. The data show several principles. Firstly, it is not necessarily advantageous to increase the number of sensors. Reasonable performance is obtained with $N = 5$ (mean $\Delta E<1$) but the error can increase dramatically when $N = 6$ (mean $\Delta E>4$ for some illuminants). Secondly, although the half width of the sensors and the choice of illuminant do not play a role in noise-free conditions, in noisy conditions there is a clear advantage for using smaller sensor half widths and illuminants which have an equal distribution of energy across all wavelengths. It is also true that in noisy conditions, increasing the number of sensors beyond 5 is detrimental to performance. These facts can all be united in the concept of the condition number[7] of the matrix **L** (see equation 4), which is given by $\|\mathbf{L}\|\times\|\mathbf{L}^{-1}\|$. We find that when the condition number of **L** is high the process is more sensitive to noise. Furthermore, condition number generally increases with increasing N and σ, and is much higher for illuminants with uneven energy distributions, all of which lead to increases in error in the presence of noise. In order to minimise error in the reconstruction process it may be sufficient to choose sensors and illuminants such that they minimise the condition number of **L**.

ACKNOWLEDGMENTS

This study is supported by an EPSRC grant.

REFERENCES

1. F. König and W. Praefcke, "A multispectral scanner," *Colour Imaging: Vision and Technology*, edited by L.W. MacDonald and M.R. Luo, John Wiley & Sons Ltd, 1999.
2. C. van Trigt, "Smoothest reflectance functions. I Definition and main results," *J. Opt. Soc. Am. A.*, **7** (12), pp. 1891-1904, 1990.
3. F.H. Imai and R.S. Berns, "Spectral estimation using trichromatic digital cameras," *Multispectral Imaging and Color Reproduction for Digital Archives*. Chiba University, 1999.
4. L.T. Maloney and B.A. Wandell, "Color Constancy: A method for recovering surface spectral reflectance," *J. Opt. Soc. Am. A.*, **3** (1), pp. 29-33, 1986.
5. L.T. Maloney, "Evaluation of Linear Models of surface spectral reflectance with small numbers of parameters," *J. Opt. Soc. Am. A.*, **3**, pp. 1673-1683, 1986.
6. J.P.S. Parkkinen, S. Hallikainen, and T. Jaaskelainen, "Characteristic spectra of Munsell colors," *J. Opt. Soc. Am. A.*, **6**, pp. 318-322, 1989.
7. G.J Borse, *Numerical Methods with MATLAB: A resource for scientists and engineers*. PWS publishing company, 1997.

Color reproduction scheme for Kodak organic light emitting diode (OLED) technology

Paula J. Alessi and Patrick L. Cottone, Eastman Kodak Company

ABSTRACT

The color characterization of organic light emitting diode (OLED) display technology is a technical challenge that must be understood. This paper will present the methodology for a full-color characterization of a prototype, which uses Kodak OLED technology. The color characterization will be centered on achieving an aim D65 white point at a luminance level of approximately 100 cd/m^2. Such a color characterization reveals the neutral scale and color reproduction characteristics of the OLED. This paper will present the results of software implementation techniques that enhance the overall color reproduction performance of the Kodak OLED prototype.

Keywords: OLED, color reproduction, neutral scale, luminance characterization, color characterization, white point.

1. INTRODUCTION

OLED display devices promise to meet the needs of new and demanding imaging and graphic applications, especially for low-power, hand-held portable devices. Such applications impose greater design constraints and require better imaging performance than other imaging devices in use today, such as liquid crystal displays (LCD) and cathode ray tubes (CRT). OLED technology provides superior performance in brightness and color resolution, wider viewing angle, lower power consumption, and compact and robust physical characteristics.[1, 2]

OLED display materials and devices are undergoing rapid development by many participants. Progress in materials, manufacturing processes, and applications are being made, although concerns with lifetime and color gamut remain. Initial applications of passive matrix (PM) OLED devices into graphic displays are underway while active matrix (AM) applications are being demonstrated in the laboratory. Kodak has successfully integrated passive-matrix OLED devices onto low-temperature poly-silicon (LTPS) substrates, a key for low-cost integrated production. These displays have been integrated into the new portable applications market in the form of cell phones and displays for the automotive industry. A 5.5" AM LTPS OLED display has been successfully integrated into a Kodak prototype with good image quality and characterized for its RGB primaries and white point.

2. METHODOLOGY AND DATA

This paper describes the approach taken to fully characterize a Kodak OLED prototype. The components of an OLED full-color characterization are white point calibration and measurement of neutral scale properties, and color reproduction properties.

The white point calibration aim is D65 chromaticity at a luminance level of 100 cd/m^2. The red, green, and blue primary voltages were adjusted until a white point as close to the D65 aim was achieved. Figure 1 is the spectrum of the OLED white point resulting from the calibration. (chromaticity: $x = 0.3125$, $y = 0.3306$). Figure 2 is the luminance characteristic response of the prototype display (max. luminance level $Y = 96.2$ cd/m^2). Figure 3 shows the spectra of the display red, green, and blue primaries. Each channel (red, green, blue) was measured at its maximum voltage level and the resulting chromaticities were computed. All the measurements to characterize the display were made with a Photo Research model 705 telespectroradiometer. The red, green, and blue primary x,y chromaticities were: red (0.6428,0.3542), green (0.2663,0.6521), and blue (0.1412,0.187). The u'v' chromaticities were: red (0.4311,0.5345), green (0.1035,0.5702), and blue (0.1138, 0.3392).

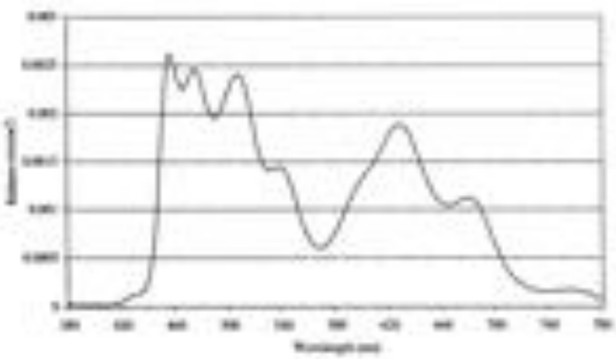


Figure 1. White point spectrum.

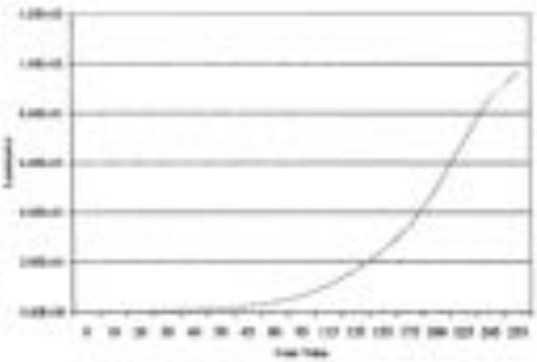


Figure 2. Luminance characteristic.

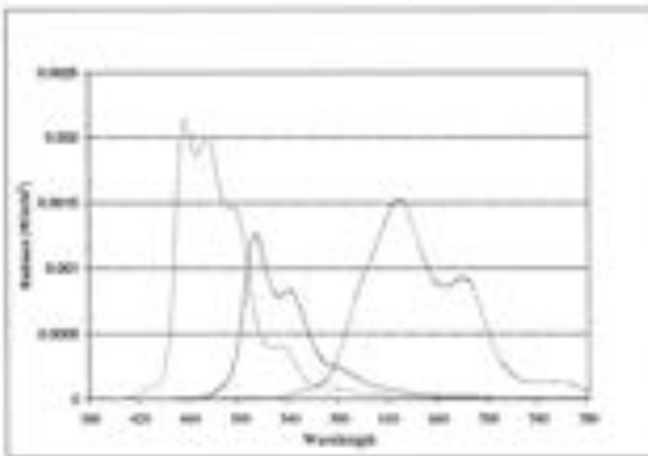


Figure 3. RGB primary spectra.

The neutral scale properties were determined from spectral measurements of a neutral scale target imaged on the OLED. The white reference for all calculations was the OLED white point. The + position in the CIELAB and CIELUV vector plots shown in Figures 4 and 5, respectively, illustrates a highly chromatic neutral scale for this OLED prototype in the magenta direction relative to the (0,0) a*,b* or u*,v* origin with C^*_{ab} or C^*_{uv} much greater than zero from white to black [(0,0) = OLED white point reference]. A neutral scale correction algorithm was developed to correct this very chromatic neutral scale to an achromatic neutral scale position at the (0,0) a*,b* or u*,v* origin with C^*_{ab} or C^*_{uv} equal to zero from white to black as shown by the triangle position in the CIELAB and CIELUV vector plots of Figure 4 and 5, respectively.

The color reproduction properties of the OLED prototype were determined from the spectral measurements of the red, green, and blue primaries shown in Figure 3, the luminance characteristic response shown in Figure 2 and a test color target intended to be displayed on the OLED. Preliminary results showed that the test target colors as imaged on the OLED display resulted in a root mean square (rms) error of 20.9 ΔE^*_{ab} or 28.0 ΔE^*_{uv} relative to the aim for these target colors. Therefore, a color enhancement algorithm was developed to move the test target colors closer to their aim color reproduction position. The CIELAB and CIELUV vector plots (Figures 4 and 5, respectively), show the comparison of before (+) and after (triangle) color enhancement for the test target as imaged on the OLED prototype. The most obvious feature of these plots is the magenta to green bias from before to after color enhancement. This illustrates that the color enhancement algorithm has a neutral correction step that corrects the chromatic (magenta) neutral target colors to an achromatic position, and also affects many of the other colors by removing the magenta bias imposed by the OLED characteristic response. The color enhancement algorithm has other features in it that significantly change the hue of yellows and blues to achieve the target colors closer to aim.

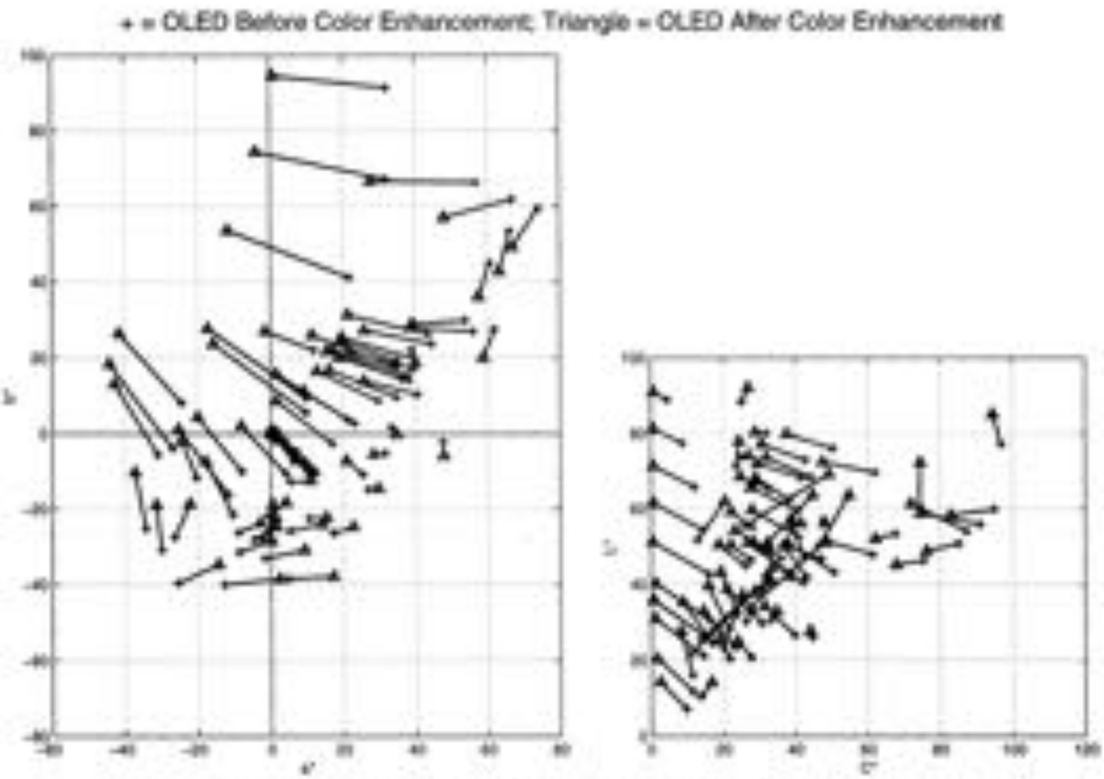


Figure 4. CIELAB vector plot showing before and after OLED color enhancement.

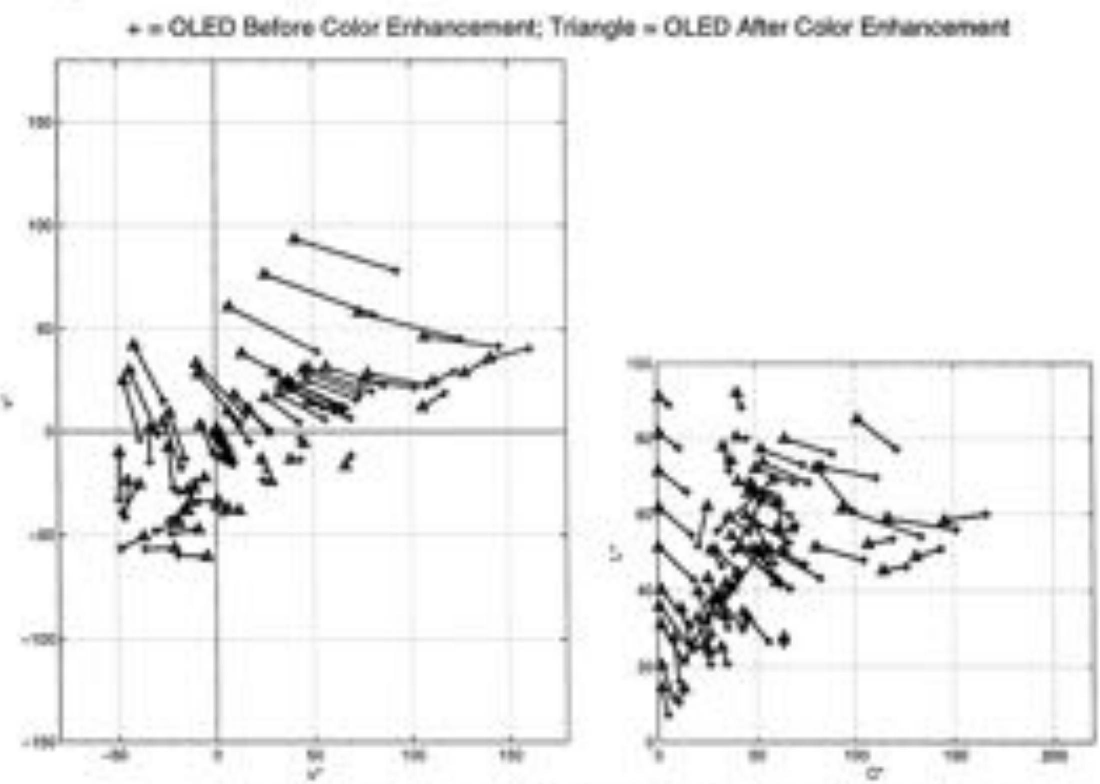


Figure 5. CIELUV vector plot showing before and after OLED color enhancement.

After color enhancement, the rms color error between the OLED position and the aim is 7.5 ΔE^*_{ab} or 8.4 ΔE^*_{uv}. This means that the color enhancement algorithm improved the reproduction by approximately a factor of 3.

Technology advancements are underway to further improve this color reproduction position of the Kodak OLED prototypes.

3. DEMONSTRATION OF RESULTS

This poster paper will feature a demonstration of the color reproduction characteristics of a prototype 5.5" active matrix Kodak OLED display. The input is digitally captured sRGB images. The color enhancement algorithm will be applied to these sRGB images so that we can demonstrate the resulting OLED images before and after color enhancement. The movements in the CIELAB or CIELUV vector plots of Figures 4 and 5 should be evident in the images. We welcome the visual assessments of all AIC participants.

4. SUMMARY

This paper has presented the methodology for a full-color characterization of a Kodak OLED prototype display. It has been shown how white point calibration and measurement of neutral scale properties and color reproduction properties can be used in development of a color enhancement algorithm that also corrects the neutral scale to an achromatic position. Software implementation techniques were used to demonstrate images before and after color enhancement on a Kodak OLED display prototype.

ACKNOWLEDGMENTS

We wish to express our sincere appreciation to our Kodak colleagues who helped develop this OLED technology: Johann Bachner, John Burtis, Ronald Cok, Richard Chapman, A. D. Cropper, Rodney Feldman, James Herbert, Mark Hettel, Thomas Niertit, Michael Siwinski, and David Williams. This work and demonstration was made possible through their generous support.

REFERENCES

1. Nikkei Microdevices 2000 Flat Panel Display Yearbook.
2. Organic Light Emitting Devices – Technology Trends and Display Market Assessment 2000.

Colour aliasing and colour reproduction in digital photography

Andrew N. Chalmers*, Department of Electrical & Electronic Engineering,
Manukau Institute of Technology, Auckland, New Zealand.

ABSTRACT

This paper reports on the development of a test method for the assessment of the colour performance of typical consumer-type digital still cameras. The colour properties investigated were colour aliasing, general colour reproduction, task-specific colour reproduction and automatic colour balance. Some typical results are presented to illustrate the types of comparisons that may be drawn.

Keywords: Colour aliasing, colour reproduction, digital photography, colour image quality

1. INTRODUCTION

This project had its origins in the New Zealand meat industry where there is an interest in the potential use of consumer-type cameras for image acquisition in technical imaging applications. An initial investigation of the problem area led to the proposal to test the candidate cameras in terms of four main colour performance features:

- colour aliasing
- general colour reproduction
- task-specific colour reproduction
- automatic colour balance (a standard feature on most models).

For the purpose of colour-balance testing, it was decided to standardize the lighting by – as far as possible – making use of only two types of light sources, having significantly different spectral distributions:

- tungsten-filament photographic lamps (one lamp type used throughout)
- each camera's own built-in flash (where provided).

Consumer-type digital cameras are becoming progressively more affordable and widespread in their applications; and the use of these cameras in technical imaging applications[1, 2] is increasing rapidly. The purposes of this paper are to outline the typical colour performance features of such cameras, and also to propose a simple and efficient qualification-testing procedure for use by those intending to use consumer-type digital colour cameras in their imaging work. In many instances, these procedures will provide the type of information that could, if required, be utilized for calibration purposes. The types of cameras examined in this project are relatively low-cost consumer products, representative of mid-1990s technology, and fall into the sub-megapixel to megapixel category (Cameras #1, #2, #3). A camera of this type is built around a single CCD sensor with mosaic optical filtering, and nearly always incorporates a high degree of automation in the picture capture process. Some cameras permit manual override of selected automated features. A semi-professional 3-CCD digital video (sub-megapixel) camera with still picture capability (new on the market in 2000) has also been tested (Camera #4) for comparison with the lower-cost still cameras.

2. COLOUR ALIASING

It is known that single-CCD colour image sensing can lead to colour aliasing in the images acquired. This usually takes the form of patterns of coloration in the image that do not exist in the original object. The cause is related to the sensor design that leads to under-sampling of the colour information. Camera designs have evolved, using signal-processing to limit this effect, but it cannot be completely eliminated without resorting to more-costly sensing systems. The test method uses a Sayce test chart, which is photographed at different distances (or with a range of different zoom-lens focal lengths) to yield chart images of varying size. The chart is made up of black bars on a white background, and the spatial frequency of the bars gradually increases from one end of the chart to the other. Images of this chart, taken with the test cameras, have consistently shown regions of colour aliasing. The onset of coloration in each Sayce chart image was judged subjectively by the author:

(i) for the first visible sign of coloration, where unsaturated colours are observed within the bar pattern,
(ii) for the beginning of the region of "solid" coloration, where the bar pattern is totally replaced by regions of highly saturated colour.

From the known structure of the chart, it is possible to determine the spatial frequencies for which the aliasing is observed. The computation of spatial frequencies takes account of the relative size of the chart in a given image, to convert to an effective spatial frequency for the specific camera sensor. The key results for the four test cameras are summarized in Table I.

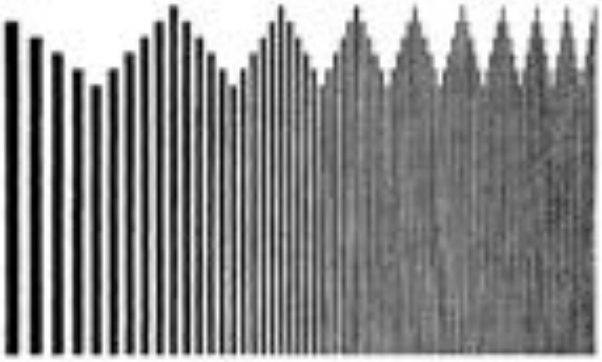


Figure 1: Image of Sayce chart used.

Camera #	Test images used	Onset of coloration (average cycles per pixel on image)		Notes (See text below)
		Light coloration	Solid coloration	
1	8	0.20	0.36	
2	5	0.23	0.37	a
3	12	0.19	0.34	b
4	4	0	0	c

Table I: Observed spatial frequencies: onset of colour aliasing

There are several points to note about the results in Table I:

(a) It was found that Camera # 2 exhibited no perceptible aliasing under flash illumination – and the analysis shown for this camera excludes five images that were acquired using the camera's own flash. The five images analysed for this camera were all taken using a mixture of tungsten-filament and tubular-fluorescent light sources (since the focusing range possible with this camera resulted in very non-uniform illumination unless the fluorescent room lights were used as "fill" lighting).
(b) Camera # 3 had no flash capability, and all 12 images in this analysis were taken under tungsten filament lighting.
(c) Camera # 4 was equipped with a 3-CCD sensor, and no colour aliasing was observed under any illumination conditions.

2.1 Discussion

2.1.1 It should be noted that all the images analysed in Table I were still images. It is possible that colour aliasing would have occurred with Camera # 4 if there had been relative motion between the camera and test chart.

2.1.2 It is surmised that the design of the signal processing system for Camera # 2 sensor must have been optimized for the camera's own flash illumination, in effect to eliminate colour aliasing.

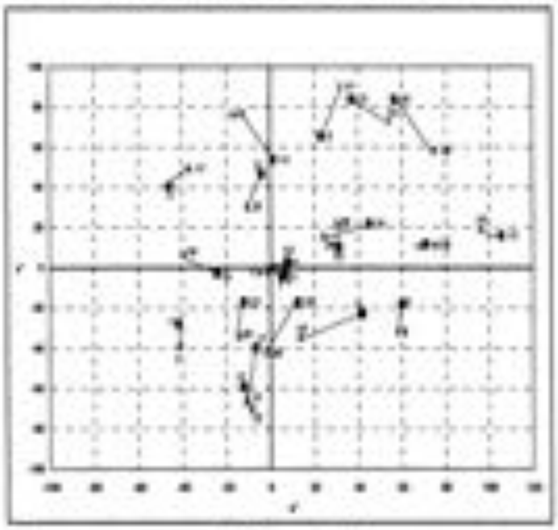
2.1.3 For all cameras other than camera # 4, some colour aliasing was visible for bar pattern periods of approximately 5 pixels per cycle (low-saturation coloration in the background regions between the black bars); and solid regions of high-saturation colour became visible at approximately 3 pixels per cycle.

2.1.4 For Camera # 1, comparative data were published in an earlier paper[7] which included an investigation of limiting resolution using images of a sinusoidal grey-scale test chart. The results showed that the Nyquist limit for this camera was at a sampling period of 2.8 pixels/cycle (or spatial frequency of 0.357 cycles/pixel – which is virtually identical to the result quoted in Table I for the onset of "solid" colour aliasing). Subsequent analysis of similar (sine chart) images acquired on Cameras # 2 and # 3 showed similar Nyquist limits, and similar correlation with Table I.

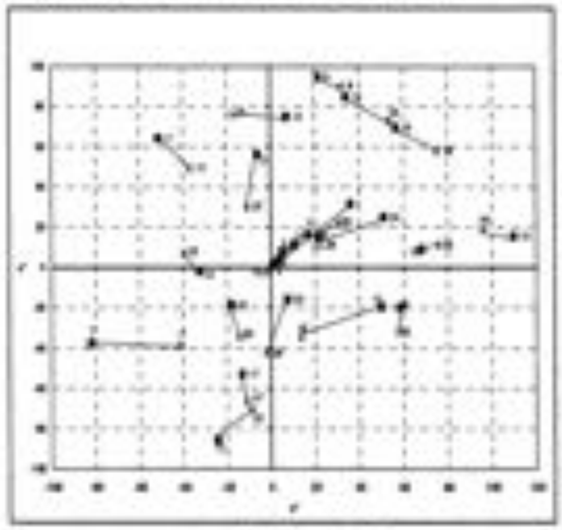
3. COLOUR REPRODUCTION AND COLOUR BALANCE

3.1 General colour reproduction

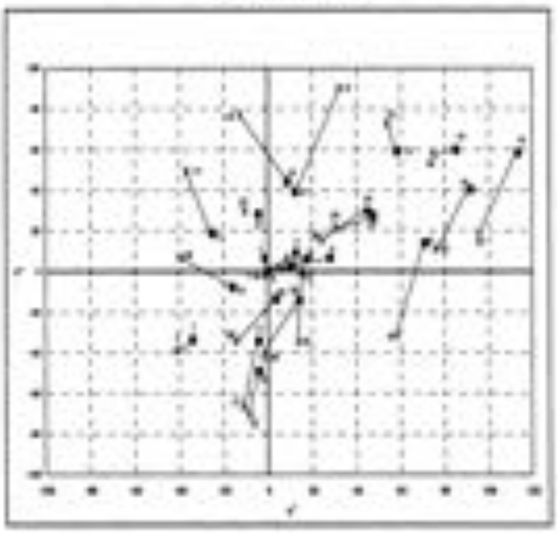
The test object chosen for this test was the Macbeth ColorChecker™ chart. With its 18 chromatic and 6 neutral colour samples, this chart provides a useful sampling of colour space for general colour reproduction assessment. Image analysis software was developed for the evaluation of the reproduced colours in the digital image format. This provides an overall assessment of general colour reproduction under the two selected light sources, and also shows the extent to which colour consistency has been achieved (in terms of each camera's automatic colour balance). Comparisons of the results from different cameras are also possible, as shown in CIE-1976 (u*,v*) coordinates in Figure 2 below.



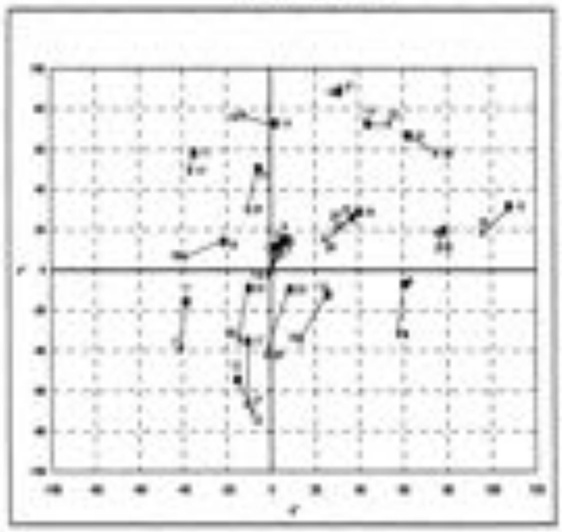
(a) Camera # 1



(b) Camera # 2



(c) Camera # 3



(d) Camera # 4

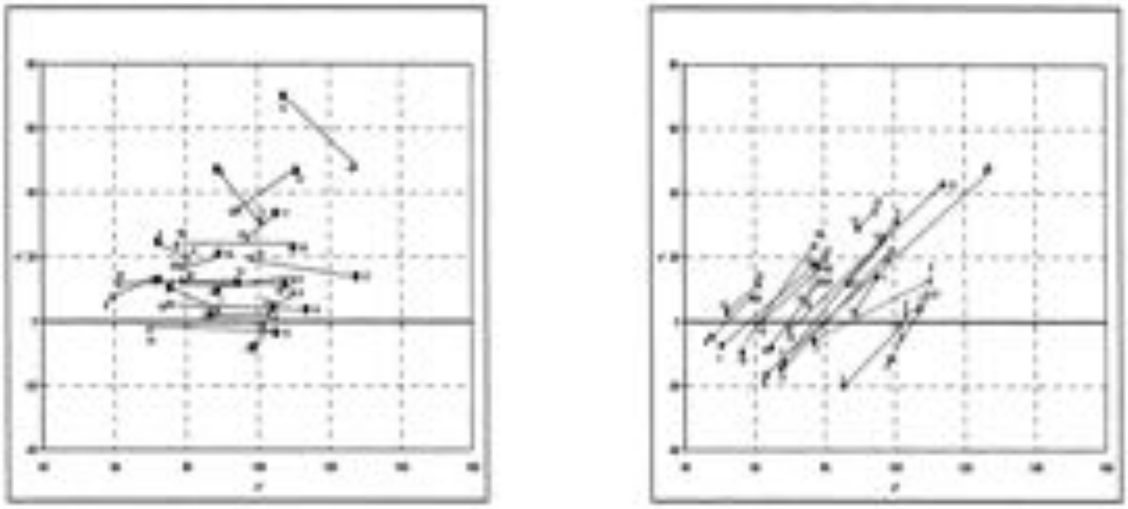
Figure 2: v* / u* plots for reproductions of the Macbeth ColorChecker™ taken under tungsten lighting:
Crosses = original colours, Squares = reproduced colours

3.2 Task-specific colour reproduction and the "All-Reds" test chart

One specific hue range was of greatest interest in this project, *viz.* meat colours. This was sampled in greater detail with the aid of a specially constructed test chart which was purpose-made using 18 chromatic samples from a Munsell Color File™. This task-specific test chart was used in the same way as the ColorChecker, and similar analysis software was developed for the evaluation of colour reproduction in the selected hue range, for images acquired under the two types of light source used. Figure 3, for Camera # 1, shows the original and reproduced colours in CIE-1976 (u*,v*) plots.

3.3 Automatic colour balance

This was a test of the ability of each camera to provide automatic "adaptation" to different light-source spectra; and it was performed on Cameras # 1 and # 2 for both the Macbeth ColorChecker and the "All-Reds" test charts. Because of space limitations, Figure 3 illustrates only one of these comparisons – *i.e.* the "All-Reds" results for Camera # 1.



(a) Tungsten Illumination

(b) Internal Flash

Figure 3: v^* / u^* plots for reproductions of the "All-Reds" test chart taken with Camera # 1:
Crosses = original colours, Squares = reproduced colours (Tungsten), Diamonds = reproduced colours (Flash)

3.4 Discussion

3.4.1 Data in the form of Figure 2 allow comparisons of general colour reproduction between different cameras. It is also possible to use this data to provide a form of colorimetric calibration for each camera[3,4].

3.4.2 Comparative (general colour reproduction) data for Cameras # 1 and # 2 was also acquired for flash illumination, but has not been included because of space limitations.

3.4.3 It can be argued that the most convincing test objects for the task-specific tests would have been real meat samples: however, this was impractical on account of the extended period over which testing occurred.

3.4.4 Figure 3 shows the significantly different colorimetry of the results achieved with a single camera (and the same set of colour samples) when changing the light source from tungsten to flash – where the latter image shows a large increase in blue content. Camera # 2 gave results of a generally similar nature.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the financial assistance provided by the Professional Development Fund Committee at the Manukau Institute of Technology. The work described in this paper was carried out under the terms of a Manukau Institute of Technology Industry Fellowship. Thanks are due to Charles Tsui for assistance with data acquisition and processing, and to Ross Clarke and Alaksandar Jelenak at AgResearch Limited, New Zealand, for their support and assistance, and the loan of items of test equipment.

