AIC COLOR 2002 SI
COLOR & TEXTILES

PROCEEDINGS

Maribor, Slovenia
August 29 - 31, 2002

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EDITED BY

Vera GOLOB
Slava JELER
Zoran STJEPANOVIČ

DESIGN BY

Tatjana KREŽE
Vojko POGAČAR

PRINTED BY

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PREFACE

On behalf of the International Color Association (AIC) the interim meeting 2002, entitled Color & Textiles, was held in Maribor, Slovenia from 29th to 31st of August 2002. The two and a half-day meeting was jointly organized by Slovenian Colorist Association and Textile department of the Faculty of Mechanical Engineering, University of Maribor. Slovenian Colorists Association celebrated the tenth anniversary, therefore we were particularly happy to host the AIC meeting on the occasion of our Jubilee. The Textile Section of our Association is amongst the most numerous and active ones, therefore it is not a coincidence that "Color & Textiles" was the topic selected for the AIC interim meeting 2002.

Textiles remain among the most important material goods needed in every day life. They are used for a variety of purposes, so they must have specific properties in order to be both comfortable and fashionable, and color is a phenomenon that greatly influences textile aestheticity. Eco-production of colored textiles requires high professional knowledge; therefore many specialists from various scientific fields collaborate as designers, color chemists, textile engineers, computer specialists, etc. It is only natural that color science, color design and many other color-related topics of great interest to the Textile Industry were discussed at this interim AIC meeting.

The aim of this AIC interim meeting was to present the most up-to-date theoretical and research achievements in color science and their implementation in textile practice and to provide an international forum for the presentation and discussion of novelties and the state-of-the art in this scientific field.

The scientific program included:

- Oral presentations,
- Poster presentations,
- Two roundtable discussion panels, that were followed by respective oral presentations,
- The exhibition of color order system, color measurement systems, laboratory equipment and various textile products.

The AIC Color 2002 meeting officially started on August 29, 2002 in the morning with opening ceremony with speeches delivered by Prof. Slava Jeler, the president of SCA, Mrs. Paula Alessi, AIC President, representatives of the University of Maribor, the Ministry of Education, Science and Sport, the Chamber of Commerce and Industry of Slovenia, the chair of the Textile Department at the Faculty of Mechanical Engineering, Prof. Alenka Majcen le Marechal, and Prof. Vera Golob, chairperson of AIC 2002 SI, who also introduced the topics and program of the meeting.

Oral presentations were grouped into 6 topics:

- Introductory lectures,
- Interdisciplinarity of Color Science,
- Color and Design,
- Color Education and Color Imaging,
- Color Evaluation, and
- Colorimetry in Textile Applications.

Two roundtable discussion panels were organized that followed the respective oral presentations on the last day of the meeting:

- Environmental Color Design, and
- Advanced Color Measurement.

It is worth to quote here a part of the closing speech delivered by AIC president, Mrs. Paula Alessi, who said: "Three years ago, this AIC Interim 2002 meeting on Color and Textiles in Maribor, Slovenia was just a dream. We have lived the dream with Prof. Dr. Jeler and Prof. Dr. Golob over the past two and half days. Now that the meeting has come to an end, is the dream over? How many of you have awakened from a dream and not been able to accurately remember your dream? Well, we will never awaken from this dream. It will live on in our memories forever for two reasons. The first is that we will soon have the written proceedings as a permanent archive of this meeting. Second, we will have our memories of what happened in Maribor as well as papers and social events in our memories forever".

At the end we would like to express our thanks to the sponsors and to all that contributed to AIC Color 2002 SI, held in our beautiful and colorful Slovenia, where visitors are received as guests, and leave as friends.

President of Slovenian Colorists Association

Prof. Dr. Slava JELER

Chair of AIC Color 2002 SI

Assoc. Prof. Dr. Vera GOLOB

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COLOR AND TEXTILES

Vera Golob[1], Slava Jeler[2]
[1]University of Maribor, Faculty of Mechanical Engineering, Textile Department, Slovenia
[2]Slovenian Colourists Association, Maribor, Slovenia

Abstract
The textile industry represents an internationally significant production outlet for various products used in every-day life such as garments, textiles in living environments and technical textiles. The design and production of bleached, dyed, printed and colored-woven textiles is one of the technologically and ecologically most demanding and quickly developing industrial branches.
The development of new textile products follows fashion trends and custumer's requirements, and color is the most important aesthetic component of their design and appearance. Color science education and its application in the reproduction of colored textiles from idea to end product is important, thus enabling the necessary flexibility for a rapid response to the fashion demands of the market. Today, color design, accurate recipe composition and color evaluation are supported by CAD-CAM systems, color imaging, color match prediction, color appearance, color management and advanced measurement methods and equipment.