REFERENCES

1. Y. Vander Haeghen, J. M. A. D. Naeyaert, I. Lemahieu, and W. Philips, "An imaging system with calibrated color image acquisition for use in dermatology", *IEEE Trans. Medical Imaging*, **19**, pp. 722-730, July 2000.
2. S. E. Papadakis, S. Abdul-Malek, R. E. Kamdem, and K. L. Yam, "A versatile and inexpensive technique for measuring color of foods", *Food Technology*, **54**, pp. 48-51, December 2000.
3. A. N. Chalmers, A. Jelenak, and C. Tsui, "Assessing the performance of the digital colour camera", *Proceedings of IVCNZ 2000*, University of Waikato, Hamilton, New Zealand, pp. 96–101, November 2000.
4. C. Connolly and H. Palus, "Colorimetric calibration of acquisition hardware" in *The colour image processing handbook*, pp. 140-146, Chapman & Hall, London, 1998.

* Correspondence: email: chalmers@manukau.ac.nz; phone: (+649)274-6009; fax: (+649)273-0711;
postal: Private Bag 94-006, Manukau City, New Zealand.

Color applied to printing graphic design: the importance of lighting in the color perception and specification process

Berenice S. Gonçalves* Alice C. Pereira** and Fernando O. R. Pereira
Universidade Federal de Santa Catarina. Brazil

ABSTRACT

This work approaches the importance of lighting in the process of chromatic categorization, selection and specification applied to the printed media. Some concepts regarding lighting are presented, such as color temperature, color appearance and color rendering index. Finally, stands out the necessity to evaluate the samples under standard lighting conditions regarding the environment where the final product will be exposed.

keywords: Color, lighting, graphic production

1. INTRODUCTION

Under a subjective view, color is the response to a stimulus captivated by the eyes and interpreted by the brain. Physically, color is a part of the electromagnetic waves spectrum that allows the distinction of differences in the quality of visual sensation when it stimulates the human vision[1].

Physically, as well as metaphorically, color results in a strong perceptive power. Chromatic language has a great communication power concerning the final product. Colors can guide the observer's eyes, emphasize important visual information, affect legibility, put together or break apart the different parts of a graphic design. The fidelity between the colors of the original and the printed material has always been a polemical issue within the graphic production field, and became even more complex with the arrival of the DTP systems (Desk Top Publish). The electronic editing based on the WYSIWYG principle (what you see is what you get) has not achieved the initial expectations. Printed colors (CMY or CMYK) are perceived when a part of the light from the light source is reflected by the support or white substratum and the remaining part is absorbed by the colorings of the printed page.

Human perception does not read radiating light and reflected light in the same way, reason why the fidelity of colors becomes an abstract ideal. In brief, the colors on the computer screen do not always match the colors of the original images, or the colors of the printed material [2]. () Thus, the specification of a certain color through the spot colors system becomes necessary. Instead of overlaying the inks during printing, the spot colors are prepared according to a certain composition. They also favor the chromatic standardizing of brands, logos, being very used in the corporative identity field in general, and reproduce the tonalities out of gamut, such as saturated, pastel, golden and metallic tonalities.

However, in the process of choice making and comparison of special colors, many professionals ignore the fact that the printed material is visualized under specific lighting conditions, therefore missing the opportunity to use consistent lighting standards during the different phases of the graphic design.

2.DEVELOPMENT

The color of the bodies does not rely only on the nature of the matter that they are made of, but also on the light that illuminates them. When a light beam reaches the body, it is known that a part of it is reflected and the other one is absorbed. The part that is reflected reaches our eyes, and a certain color is attributed to that body, according to the quality of the reflected light[3]. Thus, it is perfectly understood that the colors of the bodies change depending on the light source that illuminates them. In a day by day situation, it is assumed that a body is exposed to the day light, which we call white light. No artificial source of light can provide the same white light, despite the most recent technological improvements. A scientific objective measurement of the color is possible by using spectrophotometers, instruments that can measure the intensity of each of the monochromatic components that constitute the spectrum of a polychromatic radiation[4].

2.1 Lighting concepts that should be considered when visualizing the colors

2.1.1 Color Temperature

Every luminous radiation that reaches an object gives place to an energy exchange. It means that the radiant energy is absorbed and reemitted by this object. As a general rule, a part of the incident light beam is reflected by the surface of the bodies, a second one is absorbed by them, and a third one is transmitted. This step almost does not take place among the bodies with high optical density and the light is not totally absorbed. A metallic surface, for instance, that is perfectly polished, has a low absorbing capacity, while mat surfaces on the other hand, specially the ones called black surfaces, have a reduced reflecting capacity and a great absorbing capacity. A completely black body totally absorbs the radiation, whether it is visible or not, because it has no reflecting capacity. But this is a situation that does not exist in nature, it is an ideal example (the completely black body is a hypothetical idea, and it is simply called Black Body). The Black Body is able to reemit a maximum radiation level when it becomes hot [3].

The spectral composition of the white light is based on two premises: (a) the light source in matter should produce a continuum spectrum with all the visible colors; (b) the relative proportions of short and long waves within the luminous radiation should gradually change as the temperature increases in this light source.

The colored lights correspond to the following color temperatures of the black body:

Red	800 – 900 K
Yellow	3.000 K
White	5.000 K
Blue	8.000 – 10.000 K
Shinning blue	60.000 K

Chart 1 – colored lights and color temperatures[5]

2.1.2 Color appearance

The light sources can be separated in groups concerning the interrelation between color appearance and temperature. The following chart (chart 2) presents the apparent color of the lamp bulbs[7]:

Color temperature	Color appearance
> 5.000 k	Cold (white-bluish)
3.3000 – 5.000 K	Intermediate (white)
< 3.000	Hot (white-reddish)

Chart 2 – Relation between color temperature and appearance of color

2.1.3 Color Rendering Index - CRI

It is vital that the light sources be able to provide a correct color rendering according to the goals of the project. In places where the visual acuity is demanded, such as museums, show windows, print shops, designing offices, and others, lighting with a good color rendering index is mandatory.

A lamp bulb with a CRI score of 100 has an excellent color rendering. The lower this number is, the more different the color will be from its real appearance if illuminated by the lamp bulb in matter. In brief, CRI is a score scale ranging from 0 to 100 that represents how corresponding a light source is to the color of the natural light[2].

Incandescent lamp bulbs are very common in Brazil, especially for domestic use. They have a CRI score close to 100 and a tugstenium filament generates the light. Halogen bulbs, which are also grouped within the incandescent lamp bulbs' family, have the same CRI score. The dicroic ones are halogen lamp bulbs equipped with a reflecting device that rally reduces the amount of heat that is emitted. Its light beam is concentrated, reason why they are they are ideal to illuminate art pieces and other objects. The fluorescent lamp bulbs (also called discharge lamp bulbs) are filled with mercuric gas, that generates light when receives an electric discharge produced by a reactor. The common tubular models have a CRI score of 70. The compact new models have a CRI score close to 85. The power consumption for these lamp bulbs is 80% lower than for the incandescent ones.

Light Source	**K**	**CRI**
Natural		
Clear Sky	7.500-19.000	100
Clear sky + sun	5.000	100
Cloudy sky	7.000	100
Incandescent		
500 W	2.850	97
Halogen	3.000	89
Fluorescent		
White cold	4.350	67
White hot	3.100	55
Natural light*	6.600	75
White hot Deluxe/ overlaid	3.230	77
Mercury		
Clear	5.900	22
White Deluxe	4.000	43
Metallic vapor		
Clear	5.500	5
Overlaid	4.600	75
High pressure Sodium	2.250	25

*Sold under the name "Day Light"
Ideal color temperature to analyze transparencies and printed material :
5000 K
To achieve 5000 K mixture of bulbs in equal quantities:
PHILIPS TL 20 W/54RS – Day Light C (GH)
PHILIPS TL 20 W/37RS – Natural White C (HC)
Example: 2 bulbs from each model

Chart 3 - Light source - TCC- IRC

3. RESULTS

The quality of the light that reaches the observer's eyes determinate the color that the object seems to be. Therefore, any change regarding the illumination light color also alters the color of the light reflected by the object, consequently modifying the color that the observer perceives. Our eyes are very sensitive and can perceive many different colors. However, the visual effect can be completely different according to the conditions of the light source, the object, and the visualizing conditions of the observer.

To successfully evaluate the printed material, the sheet that is being inspected and the standard model (sample) should be placed side by side over a clean surface with adequate inclination and standard lighting (neutral white light with a color temperature of 5000 K and a CRI score close to 100). It is important to emphasize that the test sheets should be printed with the same paper or at least with a similar kind of paper that has the same absorption, smoothness, reflection index, shinning, and color characteristics. The test sheets also should be printed with the same ink that was used on the standard model. Graphic designer scan also use the "show windows" to visualize colors or even test the material in specific places to evaluate the samples under different lighting conditions.

We also point out to the fact that standard observation conditions, with standard light color and intensity, are vital to guarantee the stability during the evaluation of color samples within graphic production environments. Thus, the quality of the graphic product is guaranteed within the different phases of the project (creation, implementation, comparison between original and test material, and evaluation of printed material at the print shop). In last resort, the decision is human made. It is the designer's duty, aware of every conditioning factor of the chromatic evaluation process, to organize the adequate environment regarding lighting and space.

REFERENCES

1. PEDROSA, Israel. *Da cor à cor inexistente*. Brasilia: UNB, 1982.
2. BAER, Lorenzo. *Produção gráfica*. São Paulo: SENAC, 1999.
3. ROBBINS, Claude. *Daylighting*. Design and analysis. New York: Van Nostrand Reinhold Company, 1986.
4. CARRAMILLO NETO, Mário. *Produção Gráfica II*. São Paulo: Global, 1997.
5. PEREIRA, Fernando RuttKay. *Iluminação*. Curso de Especialização de engenharia de segurança do trabalho. Dept. de Arquitetura. CTC.UFSC

* berenice@cce.ufsc.br. Núcleo de pesquisas cromáticas. Departamento de Expressão Gráfica / UFSC Caixa Postal 476, Florianópolis – SC 88040-900. Brazil. Tel.: +55 48 331 9892.. FAX: +55 48 3319892 ** pereira@cce.ufsc.br. Departamento de Expressão Gráfica. Universidade Federal de Santa Catarina

The concept of *white light* in stage lighting

Mauricio R. A. Rinaldi
Colón Opera House, Lighting Section
National Universitary Institute of Art

Abstract

In perceiving objects, generally we see them in a white light situation. But, actually, there is not an absolute white, in such a manner that the different light sources have a determined kind of white, what it is known as colour temperature. Even the white light may be of different kinds (different colour temperature), the individual mind tends to perceive it as the same kind of white, that is to say, there is in our mind a psychological function by which we operate an integration in the perception in order to do the object perceptually invariable.

On the other hand, it is a common practice in stage lighting to use colour light sources. It is a well known phenomenon that a colour of light produces a change in the object colour perception. However, when we go to theatre, we see the objects as having their real colour, even if the lighting is not white.

In this paper the concept of *white light* in stage lighting is presented, showing its possibilities of aesthetical expression.

1.INTRODUCTION

Generally, we are accustomed in thinking that things have an invariable colour, and then, we trend to see the objects colours as the same in all of the situations. But, actually, the perceived object colour depends on the lighting. In the same way that in the case of object colour, we tend to perceive all lighting sources as producing white light; but, actually, there is not an absolute white light (that is, a light composed by all of the spectral colours). There are "kinds of white" only, what is known as colour temperature of the lighting source. On this way, all of the lighting sources have a determined colour, even very near white. This considerations permit us to distinguish two kinds of colours: pigment-colours (in the objects) and light-colours (in the lighting sources). Then, we can ask: which is the perceived colour? As it was said, the perceived colour depends on the lighting. On this way, we must remember that a pigment-colour works as a filter: when a white light falls over one surface, the surface colour reflects only a determined colour component of the said white light. The same situation exists for coloured lighting sources. For instance, if a blue light falls over one red surface, the perceived colour is violet.

2.DAILY SITUATIONS AND AESTHETICAL SITUATIONS

In our daily life we deal with object that generally we known very well. These object have a meaning given from their use, that is to say, the way in which a determined object is used defines its meaning. In addition, in the daily life we act generally in white light situations (even, as said, there are different kinds of white light), that is, coloured lighting sources are non usual situations. For this reason, we can say that in daily life the lighting has an utilitarian function. Then, we trend to consider the objectrs colours (that is, the pigment-colours) as invariable by a psychological function in our mind.

On the other hand, in aesthetical situations, like theatre, the lighting (when used) has an expressive function. On this way, the colour of lighting sources may have a determined colour that we can identify (i.e., blue light, red light, etc.). In stage lighting the most important function of colour is to create an atmosphere, a determined mood, for the different parts of the play. The use of colour in stage lighting may give different meanings to the scenery and objects on stage during the play. For this reason, the light-colour is perceived as white.

3.THE *WHITE LIGHT* IN THEATRE

As it was said, the colour in stage lighting has an expressive finction. For this reason, it is a common practice in theatre to use coloured lighting sources. But, it is necessary to use light-colours with care in order to maintain a determined visual structure of the scenic space. On this way, the concept of *white light* may be defined: In stage lighting the *white light* is a light that does not change the identity of the scenic space, even coloured lighting sources were used to create a mood.

In the daily life we need a perceptual identity in objects colours. But, in aesthetical situations the identity of objects has a different meaning, since it is a non real but representational situation. Specifically in stage lighting, there are two ways in which the colour is treated:

3.1.Bidimensional sceneries

Traditional sceneries are composed as a series of parallel painted courtains in which the space is represented by pictorial perspective. In this kind of scenic visual representation the volume of space and the chiaroscuro relationships are pinted on a plan surface; then, this is a bidimensional representation of a tridimensional space. The goal of colour in stage lighting is only to permit us to see the painted scenery, since the modulation of volumes is given by picotrial strategies and not by lighting strategies; for this reason, a general colour wash falling over the courtains is enough.

3.2.Tridimensional sceneries

In the beginings of the XX century tridimensional sceneries arised as a consequence of Appia theory. On this way, Appia considers that the scenic space must be tridimensional, and then, the goal of lighting in not only to permit to see the space, but to create a determined modulation, i.e., chiaroscuro relationships, on it. Appia proposes that space colour must be neutral, i.e., medium gray, in such a way that light-colours may be applied on this space more freely, considering additionally the position and other morphological factors (visual aspects) of the lighting sources.

In these two kinds of scenic space, the *white light* has the same goal: to use light-colours to create a mood, but without change the identity of the scenic space.

4.CONCLUSION

As it was said, in the daily life we use white light sources (even these sources have different kinds of white or colour temperature), in order to perceive objects as invarialbes. On the other hand, in aesthetical situations, like theatre, it is a common practice to use coloured lighting sources in order to create a determined mood. In this last situation it is possible to say that a *white lihgt* is used when the identity of the scenic space does not change. Our psychological trend to perceive objects as invariables permit us to use coloured lighting sources in art, since in aesthetical situations objects have not the same meaning that in daily life.

REFERENCES

APPIA, ADOLPHE, *Oeuvres completes*, 4 vols., Berna, L'age d'homme, 1983,1992.

ARNHEIM, RUDOLF, *El pensamiento visual*, Eudeba, Buenos Aires, 1973.

MERLEAU-PONTY, *Fenomenología de la percepción*, Planeta-Agostini, Barcelona,1985.

PALMER, RICHARD, *The lighting art: the aesthetic of stage lighting design*, New Jersey,Prentice-Hall Inc., Englewood Cliffs, 1985.

PARKER, W. y WOLF, R., *Scene design and stage lighting*, Orlando, The Dryden Press, Saunders College, 1991.

RINALDI, MAURICIO, *Diseño de iluminación teatral*, Edicial, Buenos Aires, 1998.
----- "A method for aesthetical analysis of the stage lighting", AA.VV., 24th Session of the CIE, Varsaw, Poland, 1999.
----- "The influence of Appia theories over colour in stage lighting", AA.VV., Colour for Life Conference, Perth, Australia, 1997.

Mauricio R. A. Rinaldi

Address: Chacabuco 651, 9º 105
C1069AAM, Buenos Aires
ARGENTINA

Telefax: ++54-11-4361 9117

E-mail: mau_rinaldi@yahoo.com.ar

How Should We Teach Color?

If we are to succeed in understanding the "What," "What For," and "How," and in "Controlling" Color, we must teach it properly, in school and in the working world of Science, Art, and Industry.

Symposium: How Should We Teach Color?

- Bergström, Ceative colour education*
- Caivano, Interactive bibliographical database on color
- Montag, Distance learning: a discussion of the implementation of graduate course of study using various on-line technologies*
- Green-Armytage, Colour zones: connecting colour order and everyday language
- Miele, Teaching color as an experiential exercise*

Teaching Aids

Oral Session:

- Tarrant, Visual colour matching equipment for teaching and research
- Gaudio, De Ponti, Interactive multimedia systems as comunication channels in color workshops
- Sobotka, Gloss, Seiter, CBT: a new approach for designing color teaching aids for the media industry

Color Education

Oral Session:

- Linton, Expanding color design methods for architecture and allied disciplines
- Ünver, Colour education in architecture
- Kwon, Kim, A study of web-based color education with an emphasis on Constructivist's theory
- Colla, Rainbow Solfege: new perspective for color theory and music education
- Appell, Colorimetry as a general model of observation in the resolution of quantum paradoxes
- Smith, The colour studio in crisis? Embracing change
- Estevez, How do we teach color?

Symposium: The Future of Color

- Turner, Future of color
- Green-Armytage, The future of colour in the visual arts, architecture, and design
- Hunt, The future of color: science and technology

**** denotes invited papers***

Creative Colour Education

Berit Bergström

Scandinavian Colour Institute AB

ABSTRACT

The colour science is a part of many different educational fields. This means that it is treated from many different aspects and according to different disciplines. If one considers the interdisciplinary features of colour science and the different angles of approach and the different facets of colour which exist, unexpected opportunities open up for the treatment of colour in an education context. The purpose of this paper is to show how the colour education can develop creative environments where creation, communication and exchanges of experiences between different disciplines are the central point and also to show the role of the AIC Study Group on Colour Education in this matter.

Keywords: colour education, colour studies, AIC Study Group

1. INTRODUCTION

What does Creative Colour Education mean? Creativity is the ability of a person to solve problems by new methods or to create new products in art or technology, for instance. Creativity has been the subject of intensive research in psychology and pedagogy since the mid-1950s. I found this in my encyclopaedia. The act of creation is an important factor in colour science, and this is what we must develop in order to stimulate the interest in colour and in the importance of colour. Without inspiring and interesting colour education, there can be no good breeding ground for colour research. I want to do my best to give a few angles of approach to how more creative colour education could be achieved.

2. TRADITIONAL COLOUR EDUCATION OF TODAY

2.1 Traditional Colour Theories

What first comes to mind when discussing creative colour education are these three colour theories:

- Goethe's colour theory in which several of his experiments on the influence of colours can be made in colour education. The experiments are not aimed at proving anything, but are merely a way of becoming acquainted with colours and making one's own observations as regards light and the perceptions of colours (Sällström 1966).
- Itten's theory of colour harmony in which harmonious combinations of three and four colours are created in a colour circle designed for this purpose. The geometrical figures can be turned to any initial position. Itten does not define his colours other than by colour words and printed pictures. Analysis of these will reveal that yellow corresponds to Y20R, orange to Y58R, red to Y96R, violet to R55B, blue to R72B, blue green to B13G, green to G18Y and yellow green to G40Y. Itten's colour harmony system is expanded here so that one mixing series with white and one with black accompany every chromatic colour. The colours of the arms of the star give harmonious combinations if they are arranged symmetrically in accordance with Itten (Sisefsky 1995).
- "Interaction of Color" by Josef Albers is a description of an experimental way of studying colour and of teaching about colour. The objective of his colour theory is to employ practical colour experiments in order to develop a sense for colour and learn to recognize the influence of colours on each other, and about the variability of colour impressions. They are aimed at opening our eyes and making us better able to see. It is only what you see that is correct (KG. Nilsson, 1981).

These three colour theories are obviously important in developing our attitude to colours, to seeing colours, to being inquisitive, to being fascinated by colours and choosing to go further. But is this enough? There are great opportunities for developing colour education further.

2.2 A Study on Colour Research in Architectural Education

In a study carried out by Janssens & Mikellides (1998) the knowledge of architectural students about perceptual and psycho-physiological aspects of colour, colour nomenclature, existing myths and beliefs, and how colour is used in their everyday work in studios was investigated. A comparison was made between five schools of architecture, three in Sweden and two in

United Kingdom. Colour is considered by all involved to be an important subject matter in the education of environmental designers. This point of view seems nevertheless to have little influence on the educational situation in most architectural schools.

The success of education is dependant on many factors: the overall goals, methods, and resources; the engagement and competence of the lecturers; the quality of the teaching materials and other educational media; as well as the students' own personal resourcefulness, interest, and motivation; all these factors combine to play a decisive role in pedagogical accomplishments. Most of the students complained about the lack of coverage of the subject area in lectures, seminars, or studio work, with very little theory and only few practical exercises. Because students perceive colour design as their own future responsibility and basic design education seems to be the main source of colour information, the problem of this deficient knowledge should be seriously addressed by researchers and educators.

From the Swedish part of the study you could find out that schools educating interior designers spent more time on colour related subjects, as compared to schools of architecture. They treated colour more as individual subject with their own teachers, giving opportunity to a both broader and deeper penetration of the subject. In schools of architecture, at the initial stage, the departments of theoretical and applied aesthetics were responsible for colour education. Here, due to time scarcity, colour was often integrated into other related subjects, thus obstructing a more thorough treatment of the colour subject itself. Student projects at architecture schools were only seldom presented with careful colour accounts, more often at schools for interior designers. Interior design students also dealt with colour questions during the entire project work, from start to finish, while architecture students often tended to skip colour problems until the final stage of the design process. However the design process should be reversed; you should start with the colour and form together.

3. THE INTERDISCIPLINARY NATURE OF COLOUR SCIENCE

Because of its interdisciplinary nature, colour science has no natural home and is therefore part of many different educational fields. This means that it is treated from many different angles and according to different disciplines. Colour science is dealt with in phenomenology, physiology, physics, psychophysics, psychology, philosophy and aesthetics. It is therefore treated from a variety of different angles and by different disciplines, which need not be disadvantage. On the contrary, it can create exciting meetings since, to many people, colour gives rise to many different notions of what it can be. Physicists think in terms of radiation and wavelengths, the chemist thinks in terms of pigment and material mixtures, the physiologist thinks in terms of anatomy of the eye and the behaviour of receptors, nerve cells and brain centres. The psychologist thinks of colour as perception of the senses and human influence, and the painter thinks of his palette or the expression of the colour. The architect and designer think of colour as a property and experience related to objects and their function in the environment.

If one considers the interdisciplinary features of colour science and the different angles of approach and the different facets of colour which exist, unexpected opportunities open up for the treatment of colour in an education context. It is possible to develop creative environments where creation, communication and the exchange of experiences between different disciplines are the central point. In this respect, colour science is unique in the field of education. There is no other branch of science which concerns so many and which can create so much involvement from the students.

Colour science often falls within an artistic subject and it is often the artist who teaches about the colour in the picture. This education often deals with how to mix a colour, the practical details of how to paint and how to use colour in the creation of a picture. This type of education does not, however, give any practical instrument or unambiguous way of communicating colour.

It is important for the colourist with a sensitivity for small differences in nuance to choose colours with great care. It is therefore important to have an unambiguous colour language from idea to result. A perceptual colour description system which describes colour as we see it,can lead to different proposals for experimenting with colour compositions. Trials in which colour combinations corresponding to the concept of beautiful have been investigated (Hård & Sivik 1989) have suggested that similarities and relationships between colours are aesthetically highly valued.

A colour system does not necessarily give pretty colour combinations, but it does provide a tool for experimenting with different colour harmonies. It is possible to test the effects of different colour compositions and colour combinations and then perhaps to build on this. Colour compositions can be analysed and documented with the help of the colour system.

Starting from a given colour, it is possible to investigate possible combinations with other colours. This gives an overview of the possible choices, which exist. It is possible to see which choices lead to a new content and which choices are less important. It must be reasonable to be able to develop one's colour concept by observing what the colours look like and how they relate to each other.

4. SOME EXAMPLES .

4.1 Metamorphoses – a study in colour compositions

The purpose of the Metamorphoses study by Jörgren Lindgren (1993) is intended to demonstrate in a simple and lucid manner how the form characteristics of a composition can be changed by consciously playing on the various properties of colours and, on the basis of the same formal basic pattern – or the same colour range – compositions can be created with entirely different expression values. Jörgren Lindgren was professor at the School of Art and Design at Gothenburg University. He used the NCS system as an analysis instrument in studies of different types of colour compositions, for which it proved to be very useful. In Metamorphoses – a study of the formation properties of colours – he reports on two different series of colour compositions, one of which is based on the same form structure and the expression of the composition is changed by different colour choices. The second series is based on a certain range of colours comprising five recurrent colours, but where the form structure is changed and gives the various expressions. It can be observed spontaneously in the two series how the form and expression changes take place when the colour relations are changed from composition to composition. In most cases, we should perhaps be content with the "immediate" experience through the senses, but a "tool" is needed in other cases for analyzing our experience. What means has an artist used for achieving the expression values that we, as observers, take in through our eyes? This may apply, for example, in an educational situation, artist education, art science studies, etc.

4.2 The rich colours of Savannah

When Byron Mikellides from the Oxford School of Architecture was lecturing at the Savannah College of Art and Design he started a project which aimed was to record in a systematic way using both visual images and scientific notation, the rich colours of Savannah's natural and man-made environments. The students did notate the colours for certain points – for example, the different ways one can look at a building – and different contexts, such as the different seasons. The NCS notation was determined for each observed colour. They recorded the colour from roofs to floorscapes but also the colour of the native plants and trees. During one weekend almost 50 students where collecting "natural colour samples" in different materials. They collected stones, sand and earth. They took photos of wrought-iron goods and plaster facades. They picked up beautiful flowers like magnolias and azaleas. This "nature colour samples" where then analysed in NCS and the result was a fan deck of the colours of Savannah. A project like this can be the basis of several proposals not only in conservation but also in upgrading and revitalizing local areas. This kind of project can also be utilized in all disciplines in colour education like in architecture, interior design, textile design (folk costumes, fabrics) and graphic design (signs and symbols).

The students have to learn the basic systems to be able to communicate colours and they also have to have discipline and practise their technical skills so the result will be a clear and structured proposal or idea. Limitations activate student's creativity. Much would be gained if knowledge and creativity could be combined, but not at the cost of artistic quality and a feeling for colour. It is all about getting to know your means of expression. And this is the task of colour science: To train one's sensitivity for colours so that one can play with them like a skilled musician on his instrument, but you also need the musical notes, a colour language with which to communicate and document colours.

5. THE AIC STUDY GROUP ON COLOUR EDUCATION

The Study Group on Colour Education of the International Colour Association (AIC) is an international network of scientists, teachers within the field of colour (colour theory, colour design, colour psychology etc.) and other professionals like designers and architects with a specific interest in colour education.

5.1 Aims of the Study Group Colour Education

- Exchange of knowledge and experiences among its members.
- Stimulation of teaching and research.
- Inform about coming congresses, seminars, workshops and exhibitions
  Which might be of interest for the members of the group.
- Share with other members news from congresses, seminars, workshops, publications and exhibitions.

5.2 Membership of the Study Group Colour Education

Membership is free, and is available for every person/organization who/which scientifically or practically deals with colour in colour education, contributes to the realization of the aims mentioned above to generally support the Study Group. The requisites for being incorporated as a new member of the Colour Education Study Group are:

- To subscribe and participate in the e-mail list
- To have presented a paper or poster at an AIC meeting

5.3 A worldwide network in colour

I think if this group shall be a good network we have to work together all of us. I also hope that you will mail me information, which is interesting for the whole group; if there is a colour seminar in your country, new colour studies, new methods of teaching colour or literature e t c. This is also a very good network for different small projects. I have many "projects" in my mind. In the Study Group we have started the work with a list over literature and references used in colour education. I thought this would be of great help for all of us. The members mailed me different titles of literature used in colour education to me and I have compiled a list over this literature.

When we are all teaching we will meet a lot of students and we can in a very easy way affect some small studies with the students. We can for example carry through some small studies in colour preferences. Today we are 27 members but we have 16 nations represented in the group, and that's makes it very interesting. I also hope that we after this AIC meeting will grow bigger. It is a very good opportunity for some small cross culture studies where the results will be useful in the colour education.

5.4 Projects within the AIC Study Group on Colour Education

Except the project with a literature list we have also started a project within colour preferences. It is very common when it comes to colour analysis to talk about colours in names of different pigments like ultra marine blue, cinnabar red, emerald-green and so on or with more or less imaginative colour names, often colour names dependent on fashions, like heaven blue, lavender blue etc. You will soon find out that this way of describing colours gives you very grave limitations and it is not an unambiguous way of describing colours. If you want to penetrate the colours in a colour analyse it is better to complete the poetic or emotionally charged colour words with colour notations based on perceptual grounds, like a perceptual colour order system. In the Study Group I asked the members to carry through this small project: Ask your students to pick up a colour sample, which they associate with:

1. Old rose
2. Plum
3. Heaven blue

The results were notated in either Munsell or NCS notations.

How can the future be in this Study Group on Colour Education? It can be the unique network in colour education if we get more members and from even more countries. So, I wish you all working with colour education very welcome, just send me an e-mail swedish.colour.center@ncscolour.com and I will send you information. I also hope that the activities among its members will increase and then we will have an even better network for exchanging experiences. We really have good opportunities for that.

REFERENCES

Albers A., Interaction of Color, Yale 1963, (Translation: Nilson, K.G. Albers färglära, Forum, Sweden, 1982).

von Goethe J.W., Zur Farbenlehre, Weimar 1810. (Translation: Sällström, P. Goethes Färglära, Kosmos Förlag, Järna, 1996).

Janssens J. & Mikellides B. Color in Architectural Education – A Cross-Cultural Explorative Study, Color Research & Education, volume 23, Number 5, October 1998.

Lindgren J. Metamorfoser (Metamorphoses) , Gothenburg University, Gothenburg, 1993.

Sisefsky J. Om färg, ICA Förlaget AB, Värnamo 1995.

Sivik L. Hård, A. On studying colour combinations-some reflections and preliminary results. Göteborg Psychological Reports, Vol.19. No.2, 1989.

Interactive bibliographical database on color

José Luis Caivano*
Buenos Aires University and National Council for Research

ABSTRACT

The paper describes the methodology and results of a project under development, aimed at the elaboration of an interactive bibliographical database on color in all fields of application: philosophy, psychology, semiotics, education, anthropology, physical and natural sciences, biology, medicine, technology, industry, architecture and design, arts, linguistics, geography, history. The project is initially based upon an already developed bibliography, published in different journals, updated in various opportunities, and now available at the Internet, with more than 2,000 entries. The interactive database will amplify that bibliography, incorporating hyperlinks and contents (indexes, abstracts, keywords, introductions, or eventually the complete document), and devising mechanisms for information retrieval. The sources to be included are: books, doctoral dissertations, multimedia publications, reference works. The main arrangement will be chronological, but the design of the database will allow re-arrangements or selections by different fields: subject, Decimal Classification System, author, language, country, publisher, etc. A further project is to develop another database, including color-specialized journals or newsletters, and articles on color published in international journals, arranged in this case by journal name and date of publication, but allowing also re-arrangements or selections by author, subject and keywords.