***Keywords**: Textiles, coloration processes, color science, color design, colorimetry*

1. INTRODUCTION

Textiles consist of natural and man-made polymers, which can be colored at different stages of the production chain in the forms of fibers, yarns, fabrics and apparel. The color of textiles depends on concentration the of whitening agents, dyestuffs or pigments used in the bleaching, dyeing and printing processes, which selectively absorb light within the visible range from 400-700 nm.
Eco-production of colored textiles requires high professional knowledge, therefore, many specialists from various scientific fields collaborate as designers, color chemists, textile engineers, computer specialists, etc. The development of new textile products follows fashion trends and costumers' requirements, and color is the most important aesthetic component of their design and appearance.
Textile styling and design is an innovative art usually based on the subjective relationship to fashion. Computer-aided color design and computer-based color systems enable designers to create unlimited variations of color patterns and combinations.
The design and production of bleached, dyed, printed and colored-woven textiles is one of the technologically and ecologically most demanding and quickly developing industrial branches. This paper emphasizes the importance of color science and its application in the reproduction of colored textiles from idea to end product, which enables the necessary flexibility for a rapid response to the fashion demands of the market. Today, color design, accurate recipe composition and color evaluation are supported by CAD-CAM systems, color imaging, color match prediction, color appearance, color management and advanced measurement methods and equipment.

2. TEXTILES AND TEXTILE INDUSTRY

Textiles include fibers (natural and manufactured), yarn, cordage, fabrics (woven, knit, nonwovens) and apparel.

Textile fibers are composed of long and flexible molecules - polymer chains, synthesized from simple compounds under appropriate conditions in nature or by chemists. Natural fibers fall into two main categories: cellulose (cotton) and protein fibers (wool, silk and hair fibers). Man-made fibers are also divided into two main classes: regenerated cellulose from wood and cotton, and synthetic fibers from petrochemical sources. The total annual world production of fibers in 2001 was approximately 50 million tons and is expected to rise to 75 million tones by 2010 [1,2,3] (Figure 1).

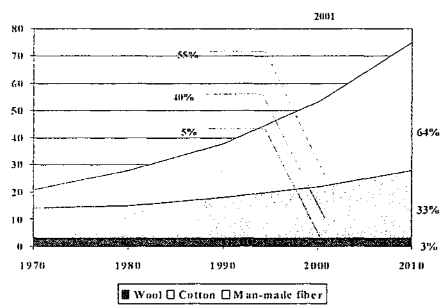

Figure 1: Worldwide consumption of fibers - in the past and future trends

Cotton is the most important natural fiber with 40% of yearly consumption, while regenerated cellulose fibers (mainly viscose) represent less than 5% of world's fiber production. Wool fibers are commercially important, although they comprise only 3% of worldwide consumption. Synthetic fibers comprise more than half of total fiber consumption and are expected to grow to 64% of the total by 2010.

The era of man-made fibers began with the invention of rayon (regenerated cellulose) in the late 19^{th} century. The discovery of nylon (polyamid 6.6) in 1935 was followed by the development of acrylic and polyester fibers. High-performance fibers such as carbon and aramid fibers were invented in the 1960's. Since then a variety of new polymeric fibers have been developed with a broad ranges of performance characteristics.

Fibers with improved functionality were manufactured, having special thermal, electrical, optical, acoustic, stretchable, water-repellent, anti-bacterial, properties. In the worldwide production of synthetic fibers during the last three decades (Figure 2) an enormous increase of PES fibers was observed and a decrease of PA and PAN fibres, whilst other fibers (Aramid, Elasthan, PE, PP, PVA, PVC, PVDC and various blends) reached a 10 % share.

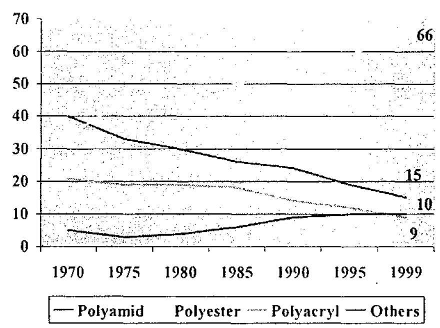

Figure 2: World-wide production of synthetic fibers

Nanofibers belong to the latest invention of high-performance fibers. They attract increasing interest due to their various applications in nanotechnology. It is also expected that the advent of genetic engineering will replace the traditional chemical routes for fiber syntheses with bioprocesses for producing polymers with specific (programmed) properties and functions.

As a raw material these fibers are used in diverse industries, including those which produce fabrics for consumer apparel and furnishing, carpets and floor coverings, nonwovens for various applications, sports goods, medical textiles and human-health protection textiles, paper products, fiber based geo-technical products, ropes and cordage, filtration media, fiber-reinforced polymer-matrix composites, fiber-reinforced rubber-matrix composites, fiber containing building and construction materials etc.

Textile industry represents a world-significant production branch for various products used in everyday life, such as garments, textiles in living environment and technical textiles. In the narrower sense the textile industry converts fibers into yarn, cordage, fabrics and apparel, whilst in a broader sense it also includes the manufacturing of polymeric fibers [3]. The vertically arranged textile industry production, where the raw fibers enter and finished fabrics or garments leave, is schematically presented in Figure 3.

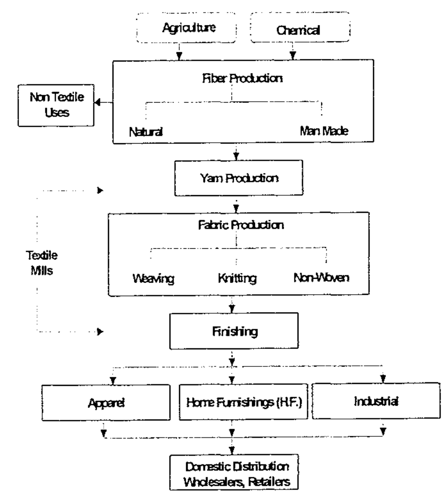

Figure 3: Textile industry

In spite of very extensive manufacturing, the share of textiles and clothing in world trade is quite low and represented in the year 2002 only 2.5 and 3.2 % respectively (Figure 4) [4].

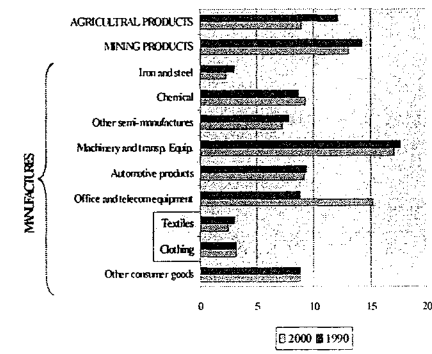

Figure 4: World merchandise export by products (shares based on value)

The advanced textiles and clothing of the 21^{st} century will be smart, intelligent textiles.

3. COLOR AND COLORATION PROCESSES

Colour is a sensual experience that depends on the spectral energy distribution of light, the objects' interactions with light and the observer's physiological and psychological characteristics. The interaction of light with textiles is affected mostly by the concentration of whitening agents, dyestuffs or pigments used in the bleaching, dyeing and printing processes. The perceived color of textiles is a consequence of:

- subtractive color mixing, which means that applied dyes and pigment in textiles selectively absorb light within the visible range, and
- additive color mixing, which means that reflected light from textiles is combined in one resulting color.

Colorants used in textile application are soluble organic dyes and insoluble organic and inorganic pigments, which selectively absorb light within the visible range from 400–700 nm. Dyes are divided into several chemical classes according to their chemical structure and into technological classes according to their ability to colored various fibers. Some technological dye classes have lost their importance due to the strict environmental legislations and high waste-water treatment costs. The main dye classes used today for the coloration of various fibers are:

- cellulose fibers - reactive, direct and vat dyes,
- protein and PA fibers - acid, metal complex and reactive dyes,
- cellulose acetates and PES fibers - disperse dyes.
- PAN fibers - basic dyes.

The total world consumption of dyes in textile industry during 2001 was 0,6 million tons and it is forecasted to increase by 5% annually. The majority of dyestuff production has been moved to the Asian region. More than half of dye production applies to the dyeing of cotton, whilst PES remains the most important among synthetic fibers. Reactive dyes account for around 25 % and disperse dyes for 20% of total dye production [5].

Coloration may be carried out at any stage in the manufacture of fibers (mass coloration) or textiles in the form of fibers, yarns, fabrics or apparel. Most textile dyes and pigment are applied from water-dyebath or water-based printing paste and, after diffusion into the textile fibers, they are bound by physical and/or chemical forces to form dye-fiber system.

3.1 Bleaching of textiles

All natural fibers are colored by natural pigment and impurities, which confer a yellowish brown color to the fibers. Cellulose fibers, whether they are natural (cotton, linen, jute, ramie, sisal, hemp, etc.) or regenerated (viscose and polynosics), natural protein fibers (wool and silk) and synthetic fibers require pretreatments, which remove natural and added impurities from the fibers and make them suitable for coloring and finishing processes.

The purpose of bleaching is to destroy colored material and to enhance the pure, white appearance of textiles. Chemical bleaching processes are performed using oxidative (hydrogen peroxide) and reducing agents (sodium hydrosulphite). Predominantly used today for bleaching of cellulose fibers is hydrogen peroxide, whilst sodium hydrosulphite is used for the bleaching of wool, but mainly in combination with hydrogen peroxide. Synthetic fibers are usually white and chemical bleaching processes are unnecessary.

The whiteness of the chemical bleached natural fibers or synthetic fibers may be significantly increased by the use of fluorescent whitening agents. These are colorless dyes, which absorb energy in the near UV spectral range (about 350 nm) and re-emit it by fluorescence as visible light of shorter wavelengths.

Various batchwise, continuous and semi-continuous processes depending on the physical forms of the textiles (loose stock, yarn or fabric) are appropriate for bleaching. Diversity of application conditions affects the quality of bleached textiles which is expressed by low chemical damage, high and uniform absorbency for aqueous solutions and whiteness of textiles.