Keywords: Color bibliography, database, internet, color sources

1. INTRODUCTION

Several color bibliographies have been published to date. We can mention the ones compiled by Richter,[1] Godlove,[2] Dziegielewski,[3] Lozano,[4] Indergand.[5] However, all of them, being printed on paper, have the limitation of incorporating data available up to the date of publication. From the moment of its publication, the bibliography remains closed for new entries until a new edition is published, if this were the case. Today, the possibility of working with digital records and publishing in the Internet allows for the compilation and publication of a bibliography that can be updated constantly within short periods of time, and that is widely available at no cost for an increasing number of scholars worldwide.

In addition, the structure of hypertexts made possible by certain computer softwares is admirably well suited for the purpose of developing an interactive bibliographical database that can grow in multiple directions and whose contents can be retrieved and organized according to the particular necessities and interests of the user. For instance, the bibliography may contain not only the basic data of every source —such as author, year of publication, title, city, publisher—, but also other kinds of information —such as index of contents, keywords, abstract, and even the complete contents of the source. Of course, some of these elements could also appear in a bibliography published on paper, and, as a matter of fact, there exist annotated bibliographies. But the main problem is that the structure and presentation in paper media is always a lineal arrangement, and the possibilities for the user to make different kinds of search are severely limited.

This article describes the methodology and results of a project that is still under development, aimed at the elaboration of an interactive bibliographical database on color, developed and published in digital format. The bibliography covers all fields on which color theory have been developed or finds applications: philosophy, psychology, semiotics, education, anthropology, physical and natural sciences, biology, medicine, technology, industry, architecture and design, arts, linguistics, geography, history.

2. ANTECEDENTS AND PRESENT STATE OF THE WORK

The project has been initially based upon a previous bibliography, published in various journals at different stages of development,[6,7,8] updated in various opportunities, and now available at the Internet,[9] with more than 2,000 entries.

For the moment, the bibliographical database is still in its first stage, i.e., a chronologically arranged list of sources. However, each entry already incorporates information of all translations and posterior editions we have found. The kind of sources included are non-periodical publications: books, doctoral dissertations, proceedings of congresses, multimedia publications and reference works. A separate database is planned that will contain information about color-specialized journals and newsletters, and a systematically arranged list of articles on color published in international journals.

In the case of the bibliography of non-periodical publications, the chronological arrangement is made by the year of publication of the first edition, or the year of writing as it can be best determined. The year of writing applies for antique sources, written prior to the invention of the printing process, but also for modern sources that have been published posthumously. The criterion is that the date of a source should always fall within the author's span of life. The purpose of this is to register the appearance of ideas and developments at the moment they were made or published for the first time. Translations and later editions are linked to the original date. In the case of unpublished dissertations, the date considered is the one of approval by the university or institution where it has been presented. Figure 1 shows the fields of an entry for a normal book, published within the author's span of life. In Figure 2, the case of a book written before the invention of printing —i.e., not having a date of publication— is shown. Figure 3 shows the case for a doctoral dissertation.

EVANS, Ralph Merril.	author
1948.	year of publication
An introduction to color.	title
English	language
(New York, USA:	city of publication, country
John Wiley & Sons).	publisher

Figure 1: Book, first edition. Note the use of italics for the title, and the author's last name in uppercase.

ARISTOTLE.	author
c.350 BC.	approximate year of writing
Peri Aistheseos Kai Aistheton.	transliterated title
Greek	language
(Athens, Greece:	city of writing, country
Manuscript).	kind of source
English translation by W. S. Hett, "On sense and sensible objects", in Aristotle: *On the soul, Parva naturalia, On breath* (Cambridge, Massachusetts: Harvard University Press, 1936).	translation, published in a book along with other texts

Figure 2: Antique source, with translation. Note the use of the abbreviation *c.* (*circa*) for a year of writing that is approximate; also, the use of double quotation marks for the title when the source is a part of a book (this only applies for translations or posterior editions).

KRIVOSHIEV, G. P.	author
1984.	year of approval
Objective quality assessment and sorting of fruits and vegetables by their color, degree of ripeness and defects by means of measuring their light transmission.	title
English	language
(Plovdiv, Bulgaria:	city of the institution, country
Higher Institute of Food and Flavor Industries,	degree-granting institution
doctoral dissertation).	kind of source

Figure 3: Doctoral dissertation.

In the case of proceedings of congresses, the place and date in which the meeting was held is also provided, but the date taken for the chronological arrangement is the year of publication (Fig. 4). In this case, as well as in any other compilation of papers written by different authors, it may happen that the book contains articles in different languages. Then, all these languages are listed in order of importance, given by the number of articles written in each language (Fig. 5).

CAIVANO, José Luis, and Rodrigo AMUCHASTEGUI, eds.	compiler or editor
2000.	year of publication
ArgenColor 1998, Actas del Cuarto Congreso Argentino del Color,	title of the proceedings
Oberá, Argentina,	place of the meeting
August 3-6, 1998.	dates of the meeting
Spanish	language
(Buenos Aires, Argentina:	city of publication, country
Grupo Argentino del Color).	publisher

Figure 4: Proceedings of a congress. When there is a compiler or editor, the name go in the place for the author, giving the clarification. Note that the place and date of the meeting is also provided, before the language and the publication data.

AIC (Association Internationale de la Couleur).	organizing institution
1989.	year of publication
AIC Color 89, Proceedings of the 6th Congress,	title of the proceedings
Buenos Aires,	place of the meeting
March 13-17, 1989,	dates of the meeting
2 vols.	number of volumes, if applicable
English, French, German	languages
(Buenos Aires, Argentina:	city of publication, country
Grupo Argentino del Color).	publisher

Figure 5: Proceedings of a congress. In a collective work like this, if a compiler or editor does not appear on the front page, the organizing institution goes in the place for the author. Note that the publication contains texts in three different languages.

Due to our possibilities, living in a Western country and using the Roman alphabet, the main languages of the sources recorded are English, French, German, Italian, Portuguese, and Spanish. But, of course, sources published in other languages are also included. When the original language of the source does not use Roman characters, the title is transliterated (Fig. 2). Also, when the language is other than the six mentioned ones, and there is no published translation to them, an English version of the title is provided by us in order to help the reader know the subject of the book (Fig. 6).

TSUKADA, Kan.	author, romanized
1978.	year of publication
Shinrisai no Bigaku	title, romanized
[Aesthetics of colors].	English translation of the title
Japanese	language
(Tokyo, Japan:	city of publication, country
Kinokuniya Shoten).	publisher

Figure 6: Book published in a language other than the six main Western languages using the Roman alphabet (English, French, German, Italian, Portuguese, Spanish), and with no published translation. Note the use of brackets to indicate the English translation of the title provided by us, to help the user of the bibliography know what the book deals about.

3. METHOD

The data search is being carried out by various procedures: 1) visits to libraries in several cities, universities, physical catalogs, embassies and cultural offices of different countries; 2) invitation to color researchers and national color associations to provide data about their own publications; 3) inspection into the bibliographical references of the sources acquired by the previous means; 4) surveys performed in the Internet, getting into databases of libraries and bookstores.

The search is performed by keywords (such as "color", "chroma", "pigment", etc.) translated into all languages we know. For the six mentioned languages, the aim is to make an exhaustive and complete coverage. We are also including sources published in other languages, such as Bulgarian, Catalan, Czech, Danish, Slovene, Finish, Flemish, Dutch, Hungarian, Latin, Norwegian, Polish, Romanian, Swedish, Turkish, Ukrainian, etc. Search is also made by the transliteration of those keywords into Arabic, Armenian, Greek, Hebrew, Hindu, Persian, Russian, etc., and by the romanization of Chinese, Japanese, and Korean.

All books dealing with color, from any point of view, are included. Exclusion of sources are not being made on the basis of criteria of importance, quality, or intended target. For instance, color books for children are also considered, insofar as they have educational purposes, but mere coloring books are excluded.

4. FUTURE WORK

The projected interactive database will amplify the bibliography that appears at present in the Internet, incorporating hyperlinks and contents (indexes, keywords, Decimal Classification, abstracts, introductions, or eventually the complete contents of the source), and devising mechanisms for information retrieval. The idea is to enable the user to make re-arrangements and selections by different fields: subject, Decimal Classification, author, language, country, publisher, etc.

Among other things, this work will allow to derive some statistics that could be of interest, or at least arouse curiosity, for instance: the ranking of the most prolific authors of books on color, the top color publishers, the fluctuations of geographical centers of color production and publication along time, etc. But mainly, with this bibliographical database, the color community will have a systematic reference work available for research in all color-related fields.

ACKNOWLEDGMENTS

The researchers joining the author in this project are Rodrigo Amuchástegui, Gracia Cutuli, Julieta Garavaglia, Mabel López, Manuel Net, Andrea Pappier, Pablo Valle, and especially Paulina Becerra. The work is supported by the University of Buenos Aires.

REFERENCES

1. M. Richter, *Internationale Bibliographie der Farbenlehre*, Musterschmidt, Göttingen, 1952; 2nd ed. 1963.
2. I. Godlove, *Bibliography on color*, Inter-Society Color Council, Rochester, New York, 1957.
3. T. Dziegielewski, *Bibliografia dotyczaca kolorystyki w budownictwie przemys lowym*, Warsaw, 1967.
4. R. Lozano, *Compilación bibliográfica sobre la visión, la luz y el color*, Boletín Técnico **4**, INTI, Buenos Aires, 1969.
5. M. Indergand, *Bibliographie de la couleur*, Société des Amis de la Bibliothèque Forney, Paris, 1984.
6. J. Caivano, B. Galeyev, and R. Lauzzana, "Chronological bibliography of color formalism", *Languages of Design* **2**, pp. 353-364, 1994.
7. J. Caivano, "Bibliografía cronológica sobre teoría del color", *AREA* **3**, pp. 53-67, 1996.
8. J. Caivano, "Chronological bibliography of colour theory", parts I and II, *Spectrum* (Colour Society of Australia) **11** (3), pp. 22-27, and **12** (1), pp. 20-27, 1997.
9. J. Caivano, Chronological bibliography of color theory, http://www.fadu.uba.ar/sicyt/color/bib.htm.

---

* jcaivano@fadu.uba.ar; tel/fax 54-11 4702-6009; http://www.fadu.uba.ar/sicyt/color/home.htm; SICyT-FADU-UBA, Ciudad Universitaria Pab. 3 piso 4, 1428 Buenos Aires, Argentina

Distance Learning: A Discussion of the Implementation of a Graduate Course of Study Using Various On-Line Technologies

Ethan D. Montag*
Rochester Institute of Technology, Chester F. Carlson Center for Imaging Science,
*Munsell Color Science Laboratory

ABSTRACT

This past fall the Center for Imaging Science initiated a distance learning option for its Masters Degree in Imaging Science. This program is identical to the local version of the degree except for the fact that students take the course at a distance. Initially, the program offered a specialization track in Color Imaging but now the program includes Remote Sensing and Digital Image Processing tracks. My course, *Vision & Psychophysics*, was one of the first courses to go online. The model we have used for this endeavor is an asynchronous one; students may take the courses anywhere and learn on their own schedule. Judging by the experience of the instructors and the feedback from our students, we feel that this endeavor has been a success. In this paper I will describe my experience in designing, implementing, and teaching a distance-learning course. The goal is to facilitate others who may be considering teaching in this way by sharing my limited experience.

1. INTRODUCTION

In the fall of 1990 the Chester F. Carlson Center for Imaging Science at the Rochester Institute of Technology initiated a distance-learning version of its Masters Degree in Imaging Science. This program enables students anywhere in the world to earn a Masters Degree in Imaging Science without having to physically attend classes at RIT. The initiation of this program presented a number of challenges to the faculty. These challenges included convincing faculty to join in on this endeavor, identifying the infrastructure for course delivery, designing the courses, and finally teaching.

The distance-learning MS program was designed to have the same courses and requirements as the local version as our project/paper (non-thesis) MS option. As such, we decided that to begin with, the instructors would teach the distance sections of the course concurrently with the local versions. We realized from the start that teaching an additional section of a course in this new format would be equivalent to adding a new course to one's teaching load. Because of this increase in teaching load, we decided that the program would be implemented gradually so that beginning students would be able to take one or two courses per quarter, as they were implemented, so that they could complete the degree within three years. This meant implementing the core courses within the first two years. The faculty in the Munsell Color Science Laboratory agreed to begin the program by implementing the courses in the Color Imaging specialty track first. Although there were times when it looked unlikely that we could match overburdened instructors with new course sections, the faculty worked together to ensure instructors were committed to teaching the courses required for a complete degree. One benefit of this exercise was that different faculty would now become familiar with courses that they do not usually teach producing more flexibility in future teaching assignments.

2. CREATING A COURSE

We met with staff from RIT's Online Learning Office to learn about distance learning and what methods and technology are available for teaching at a distance. Although RIT has been ranked as the third largest distance learning degree and program provider in the US, we were surprised that there was very little concrete advice they could offer on how to deliver a course. Instead we learned more about the philosophy of distance learning, for example, make the course modular so that different pieces could be updated and used elsewhere easily. Fortunately, the technical staff would be

* montag@cis.rit.edu; phone 1 726 475 5096; fax 1 716 475 5988; http://www.cis.rit.edu; Rochester Institute of Technology, Chester F. Carlson Center for Imaging Science, Munsell Color Science Laboratory, 54 Lomb Memorial Drive, Rochester, NY, USA 14623

able to provide us with assistance, which turned out to be very valuable when it came to the nuts and bolts of the courses. We did determine, though, that our goal was to create a program that was primarily asynchronous teaching. That is, student anywhere in the world should be able to go online and learn the course material at anytime as opposed to using live conferencing.

Our main concern was how to teach technical material on line. This concern was greatest for the faculty teaching the very math intensive courses. Faculty in the math department have been offering distance-learning courses for a number of years so I met with a couple of faculty to find out how they did it. To my surprise, their main method was to send videotapes of their lectures to their distance students! This was not an option for us. We did not have enough time to produce the videos and we did not think this was the best way to utilize the resources available especially the internet. (Personally, I was not that confident of my lecturing skills to have my lectures turned into permanent records. I was unwilling to turn my classroom into a performance stage. In addition I would hope that my time in the classroom would be described more as a conversation than a lecture, per se.) Basically, we were on our own. The instructors going first would have to decide how to teach their courses and pass what they learned on to the others.

With all of that as an introduction, I will now focus on the decisions I made for creating my course, *Vision & Psychophysics*. This course is a ten-week course in which the first half of the quarter is an introduction to psychophysical methods useful in color and imaging science applications and the second half of the course is an overview of the visual system. Although this course is not as technical and math intensive as say, Linear Mathematics for Imaging, there were still challenges in deciding how to teach the material.

The main differences between the local and distance version of the course is obviously the lack of lectures for the distance-learning students, the inability for the students to interact with me face-to-face, and the inability for the students to take advantage of the lab resources such as computers and software, color-vision tests, and other lab apparatus that may be used in homework assignments. In addition, distance students would have much limited access to reference materials available at a university library for researching their homework assignments and term papers.

I decided that I would replace the lectures with a web site. I wanted to put in the web site the parts of the course that one could not get from the textbook and readings. The web site should therefore complement the readings, focus on the relevant points, present my personal experience and philosophy, provide useful examples from the lab, and stimulate thought and discussion in an open ended way. As such, I wanted to take advantage of multimedia to make the course more interactive. I wanted to make the web site as complete and comprehensive as possible so that the course would be fully asynchronous. I tried to make the site reflect my personality by writing in the first person using a colloquial voice and asking open-ended questions with the suggestion that they be discussed on the bulletin boards. I also wanted the web site to be low-bandwidth so that the students would not spend too much time watching pages load. (RIT subscribed to a service provided by Blackboard Inc. called blackboard.com. This site allows an instructor to post course material and interact with students by e-mail, bulletin boards, and interactive chats.)

It was necessary to become bit of a web-master to make my site. Fortunately, there are a variety of software applications that make this possible at reasonable expense with academic discounts. This allowed me to make more eye-catching and interactive graphics and include demonstrations. The downside was that the more web-savvy I wanted to be, the more time I needed to spend on learning software and producing web material at the expense of actual creating learning material. In the end, there was more actual text than interactive material I had envisioned, but with time I can change and add to the web site.

There are a variety of products by different vendors that do similar things. I will briefly describe some of the software I used. I was very pleased with these products but I am describing them not as an endorsement but rather to describe what I did to create my course web site.

Macromedia Dreamweaver: Dreamweaver is a web site/page creation program that allows one to create a site with very little knowledge of html. One can put in graphics, movies, tables, interactive behaviors, links, etc. in a WYSIWYG user interface. One can also instantaneously test the site by previewing it in a browser.

Dreamweaver is also integrated with other Macromedia products so that the import of graphics and Flash movies is very easy.

Macromedia Fireworks: Fireworks can be used to create, edit, and animate web graphics as well as optimize images for presentation on the web. I found it extremely useful for optimizing scanned images for inclusion in my web site. It allows you to interactively preview images as you change the size of the image and amount of compression so that your pictures will not take forever to load over a modem.

Macromedia Flash: Flash movies are great for animation and interactive demonstrations. They use vector graphics and are extremely compact in their use of memory. Flash movies are viewed using a free and readily available plugin in your browser. For simple graphics and movies, it is quite easy to use, however one can easily devote a lifetime to its extended interactive capabilities.

Adobe Acrobat: The free reader makes pdf files universally available across platforms. Acrobat will allow you to create viewable documents from almost any application. If your students submit assignments as pdf's, you can "red-pen" their papers and return them electronically. I used pdf's to make my PowerPoint lecture notes available to the distance class and to make homework assignments and other handouts that were not part of the course web site.

Blackboard.com: I uploaded my course web site to the Blackboard web site. The student would click on a link in the course documents section to access the web site. There were a number of technical issues that made this method less than optimal. Blackboard has many capabilities, including announcements, document folders, digital drop boxes for students to send documents, and discussion boards that I found to be adequate. My colleagues who tried the interactive chat features found it to be lacking. There are a number of other features such as administrative features for recording grades and creating groups for projects that I never used.

In the classroom, going through quantitative examples can be tedious and time consuming. One would much rather get to more substantive topics than stand out the board writing equations and columns of numbers to add up. A benefit of the web is that one can add several worked out examples enumerating the steps of the problems that students can work out on their own time. The online course was made available to the local students to review the course web site, go through the examples, and participate in the discussion boards.

Homework assignments needed to be modified for the distance students. For example, one homework assignment required the administration of the Farnsworth Munsell 100-Hue Test and the Ishihara Pseudoisochromatic Plates. For the distance learners I provided the raw data for the 100-Hue test to score with additional information on the design and administration of the test and a scanned pdf version of the Ishihara Plates. Another assignment consisted of a program called "Gabori Attack," (http://vsoc.berkeley.edu/vsoc/index.html) which is a cross-platform program that is used to psychophysically measure one's contrast sensitivity function in the form of a video game. Although not used under calibrated and controlled conditions, it was possible for the distance students to get a "hands-on" feel for the assignment.

To quantify the experience, I would say that creating an online version of the course was at least twice as much work as originally creating the local version when I first started teaching it:

$$\varepsilon_{online} \geq 2\varepsilon_{local} \quad (1)$$

where ε_{online} is the amount of work to prepare the online course and ε_{local} was the amount of work needed to first prepare the local version.

A sample of the course can be found at http://www.cis.rit.edu/people/faculty/montag/sample.

3. TEACHING THE COURSE

There were five students in the course from across the country employed by a variety of companies. To some extent each student had interest in color science and psychophysics and took the course for professional development. Students were required to have access to a scanner, fax machine, and the usual suite of internet tools. In addition they needed some type of programming and statistical software for assignments.

The first couple of weeks of the course had a few rough spots while the students and I worked out technological issues involved with using the Blackboard technology, getting access to the electronic reserves at the library, and working out e-mail addresses and communication issues. It was important for both me and the students to work out a routine to ensure smooth operation of the course. I needed to make sure to post regular announcements telling the students how far along they should be in the course web site and the readings and when assignments were due. The students needed to learn to set aside study time to keep up with the course. I also needed to constantly promote discussion on the discussion boards and respond to questions and comments to keep the conversation flowing.

Because I designed the course to be asynchronous, I planned on relying on the discussion boards for the majority of the interaction with the students regarding the content of the course such as questions, comments and clarifications. The discussion boards were used less frequently than I had hoped. I would have liked to have seen more lively conversation and debate. The students claimed that they did not need too much more clarification and discussion but in the future I will make it a requirement to participate at some level in the discussions.

The best way to gauge the success of the course is by student performance and their evaluations. The distance students performed as well as if not better than the local student on average even thought the local student had access to the online course material as well as the lectures. There is however a selection bias in that students who either pay for the course or are supported by their companies may put more effort into the course and as a group are older and perhaps more self-motivated. The students commented in a survey that they were satisfied with the amount of work (averaging 10-15 hours a week), the material learned, and the amount of interaction with the instructor. Some students commented that they preferred to print out the material on the course web site and read it off-line. I would hope in the future to make the course more interactive and useable as an online experience.

Because the class was small and the students were mature and hard working, I allowed the closed-book final to be taken on the honor system. However, proctoring of exams may be an issue in the future.

In general, the amount of effort involved in the actual teaching of the class was slightly less than that of the local version. Although the amount of time spent on keeping the distance learning going was equivalent to the time I spent lecturing to the local students, the effort was not as strenuous:

$$\tau_{online} \leq \tau_{local} \qquad (2)$$

where τ_{online} is the effort expended on teaching the distance section of the course and τ_{local} is the effort expended on teaching the local version.

4. OTHER'S EXPERIENCES

As mentioned, other courses have been taught as part of this program. These courses, including Linear Math I and II, Digital Image Processing, and Geometric Optics, have been as successful as mine by the criteria of students performance an their evaluations of the courses.

The philosophy of the instructors of these courses has been different than mine. These courses did not implement a web site to take the place of lectures. Instead, extensive course notes and examples were prepared and disseminated as pdf's on Blackboard. The instructors set aside ample periods of time in which student interact with the instructors and teaching assistants to go over the notes in interactive chats which are archived for other students to read, if they wish. A number of different technologies have been employed to add interactive graphic capabilities (white boards) to the chats. In addition, voice capabilities (with archiving of the sound files) have been added since communicating by typing is in many instances too slow. These courses are less asynchronous than mine and do not take advantage of the multimedia possibilities of the web, but I must stress that these courses have been quite successful. The students are uniformly impressed and happy with the quality of the education.

As another example of teaching style, Dr. Mark Fairchild will be teaching Color Reproduction next winter using interactive Flash modules and discussion boards almost exclusively. Part of the methodology involved in teaching a distance learning course will depend on the material and resources available. For Mark's course, the textbook, Hunt's Color Reproduction, will be put to life and supplemented by the Flash movies. For the math courses mentioned above, no real textbook was used. In all cases however, the learning is guided by an actual instructor involved with the students.

5. CONCLUSIONS

All of us involved in this first round of teaching were pleasantly surprised with the success of our initial efforts in distance teaching. The results were so encouraging that we already have put two more specialty tracks, Digital Image Processing and Remote Sensing, into the program. This will provide more flexibility and choice to our students.

We feel our success is due to the involvement we have with the students. This is clearly not a correspondence course implemented on the internet. As the quarter progresses, we get to know the student even if we do not see their faces. Through our interactions, we can tell which students would be the ones who sit in the back and never ask questions, yet surprise us by acing the exams, and which students are the ones who need a little extra attention to get on track with a new concept.

We do not want the distance-learning program to replace our local efforts. We hope it is a viable alternative for people who do not have the flexibility to come to campus. As mentioned above, this program is equivalent to our MS program with a project/paper option. What these students do miss out on is the opportunity to complete a Master's Thesis working with one of our faculty members. We hope that the addition of this program will not only aid in the professional development of our distance students but will also create a larger audience for our research and teaching on campus.

Colour Zones – Connecting colour order and everyday language

Paul Green-Armytage, School of Design, Curtin University of Technology, Western Australia

ABSTRACT

This paper makes a case for a structured use of everyday language as a means of introducing the concept of a colour order system, which is seen to be of particular value to designers. A distinction is made between teaching and learning, and some of the obstacles to learning faced by design students are described. It is suggested that a step by step approach, as embodied in a system of Colour Zones, could ease the learning process. An account is given of the Colour Zones system, its antecedents, final development, and first trials in the classroom.

Keywords: Colour order systems, colour names, colour education, colour in design

1. INTRODUCTION

This story may be an old one, but it illustrates very well a dilemma commonly faced by teachers:

There were two small boys, John and Jim, who were friends. Jim had a dog. One day they were taking the dog for a walk and Jim said proudly: "I've taught the dog to whistle". "What do you mean?", said John, "He's not whistling". "I know", said Jim, "But I said I'd taught him; I didn't say he'd learned".

Rather than wonder how colour should be taught it might be more useful to consider what our students need to learn. And learning is not just the acquisition of knowledge as of facts and figures, although facts and figures do have their place. A good colour program will be one that provides the best circumstances for a particular group of students to learn the things that matter most to them.

2. TEACHING COLOUR TO DESIGN STUDENTS

My colour program for design students is based on the notion that greater understanding and control of colour can lead to more effective communication, (and all design is, to a greater or lesser extent, concerned with communication). The aim is for students to develop greater sensitivity to the visual world, greater awareness of possibilities, and greater appreciation of colour as a language. They are provided with a kind of tool kit for colour design – some basic concepts that can be used for generating, developing, refining, and communicating ideas, as well as for trouble shooting when a design doesn't seem to be developing as intended. Central to the program is a firm distinction between colour as something physical – paints, inks, etc. – and colour as a visual experience. The most important tool in the kit is a conceptual model of visual colour in the form of a 3-D colour solid with some means of indicating where in that model a given colour might belong. With such a model it is very much easier to explore and record colour relationships as a basis for building colour knowledge. The model which serves our purposes best is that of the *Natural Colour System* (NCS)[1].

3. PROBLEMS

The program is an ambitious one and it has to compete with other subjects for space in the time-table. I have found that students have difficulty taking it all in with all the other demands on their attention.

3.1 The comfort of old knowledge – Riley's Law

During a discussion about our courses, one of my colleagues, Howard Riley, identified a problem that comes from trying to teach too much in too short a time[2]. He had noticed that students who do not fully grasp a new concept might make a token attempt to use the concept in a given exercise. Then, when that exercise is over, they retreat into the more comfortable world of what they knew before. The new concept is rejected before any real attempt has been made to understand it and all that might remain is a vague memory of possibilities; the exercise itself can seem to have been a waste of time.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

3.2 More in one area means less in another

I believe that there is a certain amount of basic information about colour that every designer should at least have the opportunity to learn. More exercises, with more at stake if students don't understand and apply the new concepts, could be an answer. But the time required for that would create pressures in other parts of the course. So the problem of how to make the best use of limited time remains.

3.3 Systemophobia

Colour order systems, even one as simple as the NCS, have been seen by some students to be irrelevant, too complicated, even a constraint on their creativity. Other students have recognised the potential value of the NCS but lose heart in the face of what they see to be complexity and the inadequate opportunity to convert their brief encounter into useful knowledge. Many, also, have been alienated by the letter/number codes used to identify individual colours and seem more comfortable with colour names like red and blue, and adjectives like pale, dark, and vivid as means of describing colour appearance.

4. TACKLING THE PROBLEMS

When I have taught the students to whistle and found that they aren't whistling, I have had to question my approach. Is it possible, in the limited time, to deal with all the essential concepts in such a way that students can learn them, or must some concepts be abandoned in order to make sure of the others?

4.1 Most recent approach - Leaving it to the students

My most recent approach has been to accept that it is the students themselves who will decide what to learn and when to learn it, and to leave things largely up to them. In a very condensed program students are introduced to the basic information and are provided with a set of notes. Some of the exercises serve as illustrations for the notes. The illustrated notes are among the things they hand in for assessment and are what they retain as a permanent source of reference. But I am still concerned that the gap between the knowledge that students bring to the course and the set of concepts in the notes may be too large. If students haven't picked up some understanding during the course, they might never refer to the notes again.

4.2 New approach – Stepping stones

My new plan is to introduce a series of 'stepping stones'. During the course students move from one stepping stone to the next. At the end of the course, instead of facing an all or nothing situation such that they must either grasp all the new information or go right back to the beginning, my hope is that they might only go back part of the way to a stepping stone where they felt comfortable. From there the journey forward again might not be so daunting.

5. STEPPING STONES and COLOUR ZONES

Each stepping stone is a set of colours organised in a simple structure of what I am calling colour zones. There are six zones in step one, 27 in step two, and 165 in step three. Beyond step three is the NCS. The NCS provides the structural skeleton for the Colour Zones system, and everyday language is to be used to identify the colours. By imposing some system on the use of language I hope to ease the transition from the hit-and-miss language that students bring with them to the ordered clarity of the NCS.

5.1 Colours as individuals and as group representatives

The essential difference between a zones system and a colour order system like the NCS, is that a zone defines a range of similar colours grouped round a focal point or centroid colour, while a colour order system has single points to represent single colours. In a zones system a centroid colour acts as a reference point for all the other colours in its zone. A zones system, by definition, is not precise, its degree of precision being determined by the number and size of the zones. So it is enough to say that a particular colour belongs in a particular zone. This kind of tolerance brings it much closer to everyday language where one person's pink may not be the same as another's – but it won't be so very different either.

5.2 Border disputes

A zones system would not be immune from border disputes such as one often hears when people argue about whether something is blue or green. Having an in-between zone with a name like turquoise could solve problems in the way that orange has become a buffer zone between yellow and red. The battles would remain, but they would be more localised, and people would argue over a narrower front; is it blue or turquoise? red or orange? The intention is not to make everyday colour language precise, but more precise than it is at present.

6. ANTECEDENTS

The Colour Zones project has a long history. The present system has come from the revival of an idea which I first put forward in 1978. That idea owed a debt to the *Universal Color Language* (UCL)[3], and there are other models that have also been influential.

6.1 The *Universal Color Language* (UCL)

The UCL recognises six levels of precision for describing colours, the first three levels corresponding roughly with my zones. At levels one and two, colours are described by single and compound colour names: red, then orange-red. At level three, centroid colours are introduced within the framework of the Munsell system and modifying adjectives add precision to descriptions: pale pink, dark purplish blue. Level four is for the comprehensive colour order systems like the Munsell system itself. Level five allows for interpolation between the colour samples of a colour order system, and at level six, colorimetry provides precise specification. While I admire the concept of the UCL, I feel that at level three it is too complicated to serve its intended purpose, and I am not aware of its being in widespread use.

6.2 The Colour Map

My first idea for what I called a Colour Map was presented at a conference in 1978[4]. This was essentially a colour circle with six concentric rings. The lighter and darker colours were in the inner and outer rings respectively, with the more vivid colours in between. All the colours were named. The Colour Map failed in several ways. It looked pretty, but people did not find it easy to read and some of the names I had chosen were unfamiliar or unsuitable. But its central idea, that of a bridge between everyday language and colour order systems, has remained to be revived in the Colour Zones system.

6.3 Other systems based on Munsell

Two systems that are also based on Munsell, but which are simpler than level three of the UCL, have been introduced in Japan: the *Hue and Tone System*[5] and the *Practical Color Co-ordinate System* (PCCS)[6].

6.4 The Natural Colour System (NCS)

Another kind of zones system is implied by one of the exercises produced by the Scandinavian Colour Institute to help people learn the NCS. Colour chips are to be placed in position on a square grid according to their main and secondary attributes. So a colour chip that might be described as peach could also be described as having a main attribute of redness and a secondary attribute of yellowness together with a main attribute of chromaticness and a secondary attribute of whiteness. It would be placed on the grid accordingly.

7. THE COLOUR ZONES SYSTEM

The structure of the Colour Zones system, the names and adjectives used to identify the zones, and the processes used to establish those names and adjectives are described in more detail elsewhere[7].

7.1 Reference points at the borders or at the centres of zones

There are good arguments in favour of grouping colours in zones according to their main and secondary attributes; such grouping accords with the logic of the NCS and supports some theories of colour harmony. But when colours are grouped in that way the reference points are at the borders which separate the zones. Since the reference point colours are generally also the best examples for the most common colour names, and if the system is to connect with everyday language, the reference point colours need to be at the centres of the zones.

8. FIRST CLASSROOM TRIALS

In this first semester of 2001 a fortuitous increase in student numbers, combined with changes to the time-table, have enabled me to work with three groups of students one after the other. I was also able to get feedback from an outside group.

8.1 Describing colours - before and after

In the first session each student was given a colour sample and asked to describe it. There were no restrictions on the wording. The descriptions were then collected and redistributed so that each student had someone else's description. A comprehensive array of colours was put on display and students were asked to pick out the colour samples that matched the descriptions. The success rate for exact identification was higher than I expected, the average for the three groups being

19.6%. The same array of colour samples was displayed again at the end of the program. This time students were given descriptions in terms of the newly established colour names and modifying adjectives. For the middle group (the only results so far) the success rate was 25.7%. They were also given descriptions in the form of NCS diagrams. The success rate was better still: 27%.

8.2 Modifying the system

What I learned from the responses of the first group led me to modify the system for the second group. More slight modifications followed my experience with the second group. At the time of writing, the third group are working with the system in what I hope will be its final form.

8.3 Testing by an outside group

The system in the form used by my second group was given to an outside group who were asked to describe a set of colours using only the names and adjectives that had been established. While some protested at this restriction there was an encouraging degree of consensus in the names and adjectives they chose to describe each colour.

8.4 Feedback

At their final session I asked the second group for feedback on the program – how much had they enjoyed each activity and how much had they learned. I also asked them to pass judgement on the potential value of the three different ways of describing colours used in the program. For each they ringed a number on a five point scale. With 27 students completing the questionnaire the highest possible score for any of the three ways was 135. Unrestricted and unstructured use of everyday language as used in session one scored 75. Use of a limited vocabulary of colour names and modifying adjectives with defined meanings linked to the NCS scored 105. Use of NCS diagrams – a line on the colour circle to indicate a colour's hue, and a dot on the colour triangle to indicate the nuance – scored 123.

9. CONCLUSION

It is too early to make any firm claims for Colour Zones as stepping stones which might help students to master the concept of a colour order system. More data is needed for a clearer picture of how successfully colours can be communicated with a structured system of names and adjectives, and the data will need to be examined more closely. The results so far are encouraging, but by no means overwhelming. Meanwhile I still want my students to learn how to whistle, which means learning to use the NCS successfully. The names and adjectives are to be a means to that end. But even if the Colour Zones system ends up joining the Colour Map in the oblivion of interesting but failed ideas I may still keep some of the exercises used in its development. It might be a case of serendipity. For the students, the process of looking closely at colours, relating them to their own use of language and making fine judgements must surely raise awareness and increase sensitivity. And I would include both in what I understand as colour knowledge.

REFERENCES

1. Hård, Anders and Sivik, Lars, 'NCS - Natural Colour System: A Swedish Standard for Colour Notation', *Color Research and Application.* **6** (3), pp. 129 - 138. 1981.
2. Riley, Howard. Idea put forward in conversation, 1989.
3. Kelly, Kenneth, 'The Universal Color Language', in Kelly, Kenneth and Judd, Deane, *Color - Universal Language and Dictionary of Names*, U.S. Department of Commerce, Washington, 1976.
4. Green-Armytage, Paul, "Violets aren't Blue - Colour Sensations and Colour Names", in Condous, J., Howlett, J. and Skull, J eds. *Arts in Cultural Diversity.* (pp. 166 - 175). Holt, Reinhart and Winston. Sydney, 1980.
5. Kobayashi, Shigenobu, *A Book of Colors*. Kodansha International, Tokyo, 1987.
6. Japan Color Research Institute, *PCCS Harmonic Color charts 201-L*, Japan Color Enterprise Co., Ltd., Tokyo, 1991.
7. Green-Armytage, Paul, 'Colour Zones – Explanatory diagrams, colour names, and modifying adjecitves', *Proceedings of AIC Colour 01 Rochester*, 2001

TEACHING COLOR AS AN EXPERIENTIAL EXERCISE

Margaret A. Miele, Assistant Professor of Psychology
Fashion Institute of Technology, New York

ABSTRACT

This paper describes the evolution of the course "The Psychology of Color" that I teach at the Fashion Institute of Technology. Information was synthesized from many disciplines including human biology, physics, consumer behavior, developmental psychology, cross-cultural anthropology and sociology. After initial implementation, the course went through two additional phases of refinement. The current course is an integration of research, theory and application to our everyday lives.

INTRODUCTION

I teach The Psychology of Color at the Fashion Institute of Technology in New York City. I didn't expect or intend to do this; after all, I was employed as an Industrial Psychologist. But, it was shortly after my hire that the Advertising Design Department recognized a gap in the professional preparation of their students. Ultimately, the Social Sciences Department was asked to create a course that addressed color and psychology. So through a chain of events that essentially boiled down to the rule that it's the least senior faculty, who get the most challenging assignments, I became the resident Color Psychologist. What ensued was a process of intense research and self-training, which, as it turns out, was only the beginning of this labor of love.

Perhaps because of its rewards, teaching the Psychology of Color is a challenging activity. Teaching it to non-psychology, primarily design students arguably presents its own unique challenges. There is a wide range of topics, which might be addressed and an equally abundant number of approaches one might take.

For instance, one might study classical color theory. Perhaps the standard text and lecture model would serve best here. Students could read primary sources and have the salient points elucidated by the instructor. Is recognizing the missteps of Aristotle's primitive logic or memorizing Goethe's General Characteristics of Color the path to creating better graphic designs?

Then there is the wealth of information, which draws from research on human physiology and perception. Students could be taught the procedures and guidelines of research methodology, thus allowing them to critically review various studies. Ultimately they might learn a great deal about thresholds, receptor cells and brain structure, but would this make them more insightful package designers?

What about the social and cultural aspects of color? Color language and symbolism provide a great deal information about a people. Social Science is rife with such historical analyses. While understanding our past is an effective tool for helping us to prepare for our future, can

9th Congress of the International Colour Association, Proceedings
of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

Home Products or Interior Design students readily apply this knowledge to anticipate client needs?

And still, there is the issue of color as an indicator of our personality. How might students best become familiar with approaches that look to correlate color usage and preference with individual variables such as traits, gender and age? How does an Advertising Design student translate psychoanalytic notions about the drawings of emotionally disturbed children into an ad campaign for the Super Bowl?

In preparing the course of study for the Psychology of Color, I grappled with these and other issues. Eventually, and there was more than just a little trial and error, I came to realize the obvious, that color education in the classroom, should emulate color education in everyday life; through interaction and experience.

The purpose of this paper is to describe the process through which the course evolved. Since its inception, I have experimented with different approaches to the course material. Not all of these experiments have been as successful as others. My intention here is to offer a chronology of the course's development, highlighting how my insight into the pedagogic issues has been honed and how, more often than not, my students have contributed to this process.

PREPARING THE COURSE

With a reference list in hand, I set out to teach myself about the human response to color. To my dismay, many of the titles were out-of-print and/or available from only hard to access sources. As I continued to build my reference library, I realized that to a great degree, I was having to synthesize information from a wide range of disciplines, including, but not limited to human biology, physics, consumer behavior, developmental psychology, cross-cultural anthropology and sociology.

I felt that I needed a research oriented course which balanced theory with its application. The subsequent course outline divided the semester in two. The first seven weeks of the semester were spent on topics like *The Human Visual System, Color Symbolism in a Cultural Context, Color and Personality* and *Color and Human Development*. The second half of the semester explored the use of color in man-made environments as well as consumer applications like marketing, advertising, and package design. Throughout the semester, students would work in small groups to produce a term paper and a presentation on a color topic of their choosing.

IMPLEMENTATION

As that first semester progressed, I came to realize several important things. First, I would not run out of material before the semester had ended! As is often typical of teachers, I overestimated the amount of information, which could be covered in one semester. It was with a combination of disappointment and delight that I realized there was still more I could teach them, but no time to do so. Second, I had only produced a decent course. I was brimming with enthusiasm for the subject, and the students were eager, but, by separating theory and research from its applications, I had inadvertently contributed to the students' difficulty to recognize their interdependence. Finally, I had underestimated the abilities of our students. Those first term projects were extraordinary and greatly surpassed my expectations. Despite these flaws, I was excited and encouraged.

PHASE TWO

As the next school year approached, I decided to make some changes. There would be a greater emphasis on the integration between theory and practice through a series of exercises in self-discovery, which would take place over several weeks and culminate in an analytical, yet autobiographical essay. Students would be asked to assess their personal color preferences (as measured by the Luscher Test, 1969). They would analyze their use of color in their personal space (for most this means their dorm room or bedroom). They would measure their response to colored light and their use of color in several semi-structured art projects. Finally, case studies from the writings of Oliver Saks (1995) would be added to the required reading list as a means to illustrate the link between human color perception and behavior. To borrow from Josef Albers, who encouraged his students to "search, not research", I was attempting to have my students do a bit of each.

Once again, I fell victim to the fault of overestimating what could be accomplished and underestimating the amount of time it would take. Students were amazed at how a perceptual system they took for granted could produce such consequences as a blind man who's sight is restored only to realize that he still cannot "see" because his brain lacks the skills he needs to interpret the images the eye transmits or that a synesthete might determine the accuracy of a solution to a math problem by 'color' of the result. That year, the term projects were even more exciting than the last. Because students were able to manifest more control over their projects, by determining with whom, if anyone, they would collaborate, their creativity blossomed.

PHASE THREE

Further refinement led to the creation of a series of 'modular assignments'. The course is divided into a series of modules or units. Each module is arranged around a particular research method or thrust, the underlying theory and its historical development, the significant and sometimes contradictory findings and the resultant applications. At each step of the way, students are encouraged to draw conclusions as to the impact on their own lives. An experiential exercise accompanies each unit.

For instance, in the first module, students are exposed to as many as three different colors of light in the classroom over a three-week period. While learning about the research on human physiological and psychological response to color, they are actually, themselves subjects in a controlled experiment. Records are being kept to monitor their physiological, emotional, cognitive and behavioral reactions. At the end of three weeks the results from each individual student are combined to provide an aggregate. The results are tabulated and we, as a class, create simple graphs to display this information. A discussion of what we believe our results to show and how this may or may not be consistent with what we learned from professional research ensues. To cap this module, students are required to write a brief report entailing what took place and what they understood to be the significant outcomes.

Other modules revolve around personality measurement, human development and environmental and cultural influences. Information gathering strategies like systematic observation and interviews and questionnaires are incorporated into the activities, giving each student an opportunity to explore particular aspects of a topic which is of interest to him/her and to bring that back to class. This enables each individual to exercise some creativity while acting within parameters set for the group as a whole. The quality of the lesson and the synergy of the material are the result of a professional-like collaboration among students and between the students and the teacher. My students taught me that they needed this mentoring all the while demonstrating that they were capable of handling responsibility.

CONCLUSION

What I currently have is a course of study that is applied to our everyday lives. There is no separation of search and research. Instead, the experiential and the analytical are intertwined. Because the subject matter is real and so very pertinent, each and every member of the class, including the teacher, has an important role to play and a direct responsibility to the learning outcomes.

The problem with teaching 'COLOR' is that the students already know it. Or at least they think they do because sometime, well back into their toddlerhood, they learned their colors. Their Kindergarten teachers would require this knowledge of them. Perhaps even more importantly, long before they knew any color terminology, they were experiencing a world of color. And that's just the point, Color is an experience. In psychological terms color is the result of a physical sensation that in turn produces a perceptual event. Color happens in your head. Perhaps our job is not to teach color so much as it is to help them understand this perceptual event as well as its antecedents and consequences. We should strive to get them to think about the experience of color; to stop taking it for granted; to be observant and analytical about color. In essence, while they stop to smell the roses, they should also pause to see their colors…and the colors in the surround. Teaching color should be the process of putting the search back into research…to RE-SEARCH.

REFERENCES

Luscher, M. (Scott, I. Ed.) The Luscher Color Test. New York: Washington Square Press, 1969

Saks, O. An Anthropologist On Mars. New York: Vintage, 1995

Biography:

Margaret A. Miele is an Assistant Professor of Psychology and the Assistant Chairperson of the Social Sciences Department at the Fashion Institute of Technology in New York City. Her areas of specialty are Color Psychology, Industrial/Organizational Psychology and Research Methodology. She has spearheaded the teaching of the Psychology of Color at F.I.T. and serves as an industry consultant. She is an active advocate of color education and research. Professor Miele was on the advisory board for EduColor 2000, is Chair of the Inter Society Color Council's Interest Group on Art, Design and Psychology, is a faculty advisor to the F.I.T. Student Chapter of the ISCC and is an invited contributor and lecturer to the All Japan Fashion Teachers Association and the Color Council of the United States. Along with several of her colleagues at F.I.T., she is developing a certificate program in Color Studies, which will help to serve industry needs in the arena of Color education.

Contact Information:

Address:	Social Sciences Department, Room B634 Fashion Institute of Technology Seventh Avenue at 27Th Street New York, N.Y. 10001-5992
Phone:	(212) 217 - 8449 [Voice Mail] (212) 217 - 7095 [Fax]
Email:	mielemar@fitsuny.edu

Visual colour matching equipment for teaching and research

Arthur W. S. Tarrant, University of Derby*

ABSTRACT

Visual colour matching equipment designed to illustrate the principles of CIE colorimetry is described. It enables students to individually match spectrum colours , surface colours, or self-luminous displays. The use of a photometer enables quantitative results to be obtained.

Keywords : Colorimetry, colour matching

1. INTRODUCTION

The principles involved in colorimetry and the CIE system are not easy to grasp at first hearing. It is not only university students, but often technical staff in industrial concerns in mid-career who have to master them. The author has often used a set of lecture room demonstrations involving four projectors in his teaching[1,2], but this equipment is cumbersome and needs a lecture assistant. At the suggestion of Prof M R Luo, a similar set of equipment has been built as a laboratory instrument that students can use individually. This equipment may also find some application in studies of colour vision.

Four projection units are used to illuminate two semicircular fields on a screen. Each unit can be switched to light either side of the field. The normal pattern is for three, providing red, green and blue primaries to light the right-hand side, whilst the fourth provides a test colour on the left-hand side. The 'test' colour can be provided in various ways, thus :

(a) filters can be inserted in the beam from the fourth projection unit
(b) the fourth unit can be used to illuminate samples of surface colours
(c) light from a separate source and monochromator can be switched in
(d) light from a self luminous display can be used.

Spectrum colours can be set up on the 'test' side either by using light from the monochromator, or by placing narrow band interference filters in the test beam.

2. THE OPTICAL SYSTEM

The four projection units are mounted rigidly in a two-tier frame at one end of the instrument's case. Mirrors direct the beams to the screen at the other end. The screen is viewed with both eyes by looking through an aperture in the case just above the projection units. The screen is illuminated at near normal incidence, and the viewing angle is about 8°. The viewing distance is about 1500mm ; the field size currently used is 6°. Screen luminances of up to 60 cd/m^2 are obtained. An auxiliary aperture in the case allows a second person to see the screen, though at an angle of about 13° off axis.

The general layout of the instrument is shown in plan view in fig 1, and details of the projection unit normally used for the 'test' beam are shown in fig 2. In fig 1, the two tiers are directly one above the other, so that only the upper tier, with the two upper projection units, appears in this view. Light from the lamp **B** is focused by the condenser lens system **C** into the projection lens system **E**, after passing through the mask **M** and the colour filter **F**. The projection lens system **E** forms an image of the mask **M** on the viewing screen **S**, after reflection by the aligning mirror **G**. The mask **M** has two semicircular apertures in it, and is mounted on a slide. By moving this mask, light from this projection unit can be switched to the chosen side of the viewing field.

The current field size of 6° was chosen because experience with the demonstrations mentioned above showed that to be a convenient one ; larger or smaller sizes could be used by using masks of appropriate size. It is necessary for the illuminance provided by each projection unit to be uniform over the field to a high degree, and the optical systems are designed accordingly. Each projection unit is completely enclosed with internal shielding to eliminate stray light.

When it is desired to bring light from the monochromatic light into the test beam, it is brought from a xenon arc and monochromator, which form a separate unit, through a fibre optic bundle to the point **X** (fig 2). The mirror **Y**, is then moved in to the dashed position ; otherwise it is retracted from the beam.

The brightness of each projection unit is controlled by controlling the current fed to the lamp. This method was adopted on the grounds of simplicity. However because the spectral power distributions of the lamps change with current, the chromaticities of the primaries may change slightly with field brightness. In fact, this change is negligible in the case of the red primary. The green primary is produced with an interference filter with a bandwidth of 25nm, and the total change of chromaticity corresponds to a shift of dominant wavelength of about 1nm (0.01 in x and y in the CIE 1931 system). In the case of the blue which uses a band-pass interference filter, the total shift is about 0.02 in CIE units.

The measuring head of a photometer is mounted on a simple mechanism at the position **P**, so that it can be placed in either side of the field immediately in front of the screen, or retracted completely from the viewing field. Thus once a match has been made, the illuminance values of the three primary components can be read off. Strictly, we should be concerned with the luminance values of the screen, but since in this case the screen is a near-perfect diffuser illuminated at near-normal incidence, it suffices to measure the illuminance values. The photometer is of the Gigahertz automatic ranging type, which is colour corrected to have a sensitivity distribution which matches that of the V_λ curve. Although the V_λ correction is not strictly necessary, it is used here to make students aware of the fact that the conventionally used units of the primaries – trichromatic units – have very different luminosities.

3. TYPICAL STUDENT'S EXERCISE

In a typical exercise the student is first asked to make some matches on colours produced by filters in the test beam, and so he becomes familiar with the concept of three colour additive mixing. He is next asked to match a colour which corresponds to the equal energy white. That is produced by setting the lamp in the test beam to the colour temperature of standard illuminant A, and then placing appropriate filters in the beam. He can then measure the red, green and blue primary values of the match, and these readings establish the magnitudes of 'trichromatic units' within the instrument's system.

He can then try to match a series of spectrum colours, produced either by putting interference filters in the test beam, or by matching light from the monochromator, switched into the 'test' field. To do that it is necessary in most cases to switch one of the primaries to the 'wrong' side of the field, as most spectral colours lie beyond the triangle formed by the instrument's primaries. The R,G,B values are read off in each case. The student can then plot the spectral locus on a chromaticity diagram based on the instrument's primaries, and if relative power values are available for each of the monochromatic beams, he can plot his own colour matching functions in terms of the instrument's primaries. Since these are known in terms of the CIE 1931 system, all of the student's findings can now be transformed to that system.

Students normally work in pairs, and this exercise reveals the extent of observer differences to them ; once a whole class have gone through this procedure, it is possible to calculate 'standard observer data' for the group.

Other exercises involve matching surface colours and colours on self-luminous displays. Surface colours can be matched by placing the sample over the left hand side of the field and adjusting the test lamp to match standard illuminant A.

When displays are to be matched the back plate of the instrument is replaced by one with a semicircular aperture in it which corresponds to the left hand side of the field, and the display face is brought up close behind the backplate ; experience shows that the slight difference in viewing distance of the two halves of the field in this mode is of no consequence.

4. CONCLUSION

This equipment has proved to be effective in familiarising students with the basic principles of colorimetry. It is important to remember that it was conceived and designed as an item of *teaching* equipment rather than as *measuring* equipment, and it is not to be expected that it can match the accuracy of some of the latter-day visual instruments[3]. It is simple to use, and thus may be attractive for studies in colour vision involving (relatively) large numbers of subjects.

ACKNOWLEDGEMENTS

The author wishes to thank the University of Derby for the financial support which enabled the equipment to be built, and Messrs G Hammond, G Knight and P Evans of Bentham Instruments Ltd for their help with the mechanical design. He is also grateful to Dr Jonathan Maxwell of Imperial College for checking the optical design.

REFERENCES

1. A W S Tarrant, "Some Demonstrations to Illustrate the CIE System" *Internationale Farbtagung Luzern 1965*, p 1065, Die Farbe, Berlin 1965
2. A W S Tarrant, "The Nature of Colour – A Physicist's Viewpoint" *Natural Colours for Food and Other Uses*, J N Counsell, p1-27, Applied Science Publishers, London 1981, ISBN 0-85334-933-9
3. R Donaldson, "A Colorimeter with Six Matching Stimuli" *Proc Phys Soc (London)* **59**,554 (1947).

*contact TarrantAWS@aol.com ; phone +44 20 8894 3339 ; fax +44 20 8894 3339 ; 11 Preston Close, Twickenham, Middlesex, TW2 5RU, UK.

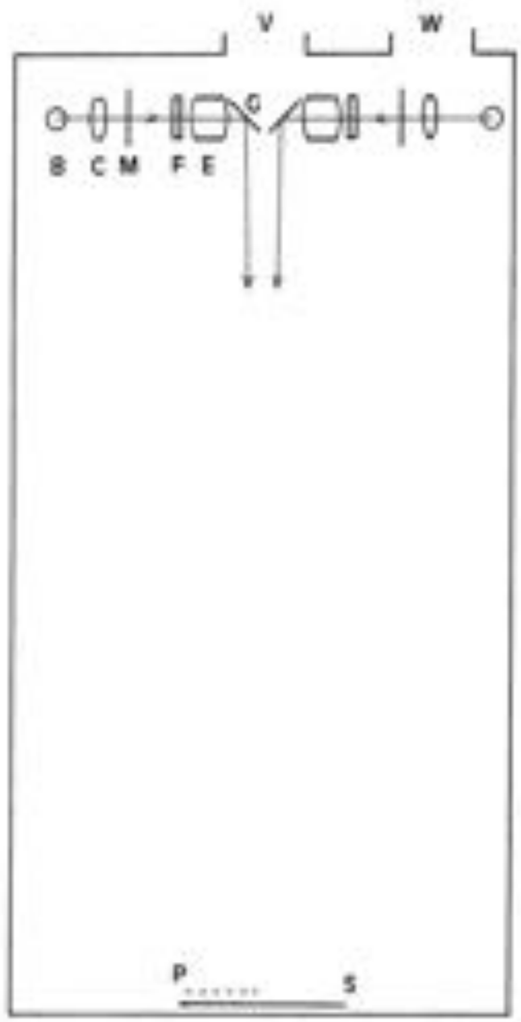


Fig 1. Plan view of the instrument

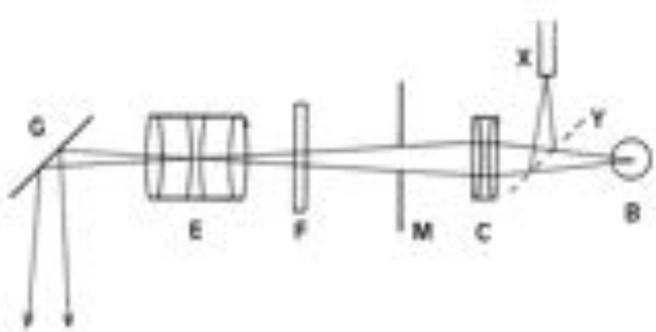


Fig 2. Optical system of the test beam projection unit

B lamp : **C** condenser lens system : **E** projection lens system
F colour filter : **G** alignment mirror : **P** position of photometer head
S screen : **V** viewing aperture : **W** auxiliary viewing aperture

Interactive Multimedia Systems as communication channels in color workshops

Alejandra Gaudio* and Javier De Ponti*

ABSTRACT

Great technological advances can help us to recover communication areas that might otherwise be lost. Media competition and visual contamination frequently appear in daily communication. A notable anonymity in human relationship has emerged as a consequence of this. Educational establishments receive an overflowing number of students. Schools and students are overwhelmed by this situation. Teachers don't know their students and students usually don't know their own classmates, with all the consequences that this implies. In front of this inadequate structure of educational institutions, technology has improved the possibilities of instant answers and the dialogue between teachers and students; the unilateral exposition pronounced by teachers in front of the anonymous mass finds an alternative in multimedia systems.

The present work describes Interactive Multimedia System's utilization for teaching the chromatic circle as a system of color organization. The proposed method intends to devise a theoretical and conceptual frame and its production for multimedia systems oriented to elaborate, represent, store, interact with and access to knowledge. Its relevance comes from the potential contribution to build up knowledge systems that value cultural codes and at the same time make creative and motivating interactive experiences. This work concerns the realization and understanding of the chromatic circle, selection of different color systems, logical strategies for playing and studying theory and multimedia. Levels of visualization: theory, practice, developing skills, works and evaluation. Levels to study: teaching chromatic circle, multimedia supports, quality, application and linking screens, help, theory, etc; without losing the interdisciplinary nature of the work, specialist participation, and Multimedia Systems in the steps of its realization.

ABOUT THEORY, TOOLS AND HUMAN RESOURCES

Both the learning and the teaching of color is one of the goals to reach in the firs level of careers relationed to design and fine arts. Color is a subject directly relationed to the basic contents in this first step in which a solid ground of color application and usability should be built for things that are used everyday (objects relationed to industrial or graphic design) as well as the aesthetic use of color in a work of art.

In this context the implementation of a practice classroom experimental system is one of the basic needs for first level students who ought to focus his perceptions in order to attain systematic use of saturation, contrast and luminosity. This ways of color application are ordered in a systematical organization called chromatic circle, that is to say the order of color according to its possible interrelations. The most important thing for primary level students is the comprehension of these interrelations applied to an specific function.

It is probable that the first study of color is linked to a sensitive dimension as the identity of color really is. That is to say the recognition of color in its pure state and its reference to its position in the circle. For example, red = primary saturated color; orange = red + yellow, etc.

A first approach to the classification of color from the point of view of its identity could result as an answer to the question *¿how would you order these colors?*. A second approach could be a practical application of pigmentary color mixtures and of projected lights.

This exercise will be useful if it is presented together with a theorical frame to reinforce an intuitive systematization. A practical application is of no use without a theory that enhances it. Without a conceptual base the exercises about color seem to be reduced to a mechanic repetition of harmonic diagrams. The ideal place for the development of this type of experimces is the workshop, a way of teaching which allows the interchange of investigation, exploration and creation processes.

At the University of La Plata, magisterial- unidirectional classes prevail over others. The great quantity of universitary students spoils a feedback between teacher and student. The unilateral exposition of theory pronounced by teachers in front of a great mass of students has become an example of anonymity. Teachers don't know who they are addressing to and usually students unknow teachers and are not interested in what they say. In the workshops this problem can be seen in the absolute lack of interchange of experiences among students, students and teachers and also among teachers. Furthermore the unrestrained increase of enrollment affects not only the classroom communication but also an interrelated knowledge among different subjects of a career.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

Massivity in the university make us search new ways of personalizing the teaching process trying to reorganize pedagogical resources so that the student becomes once more the center of education.
It is necessary to improve the dialogue among all those implied in the learning and teaching process.
The application of these open distance systems appears as a true possibility of recovering lost spaces. Color definition or its sytematization may be transmitted from a multimedia that functions as a communication channel between the student and the teacher. In this way, students can manage their own learning time according the evolution of their classroom experiences. In Johanes Itten´s "The art of color" he says "...I intend to build a useful vehicle that can help to all those who are interested in the artistic problems of color. One can also walk without a vehicle and go across unexplored ways, but it will be a slow and dangerous walk. If you are trying to reach a high and distant aim, you have better employ a vehicle; in this way you will be able to get a quick and sure advance..."(1)
Johanes Itten´s teaching of color is based on the following principles:

- The building of a vehicle that helps in the learning and teaching process.
- Consideration of the learning and teaching process as a way that has to be walked together.
- A fast and sure advance based on a previous theory.

With these principles and making a comparison with the reality previously mentioned we intend to establish a system of open distance education which functions as a channel of communication for the teaching of color. In this way, the following advantages can be obtained:

- Reduction of the communicative distances produced by the disproportionated relation teacher- student, thus obtaining fast and permanent communication.
- Students management of his own learning time according to the evolution of his practical classroom experiences.
- Making self evaluations which show the contents to be reinforced.
- Surpassing physical fences which hinder the excellency of educative quality, creating a more comfortable space for the teaching process.

Multimedial systems consist on the application of different media with only one purpose (this subject is deeply studied by Cotton and Oliver in heir book "Understanding Hypermedia"). (2) They can be considered as a useful alternative.
The following items can avoid any technical or academic disadvantage:

- To plan the use of multimedia modules with a determined objective which has been perfectly thought of during the development of the curriculum. Questions as *why?, when?, how?, or what for?* have to be done during the planning of activities. This implies to consider experiences such as color identification ordering with reference to the chromatic circle, analysis and application of cold and warm color sensations, without forgetting the objectives of each experience and the learning level of the student.
- To design the interface where the interrelation between student and multimedia is made. With the aim of avoiding actions which tend to complicate or paralyze its usability. The point is to get the satisfaction of learners community, this generates a sense of success. Interface may be considered as the simplest form of multimedia usability.
- To train the teachers in audiovisual language use to join discursive and audiovisual expressions. Teachers must be up to date in theoretical aspects as well as in the knowledge of the working tools. For instance in the knowledge of RGB and CYMK mixtures, their screen printed matter applications and the uses that can be made from a creative point of view.
- To integrate information coming from different sources to build a real knowledge design. Professional interchange contributes to production planning, development and a subsequent evaluation. Interdisciplinary work enriches the quality of the final product. The content specialist is the center of multimedia interdisciplinarity.

Considering what has been said , structures on which contents are based must be designed without leaving aside the different channels through which information can be transferred. The fact that the multimedia implies in a way a multimessage doesn´t mean that more than one content must be transferred.
As a stimulating means of a sensitive experience of selection and identification of color a multimedia may propose basic actions relationed to the interactivity proper of the computer user, the interaction of a video watcher or the passivity of a video lecture attendant. All these actions are implied in the pedagogic design and can be transformed in important elements of a new perceptual mentality, that is to say the development of a way of looking that can become a gaze.
The principal subject of this study is the teaching of the chromatic circle and color identity. First of all the contents may be organized in reference to time and space. That can be represented in a sequence starting from basic definitions derived from the following questions:

- Which are the primary colors?
- How many colors are you going to use, 16.000.000 or 3?
- What does primary color mean?
- Do you know definitions of color according to different authors?
- When we answer the previous questions, do we refer to objective laws or to subjective valuation applied to color?

The possible answers to these questions take into account:

- The acknowledgment of theorical sources provided by authors and artists that are authorities in the study of color: Newton, Runge, Goethe, Chevreul, Itten, Albers, Hofmann, Detrie, etc.
- The knowledge of the working tools to be used in the choice of papers of color, mixtures in the computer screen and pigmentary color mixtures such as temperas, acrylic and aquarelles.

These contents are part of the pedagogic design of a multimedia and can result in the nexus between the theory and the practical experience. Through the interaction the student can identify himself with the subjects he studies and with the situations lived by him accross the learning process. The objective of this design is to confront the a- priori knowledge (that is to say a knowledge aside from experience- of the student with the contents to be developed. The fact of prefixing certain number of ways which could be freely chosen by the student implies the searching of theoretical verification of a deeper study of contents to satisfy expectations or enlarge the knowledge, so multimedia an be considered as an open device.
We must be conscious that nowadays communication is fully concentrated in the screen: cinema, video, graphics, static image, animation, and sound track may be found in only one product. These imply a new form of looking and seeing and consequently new forms of expression and representation.
The different ways of using the screen are very important if we intend to give a perceptual sensibilization of color. Every day content analysis and the making of visualization exercises are basic for any theorical application.
The interchange of knowledge between the teacher and the student justifying each other his point of view, basing the teacher his theoretical application and walking together in experimental aspects, may give a solid theoretical frame. The characters of these interchange belong to a culture in which the image and the movement are part of the everyday polychrome perception. We are sure that culture has a great imaginary that can become a source of searching and recognizing chromatic variables.