3.2 Dyeing of textiles

The dyeing of the textile fibers is a physico-chemical process which involves the transfer of dye-molecules, dye-ions or dye-particles from a dyebath into fibers. The dye transfer from liquor phase-dyebath to solid phase-fiber occurs in four separate steps: dye diffusion from the dyebath to the

fiber surface, dye sorption by the fiber, dye diffusion into the fiber and dye fixation on the fiber.

Various dyeing procedures and techniques are proposed for dyeing of the same substrate and the selection of the appropriate dyeing process is determined by many factors, amongst which economics, quality, ecology and fashions are the most important. The choice of dyeing process is dictated by the equipment available, the form and amount of material to be dyed, the energy and water consumption and wastewater pollution. The quality of dyed textiles is ensured by the correct selection of dyes and dyeing methods taking into consideration the chemical nature of dyes and fibers, as well as the customers' requirements.

The dyeability properties of fibers can vary considerably depending on the manufacturing route and pretreatment prior to dyeing and technological parameters during the dyeing process. Successful production of dyed textiles and color reproducibility thus depends on a comprehensive understanding of the fiber and dye properties as well as their behavior during the dyeing processes.

3.3 Printing of textiles

Textile printing offers the production of multicolor products, designed in various patterns to obtain specific aesthetic effects. Localized color can be achieved using printing paste containing the thickening agents, dyes and all additives necessary for the coloration process. Direct, discharge and resist printing techniques require specific compositions of the print pastes respectively and enable printing of white or ground-colored textiles.

Today continuous rotary-screen printing predominates in the textile industry using screens in the form of hollow seamless cylinders. These screens, each applying an appropriate motif of colored design, rotate over a moving fabric and the printing paste is pressed through them. Dye diffuses into the fiber from the paste during the fixation process.

In traditional screen-printing a screen has to be prepared for each color in a printing design, which is costly and time consuming, therefore, the introduction of new ink jet printing techniques is playing a significant role in textile printing [6]. It can produce photographic imagery by jetting dots of colored inks onto textiles and is flexible when changing a design directly on screen in response to custumer needs.

Ink jet printing is still under development and is currently restricted to use in industrial production due to the limited dye and ink types (reactive, acid, disperse, pigment) and the need for specially prepared fabrics.

4. COLORIMETRY IN TEXTILE APPLICATION

Color science and its application in textile coloration processes are widely practiced throughout the world today. The main application areas are:

- design of textile pattern and color combination,
- production of colored textiles, and
- color consulting.

4.1 Textile design

Design of the textile 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 larger number of color drafts and color combinations. In this way the creative art of design and advanced computer technology are combined in the creating of a seasonal fabric or apparel collection.

The modern approach for the creation and production of a fabric collection is to introduce color management into the industrial production from original idea to the quality control of dyed and printed fabric. The color design of the collection is created by employing advanced computer technology. The procedure consists of pattern scanning, color selection and preparation of color combinations on the monitor, and printing out of the collection on a color printer.

Computer-aided design techniques for printing screens are widely used for the digital processing of textile pattern, and color combination. Digital printing for textiles offers the textile designer greater flexibility and shorter fashion cycles in response to market demand and seasonal trends.

4.2 Colorimetry in the coloration processes

Colorimetrical evaluation of textiles is based on measuring reflectance values using spectrophotometers. Technology in color instrumentation has advanced tremendously over recent years. The instruments have become more accurate, reliable, flexible, smaller and faster, at a much lower cost, and connected to the computer using the powerful software programs [7]. Color evaluation of multicolor fabrics with small color patterns, such as colored wovens, mélanges, jacquard and printed fabrics is still unsolved, therefore, besides conventional spectrophotometers digital still cameras (DSCs) and desktop flatbed scanners are also used as color measurement tools.

Computerized color matching systems and advanced equipped industrial laboratories with dyeing or printing machines and liquid dispensing systems assist the modern coloration processes. Numerical evaluation of whiteness, color values, color differences, color fastness, color depth, metamerism etc. enables objective color quality control, but there are still unsolved problems and experimental difficulties involved in colorimetric application for textiles production.

4.3 Color consulting

The end-consumer of colored textiles is a human being with individual personal characteristic and aesthetic demands. An advanced approach to textile color consultation for selecting appropriate wardrobes and home-furnishing colors is based on four-seasonal personal color palettes [8]. The seasonal color theory has already been proposed by artist and colorist Johannes Itten, who discovered that his students' personal colors were complimentary to the natural coloring of their skin, hair and eyes. By adapting Itten's theory on fashion, the four-seasonal color palettes were developed as guides for personal colors. Determining personal colors is still subjective, depending on the adviser's intuition or experience, therefore a more objective method using colorimetry needs to be developed.

5. CONCLUSION

Since 1990 the textile industry has undergone enormous changes. The challenge for the future is to revitalize the industry through technological innovation in product and processes. The producers of colored textiles are confronted with rapid fluctuations of fashion trends, extensive competition in the market and specific requirements for high quality eco-products in the shortest time-period. The introduction of colorimetry and color management systems in the textile industry enables the efficient color communication and production of colored textiles from original idea and design to the end-quality control and marketing of textile products.