We have intended to describe the contributions that may be given to the teaching of color by the use of the multimedia as a channel of knowledge, considering that the learning begins at the ending of the course, when the student reflects and finds specific solutions relationed to the use and application of color in creative production. The verification of the hypothesis previously stated can be checked once the multimedia product is finished and through an evaluation intending a permanent revision of contents. We have the theory, the tools and the human resources. The integration of educative resources may contribute to attain solutions that personalize the teaching. Its conscious application to the specific characteristic of each institution is left.

References

1. J. Itten, El arte del color, ed. Noriega Limusa, México 1992 (author's translation)
2. B. Cotton- R. Oliver, Understanding Hypermedia 2000, ed. Phaidon, UK, 1997

Bibliography

1. B. Cotton- R. Oliver. Understanding Hypermedia 2000. e. Phaidon. UK. 1997
2. E. Satue. Diseñador. Ed. Grijalbo. Barcelona. 1994
3. G. Bonsiepe. Del objeto a la interfase, mutaciones en torno al diseño. Ed. Infinito. Buenos Aires. 1999
4. J. Itten, El arte del color, ed. Noriega Limusa, México. 1992
5. T. Maldonado. (Reale e virtuale) Lo real y lo virtual. Ed. Gedisa. Barcelona. 1999
6. T. Maldonado. Crítica de la razón informática. Ed. Paidón Multimedia. Barcelona. 1998

* This work refers to the investigation "Interactive Multimedia Systems. Analysis and systematization contribution to make its utilization in university education easier, especially in open and distance education." Facultad de Humanidades y Ciencias de la Educación, Universidad Nacional de La Plata. Correspondence: jdeponti@aol.com.ar / agaudio@huma.fahce.unlp.edu.ar

CBT – a new approach for designing color teaching aids for the media industry

Werner Sobotka and Carina Gloss and Martin Seiter, VFG*

ABSTRACT

CBT – Computer Based training, an approach for designing teaching aids was tested in this project and it will be shown how this new teaching instrument can be used for teaching basic color theory and advanced color technology for the media industry.

The different types of media were tested in this project and the advantages and disadvantages of CDs, DVDs, online-services and tele-teaching facilities in the field of color technology will be pointed out.

Examples of CDs and online-activities will be shown and a complete course outline system for different levels will be pointed out starting with apprenticeship level, high school level up to company training and college course training materials. Mainly a lifelong learning approach will be emphasized to give especially SMES (small and medium enterprises) in media industry the possibility to train their professionals properly without too much absence from the company necessary.

Keywords: CBT, learning approaches, color teaching, learning media

1. INTRODUCTION

The learning part of the types of different training was designed to be incorporated inside the different modules of learning and it has to be adapted by the different levels taking in mind their specific educational needs for the subject of color. The new learning modules have to be put in consideration education goals for worker and student profiles and also SME's structures in future media environments.

It is very important to help learners to adjust their approach in using flexible or open learning material. There must be a special developement of advice to the learner:

1. Checking the abilities of your learning group about understanding color.
2. The material has to give objectives or must intend learning outcomes in one way or another.
3. The computer based learning materials are "interactive" and contain things to do as students work through them.
4. CBT learning is highly productive because no one else is watching you.
5. CBT learning modules especially for color have to contain a great deal of information.
6. The learning modules have always to remind you about the subject you have already done before.
7. The ability of learning something difficult depends more on how often you have tried doing it than on how thoroughly you did it once.

2. THE BASIC IDEA

Color-teaching.com is a new approach on the international teaching market. Media teachers and internet experts will design this learning environment *"color"* designed for SMEs, universities, colleges and professional training facilities as well as end consumers.

2.1 Target groups

This environment serves all ,as well in the learning and teaching environment as an information source. Therefore different target groups are necessary:

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

1. Companies, universities, professional training facilities ⇨ content providers; teaching
2. End-consumers as pupils, students, adults (practically each age group) ⇨ consumers of training and lifelong learning programs; learning
3. Information-source ⇨ consumers of information; information

2.1.1 SMEs, universities, professional training institutes; content providers

For the rest of the paper the synonym "company" is used for SMEs, universities, colleges and professional training facilities.

Color- teaching.com is providing companies a learning environment to design company specific training. To establish such training programs no programming skills are necessary. Therefore company employees can develop training programs for other company employees. As a specific advantage of *color-teaching.com* it is possible to adjust the training aids easily to the company CD and therefore the learning environment is a perfect marketing tool, too. Companies can use consulting features from *color-teaching.com* for the design of methodically well designed learning concepts and media adapted solutions. Therefore high quality and successful use of this training aids is provided.

color-teaching.com gives each company the opportunity to support all customers with this perfect designed training aids and also all courses can be given to clients and the company can share a special rate of the profit of this teaching aid. Companies have also the possibility to offer this training to partners and clients.

Advantages for companies

color-teaching.com offers a world-wide entrance to company generated knowledge – without any additional software necessary. The learning environment can also act as archive where all material about color is stored and put in order (images, graphics, content, video, animations).
Training activities using the internet are not causing travel activities and the company can save time and money of the employees. Cost saving from 50 % to 70 % is possible.
Using the teaching environment it is easy to keep all employees on the same level of knowledge.
color-teaching.com gives also an overview about all consumed trainings and the level of knowledge of all people using color can be easily derived.
CBT-learning includes a lot of additional advantages as learning according to individual needs and abilities. Individual learning is quite easier, because you are able to control your speed and order and therefore it is best suited for adult training. Direct and permanent anonym control of success as correction and rating of the results are possible.

2.1.2 Individuals as pupils, students, adults; consumers of training and lifelong learning

The aim of the project *color-teaching.com* is to collect a lot of different courses to offer them to interested companies. These courses are of high quality, because the were designed by color specialists together with color.teaching.com a pedagogical teaching concept and its media suited application.

Advantages for individuals

E-mail, chat and discussion groups allow synchronous and unsynchronous communication with the course leader, tutors and all other course participants.
The user can publish his own papers, his homepage a.s.o.
The user can direct the procedure of learning himself – repeating of difficult contents, skipping of known contents, intensifying of new chapters.
User profiles can be made by the user himself – it is possible to personalize, to store personal notes and make a profile about finished chapters.
color-teaching.com offers services like a glossar, FAQ (Frequently Asked Questions) and literature abstracts, etc.

2.1.3 Information search; consumer of information services

For information search *color-teaching.com* is the center for questions about "color", e.g. for pupils and students Here you can also find material about scientific work like thesis generation.

Advantages for information searching

The learning environment is supplying news, interesting links, literature lists for the topic "color".
A big browser enables the search for topics and terms of the learning environment.
Chat and discussion-forums enable communication between interest groups.
A user can set up its own profile – personalization of the learning environment.

2.2 Service of color-teaching.com

Input tool: the creating and managing of the teaching courses is possible without any programming skill.
Storyboard: *color-teaching.com* is supporting content providers in creating courses.
Categorizing: the course-units will be categorized during input and with a finder function it is always possible to find the suitable content/course.
Quality-control: *color-teaching.com* is controlling quality, actuality and consistence.
Future-oriented: *color-teaching.com* is developing the learning environments as an ongoing procedure, therefore the future security for new technological developments is guaranteed.
Group-oriented environments: the learning environments can be fitted to the CD of content suppliers especially for internal teaching courses.

3. ADVANTAGES AND DISADVANTAGES OF DIFFERENT MEDIAS FOR COMPUTER BASED LEARNING

Media	*Advantages*	*Disadvantages*
CD-ROM (CBT)	CD-ROM drives are widespread: ⇨ CD-ROM can practically be played everywhere	Low storage capacity: ⇨ quite limited for film and animation ⇨ bad quality of movie and audio material
DVD	High storage capacity: ⇨ movies and animation can be easily integrated in the learning program ⇨ good quality of movie and audio material	DVD players are not widespread in use as CD-ROM players.
Internet (WBT, E-Learning)	Worldwide use for learning systems (not dependent of DVD and CD-ROM). Platform and software independent (only a web-browser is necessary). Direct communication with course authors and tutors. Knowledge exchange with other learning partners via chat and discussion forums.	Very low transfer rates: ⇨ high costs for permanent online connections ⇨ very slow page appearance

4. TIME SCHEDULE

June
Presentation of the project *color-teaching.com* at the AIC congress in Rochester including idea, concept and timetable.

April till August
Presentation of the project *color-teaching.com* to the big color using companies.
Cooperation will be signed and the further progress defined.

June till August
- Developing of a prototype
- To consult companies to select content and structure of courses

⇨ designing storyboards

September till October
Production of the environment *color-teaching.com*

October till December
- Content–input from different companies or *color-teaching.com*-team
- Quality control especially for consistency of contents via *color-teaching.com*

⇨ Content will be actualized and expanded during this period.

November till January
Test-phase

Parallel (November till January)
Promotion of the color environment *color-teaching.com*

January
Official start of *color-teaching*

5. REFERENCES

1. **Dohmen, G.:** Zur Zukunft der Weiterbildung in Europa. Lebenslanges Lernen für alle in veränderten Lernumwelten, Bundesministerium für Bildung und Forschung (BMBF), Bonn, 1998
2. **Friedrich, H. F., Eigler, G., Mandl, H., Schnotz, W., Schott, F. Seel, N. M.:** Multimediale Lernumgebungen in der betrieblichen Weiterbildung. Gestaltung, Lernstrategien und Qualitätssicherung, Luchterhand, 1997
3. **Gieringer, H.:** CBT in der Führungskräfte-Weiterbildung. Die besten Lernprogramme im Vergleich. Tipps und Hinweise für Praktiker, 2. Aufl., managerSeminare, 1999
4. **Gloss, C.:** CBT – Entwicklungskonzept und Qualitätsanforderungen, Diplomarbeit, 2000
5. **Holz, H., Schenkel, P.:** Evaluation multimedialer Lernprogramme und Lernkonzepte. Berichte aus der Berufsbildungspraxis, BW, Bildung und Wissen, Verlag und Software, 1995
6. **Kailer, N.:** Innovative Weiterbildung durch Computer Based Training. Ergebnisse einer europaweiten Studie, Signum, 1998
7. **Kuwan, H., Stock, J., Waschbüsch, E., Wolff, H.:** Delphi-Befragung 1996/1998. Potentiale und Dimensionen der Wissensgesellschaft – Auswirkungen auf Bildungsprozesse und Bildungsstrukturen, Bundesministerium für Bildung und Forschung (BMBF), 1998
8. **Light, P., Littleton, K.:** Learning with Computers. Analysing productive interaction, Routledge, 1998
9. **Schreiber, A.:** CBT-Anwendungen professionell entwickeln, Springer, 1998

---

* Correspondence: office@color-teaching.com; phone: +43-1-9823914/121; fax: +43-1-9821710; http://www.color-teaching.com;
VFG – Verein Forschung für die Graphischen Medien, Cross Media Academy, Leyserstraße 6, 1140 Vienna, Austria, Europe

Expanding color design methods for architecture and allied disciplines

Harold Linton

ABSTRACT

The color design processes of visual artists, architects, designers, and theoreticians included in this presentation reflect the practical role of color in architecture. What the color design professional brings to the architectural design team is an expertise and rich sensibility made up of a broad awareness and a finely tuned visual perception. This includes a knowledge of design and it's history, expertise with industrial color materials and their methods of application, an awareness of design context and cultural identity, a background in physiology and psychology as it relates to human welfare, and an ability to problem-solve and respond creatively to design concepts with innovative ideas. The broadening of the definition of the colorist's role in architectural design provides architects, artists and designers with significant opportunities for continued professional and educational development.

Keywords: Industrial color materials, cultural identity, problem-solve

1. INTRODUCTION

During the closing decades of the 20th century, a broadening of the definition of the colorist's role within architecture and the allied design professions has helped to distinguish the discipline of color design and increase its relevance and significance in design industry and education. The methods that the color designer utilizes for work continues to expand due to the imaginative application of science, technology and the integrative processes of art and design. What the color design professional brings to the architectural design team is not only an expertise devoted to supporting the guiding design concept of a building, but also a richly diverse sensibility made up of a broad awareness and a finely tuned visual perception. This includes a knowledge of design and it's history, an expertise with industrial color materials and methods of application, a knowledge of new technologies for visualization, an awareness of design context and cultural identity, a background in physiology and psychology as it relates to human perception and human welfare, and an ability to problem-solve and respond creatively to design concepts with innovative ideas.

2. RECENT PRECEDENTS OF ARCHITECTURAL COLOR

The role of the color designer striving to complete the work of the architect did not really appear until the 1950's, shortly after the end of the Second World War. Historically, in Europe, it was industrial architecture that made use of and supported the work of colorists. A little later in the 1960's, the appearance of huge apartment complexes that tended to be somber and repetitive in appearance created the need to personalize these buildings with color. In France, beginning in the early 1970's, new multi-disciplinary teams came together to build new cities: urban planners, architects and colorists. It became evident that colorists had found themselves in a new, experimental territory and there was neither formal education nor school for color applied to architecture. Colorists and architects used traditional studio media for planning color for architecture, i.e., drawing tools, paint and paper to visualize color as well as different planning methods in a way one could describe as fumbling and speculative that, with experience, progressively became more concrete.

From the burgeoning corporate giants of the entertainment industry in the 1980's and 1990's including the architecture of urban renewal and the ubiquitous urban mall, office buildings and office parks, restaurants, environmental graphic design and signage, the practical role of color in the landscape and design of our time demonstrates that the creative processes of architects, visual artists and designers, theoreticians, and those of a more analytical and rational method are together opening a new and essential chapter. The wealth of color design accomplishments in the last half of the 20th century have engaged the public and sparked more than passing interest in color in architecture. A few examples of current methods of color design follow that reflect contemporary practice and beckon us to imagine what lies ahead – a future where the expectation will be for color throughout the built environment.

3. COLOR FUNCTION AND LEGIBILITY

With more than twenty-five years of experience in the field of architectural design, Gerald A. Reinbold, vice president of SHG Incorporated, considers himself an architect who frequently uses color to enhance legibility, clarify function, and (particularly in healthcare projects such as the Veteran's Administrative Medical Center Replacement Hospital and Research Center) promote an attitude of optimism and hope. Mr. Reinbold states, "Everything in the designer's toolbox must be brought to bear in the process of developing large-scale polychromatic architecture. Typically these tools include: conceptual sketches, renderings, 3-D models, material samples, large-scale mock-ups, etc. However, it is very difficult to simulate in the design process the effects of scale and distance on the perceptual quality of the built work. Here, our most reliable tools are experience and intuition."

The hospital occupies three full blocks in the mile-long, nine block Detroit Medical Center superblock. With siting requirements to reinforce the existing setback and green space adjacent to the facility, the program for three major building components included: diagnostic and treatment, medical and surgical nursing, and psychiatric nursing. Each component is expressed as its own building, both in color and massing, and all three are joined by an inner court.

As the project evolved during the conceptual phase, it became clear that a spirit of optimism, clarity of organization, and sense of scale could be effectively delivered through the use of color. The question then became one of selecting the appropriate materials to execute the concept. The criteria for material selection included: wide variety of colors available; permanent, nonfading or chalking characteristics; reasonably low first cost; low maintenance, low life-cycle cost.

A local project, 30-year old Saarinen-designed General Motors Tech Center in Warren, Michigan, provided inspiration for the major material: sand-molded ceramic glazed brick. This material not only met the primary requirements but also offered the additional benefits of a subtle range within each color; a tactile, handmade quality; and the desirable images of tradition and solidity. Complementing this material is another material popular in the same era: porcelain-enameled metal panels. Used as cornices, copings, sills, column covers, and spandrels, these panels provide brightly colored accents with the same assurance of permanence as the glazed brick.

Just as the plan is a three-part composition, the articulation of the hospital's exterior uses a palette consisting of three saturated colors and three neutrals to identify the three major building components and to create a system of pattern to further break down the scale. The primary facade, along John R. Street, is articulated as a tripartite composition in which the two main nursing units are clearly identified and are separated by the silver tones of the third unit, which identifies the main entry. Overlaying this composition is a second layer of smaller tripartite compositions of vertical elements offering a reading of the facade as an urban streetscape. The exterior color concept is also carried through on the interior, providing an additional aid in way finding, and creating a cheerful and optimistic environment.

4. ICONS, THEMES AND IMAGES

John Outram, a British architect known for his provocative use of interior and exterior color and decoration, believes in an architecture of ideas and themes. His use of building materials and his innovative applications of color, texture, form and space has been considered a new visual language for interior and exterior design and surface treatments. As he believes that buildings and their inhabitants interact in fundamental ways, his architecture employs ideas and themes to create thought-provoking spaces. His recent commission for the new Computational Engineering Building at Rice University in Houston, Texas, surrounds a striking and colorful interior with a deep facade of brick and pre-cast concrete. The design successfully bridges across the academic landscape of various departments with the physical attributes of large interior distances between offices and internal functions. The interior vistas catch the eye, as do the building's exterior materials, which harmonize with the campus. But most of all, it is the visual language of Outram's ideas – an extension of material innovation and design research –together with his narrative for the project at hand that create an extraordinary lively and provocative environment.

One of the most remarkable aspects of Outram's architecture is the planning and execution of the ceiling decoration for the main hall. The study was created in Outram's office by Tanya Hunter and printed onto canvas by 4-color inkjets driven by computerized information, and then transferred to a giant 70 x 50 foot vaulted ceiling. The process, originated by Anthony Chanley of Outram's office, reproduces his A-1 size watercolor painting and explicates its narrative of Cosmic Time. All of the surfaces of the interiors are colored from the floor to the ceiling. Outram uses color to convey larger ideas; each choice is rich in symbolism. Color, therefore, is included to covey meaning and to stimulate both conscious and subconscious thought. The entrance hall is an expression of multihued columns, tiled flooring, and painted ceiling that create a spectacular fusion of volumetric color.

5. SIGN AND IMAGE

The London architectural firm of Madigan and Donald approaches design from an intellectual and scholarly point of view. The richness of these architect's methods and style is reflected in a recent project, the Cube Bar, which inhabits a former bank in a multilevel adaptive reuse project in London's Swiss Cottage district, north of Regent's Park.

The Cube Bar is situated at the intersection of the Jubilee and Metropolitan transportation lines and presents itself as an urban oasis for pedestrians anxious for a break from the frantic pace of the city. With signage in cold blue cathode tubing advertising the building as a place for rest and relaxation, highly visible graphics and signage help to frame a dominant window true to the scale and formidable presence of the building towers above it.

Stephen Donald states, "Contemporary science provides contemporary artists, architects, and designers unlimited access to a phenomenal range of polychromatic media with which to express and represent ideas…however, colors are not out there in the world-not an automatic correlate of wavelengths-but rather constructed in the branch…"

The color design was planned in part on a computer to understand the basic composition and possibilities of materials. The interior is a reflection of machine-age materials and a vision of the urban culture inside out. Painted panels and overlapping planes with recessed lighting in deep tones of blue-violet, yellow, and green recall both today's street culture and the Carnaby Street of the era in which the original bank was first opened. The spatial ambiguity between levels of café and bar is visually inseparable, allowing one space to flow into the next without artifice of separation. Colored light is also directional and pulls the visitor into the space, acting as a visual cue to explore and read the interior design as a three-dimensional abstract composition. The Cube Bar is more than a bar. Reflecting an architect's determination to explore everything, no matter how modest, as possibly being beyond the literal reality of its material, it is a celebration of the interacting elements of light, color, form, and space.

6. VIRTUAL SPACE

As we look ahead to the future, the new technology of Virtual Space will be a formidable color design tool. Immersive environments such as the CAVE (Computer Animation Video Enhanced) system-a rear-screen, three-dimensional stereo display device allows the viewer to step into a stereo-viewed theater plunging into the three-dimensionality of the synthetic computer world. Architectural spaces can be designed and then viewed from within the CAVE. Although true color will require advances in technology for the system, the experience is profoundly better than seeing a computer graphics view on the front of a small computer screen; rather, the viewer is surrounded with a stereo view of a three dimensional modeled world for a total, immersive experience.

REFERENCES

1. H. Linton, *Color in Architecture: Design Methods for Buildings, Interiors and Urban Spaces*. McGraw-Hill Professional Books, New York, 1999.
2. H. Linton, *Color Forecasting: International Survey of Color Marketing*. John Wiley and Sons. New York, 1994.
3. H. Linton, *Color Consulting: International Survey of Color Design*. Van Nostrand Reinhold, New York., 1991.
4. R. Rochon, H. Linton, *Color in Architectural Illustration*, Van Nostrand Reinhold, New York, 1989.
5. H. Linton, *Color Model Environments: Color and Light in Three-Dimensional Design*. Van Nostrand Reinhold, New York, 1985.

Colour education in architecture

Rengin Ünver
Yıldız Technical University, Istanbul, Turkey

ABSTRACT

Architecture is an interdisciplinary profession that combines and uses the elements of various major fields such as humanities, social and physical sciences, technology and creative arts. The main aim of architectural education is to enable students acquire the skills to create designs sufficient both aesthetically and technically. The goals of the under graduate programme can be summarised as; the information transfer on subjects and problems related to the application of the profession, the acquisition of relevant skills, and information on specialist subjects. Colour is one of the most important design parameters every architect has to use. Architect candidates should be equipped in the field of colour just as they are in other relevant subjects. This paper deals with the significance, goals, methods and the place of colour education in the undergraduate programme of architectural education.

Keywords: Colour lectures, undergraduate education, architecture

1. INTRODUCTION

Architecture is the profession of creating, ambiences, environments and buildings that meet the required functional, physical, social, and environmental conditions. The perfection of architectural products depends on dealing with and resolving all needs as a whole. Solving some problems may require the specialist's care, but the responsibility of an architect is to detect and determine the problems and route them to the correct address. Due to this, being the primary determinants in architectural designs; the architects should be equipped in a range of subjects

Colour is one the important design parameters in architecture. There are both outdoors and indoors materials in various colours and light has the vital role in the perception of such material shaping the characteristic of a space. The colour arrangements in the space should have effective, aesthetic and meaningful visual appearances. To create such perceptions, it is essential to learn basic knowledge on colour having both aesthetic and technical aspects. For example, in an interior design, the relation/interaction between the colours of light and the colours of the internal surfaces is important. The relation between the features of the natural and artificial environment and the specifications of the building while selecting facade colours is crucial. This study aims to emphasize the significance, goals, methods and the place of colour education in the undergraduate programme of architectural education.

2. GOALS OF COLOUR EDUCATION IN ARCHITECTURE

The goals of the undergraduate programme can be summarised as; the information transfer on subjects and problems related to the application of the profession, the acquisition of relevant skills, and information on specialist subjects. The graduation of competent and contemporary architects fully depends on a programme combining sub-disciplines not only in theory but also in practice.

Architecture is created in a field of tension among reason, emotion and intuition. Architecture is an interdisciplinary field that comprises several major components; humanities, social, physical sciences, technology and creative arts. The basic goal is to develop the architect as a generalist able to resolve potential contradictions between different requirements (1).

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002)

It is quite obvious and well known that architecture students are somehow different than students of other technical departments. The interrelation of art and architecture would appeal most students and sometimes even the academicians more compared to the technical subjects of architecture. For this reason, the technical aspects of colour, which can be defined as subjectively an element of sensation and objectively the stimuli of the light causing this sensation, might not attract students.

What should the goal of colour education in the undergraduate programme of architectural education be? The answer to this question is rather simple; the goal should be to convince the students that colour is one of the design parameters of architecture and that all architects are responsible of it. It should also be mentioned and proved through exemplification that scientific education on colour would increase the architecture's success. For us, who are all specialists on colour, this can sound too simple to emphasise, but we should not forget that the success of a fruitful education depends on the acceptance of the knowledge by the learner.

The first step of colour education should be to stress out the priority of colour in terms of visual perception, and that colour designing should not be done by pure intuition and taste/preference. Other basic topics to be pointed out at the very beginning of the courses could be stated as follows:

- Every architect should be able to differentiate elements of colour as a design parameter and be able to perceive colour other than its features such as texture, form and shape.
- Every building component or finishing material has colour, thus every architectural design should also be evaluated according to the colour composition applied.
- To create positive visual effects, colours should be used in a designed arrangement.
- Colour arrangement in interiors, visual/colour perception and lighting conditions should be considered altogether. Outdoor and building facade colours should be designed considering the relation between the features of the natural and artificial environment and the specifications of the building.

3. COURSE CONTENT, WEIGHT AND PLACE IN CURRICULUM

While forming the course content two questions should be kept in mind:

- What should a recent graduate architect know about colour?
- What are the potential problems that a future architect might face and how far should s/he deal with the problem her/himself?

Although, the taste, cultural background of the society, the major aims of the architecture school and the total time allocated to education would directly influence the answers to these questions, the fundamental subjects to be covered in the programme could be listed as follows:

1. The effects and importance of colour on architecture.
2. Fundamental knowledge on the colour perception parameters (light, surface, visual organ).
3. Colour systems and introduction of the colour elements (hue, value, chroma).
4. The effects, features and importance of the contrasts in colour elements.
5. Colour contrast arrangements and general rules on colour usage.
6. Technical knowledge on colour perception parameters and the relationship among them.
7. Light and colour relation in interiors, colour interaction and changes in colour elements.
8. Effective parameters on colour design of interiors.
9. Effective parameters on facade colour design.
10. Effective parameters on outdoor colour design.
11. Usage of the computer simulation techniques for colour design.

Colour education should be compulsory. Architecture candidates should be able to understand the differences among the colour elements and features besides being able to use colour contrast arrangements appropriately/accurately. The topics specified above, when evaluated in the aspect of knowledge to be learned could be classified into two groups:

- Basic theory/knowledge and practice on colour elements and colour arrangements (items 1-5)
- Technical knowledge teaching and practice about colour designs in three dimensional spaces (items 6-11)

The first group including basic knowledge should be placed in the first semester in which architectural concepts are also introduced. The second group should be in the second or the latest fourth semester in order to leave enough time for electives and implementation in later projects. It is known that, repetition reinforces knowledge learned. For this reason the application in student assignment projects of colour knowledge studied in compulsory courses would help students receive better results. In addition to this, a correlation among the lectures on human comfort (lighting, thermal) and colour should be established. Total time should not be less than 30 hours in 4 years education, having an approximate distribution of 40 % first group, 60% second group.

In architecture schools, where colour lectures are not compulsory, elective courses related to the colour design on spaces should be offered. Contents of the elective lectures should be designed allowing the students practise their knowledge in their projects.

Even though students of architecture usually detest, the teaching of theoretical and technical knowledge in colour lectures is inevitable. Therefore, supporting the lectures by computer simulations, demonstrations, experimental studio studies will make the course more vivid and fruitful.

4. REVIEW

The state and qualifications of colour teaching in undergraduate architecture education varies from one country to other and from one school to the other in each country. There has been a pre-investigation done to determine the period of education in architecture and the state of colour education. The course contents, the place of the courses in the curriculum and whether they are compulsory or elective, were the main evaluation criteria. The simplified version of the investigation with a reduced number of schools is given in Table 1.

Country	University/school	Education years	Individual		Together other subjects
			Compulsory	Elective	
Austria	Technishe Universitat Graz/ Arc. Dep.	5	-	+	+
	Vienna University of Technology/ Arc. Dep.	5	-	-	+
Australia	University of Sydney /Arc. Fac.	5	-	+	+
	University of Melbourne/ Arc. Fac.	5	-		+
England	University of Westminster/Arc. Dep.	5	-	-	+
	University of Liverpool/Arc. Dep	5	-	-	+
Japan	Kyoto University /Arc. Dep.	4	-	-	+
Netherlands	Eindhoven University of Technology /Arc. Fac.	5	-	-	+
	Delft Universtiy of Technology/Arc. Fac.	5	-	-	+
Turkey	Istanbul Technical University /Arc. Fac.	4	-		+
	Middle East Technical University /Arc. Fac.	4	-	-	+
	Yildız Technical University /Arc. Fac.	4	-	+	+
Uruguay	Universidad de la Republica/Arc.Fac.	6	-		+
USA	Cornell University / Arc. Coll.	5	-	-	+
	Virginia University /Arc.	4	-	-	+
	University of Kansas / Arc. Prog.	5	-	-	+

Table 1. Specifications of architectural faculties

According to the investigation on content,

- Colour subjects are not in the curriculum as individual compulsory lectures.
- In the first semesters of the departments, simple information and practice on colour and colour composition are placed in compulsory courses such as basic design, graphic communication, design graphics etc.
- There are only a few faculties offering elective courses on colour.
- In some institutions, as a part of compulsory courses, such as environmental control, building physics, environmental science, colour of light and colour perception are included.

As colour courses are not individual compulsory classes, it was not possible to track the number of credits they have in the total number of credits or time of education.

Recently, in the frame of globalisation, there are studies to determine a common standard of what is expected from a professional architect and to standardize the education systems and curriculum worldwide. For instance in Europe; EAAE (European Association for Architectural Education), in USA; NAAB (National Architectural Accrediting Board Inc) are suggesting the topics to be taught and general curriculum in the field of architectural education (2, 3). Schools and universities that are members to such organizations are revising their curriculum according to the programmes recommended by these organizations. Before forming a new programme, the specifications of the existing programmes should be examined and necessary changes relevant to contemporary needs should be done accordingly. Significant, reliable and useful results on this subject can be achieved from wide frame investigation realised under the partnership of colour and architectural international organizations. These results can be used to improve colour education in architecture and help to constitute an international generation of better and equivalently educated architects.

5. CONCLUSION

Colour is an element of physical environment, surrendering people like air, like odour, that every architect has to make use of. Today, in the subject of colour, approaching only with ability and/or intuition would cause one to use the power and effect of colour insufficiently. For a successful colour design, a colour education having technical knowledge is a must. The future's architects must have learned the basic knowledge in colour so they can be able to solve problems that can afford basic solutions, but on the other hand, be aware that they might need to ask for the support of an expert. The topics that will enable these to be realised should be implemented in the courses as soon as possible. It is hoped to contribute to the betterment and improvement of such courses and curriculum, via this study on colour and its present state in architectural education.

It should also be noted that the importance of the qualifications/profession of the lecturer should not be underestimated. Instructors, lecturing on colour, should be specialised architects actually working in the colour field. This will help in emphasising architects role in colour issues in students mind and better results will be achieved in the field.

REFERENCES

1. Anon, "UIA Work Programme-Education, UIA/UNESCO Charter for Architectural Education", 1996.
2. Anon, NAAB, National Architectural Accrediting Board Inc., http://www.naab.org .
3. Anon, EAAE, European Association for Architectural Education, http://www.eaae.be .
4. Anon, WEB Sites of the Universities-Schools
5. Karabiber Z. "*Acoustics Education in Architecture*", Proceeding of Internoise, Vol. 1, pp 21-24, Florida, 1999.
6. Ünver R., Karabiber Z, "*Visual-Acoustical-Thermal Comfort Design and Architectural Education (Turkish)*", Proceeding of Building Physics Congress, pp. 7-12, YTU, Istanbul, 1999.
7. Ünver R., Karabiber Z, "*Building Physics Subjects at Undergraduate Education of Architecture (Turkish)*", Proceeding of Education in Architectural Faculty Congress, pp. 79-84, YTU, Istanbul, 1998.

* Correspondence: runver@superonline.com; phone +90 212 259 70 70 /ext 2255; fax +90 212 284 94 30; Yildiz Technical University, Faculty of Architecture, Building Physics Department, Besiktas, 80 750, Istanbul, Turkey.

A Case Study of Web-Based Color Education With an Emphasis on Constructivist's Theory

EunSook Kwon*, YuJin Kim, Dept. of Industrial Design, KAIST

ABSTRACT

This study focuses on the ways for providing alternative color education with Web-based instruction. The Web-based color education enhances the effectiveness of learning by integrating the multi-modal features of digital color experiences. The newly developed Web-based education color is designed for applying constructivism as educational pedagogy. This study shows how the web environment can be used as an ideal learning platform for educators and students holding the frame of constructivism.

Keywords: Digital Color, Web-based Color Education, and Constructivism

1. INTRODUCTION

The rapidly changing computer technology makes it possible for designers to understand color theories and use it in a new way in their design process. Web designers, interface designers, and VR game designers have expanded the ways of using color theories with digital media comparing with the traditional industrial or interior designers.

As the medium of interactive representations evolves, it may be that text and color will coexist in new ways in new interactive forms. With rapid development of interactive media, there has been a growing concern on the Web as one of the most important tools in the instruction media. But most of Web-based instructions have only emphasized technical applications of the instructional contents and transformed it into the digital form. The purpose of this study is to investigate a new way of developing an education system with the Internet.

2. WEB-BASED EDUCATION AND CONSTRUCTIVISM

When speaking of multimedia design or the Internet in education, it is easy to equate the new medium with a new pedagogy. However, it is not the delivery medium that defines the instruction; the delivery medium is very instrumental in the learning approach and its capabilities should be integrated in the instructional design. The problems of design educators encounter these days are in the missing links between the way of using computer technology in the design creation processes, and the way of teaching students about and with the computer technology. Although the elements of non-linear information flow and concurrent design processes are included in some parts of design curriculum as teaching subjects, it is not integrated into the philosophical base of constructing design curriculum. The idea of intertextualizing content and context in color education, therefore, is very important to connect and integrate useful knowledge in ways that are suited to the learning theory and activities.

The Internet has a powerful potential for creating new educational content as well as context. For example, the WWW can support design education in a variety of ways: as Web-Assisted Instruction (WAI), the Web can be used to supplement face-to-face teaching, and to provide students with easier access to course-related materials (Lai 1999); as Web-Based Instruction (WBI), the Web can deliver courses at a distance, in which concurrent and dynamic elements must meet to create a successful hypermedia learning environment. The WBI includes active, intentional, authentic, cooperative and non-linear learning. Because communication and interactions in the Internet are horizontal rather than vertical, the networked learning environment becomes more democratic and learners have more control of their learning (Levinson 1995; Lai 1999). The learning with WBI, therefore, can be a meaning making process for the student, emphasizing their active participation. This learner-centered approach of learning is deeply related with an emerging educational paradigm, constructivism. Constructivism focuses on learning rather than instruction. It also emphasizes that: knowledge and context are inextricably connected; meaning is uniquely determined by individuals and is experiential in nature, and the solving of authentic problems provides evidence of understanding (Hannafin et al., 1997).

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

3. CASE STUDY: WEB-BASED COLOR EDUCATION

Combined with constructivist theories, the WWW and the Internet have a powerful potential for creating new color education. The multi-modalities and multi-tasking functions of the Internet can provide a different approach of learning color theories for design students. The visual, audible, tactile, and kinetic experiences created by digital color cannot be taught well by reading books with traditional lecture-based learning.

In order to identify the effectiveness of Web-based color education, one case study was conducted at the Korea Advanced Institute of Science and Technology (KAIST) in 2000. The case study was designed for teaching two weeks of "digital color theory" to the freshman design student at KAIST. As a WBI, the newly developed education system includes all course materials, discussion room, and virtual connection between instructor and students. The importance of learning among students is strongly emphasized in the new constructivist learning environment with the WWW, which provides an explicit representation of a learner-centered model. The system consists of four major learning sections: Information, Study, Communication, and Assessment (ISCA). These four sections provides a student with diverse learning activities such as studying course materials, searching color information, discussing with other students, and creating and evaluating color projects. The Figure 1 explains how different learning activities occurred in the Web-based color education. The following Figure 2 shows the information structure of Web-based color education having four ISCA shells.

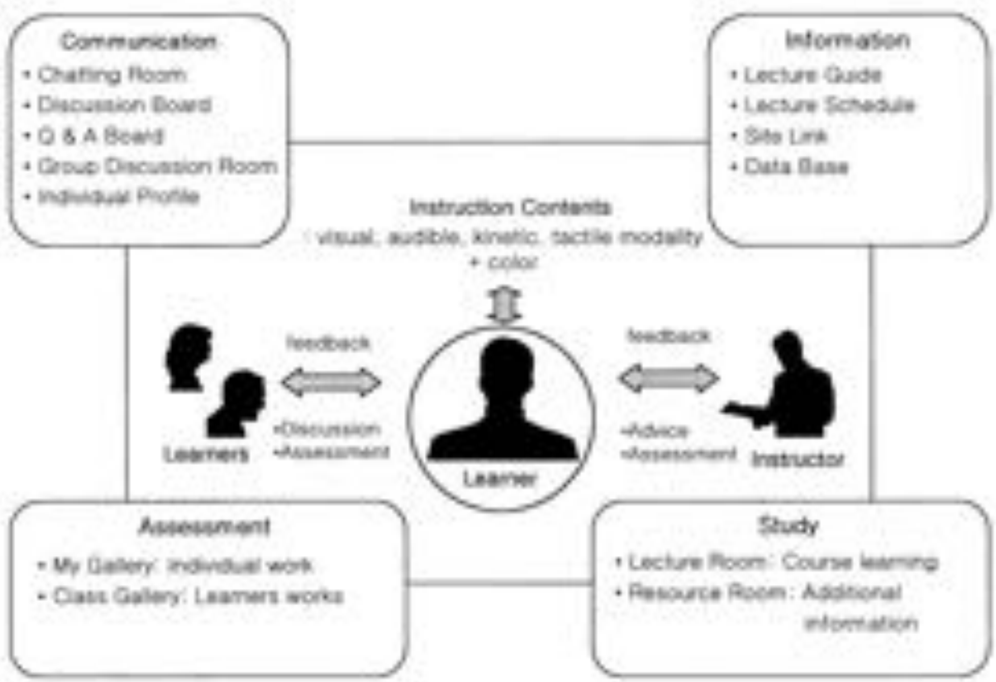


Figure 1. A learner and four different learning activities with WBI

After learning the fundamentals of digital color at Lecture Room, a student was asked to choose one dominant color and create about 15 seconds animation with Flash software. The associated feeling of one color creates a story of color. The purposes of this exercise are: (1) to understand the expanded knowledge base of digital color theories and applications from two-dimension to three- or four-dimension; and (2) to integrate multi-modalities within digital color studies.

The following Figure 3 shows the process of creating a color story and several images captured from one student's work. Each student's design process and final design was saved at Gallery Room, and all students were asked to participate in the assessment phase of learning by reviewing other students' works. The Gallery Room and discussion board are used for constructing knowledge between students, emphasizing collaborative and social knowledge construction.

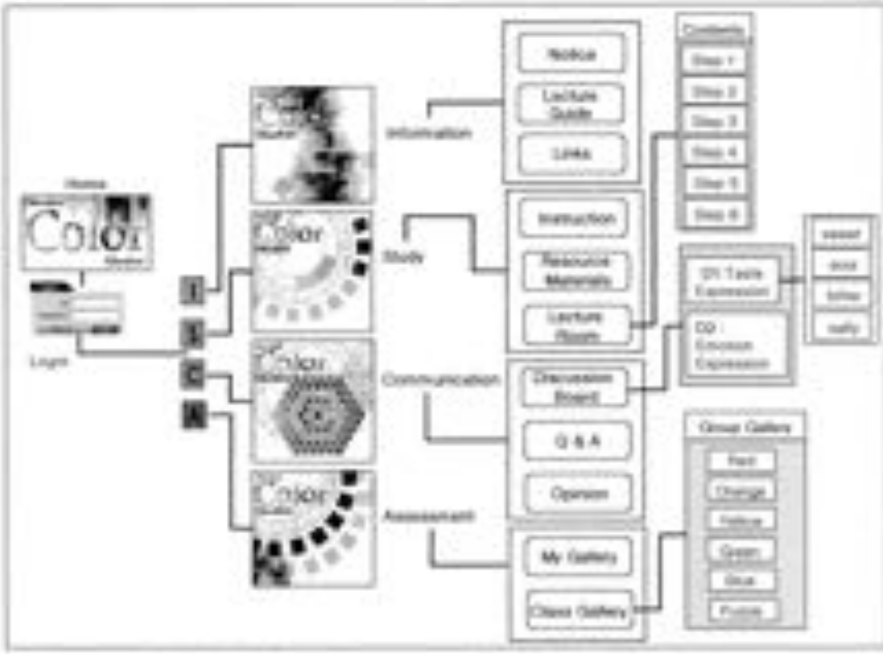


Figure 2. Information structure of Web-based color education

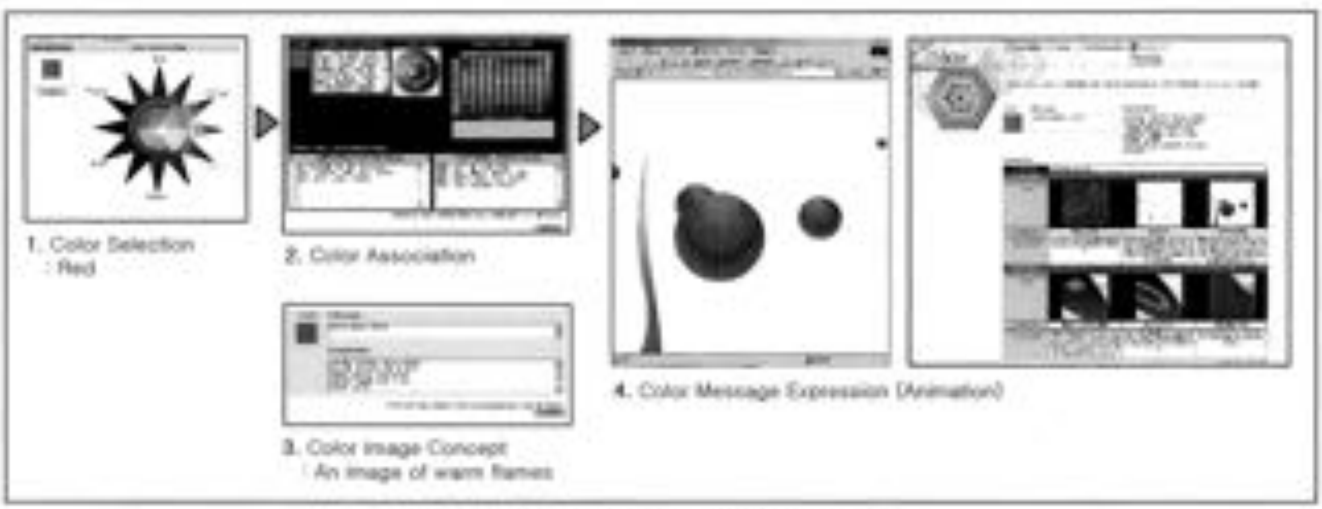


Figure 3. One student's work for digital color study

4. ANALYSIS OF THE CASE STUDY

The effectiveness of Web-based color education was analyzed by student works, peer reviews, and questionnaires. The data analysis was conducted on the basis of qualitative research analysis, emphasizing triangulation (Lincoln & Guba 1985). From the data analysis, the effectiveness of 'group learning' and 'time management' were highly acknowledged by the student respectively. Each student received quite large amounts of feedbacks from the instructor and other students, and the discussion about their designs were continued even after two weeks program was finished. The easy access to the Web and learner-controlled learning process provided students better time management for their learning, and enhanced the quality of learning. Because the Web-based color education system was designed the contents of Lecture Room as a thinking map, students can access easily to any part of learning materials, and integrate them into their own ways of building knowledge. The following Figure 4 shows the non-linear learning materials composed in the Web-based color education system.

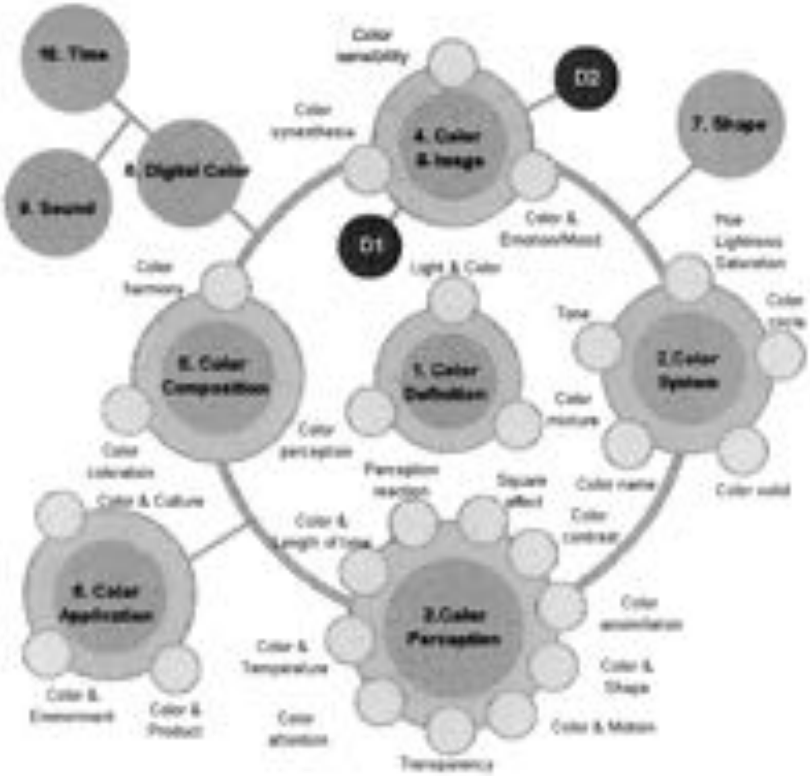


Figure 4. A non-linear structure of course contents as a thinking map

5. SUMMARY

This study focuses on developing alternative color education with Web-based instruction. From the literature review, technological foundations emphasize how available technology can be optimized in ways that are consistent with psychological and pedagogical foundations. The WWW and other multimedia technology are only information resources and tool, unless we provide meaningful learning content and contest. The Web-based education based on constructivism demonstrates the possibilities for developing appropriate and effective color education system.

ACKNOWLEDGEMENT

This study was supported by the research support from the Virtual Reality Research Center (VRRC) at KAIST.

REFERENCES

. Hannafin, M., Hill, J.R., & Land S.M. (1997). Student-Centered learning and Interactive Multimedia: Status, Issues, and Implication. *Contemporary Education*, Vol.68, No.2, pp.94-99.
. Lai, K. (1999). Designing Web-based Learning Environments. In K. Lai (Eds.), *Net-Working: Teaching, Learning & Professional Development with the Internet*. New Zealand: University of Otago Press.
. Lincoln, Y.S. & Guba, E.G. (1985). Naturalistic Inquiry. Newbury Park, CA: GABE Publications.

---

* Correspondence: eunsook@mail.kaist.ac.kr; phone +82.42.869.4516; fax +82.42.869.4510; http://id.kaist.ac.kr/dcod/, KAIST Dept of Industrial Design, 373-1 Kusung-Dong, Yusung-Gu, Taejon, 305-701, Korea (S).

Rainbow Solfege: new perspective for color theory and music education

Ginger Covert Colla*
California State University, Stanislaus
Rainbow Arts Studio

ABSTRACT

The Rainbow Solfege System is an innovative, interdisciplinary music teaching method that illustrates in living color the linear and vertical energy of melodic movement and harmonic progressions: a synthesis of color, shape, sound and language. The system is rooted in proven pedagogical practice, while providing a fresh approach to educational methodology. Rainbow Solfege is based upon principles of tertian harmony and concepts of tonality in music and is analogous to color theory and shape theory in art. The pedagogy is holistic in design involving a variety of learning modes --visual, aural and kinesthetic-- and is an effective learning tool for all ages and stages. Educational uses run the gamut from teaching musical concepts and color/shape theory for very young children to applications in college level music theory and analysis courses. With consistent application, particularly in early childhood, the method has potential for increasing musical, artistic and linguistic abilities for life.

Keywords: rainbow, solfege, color, music theory, early childhood, education, interdisciplinary, pedagogy

1. INTRODUCTION

The essence of Rainbow Solfege is its unique color-phonic code founded upon principles of tertiary harmonic practice and the system's capacity to link sensations of sound and sight in meaningful ways. It is an educational method that is holistic and interdisciplinary in nature, incorporating the three basic modes of human perception: cognitive, kinesthetic and affective. The development of Rainbow Solfege and its application to education has been influenced by the theory of multiple intelligences by educational psychologist, Howard Gardner[1] (Figure 1). While the Rainbow Solfege color-code is innovative, certain components of the System are indebted to pedagogical methods and theories postulated by many historical figures as well as those proposed by contemporary color music theorists and educational pedagogues. The term solfege refers to an aural syllabic code (*Do, Re, Mi, Fa, So, La, Ti*), which has been utilized by music educators since the 11th century to teach scale patterns and fundamentals of sight singing.[2] In some ways Rainbow Solfege is a revolutionary concept but, like most innovative ideas, the term evolutionary is more apropos than revolutionary. A brief look at the evolutionary process is appropriate prior to exploring Rainbow Solfege and its uses in more detail.

2. GENESIS

Rainbow Solfege sprang from the pure spirit of pedagogical spontaneity, intuition and imagination. The idea began with a simple analogy for my music fundamentals class: the comparison of primary chord root tones in harmonic practice to the three primary colors of the artist's palette, *Blue Do* for the Tonic, the key center and resting tone; *Yellow So* for the active Dominant, five scale degrees above Tonic; and finally *Red Fa* for the Subdominant, five tones below Tonic (Figure 2: Middle *C* Blue, Yellow *G* and Red *F*). Following the planting of those color-phonic seeds, a logical order emerged for the remaining scale tones (Figure 3) and the entire diatonic system of tertian harmony bloomed in living color on that chalkboard.

The Rainbow Solfege System is based upon the harmonic principles of tertian harmony. The vertical and horizontal energy of music is illustrated with the warm, active colors representing the active tones harmonically and melodically, while the more restful and stable tones are represented by the cool colors of the spectrum. This system differs from the music color-codes of Isaac Newton and his followers, whose color analogy for the diatonic scale was devised in spectrum order. Newton's color-code included the colors of red, orange, yellow, green, blue, indigo and violet.[3] The diatonic scale in Rainbow Solfege is not in spectrum order. Instead, the linear character and energy is formulated in a functional color-code based upon principles of harmonic function. Diatonic eight-tone scales are based upon formulas of whole step and half step intervals contained in an octave. This dynamic effect is most striking and made self-evident by employing an Equidistant Half Step Chart to illustrate the position of the half step relationships in the Major Scale formula (Figure 5). The midline represents the white keys or natural pitches on a keyboard, while the cross bars represent the black keys. The chart illustrates the pattern of whole steps and half steps found in the Key of C Major. Tonal relationships between these intervals are vividly represented in Rainbow Solfege. The half steps in the Major scale formula obviously fall between *Mi-Fa* and *Ti-Do* with the bright vowel sound, *ee*,

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

providing an aural cue. In addition these half step relationships feature color complements. For example, in harmonic progressions the Leading Tone, *Orange Ti*, usually resolves up to *Blue Do*, a half step away. These tones are complementary colors in art. Red and Green are also color complements, and the harmonic resolution of *Red Fa* is often down to *Green Mi*.

Even though the diatonic scale is not in spectrum order (Figure 3), the rainbow effect is still present in the structure of tertian harmony (Figure 2). For example the Minor Mode Tonic triad [purple bracket] consists of the reflective and moody colors of purple, blue and green, while the Major Mode Tonic triad [blue bracket] is comprised of restful blue, serene green and optimistic yellow. The Rainbow effect of the vivid Dominant 7 chord [gray bracket] and its resolution to the Major Tonic triad is striking. Both half step intervals contained in the octave scale are involved in this resolution, *Red Fa* to *Green Mi* and *Orange Ti* to *Blue Do*. The chord tone, *Turquoise Re*, resolves either up or down to an analogous color neighbor, *Blue Do* or *Green Mi*, while *Yellow So* serves as a common tone between the Dominant chord and its resolution to the Tonic triad. The conjunction of the linear aspect of melodic energy with the tonal power of vertical, harmonic structures creates a musical landscape unfolding before our eyes and in our ears in living, vibrant color.

The System eventually evolved from the original eight-tone diatonic scale to include all shades of tones in a chromatic scale. The term chromatic was borrowed from art to express a musical phenomenon for the ear. Now musical nomenclature returns the favor: the chromatic scale, a musical phenomenon, is expressed in visual terms for the *eye*. The Rainbow Solfege chromatic scale is illustrated via the Equidistant Half Step Chart, a visual that captures the dramatic effect of this multihued scale (Figure 6). The mid-line represents the diatonic scale formula of *C* Major, while the crossbars represent the chromatic alterations to those original scale tones: the lighter shades are utilized for sharps (*Di, Ri, Fi, Si, Li*), while the flats are represented by the darker shades of diatonic pitches (*Ra, Me, Se, Le, Te*).

3. EDUCATIONAL APPLICATIONS

With my moment of inspirational pedagogy behind me and the logical development of the Rainbow Solfege color-code complete, I determined to expand my knowledge of color music and to pursue additional ways to utilize the method. I began to examine concepts of color theory, color music, and the areas of physiology and psychology of color in humans for possible uses of this color-phonic tool for a variety of educational applications. I found that educational uses run the gamut from teaching musical concepts and color/shape theory for very young children to applications in college level music theory and analysis courses. Recent research on the brain and the affect of music upon the developing neural network of children from birth[4] to age seven is a particularly fertile area for exploration and application.

The development of Rainbow Solfege and its application to education has been greatly affected by the tenets of Howard Gardner's multiple intelligence theory, a theory that recognizes the importance of identifying, valuing and nurturing the intuitive, genetic gifts of each individual. His theory began with identifying seven types if intelligence–verbal/linguistic, logical/mathematical, visual/spatial, musical, kinesthetic, intrapersonal and interpersonal–and has evolved thus far to include the naturalist and an existential/spiritual intelligence for a total of nine. The circle chart (Figure 1) represents the Rainbow Solfege connections and educational applications to Gardner's multiple intelligence theory. The interior circle comprises the more subjective, spiritual aspects of human intelligence: the inner compass or essential core. The outer circle represents the more objective, quantitative categories of intelligence; the external expression of what one might call the 'inscape' of the human mind and soul. As you can see Rainbow Solfege is a valuable, interdisciplinary tool for teaching all kinds of concepts across the curriculum to a wide variety of learning types: aural/oral, visual, and kinesthetic.

Space does not permit exploring this holistic circle in detail, but I would like to share one example of a cross-curricular model combining shape, color, music and language. The inspiration for the model came from the theories of color and shape energy of artist, Wassily Kandinsky, as explained and expanded upon by color theorist, Faber Birren.[5] Kandinsky believed that color and shapes both imply energy. For example, he felt that the circle shape should be blue, receding in nature and implying a feeling of repose and peace; while the triangle is analogous to yellow, expansive and engendering a feeling of energy. Birren concurred with Kandinsky's theory and expanded the idea to include other colors. For instance, the green hexagon is serene and similar in mood to a circle, but is more stimulating in character than blue. I applied these concepts to a Rainbow Solfege color-shape design to illustrate the harmonic energy of the Major Tonic triad, *Do-Mi-So*, and its inversions, *Mi-So-Do* and *So-Do-Mi* (Figure 4). Musicians sense by ear that the Major Tonic triad in root position is the most stable chord in the tonal hierarchy. The first inversion with Mediant *Green Mi* in the bass is somewhat less stable, while the second inversion chord with the Dominant *Yellow So* in the bass is the most active version of the Major Tonic triad. The vibrant Kandinsky-esque graphic with its superimposed shapes expresses that same energy visually (Figure 7). It reinforces the concept and creates an atmosphere of synesthesia aurally and visually. A kinesthetic effect can be added by applying the various Kandinsky-esque graphic shapes to a surface utilizing manipulatives, such as Rainbow Solfege Shape-note magnets.

4. CONCLUSION

Humankind's quest for a synthesis of the sensations of color and music is ancient. The fascination with and combination of those aesthetic, psychological and physical phenomena have occupied the minds and imaginations of philosophers, scientists, psychologists, artists and musicians from Aristotle to the present day. My quest has been to find a more concrete correlation between musical and visual phenomena, and to develop a practical and effective visual/aural color-phonic vocabulary.

5. FURTHER STUDY AND FUTURE APPLICATIONS

I propose two areas for future study and applications of Rainbow Solfege in the educational area. I believe that with consistent application, particularly in early childhood, the method has potential for increasing musical, artistic and linguistic abilities for life. I hope to form a research team and develop a study involving preschool and early elementary children to prove my thesis. Secondly, I would like to encourage interdisciplinary applications For example, creating visual art works by translating musical compositions into color via the Rainbow Solfege code. Artists like Roy DeMaistre,[6] and Bruce Lee[7] have endeavored to do so with intriguing results, but the attempt to express musical energy with a spectrum order code inevitably results in a sequence that associates Tonic, the resting tone, with a warm, active color and the restless dominant with a cool, serene color. The tertian harmonic order of Rainbow Solfege provides a more logical color palette to mathematically calculate color harmony. Creative teachers would no doubt find a variety of ways to utilize the system across the curricula.

REFERENCES

1. Howard Gardner, *Intelligence Reframed: Multiple Intelligences for the 21st Century*, New York: Basic Books, 1999.
2. C. V. Palisca, *Guido of Arezzo, New Grove Dictionary of Music & Musicians*, Ed. S. Sadie, Vol.7, p.p. 803-807, 1980.
3. Isaac Newton, *Opticks* (4th Ed. 1730), New York: Dover Publications, Inc., Dover Reprint, 1952.
4. Sharon Begley, "The Brain: How to Build a Baby's Brain," *Newsweek* Special Edition, Spring/Summer, p.p. 28-31, 1997.
5. Faber Birren, *History of Color in Painting*, New York: Reinhold Publishing Corporation, 1965.
6. Niels Hutchison, *Colour Music in the New Age: De-mystifying De Maistre*, 2000, Victoria Network Website: http://home.vicnet.net.au/~colourmusic/maistre.htm
7. Bruce Lee, *Color Theory*, 1998, Design Culture Website: http://www.re-action.com/dc/design/chapter1.html

FIGURES

Figure 1: Interdisciplinary Relationships of Rainbow Solfege to Gardner's Multiple Intelligence Theory

Figure 2: Rainbow Solfege Grand Staff: Applications of Tertian Harmony

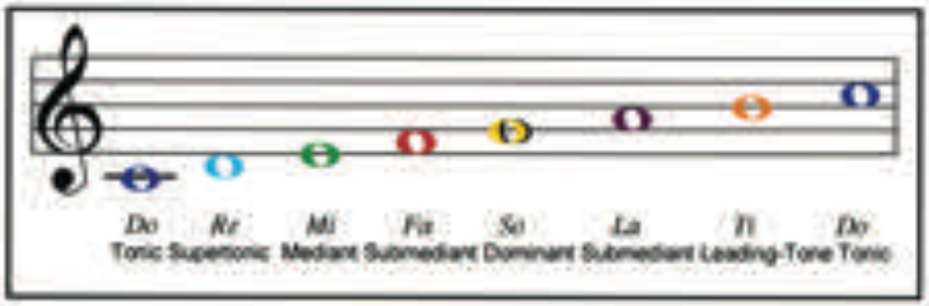


Figure 3. Rainbow Solfege Diatonic Major Scale

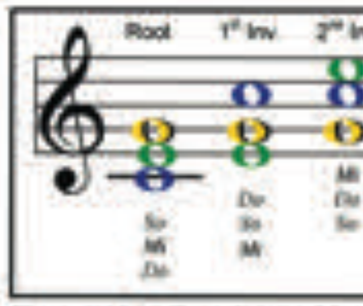


Figure 4. Major Tonic Triad & Inver

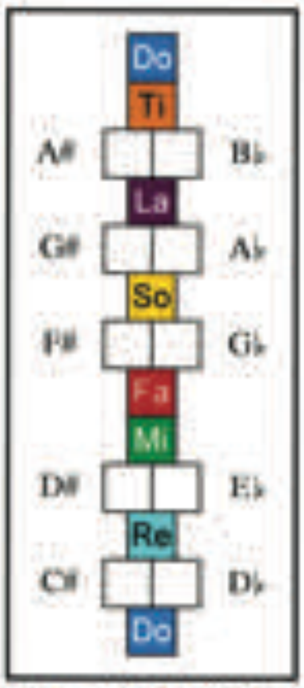


Figure 5. Rainbow Solfege Equidistant Half Step Chart Major Scale Formula

Figure 6. Rainbow Solfege Equidistant Half Step Chart Chromatic Scale

Figure 7. Kandinsky-esque Rainbow So Tonic Triad and Inversions Superimposed Shapes

* Correspondence: gcolla@msn.com; (209) 523-8941; Rainbow Arts Studio of Kindermusik® and Voice, 3717 Apple Hill Road, Mod CA, USA 95355 or California State University-Stanislaus, Turlock, CA 95382

"Colorimetry as a General Model of Observation in the Resolution of Quantum Paradoxes"

or

"What Color was Schrodinger's Cat?"

C. H. Appell

ABSTRACT

The early 20th century saw the development of the two branches of post-classical physics: quantum mechanics and relativity. After nearly a century quantum mechanics remain paradoxical and incompatible with relativity. The main feature differentiating post-classical physics from classical is the role of the observer. Classical physics describes observer independent phenomena whereas postclassical models require an observer. Observer dependence is the source of quantum paradoxes. Most attempts to resolve these paradoxes have used a highly simplistic model of observation. Interaction and observation were assumed to be functionally equivalent. This presentation will explore the possibility of using a more realistic model of observation. Colorimetry will be used as an archetypal model of observation wherein interaction and observation can be differentiated. Some of the difficulties one would encounter in deriving electromagnetic wave equations from a color space coordinate system are highly analogous to quantum paradoxes. While resolving no paradoxes, this approach may provide a fruitful new perspective on these problems, along with a unique role for colorimetry and colorimetric education in the field of theoretical physics.

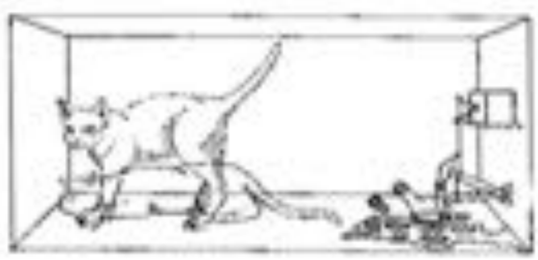
DISCUSSION

The major paradigm underlying classical physics is the assumption that the world as perceived and measured is objective. One should never forget that sense organs and cerebral tissue mediate all that we perceive, and that scientific instruments are merely extensions of our sense organs. These sense organs evolved to facilitate survival on the surface of the planet Earth, not to perform scientific research.

The one feature that defines both relativity and quantum mechanics as "non-classical" is the observer dependence of the equations. Relativity, though counterintuitive, is not paradoxical. The introduction of the observer as an acceleratory frame of reference resolved all relativistic paradoxes. This is not so for quantum mechanics. The "Schrodinger's cat" paradox is a case in point.

Quantum wavefunctions when squared become probability distributions (the Born interpretation). These probabilities are mutually exclusive and taken together violate the principles of causality and conservation. This major conundrum was initially dismissed as applying only to the world of the very small. Schrodinger, however, designed a thought experiment involving his infamous cat wherein quantum probabilities produce macroscopic effects.