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Assoc. Prof. Dr. Vera Golob, University of Maribor, Faculty of Mechanical Engineering, Textile Department, Smetanova 17, SI-2000 Maribor, Slovenia. Phone: +386 2 220 7891, Fax: +386 2 220 7990, E-mail: vera.golob@uni-mb.si

DYES AND COLOR OF TEXTILES

Marija Gorenšek, University of Ljubljana, Faculty of Natural Sciences and Engineering, Department of Textiles, Ljubljana, Slovenia

Abstract
This paper describes the application of dyes in the dyeing process of textiles. The correlation between the chemical structure of a dye and its color is described through the example of a simple azo direct dye. In this context indigo is mentioned for its extraordinary cross conjugated system which is responsible for its long wavelength absorption. The indigo dyeing process of cotton fibres is explained.
Although the main purpose for dyeing of textiles is the production of attractive and usable textiles, the process may also have another benefit. Nowadays people are afraid of the cancerogenity of UVA and UVB waves due to the damaged ozone layer. Now is probably the best time to point out the protective effect of some dyes on textiles. The transmittance of UVA and UVB waves and Ultraviolet Protection Factor (UPF) for pale and dark dyed cotton and polyester fabric are discussed.

Keywords: *azo direct dye, indigo, chemical structure, color, protective effect*

1. INTRODUCTION

Although the purpose of this symposium is the exchange of research achievements in the color science, particularly the novelties in the field of the color matching, it should be noted that color matching does not help us to understand how colors appear. Since this year's symposium is based on color and its relationship to textile, I have intentionally focused on known facts about the influence of dye structure upon the color effect, and the color effect on textiles in two examples. Besides discussion and summarization of previously published topics, I have included some new experiments which define the color on textiles as a protection of people against harmful UV radiation.

2. TEXTILE FIBRES

The first step in discussing dyes for textiles begins with a survey of usable textile fibres. Cotton, silk and wool, which are used every day, are classified as natural fibres. Viscose rayon is produced by chemical processes from cellulose; polyamide, polyacrilonitrile and polyester are examples of synthetic fibres. Modern blends of natural and synthetic fibres are also in wide use.
Natural fibres are polysaccharide and polypeptide polymers. Cotton is the most important cellulose fibre, and is composed mainly of pure cellulose (up to 95 %) [1,2]. Others, like flax, ramie and jute contain less cellulose. Cellulose, consisting of glucose units, is a linear polymer which belongs to polysaccharides family.
Cotton cellulose is built from approximately 1200 to 3000 glucose units. Each unit contains three hydroxyl groups and the fibre is highly hydrophilic. Hydrogen bonding between the hydroxyl groups causes high crystallisation of cotton fibres. Cotton's open structure swells in water. There is no problem in dyeing it. Wool and synthetic fibres are among other fibres that may be described in the same way.
Wool is comprised of protein keratin. This

polymeric substance consists of 18 amino acids, and is best dyed with acid dyes.
Concerning synthetic polymers polyester is still the major commercial textile fibre. Polymeric chains are packed tightly side by side. Fibre contains no voids, posseses high density, and is extremely hydrophobic. It cannot be dyed under normal conditions.
A brief review of the main textile fibres was conducted to explain the use of thousands of synthetic dyes on the market. The most usable dyes for dyeing textiles are:
1. direct, sulphur, vat and reactive dyes for cellulose fibres,
2. acid and metal-complex dyes for polypeptidic polymers, and
3. disperse dyes for synthetic polymers.

3. DYE CHEMICAL STRUCTURE AND COLOR

Regarding the chemical structure of dyes, we must remember Kekule who postulated the theory of valency in carbon compounds [1]. He proposed and disclosed the structure of benzene. Graebe and Liebermann elucidated the structure of alizarin and discovered that all dyes contain a system of conjugated double bonds [1,3]. Von Baeyer reduced indigo and obtained indol. In this was the way he deduced the structure of indigo. The reason that some organic compounds are colored lies in the capability of those compounds to excite electrons to higher states after the absorption of the electromagnetic radiation. The absorption of the visible light (wavelengths from 400 nm to 700 nm) in these molecules causes the transformation of electrons from ground to excited states. This process produces electronic spectra. This is also in accordance with quantum theory based on the Einstein-Bohr equation:
$\Delta E = h\nu$, where
h = Planck's constant = $6{,}6 \times 10^{-34}$ Js.
Thus the light of lower frequency has a lower energy and a longer wavelength. It is known that colored compounds need only 170-300 kJ/mol of energy to promote their electrons to excited states.
A wave-mechanical model for the three-dimensional electron distributions has been proposed. Schrödinger developed a wave equation which describes the possibility of motion of an electron in a three-dimensional orbital space.
The structure of benzene is perhaps the best example of the limited delocalisation of electrons [2,3,4]. Benzene contains six π electrons. A linear combination of six atomic 2p-orbitals produces 3 bonding (occupied) molecular orbitals (MO) and 3 anti-bonding (unoccupied) MO. In the ground state electrons are in the bonding MO. Absorption of electromagnetic energy, for example light, causes the transfer of electrons from bonding to energy higher anti-bonding molecular orbitals. Those processes are shown in the figure 1.