The heart of the experiment is a single atom of a radioactive element with a half-life of X hours. This is placed in a sealed box along with a live cat and a device designed to kill the cat after detecting the decay event. The probability function of the unobserved cat after X hours will be 50% alive/50% dead. The observed cat will obviously be either 100% alive or 100% dead.



9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

There are presently three major schools of thought on how to resolve this paradox: 1. The Copenhagen school, 2. The many worlds school, and 3. The hidden variables school. Each has major problems.

The Copenhagen school invokes a phenomenon known as wavefunction collapse. The observer, through an unexplained process, somehow picks one probability and collapses all others. By looking at the cat, or even by using a measuring device to observe the cat, the observer causes the half live/ half-dead cat to collapse into a completely live or dead cat. This interpretation falls completely apart when one attempts to use the cat as the observational reference point. In my opinion the Copenhagen interpretation, by not offering a mechanism for wavefunction collapse, and by ignoring the cat's frame of reference, simply sidesteps the issue.

The many worlds school proposes that both cat, observer, and indeed the entire universe splits in two, the first universe containing a live cat paired with an observer of a live cat, the second containing a dead cat paired with an observer of a dead cat. This successfully addresses the cat's frame of reference but cannot at present be considered a scientific theory. These other parallel worlds would not be detectable, hence the theory is untestable. In addition the introduction of such huge numbers of alternative universes is about as big a violation of the principle of Occam's razor as one can have.

The hidden variables school claims that quantum mechanics is not a complete theory and deterministic phenomena hidden from the observer govern the nature of waveform collapse. Despite the fact that quantum mechanics is lacking as an explanatory theory, it has had excellent performance as a predictive theory. One would assume that any hidden variables would sooner or later manifest themselves as experimental deviations.

In each of the above three schools the observer is introduced as nothing more that a frame of reference. No distinction is made between observation and simple interaction. Unobserved measuring devices are treated as equivalent to observers. This appears to be a problem of interdisciplinary communication since research within the psychophysics community has produced several models of perceptive phenomena.

Of all of these models colorimetry is perhaps the best understood. Empirical equations exist that model how both the eye and brain process color information. Color can be empirically modeled at three distinct levels: 1. Electromagnetic waves, 2. Tristimulus values, and 3. Color space. I propose that these same three levels exist for all perception: 1. Objective reality, 2. Sense organ sensitivity (interaction with objective reality), and 3. Awareness. The origin of quantum paradoxes may be the assumption that observation is a single step operation wherein the parameters of time and space of the observed world have objective reality.

The development of spectroscopy demonstrated the existence of forms of light outside of the range of human perception. In addition, the unequal sensitivity to light within this range was also demonstrated. Experiments with the Wright observation box on representative human subjects produced tristimulus functions, which plot the sensitivity of retinal cone cells to monochromatic light. These functions enabled the calculation of the degree of cone stimulation that a light source or illuminated surface would produce. Initial assumptions were that tristimulus functions captured all aspects of human color perception and that the brain processed color information through a simple triangulation process.

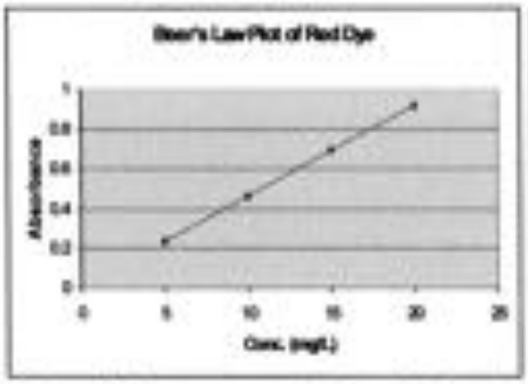
Colors, however, come in opposing pairs. Every color has a complement that can neutralize it. For example, red and green neutralize each other, as do yellow and blue. In a triangular coordinate system none of the three axes are antiparallel. They are incapable of opposing each other.

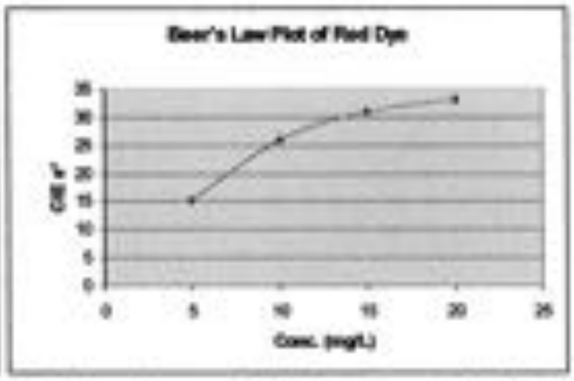
A different approach to measuring subjective color perception was undertaken by an artist, Albert Munsell. He developed a coordinate system with hue, chroma, and value as parameters, and just noticeable difference (JND) as a unit. Munsell used his own artistic sensibilities to prepare color plates capturing each combination (at 5 JND intervals). These are collected in the Munsell Book of Color. The Munsell system is polar, with hue being angular, chroma radial, and value orthogonal. Each hue has a complementary hue at 180°. This system captures the phenomenon of color opposition. It lacks a connection to spectrophotometry.

The connection was made in the mid 1970's by the International Commission on Illumination (known as the CIE, its French acronym). Reflectance spectra were collected of each Munsell color plate and tristimulus values calculated. Empirical transformations were developed, allowing the conversion of tristimulus values to Munsell coordinates. Systems using Cartesian coordinates were also developed, the most popular being CIE (1976) ($L^*a^*b^*$) color space. In this system L^* (lightness/darkness) corresponds to Munsell value, a* is the red/green axis, and b* the yellow/blue axis. These transformations approximate how the brain responds to optical nerve impulses from retinal cone stimulation

Imagine Munsell working in a world without spectrophotometers. Consider the difficulties he would encounter when using his system to study the nature of light. Would it be possible to discover E=hc/λ without a knowledge of tristimulus functions? Many of his difficulties have striking similarities to those encountered when using classical time and space to interpret relativistic and quantum phenomena.

Beer's Law relates dye concentration to spectrophotometric absorbance in a simple linear way. Color space coordinates respond linearly to dye concentration over a small range, but become non-linear over large ranges. In relativity, space and time are Euclidean over small ranges, but become non-Euclidean over large ranges.





Two visible spectra may be quite different yet still produce the same tristimulus values. This is known as metamerism. A single tristimulus coordinate therefore represents a metameric set of visible spectra. Only one member of the set is responsible for the stimulus, but which member is impossible to determine from tristimulus values alone. A quantum wavefunction represents a set of physical probabilities. In retrospect only one probability is actualized, but from the quantum wavefunction alone it is impossible to predict which.

Single Deterministic State of Classical Physics	Quantum Superposition of Multiple Physical States
Single Point in Color Space	Set of Multiple Metameric Spectra

Sociologists and biologists report that humans in primitive societies and animals perceive time as cyclic whereas modern, abstract thinking humans perceive time as linear and historical. In colorimetry cyclic electromagnetic waves are converted into points on a linear Cartesian grid.

Color space is similar to "physical" space in two ways. First both are constructed of three orthogonal axes. Second, both are part of our every day experiences. But whereas color space is recognized to be the result of neural operations, conventional thinking assigns the parameters of space and time an external reality.

Perceiving the world as an orthogonal spacio-temporal (Euclidean) grid appears to be a uniquely human phenomenon closely tied to, and perhaps enabling, abstract thought. Perhaps the mental machinery to construct such a grid was originally developed to perceive color. Evidence for such crossovers is provided by the phenomenon of synesthesia.

One should never forget that coordinate systems are simply tools designed or chosen to facilitate the organization of data and the expression of equations. Attempts to derive the coordinate system from the equations can only yield circular tautologies.

An example of this can be seen in attempts to devise Grand Unified Theories. These theories are expected to explain the "Big Bang", the emergence of existence from the primordial void. Big Bang is a rather unfortunate choice of words. A conventional bang, such as a firecracker, is the sudden expansion of matter and energy into pre-existing time and space. In the primordial Big Bang, matter, energy, time, and space all emerge together from an unknown primordial condition. Any explanation of this event must also explain space and time, along with matter and energy. Clearly space and time are not available for use as a coordinate system for this problem, yet most researchers continue employ them.

For many years physicists used a spacio-temporal point model for fundamental particles. The choice was based less on evidence than on the assumption that the simplest constituents of matter should have the simplest geometric shape. It is hardly surprising that the next simplest shape, the line, or string, should prove to be a somewhat more versatile model. However, to use this model a space of at least eleven dimensions is needed. From my limited survey of the field I have not found one theorist who has failed to assign four of these dimensions to space and time.

The Munsell analogy can provide much insight on the nature of this situation. Would not Munsell's ability to derive electromagnetic equations from colorimetric data be impossible if he insisted on the retention of hue, chroma, and value? Attempts to do so would produce a system that captures some aspects of electromagnetism, and would certainly provide a few insights beyond the original colorimetric description, but without abandoning the old coordinate system the new model would have insurmountable limitations.

The abandonment of a familiar coordinate system is a difficult thing. This can be illustrated by one final example. How often has the explanation been given that the stars in the sky appear not as they are "now", but as they were many years in the past, that the light took X years to travel to earth, that the view of the star is as it was X years ago, and that Einstein's theory of relativity is responsible for this explanation? In truth relativity offers no such explanation. This explanation is an illogical hybrid of relativity and classical physics cobbled together for the benefit of those unable to comprehend the pure abstraction of relativity.

The main point of relativity is the relative nature of space and time. There is neither absolute space nor absolute time. There is no universal "now". A proper relativistic explanation of the age of starlight would be: Space and time are linked through the speed of light (actually nothing more than a unit conversion factor). Separation in space is the same as separation in time. Since the star is far away in space, it must be far away in time as well. "Now" is subjective and relative to the observer's frame of reference. There is only "here and now". "There and now" is not a valid concept in relativity.

While such hybrid explanations may have some short term instructional utility, in the long run they serve more to confuse than to elucidate. To avoid this problem the explanation must completely transcend the subjective coordinate system. The explanation of color as electromagnetic waves completely transcends subjective color space. Perhaps this example can offer insights on the transcendence of subjective time and space.

SUMMARY

I propose that space and time are primarily devices of the human mind to facilitate the organization and integration of action, perception, thought, and memory. Space and time relate to a more fundamental and objective frame of reference in a way analogous to the relationship between color space and the parameters of electromagnetic waves. Quantum and relativistic paradoxes result when time and space are treated objectively.

In order for scientific method to work properly, objective and subjective parameters must be clearly distinguished and the relationship between them succinctly defined. Nowhere is this done more succinctly than in the field of colorimetry. The use of colorimetry as an archetypal model of observation in the resolution of quantum paradoxes may provide a platform for new ways of thinking about these issues. One must never forget that the brain and sense organs are integral parts of every piece of scientific instrumentation.

REFERENCES

1. Color: A Multidisciplinary Approach, Zollinger, Wiley-VCH, 1999
2. The Prehistory of the Mind, Mithen, Thames and Hudson, 1996
3. Quantum Reality, Herbert, Anchor Press, 1985
4. In Search of Schrodinger's Cat, Gribben, Bantam, 1984
5. Thirty Years that Shook Physics, Gamow, Anchor Press, 1966
6. The Man Who Tasted Shapes, Cytowic, Tarcher/Putnam, 1993

7. 100 Years of Quantum Mysteries, Tegmark and Wheeler, Scientific American, Feb 2001
8. String Theory: Superstring Theory and Beyond (2 Vols.), Polchinski, Cambridge Monographs on Mathematical Physics, 1998

Correspondence: bufoetra@frontiernet.net 716-865-5373

THE COLOUR STUDIO IN CRISIS?
EMBRACING CHANGE

Dianne Smith
School of Design and Built Environment, Queensland University of Technology,
Brisbane, Australia 4000

ABSTRACT

Teaching colour to students of architecture and design within the higher education sector is becoming more of a luxury than of core business. With increasing financial demands, reduced resources, and increasing student numbers, educators are required to think laterally to cater for change without sacrificing learning objectives. This paper raises some of the issues involved in the educative climate within one Australian university setting. Using a reflective narrative, educational objectives are defined, the implementation of new modes of 'teaching' as a means of coping with higher student numbers and reduced staffing and technical resources are described, and the outcomes in terms of student learning over an eight year period are critiqued. Institutional management policy is forcing the educator to re-evaluate the value of the traditional studio, and the intensive 'hands-on' interactive approach that traditionally is integral to such an approach. As curriculum development involves not only theory and project work, the classroom culture, the physical environment, and the University and School context need to be addressed. Generic skills, in association with professional knowledge and skills, should be addressed, and therefore, opportunities for teaching a traditionally studio-based subject on-line as a computer based unit would appear to be limited. This discussion aims to pose questions, as well as reflecting upon successes and failures in this area of education within the University context. There is a need to embrace the contextual demands while ensuring that the student knowledge of colour, and the joy of discovering its characteristics in practice, are not sacrificed but enhanced.

Key words: education, colour, curriculum development, university context

1. INTRODUCTION

This paper reassesses the development of a colour course in one Australian university by placing it in the field of curriculum design. The University education sector is in a state of change, and as a consequence, consideration of the content and structure of University courses and units must be placed within this broader context that constitutes the 'learning environment'. Due to these changes, past ways of understanding 'how things should be done' need to be revisited if the learning objectives are to be meet for the current and future cohort of students.

Through reflection upon the evolution of the course, or unit, for which I am responsible in the area of colour studies, it has become evident that the studio is in fact facing a crisis. Is 'the crisis' a signal for the studio's demise or a stimulus for its reconfiguration? A curriculum involves the unit structure, subject matter and teaching strategies. However, it also encompasses all aspects of university life—students, staff, building, social and cultural aspects of the Discipline, School, Faculty, University and Profession. Therefore, the changes identified are part of this framework.

As a consequence the studio, as a component of the curriculum, may need to reconfigure rather than simply adapting as it has up to this point. Taking such a position forces questions such as: What is the context? How can the studio change? How will the educational objectives be met? Will the contemporary student's learning requirements be catered for? What can be changed and what shouldn't be altered?— to be posed.

2. RECOLLECTIONS

In addressing these issues I will relate my experiences of the past nine years as an academic in the area of colour studies. As I stand on what appears to be a precipice, I experience emotions of uncertainty: the exhilaration of the unknown or new, combined with a desire to cling to what has gone before or is tested and known. By narrating my experiences as a reflective practitioner, I aim to capture the richness and complexity of the evolution of a course. To direct the learning experiences of others is not removed from the art of doing-it or the craft of curriculum design. Therefore, this account is simultaneously a reflection on what has occurred and an insight into how things could be. The major concept that my colleagues and I have sought to protect is "the studio". In times of change it appears to be threatened, and therefore, it is an opportune time to stop and reflect on our experiences and potential direction.

The university and higher education sector has changed dramatically in Australia over the last decade. As a novice educator I commenced my teaching with between 15-18 students and the assistance of another practicing designer and colourist. This two-hour unit evolved into two three-hour units due to student interest and demand. The content broadened and we experimented with colour mixing exercises, research activities, site visits, lectures and student seminars. The content also broadened from colour theory that was more applicable to two-dimensional design, to exercises that relate to three-dimensional work, and therefore, to interior design and architecture. In addition, the content expanded to include investigations of colour application in society with particular reference to the built environment. A problem based project was also introduced to address student learning concerns in regard to workload, external pressures on their time and finances, and/or a fear of applying colour principles to 'real-life' projects. Consequently, improvements were integrated into the course development through reflection and evaluation.

Unfortunately and concurrently change was occurring politically and economically in the higher education sector. The higher education system has moved from an 'elitist' system to a 'mass unitary' system in association with the amalgamation of the colleges and universities[1]. Such reforms also meant more government control through budgetary devolution and quality control[1]. The current government's pressure to 'commercialise university operations has had a substantial effect on university culture, to the extent that university managers exalt entrepreneurial...initiatives at the pursuit of knowledge for its own sake'[2].

This national organisational shift manifested in the local studio as rapidly increasing numbers, a reduction in tutorial staff, a reduction in contact hours, a changing and diverse student cohort, and a shifting level of student commitment and demand due to external influences such as increased HECS (student fees). Our University is also a multi-cultural domain in which students seek relevance to their home countries, and from which, they bring different learning styles and expectations. As a decreasing number of our students come straight from School many students also need to work long hours or have outside commitments such as children or ageing parents. The outcome is a changed and changing culture that directly impacts on the learning environment.

Traditionally the studio at present is the core of the colour work (as it is in the design units) in which exercises that explore and/or challenge the lecture series content and/or develop the three dimensional exercises are undertaken. The student is encouraged to undertake a number of exercises to foster 'an eye' for colour and a 'feel' for its use. The tutor, who contributes in response to student needs, guides the students. With increased student numbers and reduced staff it has become impossible to undertake this collaborative and responsive attitude in the same manner. With an increasing pressure by the community and the design professions for the graduates to be 'ready' for practice, Sidhu[3] is correct to ask, How do we facilitate intellectual development given those trends towards vocationalism? (p362).

Our learning objectives may be summarised as the provision of a learning environment which potentiates the development of self-directed learning skills, student motivation, student-decision making skills, an ability to structure and integrate knowledge, and reflective practice through self-awareness. In association the student is to develop an awareness of light and colour in the environment, an understanding of the theory of colour, an awareness of colour as a phenomenon and the human interpretation of it, as well as, an ability to integrate its application with space, form and context. The student, it is envisaged, should have the skills of a beginning professional, but in addition to be an autonomous and 'active' learner[4]. The change in the university culture is creating a need to address the latter more actively as we (the staff) cannot provide the same level of interaction, ongoing feedback, or formal assessment. However, the former is potentially under threat, as it would appear from my observations that 'the eye for' colour and 'the feel' for application involves a maturation time. In some cases this requires exploration in collaboration with 'experts' in association with the individual's own exploration and discovery. This impression is supported to some degree by the results of student surveys undertaken in 1993-95 to evaluate the PBL as a teaching strategy. The majority of students, although they felt their knowledge had increased by 44%-53% during the self-directed PBL exercise, felt that it was necessary to complete the lecture/studio exercises before hand.

3. MANAGING CHANGE

So how do we manage this shift in our learning culture or 'crisis' in the studio? Hughes-Hassell[5] states that to manage change we must have knowledge of what we are dealing with. Therefore, as colour educators some of the aspects we must confront are the lecturer as a change agent, the nature of curriculum, the potential of computers or technologies to assist in learning, and how the student cohort, as adults, learn.

- change agent

There are numerous theories of change, however, Hughes-Hassell states that each describes an aspect of what it means as a multi-dimensional concept[5]. The aspects of change include psychological aspects including attitudes, cultural, conflict and notions of power relationships, structural, and the more macro or social aspects[5]. In association, Hughes-Hassell states that we are all agents of change wether we influence change as a passive, negative or affirmative agent. In order to fulfil our role it is important to have knowledge of the people involved, lead to encourage collaboration and motivation, look to be positive in embracing change, and to shift to the focus toward growth.

- the nature of curriculum

As stated earlier, curriculum includes all aspect of learning and the university. In addition, Glatthorn[6] identified eights modes of school curriculum which would appear to be just as applicable to university settings. These are hidden (the surrounding culture or unintended), excluded (those things left out or with nil effect), the recommended (that advocated by experts), written (the recorded version), tested (the things assessed), the taught (those delivered or put into operation) and the learned curriculum (that which the students actually learn)[6]. By identifying these different modes, aspects that are considered to be necessary or of value may be revealed to be different in the reality of the studio. As a consequence, opportunities may present themselves. In addition, in times of change and consequent stress we may need to reassess what the hidden curriculum communicates to the student and what is the affect of this information on their learning.

- the potential of computers or technologies

With the trend for University management to focus on the technically based delivery of courses, it is an opportune time to reflect on the correlation between educational objectives and technological ways to address these. For example, at present I am developing a series of computer modules to teach colour practitioners and students in our course. This involves three components—information delivery, exercises, and analysis and reflection. The hands-on component's development, although theoretically available, is economically prohibitive without intense sponsorship. The trade-off between limited resources is a critical consideration in today's climate. In classroom co-ordination, Laurillard supports its potential for enabling academics through the "associated services" it can provide such as discussion forums[7]. In addition to these logistical limitations, however, Zwimpfer[8] states that hand-mixing of colours is a different process to computer work and therefore the criteria for judging its success are different pP46. In the area of colour and the personal engagement with the phenomena I would agree with Bates that; '...technological-based teaching is not the panacea for every learning problem: there is no super technology that can meet all teaching and learning requirements. The formula lies in synergising tried and tested traditional approaches to teaching with a range of technologies...'[3] p363.

Colour education is an essential aspect of designing. In a recent survey of local interior designers all of the sixteen participants noted that colour should be part of interior designer and architects education. Only two of these participants explicitly stated that it should not be separate unit from the design units. The integration of material selection with a knowledge of colour was also implied, as most of the designers selected colours and colours at the same time.

So how do we manage this shift in our learning culture in regard to colour education? I would propose that technological advances can assist in the areas of information delivery and resource acquisition. It can also assist in environmental simulations and experimentation with 'colour schemes'. However, in the development of 'a sense of colour' and intuition in regard to its use the studio still has a role to play. The form of the studio should also encourage the independent and creative learner who—in our case—is to become a professional interior designer, industrial designer or architect. By doing so the limited resources and staff time can be more constructively utilised to enhance the more il-defined qualities of colour work for those who design with colour. In the words of one of our tutors:

> '...finally, in my experience, students need personal guidance, discussion, encouragement and the transfer of enthusiasm, in this case about the joy of colour. This happens best when both the students and the lecturer are together vis-a-vis. I don't think human nature has changed that much with the advent of technology...'

It is time to develop new definitions of 'the studio' and its role in addressing educational objectives. Harold Arnkil in his introduction to "Aspects of Colour"[9] stated that we need literature and methods that are of a significance to equal Itten's and

Alber's contribution to colour education that are based on 'up-to-date findings'. The additional challenge is to explore the context of learning which extends the discourse of colour education to the University environment and to adult learners. It is the marrying of the learner, as they experience the learning environment in a contemporary context, with the phenomenon that is colour and its integration with practice that will pave the way to new ways of addressing colour education.

4. SUMMARY

In summary, in these times of change, the new context in which we teach must be integrated into our curriculum. In order to do so we must understand the context, not just the content with which we want our students to engage. As a consequence, the studio will need to reconfigure. The students as part of the new order that is present in our universities today and the future appear to engage with the learning environment in new ways that challenge past paradigms of the teaching situation; for example, the shift to adults rather than school leavers as learners. The integration of self-directed learning and advances in technology will assist in this change. In conjunction, however, the role of the tutors, as facilitators in the hands-on experimentation and exploration, could become more focused and collaborative as the share their knowledge and challenge students to inquire and to evaluate their own work. An opportunity to reassess this student-tutor relationship and as a consequence the course-content has therefore arisen. More collaboration across units, subject areas, and universities may also be possible to enhance the integration of 'the studies' with new ways of looking at the world and the relevance of the experience in an exploratory and applicable manner.

ACKNOWLEDGEMENTS

I would like to acknowledge the ongoing work of my colleagues Mary Durack, Diane Darin de Barbara, Rita Pereira, Lynda Fisher, Dr Anoma Kumarasuriyar, and Angela Blakely who have been at various times part of the ongoing evolution of the course in a spirit of co-operation, reflection, and genuine concern for our students. In particular, I would like to acknowledge Lexie Smiles contribution to this paper.

REFERENCES

1. R.Winter, T. Taylor, & J.Sarros, 'Trouble at the mill: Quality of academic worklife issues with a comprehensive Australian university, *Studies in Higher Education*, October, Vol.25, No. 3, 2000, pp.279-294.
2. Marginson in R.Winter, T. Taylor, & J.Sarros, 'Trouble at the mill: Quality of academic worklife issues within a comprehensive Australian University, *Studies in Higher Education*, October, Vol.25, No. 3, 2000, pp.279-294.
3. R. Sidu, "What kind of university: International perspectives on knowledge, participation and governance", *Studies in Higher Education*, October, Vol. 25, No. 3, 2000, pp.362-363.
4. D. Smith, 'A comparison of teaching strategies: Student perceptions of PBL & lecture/studio sessions', *Research and Development in Problem Based Learning*, Vol. 3, Proceedings PBL conference, Sydney, Australia,1995, pp.379-388.
5. S. Hughes-Hassell, 'Implementing Change Knowledge', *Quest*, Jan/Feb, Vol.29, No. 3, 2001, pp.11-18.
6. Allan A. Glatthorn, 'Curriculum alignment revisited', *Journal of Curriculum and Supervision, Alexandria*, Fall,Vol.15, No.1,1999, pp.26-32.
7. R. Brown, 'Higher Education re-formed. A book review' , *Studies in Higher Education*, October, Vol. 25, No.3, 2000, pp.359-360.
8. M. Zwimpfer, 'Development of Colour sense—Basic colour education at the Basel Design School' in Arnkil, H., Hamalainen, E. (eds), *Aspects in Colour University of Art and Design*, Helsinki, Finland, UIAH, 1995, pp.45-46.
9. H. Arnkil & E. Hamalainen, (eds), *Aspects in Colour University of Art and Design*, Helsinki, Finland, UIAH, 1995.

How do we teach color?

Arq. Silvia Estévez , Ceramic Companies Consulting

ABSTRACT

I was a Consult in important Ceramic Companies in Argentina: San Lorenzo, Acuarela, Loimar, Piu; I also made products and color developments for Losa Olavarria. This is my experience about conveying to young designer's desires of creating: investigating and showing their ideas.

The "Ceramic Designer" career doesn't exist in my country. The experience was and is: to form design groups with young people in the areas of "Graphic Design", "Textile", and "Arts".

I transmit to the designers to have liberty to create and to investigate.

MY EXPERIENCE

I am an Arquitect, when I studied, there weren't Design Careers that there are now in Buenos Aires University, but we were formed like integral designers.

But our formation depends always of our effort and our necessity to have experience about color development and searching about design in History, in Nature, in life.

When I was twelve years old, I was invited by my parents to go to Paris, they are Doctors in Medicine, and when they had a Congress they invited one of us to go with them: we are three brothers, we always accepted, of course.

They explained us the conditions of our trip, we have to look for information about the place that we are going to visit and we have to read all and look the pictures before de departure,

Then, we talked a lot about the places, the history, the artists, etc. And we looked for also in the big library that they have at home.

When I walked through Notre Dame first time, in my twelve years old, it wasn't for me the first time, I felt Quasimodo steps, I saw the ancion artists making the vitreaux, and I heard the multitude crying outdoors in 1789.

LOOK AROUND US

I know that we can learn all our life. We can be "open-mind" and look around us.

My photography teacher saids, "I look around me with amazement and wonder. I look... then, I can see..." He is now 93 years old and his eyes keep innocence and he knows how to look things.

This is the most important concept that I transmit to the designers. If we try to keep the innocence and the spontaneity to create we can have liberty to re-create taking ideas from nature, the history of art and form common life.

The color comes out with the design. In our market, permanence is very important. In our common and daily environment, we look for a stability sensation, hard to find it in our work and our economy.

In the photographs you can see some of the inspiration sources, that I show to the designers.

SEARCH INFORMATION

If we can open our eyes, and look around us we can arrive to colors and designs.

In one of the company I formed the design team with "textile-designers". In the other company I formed the team with people from "Art-school".

In the first group they look for textile-designs and colors, I show you the results.They had better technical prepatation to apply serigraphy.

I the second group our source where Arts-History and Architecture-History looks.

They mixed the dimensions with their sculpture-formation and they left the paper with its two dimensions, it appears relief and walls classical colors.

We can see the photographs of some of the results.

WE ARE CREATORS

The research and direct experience is the way to discover the creation in our interior.
My daughter Daniela (ten years old) told me last month "mom! I discover that colors are infinity!!!" I promise her to tell you her discovery.

We look for the neutrals, perhaps with the wish to live on a white sheet of paper where we can write day by day our life, our souvenirs, our beliefs.

I'm trying to appraise our origins, our roots. In other design group we made a research about "precolombines -designs"

I teach a constant respect for that unknown person for whom we design, and to offer suggestions so he can re-create his environment and improve his quality of life.

THE FUTURE OF COLOR

Mr. Jack A. Ladson, Color Innovation, LLC - Session Chair
Ms. Laraine Turner, Jolley/Turner Group, Inc.
Mr. Paul Green-Armitage, Curtin School of Technology
Dr. Robert Hunt, Color Consultant

ABSTRACT

We live in a world in which styles and technologies are nearly the same from place to place, but change daily. This changing global culture is unprecedented, and reinforced by emerging new technologies that affect us all. The Future of Color, examines new technologies, how they will affect the selection and promulgation of color in the near future, and their impact upon us. We examine this topic from many perspectives--technological, business and commercial. Most importantly, as we understand how our world is emerging, we can position ourselves strategically for tomorrow.

INTRODUCTION

Jack A. Ladson
Color Innovation, LLC

I want to begin by thanking each of you for attending. This session is very, very exciting to me, and I know that it will be exciting and rewarding to you as well.

We will begin by acknowledging Dr. Allan Rodrigues and Dr. Danny Rich. We are the progenitors of this session. I believe that it is incumbent upon us to prepare ourselves, our companies or organizations for tomorrow by staying abreast of the state-of-the-art, changes in technology, science, and trends, in our ever-changing world.

Remember with me the artist, Peter Paul Rubens, born in 1577 in Westphalia to a Flemish family. Unlike many starving artists of his time, he did very well financially indeed, because he mastered his skill. His home in Antwerp is a testament to his financial success. Even though we delight in his work, he reaped the rewards of his mastery of his art.

What I hope is this that each one of you extracts from this congress, and especially from today's remarks, mastery in your skill, whether that is science, business or art. In addition, that you will use this knowledge in the days, weeks, months, and even years ahead. To do this, we need to pull these concepts, trends and information together. After attending this congress, with all the information presented, with all the time we talked and exchanged ideas and concepts with one another, let us now gaze into the crystal ball of the future and see what lies ahead for of us. To do this I am pleased to introduce Ms. Laraine Turner, Past president of the of the Color Marketing Association, Mr. Paul Green-Armitage of Curtin School of Technology, and Dr. Robert Hunt a consultant in color science.–We will now listen as the world's color expert's pull back the veil and gaze into the crystal ball with us.

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

Future *of Color*

Laraine Boren Turner, CMG
Vice President Marketing & Color Research, NCS Color Center/USA
Principal, Jolley/Turner Group, Inc.

Following is the text from the fifteen minute slide presentation of 68 images during the closing session of the AIC/ISCC Conference highlighting the 2003 Color Directions® palette from the Color Marketing Group (forecast during the Spring 2001 conference). Additional information has been added in *italics*.

Thank you, Jack and for the marvelous quote during Monday's opening session…(a version of) "do you dream in black and white or Color"? After this week, I'm sure it's Color – multi-color!!!

CMG (Color Marketing Group) and ISCC (Inter Society Color Council) have "Color in common" … together covering "all facets creative to technological." CMG began as an extension from the ISCC in 1968, and is participating in the Member-Body category.

CMG's mantra is "Color Sells & the Right Color Sells Better!" Just look at success stories we've heard this week, like Target Stores' new ad campaign and image. CMG has approximately 1700 members from 28 countries; and is comprised of Color Designers and Color Decision Makers; plus, members in the fields of color related areas consisting of Marketing, Technology, Design and Academia.

A quick summary of our meetings' methodology for "Forecasting Color Directions®":
CMG meets two times a year, spring and fall. The "Direction" is not a specific color, but, the "shifts and directions" of the "color families".