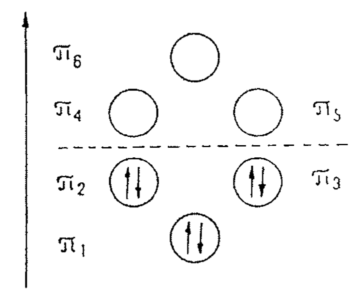


Figure 1: Energy diagram of bonding and anti-bonding molecular orbitals of benzene [4]

The absorption of visible light causes the excitation of electrons, but the absorption maximum of the spectrum lies in the ultraviolet region. As we cannot detect this frequency of light, benzene appears colorless to human eyes.
The delocalisation of π electrons in azobenzene is higher and the light absorption takes place in the visible and

near ultraviolet spectrum. In spite of its orange color, azobenzene cannot be used as a dye since its molar extinction coefficient in the visible region is too small.
Spectroscopic analyses confirm that organic compounds absorb electromagnetic waves. The fact that they will be colored makes the energy low visible light possible to cause the excitation of electrons. An example of such an organic compound is C.I. Direct Yellow 120 shown in figure 2.

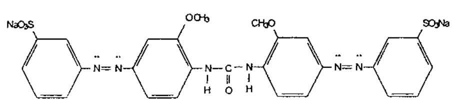
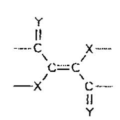


Figure 2: Chemical structure of C.I. Direct Yellow 120 [5]

The structure of this simple disazo dye shows the possibilities of the delocalisation of π electrons according to its coplanar position and the influence of its substituents. The coplanar structure of the molecule enables the maximal covering of atomic space. The absorption spectrum of the dye has a band at 440 nm. The reflected light is yellow.
Another interesting molecule that represents a usable blue dyestuff is indigo [1,3,5]. This deeply colored yet chemically simple molecule was for a long time the object of the investigations of several researchers. Luttke and Klessiger finally determined the structural elements, which were responsible for its long wavelength absorption. They found out that a "cross-conugated" system or a H-chromophore is the basic color producing structure in indigo (figure 3).



X= NH
Y= O

Figure 3: H- chromophore, indigo [5]

It is known that the benzene rings play only secondary role in the indigo spectrum. Spectrum of reflectance of cotton fabric dyed with indigo reaches its maximum at 420 nm (figure 4).

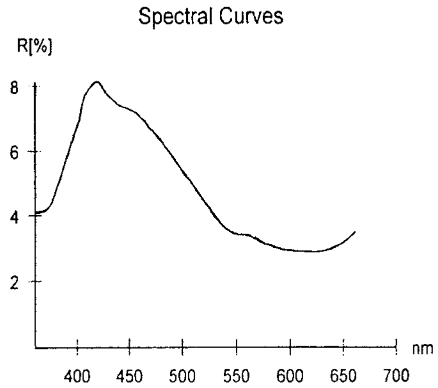


Figure 4: Reflectance curve of indigo dyed cotton fabric

This curve confirms the blue color of indigo. Its color is very dependent on conditions. It is blue in the polar solvents and in the solid state. Depending on inter- and intra-molecular hydrogen bonds it exists in an amorphous or in the crystalline form. It is known that in the amorphous parts of cotton indigo forms aggregates. The chromogen of indigo is otherwise red. The color of the monomolecular indigo in the vapour state is red.

4. DYEING PROCESS

The structure of the direct yellow dye may be written in a short form D-SO_3Na.
In a water solution, the dissociation of dyes takes place:

$$D\text{-}SO_3Na \rightarrow D\text{-}SO_3^- + Na^+$$

Depending on the dye concentration, the dyeing solution consists of the dye agreggates and the dye monomolecules in an ionic state [3,6,7]. The cellulose fibres prepared for dyeing acquire a negative potential in water. The addition of electrolyte to a solution of the direct dye tends to lower the long-range forces of the repulsion between the negatively charged fibre surface and the dye anions. The closer approach of the dye anions to the fibres allows hydrogen bonding and short-range attractive forces. These forces operate on the dye molecules and the cellulose fibres. Substantivity of dyes to fibres is thus a consequence of short-range forces originating from the linear coplanar structure of the dye molecule. After diffusion, short-range forces also play an important role when direct dyes form aggregates in the amorphous regions. The rate of diffusion depends primarily on these two factors: linearity and configuration of the dye molecules and the hydrophile-hydrophobic nature of the dyes and fibres. The dyeing process is based on adsorption and diffusion sub-processes. Wet fastness and the color of dyeings depend mainly on the form of dyes in the amorphous regions of fibre. The influence of intensity of soaping on wet fastness of dyeings is of crucial importance after dyeing with reactive dyes.
The dyeing process with water insoluble indigo takes place in another way. The substantivity of the reduced water-soluble form depends on the constitution of the dyes. Indigo in reduced form is yellow colored as it is shown from an absorption spectrum in figure 5.

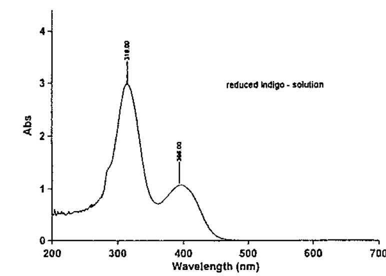


Figure 5: Absorption spectrum of reduced indigo solution

The characteristics of vat dyes are rapid exhaustion and uneven dyeing. Hydrolysis and oxidation of soluble dyes take place after the diffusion of dyes into the amorphous regions of cellulose fibres. In the substrate indigo forms crystals and cotton fabric dyed with indigo is blue as is shown in figure 4.

5. COLOR OF TEXTILE

The color of textile depends on the numerous different factors:

1. The characteristics of dyes (the chemical structure of the molecule, the position of substituents, the length of the molecule, the delocalisation of π electrons, inter and intra-molecular forces between dyes, the possibilities of aggregation of dyes in amorphous regions of fibre...).
2. The characteristics of fibres and textiles (the chemical structure of fibre, the supermolecular structure of fibre, the basic fibre color, pre-treatments, the yarn structure, the fabric structure...).
3. The dyeing process (the influence of water and other solvents, the traces of metals, the mode of dyeing: HT acid or alkaline dyeing processes of PET, soaping, after-treatments...).
4. The finishing processes
5. The light for color vision, etc.

6. THE PROTECTIVE EFFECT OF SOME DYES ON TEXTILES

The solar UV spectrum contains UVC (wavelengths 100-280 nm), UVB (280-315 nm) and UVA (315-400 nm) radiation. Due to the absorption by the ozone layer in the upper athmosphere, no UVC and only half of UVB rays reach the Earth surface [8,9]. Thinning of the ozone layer prevents atmospheric UV absorption and increase

the risk of sun-induced skin cancer. One of the possibilities for the sun protection is also the use of suitable textiles. Australia was the first country to develop a standard for the Ultraviolet Protection Factors (UPF) of apparel fabrics in 1996.
UV transmission of textiles depend on several factors: cover factor, fibre type, yarn construction, chemical structure of the dye, fabric construction, finishing process, dyeing process, UV absorbers...

As to the UV protection of textiles that are used for special occasions (tents, pavilions, protective textiles for sailing...), low transmission of ultraviolet light is important. It is known that synthetic fibres show a better absorption capacity for UV radiation than natural fibres. Polyester shows the best UV absorption due to the aromatic nature of its fibre. Protection factors are mostly dependent on fabric construction. It is known that bleached cotton provides low protective values.
Figure 6 shows the transmittance of bleached cotton fabric, which is very high, being in the region from 280 to 400 nm.

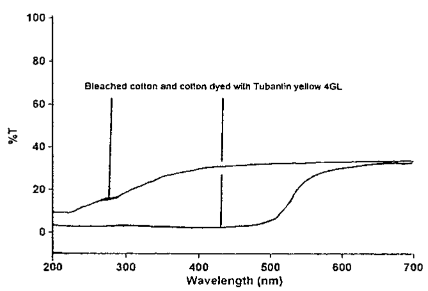


Figure 6: Transmittance of the bleached and dyed cotton fabric

The dyes used to color fabric may change its protection factor. To achieve a given color, a dye must absorb visible radiation. However the absorption band for some dyes extends into the UV spectral region. Such dyes act as UV absorbers. Bleached cotton fabric which was dyed with 2 % Tubantin Yellow 4GL (Bezema) transmits less UV and visible radiation in the region from 200-500 nm (figure 6).
Another example is a good covering polyester fabric for curtains. The untreated fabric (UPF 26,6) is HT dyed with 0,2 % and 4,4 % Terasil Blue R-01 200 % (Ciba). The transmittance of untreated, pale blue dyed and dark blue dyed polyester fabric is shown in figure 7.

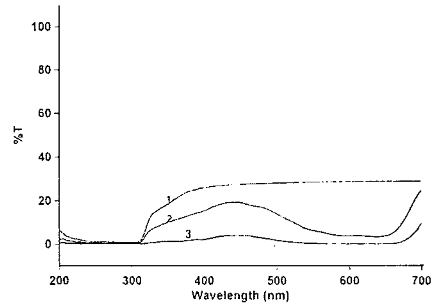


Figure 7: Transmittance of untreated (1), pale blue dyed (2) and dark blue dyed (3) polyester fabric

The pale blue fabric shows better protection (UPF 54) and the dark blue dyed sample shows an excellent protection (UPF 311). UPF were calculated according to AATCC norm, the values of UV transmission were measured using Varian Carry 1E UV/VIS spectrophotometer equipped with an integration sphere.

7. CONCLUSION

Color of textiles depends on highly different factors. Beside the mentioned facts the color can impart to textiles an ultraviolet protection effect. But this is a topic which is not widely discussed. As people are exposed to greater amounts of UV radiation, the measurement of textile's UV transmittance should become obligatory.