Spring has the color focus for "consumer products", Home, Building, Transportation, & Graphics Communication. The Fall meeting concentrates on "contract or commercial" industries and products, like Office, Hospitality, Health Care & Retail/Public Spaces". Both meetings develop color palettes that are two years in the future and both are based on "Design Influences" (from fall workshops). *Colors Current workshops are current to 18 months in the future – colors committed to products with a shorter production time.*

Design Influences are: Exposures all around us – Lifestyles, politics, economics, cultural nuances, and generational focuses… Entertainment, the media, fashion, sports, health, education, urban, suburban, and rural…and naturally, technology.

CMG Members create worksheets for Color Directions and Design Influences before each conference – then attend workshops in the subject category that best suits their personal industry with the completed worksheet.

In the Workshops, with twenty members, each person presents where and what is happening in their industry; and what the influences are that are affecting color changes. Plus, how Design Trends and Color Application will enhance their product or industry in its marketing niche.

The results of each workshop are then taken to a "Steering Committee" where the process continues… this part identifies the importance of Color Directions® for specific products or industries. The Final Palette is the end result from this "forum of discussion" – thus, the Final Palette is the result of input from 1000 or more industries in the Global Arena.

Back at the office: the members take this Color Directions Palette and "individually interpret it for nuance and chroma into their company's products and materials – paints, plastics, pigments, textiles, metals, films, etc.

So without further ado… I will present to you an "hors d' oeuvre of the Color Directions® Palette in visual form – the influences around us and the colors.

Colors over the last few years have been brighter – reflecting the good economic growth. But, economies have slowed since the New Millennium and people have stepped back to take stock of their lives. Maybe "Less IS More!" Life has been hectic, stressful and chaotic! People are trying to take time out to spend quality time with families, children and friends. *Color inspiration has come from the "prosperous 20's and 60's; and the glamour of the 30's and 40's. Globally, we've turned to colors of the Old World; it's land, people and architecture. We can't resist the beauty of fading frescoes, weathered patinas, ethnic motifs, exotics and rolling vineyards.*

We want "humanism" – positive life seeking "calmness", tranquility of Blue…
And all aspects of "water related influences"… a fascination with air and light
Atmospheric blues and translucence – a spa attitude …(travel agents reported clients seeking water related vacations; and home spas are the most requested feature of choice)

All of these feelings and the search for "the perfect blue" are reflected in our 2003 Color Directions® Palette, starting with four blues, *needed by the various industries…stable and reassuring…*
BLUE AIR: Retro Blue of the '60's classic cars. *Transportation.*
OCEAN CRUISE: Color of purity and energetic, somewhat greener and softer, *with a sporty edge. Action/Rec, Communications/Graphics, Fashion, Home Fashion.*
DEEP ARTIC: Dusty Navy of a safe harbor; silent & strong, *conservative.*
CINDER BLUE: Silvered Blue, *mechanical*, hinting at gray. *Transportation.*

SPECIAL EFFECTS and surface treatments continue as an important visual story as specific as the colors themselves. *Colors can now "radiate from within" thanks to new technologies.* Layering, shimmering elegance, by Nature & by Man, shown against continuing Silver Aluminums, into Meg's "Sky Blue Pink" – does this qualify??

Moving to GARGOYLE & SILGER – visions of burnished Gold, Pewter, Silver and Bronze textures; a *complex alloy.*
SHIMMA: warm hue of pearlized metallics and soft browns.
LION KING: (the conference was in Disney World, hence, name) – a regal Gold, King of the Jungle; *or Moroccan markets.* Supported by Action Recreation, Fashion and Home.
IRON ORE-ANGE: influenced by Copper, sophisticated shimmer. Youth, Action Rec. and Communication/ Graphics. *Orange family loses some of its influence, but appears as metal and wood in deep tones, bronzed skin in mid-tones, and almost neutral for home.*

Red and red-violet are important to this year's forecast. Blue-based for Transportation and Communication/Graphics industries; and the Latin influence of 2002 broadening to vibrant reds of Asia and full brilliant reds of a salute to traditional heritage.
Canpy is CHEEKY: the marriage of pink and peach…*blushing bride*, Deco fun, big for Home Products.
PINKLE: Pink meeting Purple (hence, the name) – hints of the Mauve of the past – *"aged pink" of vintage velvets and Victorian rose gardens.*
CURRENT: Brown veils Violet with sophistication. Durable Home Goods.
RED SATIN: Old world opulent Red; vehicles of future are "revved-up". Supported by Transportation & Graphics.
Finishing the Reds, SWEETHEART: showing the romance of the 40's; *vintage with Blue side – lighter becomes fashionable pinks.* Big for Fashion.

Iridescence and Natural Dyes transition the hues to Yellows, with
LEMON MERANGE: Zesty, silver flirting with Gold; Gatsby & vintage roadsters.
CHAMPAGNE BUBBLE – continues marriage of Silver to Gold; shimmer of Art Deco Glamour. Fashion & Home

Greens continue to show Nature's stability, with undertones of Brown, Yellow, and Blue, in three new hues:
FROND: tropical natural green, *with a commercial edge.* Action Rec & Transportation.
SODA GREEN: *Effervescent, "quenches our thirst for* serenity" & illuminates from within… Home Fashion & Transportation. These move to EXPLORING KHAKI: Complex Green Moss, *recalling rain forests & buried treasure* -- the transition to the Neutrals….

Natures NEWTRAL: the essence of nature, dry rock, sand, unglazed (ceramic & bisque ware);
3-D textures, matte warms, *softened gray* of raw plaster. Fashion favorite.
A perfect backdrop for all colors.

Now, back to tranquility…. (mountains)
(Show: Color Spectrum)
Remember, Color is around us… everywhere, in many dimensions.

We all love color and all contribute in our many ways from the Design Influences, to Color Application to Technology….

Making life better by developing future ideas in Color and Design.

This has been a fabulous week, loved the conference, and all the contributors, association members with the inspiring interaction of ideas.

Thank you for having me, and let's all stay in touch!

Note:
All CMG Palettes are "member exclusive for 12 months after initiation"; Color Curve, Munsell, NCS Natural Color System®, Pantone®, and RAL provide color notations.

The Future of Colour in the Visual Arts, Architecture, and Design

Paul Green-Armytage, School of Design, Curtin University of Technology

INTRODUCTION

My brief for this report was to reflect on the congress from the point of view of the visual arts, architecture and design, and to say something about how I see the future of colour in these fields. I will say a bit about the congress itself, a bit about some of the topics that particularly struck me, and a bit about the future – the future that seems likely and the future that I hope for.

THE CONGRESS

Like every AIC congress this was not one conference but many, as many as the number of individuals attending. For each of us the experience was different, made up of the particular papers we heard, the posters we studied, the exhibitions we looked at and the discussions we had with other participants, individually and in small groups. Some discussions were planned, others the result of chance encounters such as with the person you happened to sit next to on a tour bus and from whom you could learn unexpected things. It is this combination of formal, informal and chance that has made me such an addict of AIC meetings, and from that point of view AIC 2001 was particularly rich. Perhaps this was partly because the congress was essentially residential with the hotels linked to the conference centre, and all sessions, displays, and refreshment breaks being concentrated in the same place. Perhaps another reason was the contribution of the Internet.

The Internet has changed conferences and greatly extended possibilities. This was my first Internet enriched conference. Time at a conference is limited; the Internet made it possible to get maximum benefit from the congress week. Advance access to the abstracts made it possible to get a sense of the issues that are uppermost in people's minds. It also made it possible to plan attendance at sessions strategically and to target individuals for informal discussion.

One way to measure the success of a conference is to work out the ratio of total time spent to time spent profitably. By taking full advantage of the conference venue and the internet the organisers had made sure that this ratio could come close to being one to one. Clearly this required an enormous effort on the part of the organisers and a great deal of support from their employers and their families. So I would like to record my heartfelt thanks and congratulations.

Internet publication of the abstracts also helped me to prepare this report. Before the congress I was able to download all the abstracts that seemed to fall within my scope, read them, and make notes. I prepared a big chart on which I recorded the issues and, under those as headings, listed the papers that dealt with each. This was a rather blunt instrument in that my headings were rather general, but it did reveal areas of most widespread interest. I also made notes during the congress presentations themselves and enlisted the help of colleagues to cover other sessions when there were papers of interest in parallel. Many people made helpful comments, but I am particularly grateful to Dianne Smith, Harald Arnkil, and Karin Fridell Anter who put their comments and suggestions on paper.

THE TOPICS

In a brief report like this there is not space to do justice to the full program or to list all the papers that dealt with particular topics. Rather than mention the names of a few authors, and so risk the implication that others were less significant, I prefer not to name any of them. I should also stress the personal nature of this report; it reflects mainly my own feelings about what was interesting or significant.

Social issues

I was glad to see a growing concern with philosophical and social issues. I think this is important. I teach in a university of technology, which was once an institute of technology, and before that a technical college. The emphasis used to be on training - how to do things - and it was taken for granted that those things were worth doing. Now that we are a university there is more emphasis on the bigger picture, the social context of our programs, why we do what we do and what the

9th Congress of the International Colour Association, Proceedings of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

consequences might be for society at large. For me the AIC is a kind of world university. We have all the disciplines represented and are in a position to see how our individual concerns are related.

Colour in the built environment

From the listings on my chart, the heading that got the most entries was colour in the built environment. There was acknowledgment of the cultural role of colour and the way it can contribute to a sense of place and a sense of community. This seems to be threatened by globalisation. One notion that emerged during the congress was that of colour as an agent of cultural colonisation, greatly facilitated by technological advances. We saw some wonderful examples of colour traditions from different parts of the world. We also saw the results of colour colonisation - blind adoption of international colour trends out of context and the excessive intrusion of advertising in the urban scene. So the question arises: whose colours should they be? Are the colours to promote the interests of the multinational corporations or are they to reinforce the sense of belonging for members of a community? If we believe in protecting and preserving local identity, should colour guidelines be introduced and reinforced? Or should we acknowledge that the world has moved on and allow market forces to dictate the colours of our cities? Would enforcement of traditional colours turn our older cities into theme parks? If we don't like what is happening and want to restore the colours of past traditions, how do we do that? Should we try to turn back the clock? And, if so, how far back?

Light

A theme that emerged for me from hearing the papers at the congress itself, a theme that I hadn't fully appreciated from the abstracts, was the role of light. We have come a long way from colour chips. In the case of the built environment I was struck by comments about the influence of prevailing light conditions on colour treatment. For example, in places where overcast conditions are particularly prevalent, colour contrast can compensate for the lack of contrast that elsewhere would be provided by shadows.

Considerations of light had been a subset on my chart under a general heading of modes of colour appearance and other aspects of appearance related to colour. These things depend so much upon the observer and there seems to be growing attention being paid to ways of studying them through psychophysical methods. I mean things like the way in which our judgement of the colour of the light affects our judgement of the colour of surfaces. I also mean things like gloss, texture, transparency and the way all these things interact and how it all affects us as we experience them.

And I was struck by presentations where we were shown the use of coloured light in space as a particularly rich visual experience and as a vehicle for artistic expression.

Meanings and colour harmony

Two other areas that I had listed separately but could now group together were issues of meaning and harmony. What kinds of meaning can be derived from colours, lights, textures and so on? What kinds of combination are harmonious? And what do we mean by harmony anyway? When applied to a colour combination, is harmony a descriptive term or an evaluative one? Harmony is such a slippery concept that one might think it wise to leave it alone, so I was intrigued to see how much interest there is in the topic. There seems to be much unfinished business here.

Planning

Related to all these were other areas of concern: the difficulty of predicting colour appearance and the difficulty of predicting the likely response of people to a planned colour scheme. We heard about the difference between colours as isolated samples and the 'same' colours in an environmental context.

I can imagine a new kind of colour chart that might be the objective of those researching this area. The chart would still have colour samples, but the samples would represent the ultimate appearance in particular applications rather than the actual paint. So if ultimate appearance A were to be selected it would imply specification of paint B. It might be necessary to list several different paints for a given appearance, the paint to be used being dependent on the particular applications. So paint B might be the one for a south facing room, paint C for a north facing room etc. We could work backwards: This is how I want people to respond to this space, this is how I want them to feel. Therefore, this is the colour appearance I need. These are the special circumstances for this particular application. Therefore, this is the paint I need to use.

So how to study all this so that predictions and specifications can be made with some confidence? We heard about full-scale studies, models, and virtual reality.

Colour management

The problem of predicting colour appearance is one of particular concern for graphic designers. For my students, a source of frustration and bewilderment is the disparity between what they see on the computer screen when they are working on a design and how it turns out in hard copy. Given the subtleties of colour interaction – and we were shown some of these – the time spent fine tuning a design on the screen can turn out to have been wasted when the design is reproduced in hard copy. In the process of refinement a designer's aim is to make the design 'sing', meaning that all the elements – shapes, colours, textures etc – seem to be just right in relation to each other. The judgement is of the design as a whole so it is not enough to be able to refer to a swatch in order to check how a single colour area will appear when printed. Simultaneous contrast and other effects can make sure that two areas of the 'same' colour will not appear the same in the context of the whole design. There is a sense of losing control over what we design, especially when designing for the Internet. I was struck by a term that was new to me: 'websafe colours'. It was good to see how big an issue this is for the colour community, and to learn how extensive is the research that is going on in this area of colour management.

If designers are to have some appreciation of what is going on they will need to learn more about colour science. I was very grateful that a full two hour session was devoted to presenting the colour management problem at a level that someone like me could get some understanding of the issues. This seems to be an area where the colour scientists and the designers must work together. To use an example from the session: when I drive a car I don't want and I don't need to know about things like spark advancement. I just want to know what to do if I want to go faster, to stop, or to turn a corner. Designers could provide a wish list. Then the colour scientists and technologists could either figure out ways to grant those wishes or explain why the wishes can't be granted and what designers would need to do about that situation.

'Russian Blue'

An incident that seemed like a microcosm of the whole congress in that it tied together many of the issues as well as reflecting on the organisation of the congress itself happened during the Thursday session on environmental colour design and architecture. It happened because the congress was well planned and it happened because of a breakdown – one of the scheduled speakers had not been able to attend. The organisers had insisted that the rest of the schedule remain intact, so there was an enforced gap of twenty minutes, which made possible what followed. The enforced leisure in an otherwise extremely tight schedule seemed to act as a release. I hope I have got the details right.

The paper before the gap had been about colours in the domestic interiors of post war Finland. Somehow, in the discussion that followed, a particular colour was mentioned that had been used on exteriors and was known, apparently, as 'Russian Blue'. This, I was told, was a kind of light turquoise. It was a colour that was a part of Russian tradition but not Finnish and its introduction by Russians who occupied parts of Finland after the war made it doubly unacceptable to the Finns.

Then we heard about people encountering this colour on the exteriors of houses in Western Russia. The inhabitants told them that the colour was to keep the flies out. So a colour might be used for cultural and practical reasons, and the same colour might be avoided for cultural and political reasons. Then we heard that this same colour could be seen on the porches of houses on the island of Åland in western Finland, where the other parts of the houses were painted Falun Red. Falun Red is a traditional colour in that part of Finland and we were asked to assume that the Russian Blue was being used on the porches to keep the flies out. The combination of Falun Red and Russian Blue was reported to be particularly unfortunate – so ideas of aesthetics and colour harmony had entered the conversation. In this case it was suggested that the practical considerations of keeping out the flies outweighed any objections on aesthetic grounds. This prompted someone to wonder whether there were colours that could be used to keep away certain undesirable kinds of human being, but the session chair wisely intervened to cut short that line of speculation.

But that wasn't the end. There are other social, physical and economic reasons for choosing colours. We heard about a tour group in India being told that the blue used on houses in a certain part of town marked the Brahmins' district. On another occasion the same question produced the answer that the blue helped people keep cool (we were not told whether the cooling effect was supposed to be physical or psychological). On yet another occasion the answer was that the blue pigment was the cheapest, so that was why people needing to renovate their houses chose it.

Then we heard from South Africa that blue helped to restrict bird droppings. And finally, from Yorkshire in England, we heard about 'Loo Blue', used to paint the inside walls of outhouses – and we were back to keeping the flies out. The obvious question was: Does it work? So there is a research project for someone.

THE FUTURE

The future that I anticipate includes sustained research and debate about colour in environmental design and the various cultural, political, ecological, physiological, psychological and economic reasons for choosing particular colour combinations for particular purposes in particular places. I expect there to be more attention paid to the different modes of colour appearance, especially the colour of light and illumination, and more attention paid to other aspects of appearance including texture, surface quality and transparency (cesia). Increasingly sophisticated modelling, combined with a growing body of knowledge about people's responses to appearances, should enable designers to plan and specify paints and materials with more confidence. And the problems of colour management will surely continue to engage some of the best brains in the colour community.

Art and Science

In the future that I hope for there will be more interaction between the arts and sciences in the field of colour. Artists and scientists each have their own way of contributing to knowledge. I hope we can encourage more artists to join the designers and architects in the AIC. If scientists draw a distinction between basic research and applied research I think one could say that artists are engaged in the equivalent of basic research and designers in applied research. I was struck by an instance during the congress where an artist and a scientist had come to similar conclusions, but through their own distinct ways.

I have two favourite quotations which cast the artist in the role of researcher, one from the British artist Patrick Heron[1], and the other from no less a figure than Hermann von Helmholtz[2]:

> Painting's role in civilization is that of man's laboratory for the disinterested exploration of visual appearances as such, an exploration carried out uninhibited by any practical demands whatsoever.
>
> Heron, 1974

> We should look upon painters as individuals whose awareness of sense impressions is unusually vivid and exact .... What a long tradition has handed down to the men (sic) most gifted in this art and what they have discovered themselves by incessant experiment concerning various means and techniques of representation – all this forms a body of very important information which the physiologist, who here has much to learn from the artist, cannot afford to neglect.
>
> Von Helmholtz, 1871

If there is to be more co-operation between the disciplines, between people in the sciences and the humanities, and if that is to be productive, a first move might be to tackle the thorny problem of terminology. It will be a good way to start if we can learn to speak each other's colour languages.

REFERENCES

1. Heron, Patrick. 'The Shape of Colour', *Studio. International Journal of Modern Art*, vol. 187, no. 963, Feb. 1974.
2. von Helmholtz, Hermann, 'The Relation of Optics to Painting' in Kahl, Russell ed. *Selected Writings of Hermann von Helmholtz*. Wesleyan University Press, Middletown, Connecticut, 1971 [1871]

The future of color – science and technology

Robert W.G.Hunt
Colour & Imaging Institute, University of Derby, Derby, DE22 3HL, England

ABSTRACT

The present position and future goals of color science and technology are reviewed under the following headings: Color vision, Color appearance, Color differences, Color measurement, Color rendering and metamerism, and Color imaging.

Keywords: Color vision, color appearance, color differences, color measurement, color rendering, metamerism, and color imaging.

1. INTRODUCTION

The science and technology papers presented at the 9th Congress of the International Colour Association held at Rochester, New York, in June 2001, can be assigned to the following categories, the number of papers in each category being as shown.

Color imaging	32
Color appearance	23
Color measurement	22
Color differences	18
Color vision	13
Colorants	8
Color rendering	7
Color order systems	6
Instruments	3
Spectral estimation	3
Observer metamerism	3

For the purposes of this review, observer metamerism is considered under color vision, order systems under differences, instruments under measurement, and colorants, spectral estimation, and rendering under color rendering and metamerism. In a review of this length only a selection of topics can be included. The aim has been to identify areas where there is considerable interest and activity and to describe the present state of the subject and desirable goals for the future.

2. COLOR VISION

2.1 Cone spectral sensitivities

Present. A continuing subject of interest in color vision is the nature of the spectral sensitivities of the cones of the retina, with due allowance for absorptions in the ocular media. The identification of the genes responsible for defective color vision is well advanced, thanks to the technique of expressing them in tissue culture[1]. CIE Technical Committee 1.36 is making proposals for colorimetry based on sets of color matching functions derived for various field sizes, using the best available data for cone sensitivities and absorptions in the ocular media.

Future. More information on the variation of cone spectral sensitivities, and the spectral transmissions of the ocular media, for normal observers, is desirable, and could lead to a basis for an Observer Metamerism Index that would be more comprehensive and representative than is available now.

9th Congress of the International Colour Association, Proceedings
of SPIE Vol. 4421 (2002) © 2002 SPIE · 0277-786X/02/$15.00

2.2 Unique hues

Present. Observers can recognise unique red, yellow, green, and blue hues with considerable precision, and the CIE model of color vision, CIECAM97s, predicts these unique hues for all color purities from achromatic to spectral quite accurately using the following criteria:

Unique red:	$C_1 = C_2$
Unique green:	$C_1 = C_3$
Unique yellow:	$C_1 = C_2/11$
Unique blue:	$C_1 = C_3/4$

where

$$C_1 = R_a' - G_a'$$
$$C_2 = G_a' - B_a'$$
$$C_3 = B_a' - R_a'$$

and R_a', G_a', and B_a' are the long, medium, and short wavelength cone responses, respectively, with due allowance having been made for both chromatic and luminance-level adaptation. The above criteria are empirical and were chosen to give good predictions of experimental unique-hue data.

Future. There must be some physiological basis for the recognition of unique hues, and its absence represents an important gap in our present knowledge of color vision. It is to be hoped that this gap will be filled before too long.

3. COLOR APPEARANCE

Present. The CIECAM97s model of color appearance is being used in imaging technology, and has filled an important gap in the requirements for the quantitative management of images in different media.

Future. As CIECAM97s has been used, experience with it has revealed several areas where problems have occurred.

3.1 Surrounds

The categories of surround used in the model are average, dim, and dark. Average is used for reflection prints, and dark is used for projection in dark auditoria; dim is appropriate for typical domestic television viewing, but not for typical monitor viewing, because in this latter case the luminance of the surround is usually not appreciably different from the average of the display, so that the average surround is more appropriate to assume. Future research is needed to define these conditions more precisely, and a revised model could then allow interpolation between the different categories where necessary [2].

3.2 Achromatic signal zero

Because of the constant 2.05 in the formula for the achromatic signal A, there is a noise constant of 1.0 in the values computed, and this means that the computed lightness values, J, are not zero for stimuli having Y-tristimulus values of zero. This is not necessarily physiologically incorrect, but it is untidy computationally. By changing the constant in the formula for A from 2.05 to 3.05, J is always zero when Y is zero.

3.3 Chromatic surround induction factor, N_c.

Dark and dim surrounds tend to reduce colorfulness, and the chromatic surround induction factor, N_c, allows for this effect. The values originally allotted for N_c were 1.0, 1.1, and 0.8, respectively for average, dim, and dark surrounds, but to provide a smooth progression from average to dim to dark surrounds, it is desirable to change the value for the dim surround from 1.1 to 0.95.

3.4 Chromatic adaptation transform

The modified Bradford chromatic adaptation transform used in CIECAM97s involves a power function in the blue channel. This makes reversing the model difficult, and alternative chromatic adaptation transforms without any power function that perform equally well have been suggested [1,3].

3.5 Prediction of saturation

Recent research has produced data on the magnitude estimation of perceived saturation [4]. This has shown that the predictor of saturation in CIECAM97s performs poorly. A new predictor of saturation, based more closely on the CIE definition of saturation is possible [5], and could be included in a modified model. It has also been realised that, in CIECAM97s, for a color of constant chromaticity, as the luminance factor is varied, there are significant changes in the values of the predictor of saturation, and also some small changes in the value of the predictor of hue; however, it would be expected that these predictors would remain constant. By changing the dynamic response function in the model to a power function these changes in the prediction of saturation and hue can be avoided [7] and this may be a desirable feature in future models of color appearance.

3.6 Comprehensive model

Several effects not featured in CIECAM97s need to be incorporated in a Comprehensive Model. These include: the contribution of the rods; the Helmholtz-Kohlrausch effect; the Helson-Judd effect; cone-pigment bleaching at very high stimulus levels; simultaneous contrast; and the spreading effect for stimuli of small angular subtense.

3.7 Model for unrelated colors

Unrelated colors are important in signalling, and in some displays used in avionics for example. A model for predicting the appearance of unrelated colors is therefore a requirement in these applications.

4. COLOR DIFFERENCES

4.1 Small differences

Present. The CIELUV and CIELAB color difference formulae introduced by the CIE in 1976 were a very important step in the advancement of color technology. Since then the CMC and CIE94 formulae have offered some improved performances. The latest CIE formula, DE2000, is currently under test, and promises improved performance, but at the cost of considerable extra complexity.

Future. It is to be hoped that eventually a unified color space will be available that offers both a color difference formula of high performance, and also good predictors of color appearance. Some attempts to reach this goal have already been made [8].

4.2 Large differences

Present. There are at present no color difference formula specifically designed for large color differences, by which is meant differences that are from about 5 to about 20 times a just noticeable difference. Since the Munsell System was based on the uniform spacing of large color differences, it could perhaps provide the basis for a large-difference formula, but there are some doubts about the uniformity of the Munsell spacing in some areas of its space.

Future. The color differences commonly encountered in imaging are in the large range as defined above. There is therefore a need for a formula that can be used to evaluate such differences appropriately. A special feature of images is that there is inevitably a separation either of space or of time, or of both, between the colors being compared, whereas, in the colorant industries, comparisons are usually made side by side with either no, or else a very small, separation between the samples.

5. COLOR MEASUREMENT

5.1 Geometry of illumination and viewing

Present. The CIE document on Colorimetry, Publication 15.2, provides diffuse/0, 0/diffuse, 45/0, and 0/45, geometries with tolerances on the angles involved.

Future. In Publication 15.3, the revision of Publication 15.2 currently being prepared, a wider range of geometries is included with closer tolerances; the geometries are: diffuse/eight-degree, specular included (di:8°); diffuse/eight-degree, specular excluded (de:8°); eight-degree/diffuse, specular included (8°:di); eight-degree/diffuse, specular excluded (8°:de); forty-five degree annular/normal (45°a:0°); normal/forty-five degree annular (0°:45°a); forty-five degree directional/normal (45°x:0°); normal/forty-five degree directional (0°:45°x)

5.2 Standard sources

Present. The only Standard Source available at present is that which realises Standard Illuminant A. The lack of sources that realise the Standard D Illuminants is a handicap for two reasons. First, colorimetric measures are very often calculated using one of the D Illuminants, but visual inspection of samples has to be carried out with a different illuminant, typically some unspecified sample of real daylight, or a fluorescent lamp or filtered tungsten light in a viewing booth. The correlation of visual inspection with colorimetric computations is therefore insecure. Second, with materials that fluoresce, it is essential in color measuring instruments to illuminant the samples with a specified illuminant, and usually one of the D Illuminants is desirable; but the D Illuminants can only be approximated, typically by using filtered tungsten-halogen or xenon sources, and again this leads to insecurity of the measurements. Fluorescent materials can be measured with double-monochromator instruments, and this can result in the correct colorimetry for any specified illuminant; however, such instruments are costly and take longer to produce their results than conventional color measuring instruments; moreover, the problem of correlating visual inspection with the colorimetry remains.

Future. It would be useful if the CIE were to introduce some additional Standard Illuminants that could be realised as sources. These could include approximations to D65 obtained by filtered tungsten-halogen and by filtered xenon, and a few widely used fluorescent sources such as those used for cool white and compact domestic fluorescent lamps [7].

5.3 Additivity

Present. Colorimetry is based on the assumption that the additivity of color matches is valid. The widespread use of the CIE system of colorimetry suggests that this assumption is sufficiently valid for practical purposes. However, some recent work has cast doubt on the assumption [8].

Future. It is important to know what factors, such as rod intrusion for example, may affect the additivity of color matches, and it is to be hoped that research will be conducted in this area.

6. COLOR RENDERING AND METAMERISM

6.1 Color Rendering Index

Present. Several attempts to revise the 1998 version of the CIE Color Rendering Index failed to result in a new version.

Future. The consolidation of a color difference formula, a color appearance model, and a color rendering index, into a single framework is a desirable aim for the future.

6.2 Colorant formulations

Present. Recipe predictions in the paint and dyestuff industries are well established.

Future. For marketing on the web, it will be even more important than for normal applications, that colorants are chosen for goods that have illuminant and observer metamerism indices that are as low as possible. This should be an emphasis in the future.

7. COLOR IMAGING

7.1 Self-luminous displays

Present. The market for self-luminous displays is at present dominated by cathode-ray tubes and liquid-crystal displays. The former are bulky and heavy, and the latter are costly.

Future. The search for a display that is less bulky and heavy than the cathode-ray tube, and less costly than the liquid-crystal display continues, as it has done now for many years. Plasma displays have made some impact, and organic light-emitting diodes offer promise for the more distant future.

7.2 Film spectral sensitivities

Present. Some progress has been made in moving the peak of the red-sensitive layer of films to shorter wavelengths to reduce the excessive redness with which some blue flowers are rendered and to reduce other color distortions.

Future. The improvement of the spectral sensitivities of red layers of films needs to be applied more uniformly to different types of film. Special films having spectral sensitivities close to a set of color-matching functions are required for applications where the film will always be scanned; electronic matrixing can then be used to restore the colorfulness lost by using the greatly overlapping color-matching functions.

7.3 Technology

Present. Film is still dominant in the huge consumer-imaging market, but digital is growing fast.

Future. Both film and digital are expected to grow in the future; it appears likely that the very popular single-use film camera will maintain an important cost advantage in the consumer market.

7.4 Color reproduction index

Present. Some proposals have been made for a color reproduction index [9].

Future. Further work needs to be carried out to produce a color reproduction index which can be used with confidence for imaging in different media.

8. CONCLUSIONS

Color science and technology are as exciting as ever. Much progress has been made in many areas, but fascinating problems remain to be unravelled. The future is bright indeed!

ACKNOWLEDGEMENTS

I am grateful to Dr M.R.Pointer for helpful discussions in the preparation of this paper.

REFERENCES

1. T.Hayashi, T.Yamaguchi, K.Kitahara, L.T.Sharpe, H.Jagle, S.Yamadae, H.Ueyama, A.G.Motulsky, and S.Sdeeb. The importance of gene order in expression of the red and green visual pigment genes and in color vision. *Color Res. Appl.*, **26**, 579-583 (2001)
2. M.D.Fairchild. A revision of CIECAM97s for practical applications. *Color Res. Appl.*, **26**, to appear (2001)
3. R.W.G.Hunt, C.J.Li, L.Y.Juan, and M.R.Luo. Further improvements to CIECAM97s. *Color Res. Appl.*, **26**, to appear (2001)
4. L.Y.Juan. Verification of colour appearance models using magnitude estimation data. PhD Thesis, Color & Imaging Institute, University of Derby, UK, December 2000.
5. R.W.G.Hunt and C.J.Li. Dynamic cone response functions for models of colour appearance. *Color Res. Appl.*, **26**, to appear (2001)
6. M.R.Luo and J.Morovic. Two unsolved issues in colour measurement – colour appearance and gamut mapping. *5th International Conference on High Technology*. Chiba, Japan, pp. 136-147 (1996).
7. R.W.G.Hunt. Standard sources to represent daylight. *Color Res. Appl.*, **17**, 293-294 (1992).
8. W.A.Thornton. Spectral sensitivities of the normal human visual system, color-matching functions and their principles, and how and why the two sets should coincide. *Color Res. Appl.*, **24**, 139-156 (1999).
9. G.G.Attridge, M.R.Pointer, and R.E.Jacobson. A summary of applications of colour reproduction indices to imaging systems. *J. Photogr. Sci.*, **44**, 187-192 (1996).

Conclusion

Jack A. Ladson
Color Innovation, LLC
ISCC Presdient

Aristotle said that the unexamined life is not worth living. My challenge to you is this: "Examine your life in light of what you have heard today".

Leadership is defined as the ability to motivate others towards a common goal – a guiding light. Let each one of us leave this conference being committed that we will be the guiding light to propagate color to the ends of the Earth and beyond. Remember my challenge to you at the beginning of the conference – "***Become involved make a difference and have the time of your life***".

Author Index