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Assoc. Prof. Dr. Marija Gorenšek, University of Ljubljana, Faculty of Natural Sciences and Engineering, Textile Department, Snežniška 5, 1000 Ljubljana, Slovenia.
E-mail: marija.gorensek@ntftex.uni-lj.si

COLOR APPEARANCE OF COMBINATIONS OF TEXTILES

Lucia R. Ronchi, Associazione Ottica Italiana, Florence, Italy

Abstract
The progress of technique has favoured the evolution of the test objects used in visual laboratories. It allowed the progressive enlargement of the horizon of studies on visual functionality. Now, this basic research field has been flanked by a collateral field, running parallel, in which <u>*textiles*</u> *were used as test objects. After an abridged review of the literature, we describe an experiment where pairs if juxtaposed (cotton) samples, differing in lighthness (brightness) and hue are used. We determine the balance condition, as a match of the visual weights of either sample. Early investigators maintained that the balance (assumed as an ingredient of visual harmony) would be based on an internal reference, represented by the average of the two component stimuli in addition to the interchangeability of the effects produced by a number of factors, such as Area, Value and Chroma (according to Munsell's inverse area ratio relation).. The results of our experiment aim at facing the early hypotheses and controversies with some results of the modern research on visual appearance, in the framework of perceptual organization..*

Keywords : *paired colors, visual balance*

1. INTRODUCTION

The structure of the surface of the textiles may be so fine, as to evoke peculiar optical effects investigated since long in the laboratories of Applied Physics and Optics. This is the case, for instance of the goniophotometric effects, often a consequence of polarization of incident light, (due to the structure and orientation of the textile filbers), and of interferential effects, both also depending on the direction of illumination and on the observation angle. The related changes in appearance are known as the Moiré fringes of the velvet, the "cangiante", and a variety of effects, such as gloss, chroma flair, lustre, and so on . [1-6]. The new generation of the so-called "effect pigments" are nowadays becoming popular in the textile industry, being highly appreciated by the stylist and designers [7].
Stated in another terms, let us recall that the "texture" of the textile (at a macrosopic level), also affects its brightness and color appearance. As a known example, let us quote knitting, The appearance changes significantly when passing from a fairly flat knit, to a gross knit , where the relief depends on the proper frequency.
In matter of dependence of textile appearance on illumination, in the visual laboratories various experiments have been devoted to the Purkinje effect. For instance, Ashizawa and Ikeda [8] have carefully analyzed both brightness and conspicuity of (uniform) samples at different luminance levels, in conjunction with the brightness-luminance discrepancy. Ronchi et al [3] recorded the changes in appearance of ancient-like tapestry, around sunset, by making inferences on the aesthetical consequences. The magic appearance they can create has been modeled, for the sake of prediction [9].
Textiles are konwn ti be excellent displays for visual effects such as contrast and assimilation. The latter has been one the secrets of the Gobelin family [10].
Various visual illusions are displayed in commercially available textiles. This is the case, for instance, of some red-blue (or green) combinations, producing the so-called "fluttering hearth" illusions. In the seventies, several patterns created by the Op-Art were becoming popular, being abundantly displayed on textiles. The perceived diagonals in grids and lattices [11] are expemplified, for instance, in authentical tartans. Luminance and illusory contours [12], in turn, are frequently met in patterned textiles.
Textiles have been sometimes used as tests for color deficiencies. The classical case is that of the so-called Holmgreen Wools, used for occupational screening.
Textiles as test objects may be used (for instance, for educational purposes) to show what "brightness and color constancy" means. This perceptual-cognitive phenomenon is generally referred to as "discounting the illuminant", or as the ability of distinguishing from, and correctly attributing the changes in illuminant color (and, in particular, in the direction of illumination) to the changes in material color (depending on its reflecting properties) [13]. The learned knpwledge of the effects of illumination (and of the natural ones, in particular), leads to a synthetization of the internal representation of objects, which is rescued preattentively and without scrutinity, even in three-dimensional situation and without scrutinity [14]. For instance, when one is faced with a building, one façade of which is directly exposed to sunshine, and the others are in various degrees of halfshadow; or when looking at a modern luxury car, coated by pearlescent pigments [15]; or when listening to a speaker wearing a silk dress , on a stage.
Interestingly, this latter effect is well known in painting. The changes in hue, saturation and brightness of a dress (e.g. that worn by Pope Innocenzo X , in Velasquez's picture) [16] and in numerous other paintings are not consciously perceived by the observer, and give (unconscious) information about the direction of illumination within the painted scene, according to the intuition of the artist.
In matter of color combinations, the simultaneous presence of two or more different colore evokes sensory-perceptual effects like contrast and assimilation, quoted here above. Now, the term "contrast" is also used to include some cognitive aspects, resulting in acceptability and preferences, at the site of "evaluation". Apart from individual idiosynchrasies, such responses are storngly conditioned by the socio-culturand background and by the affective drives., by complicating and even biasing the visuo-functional dependencies on the environmental factors. In practice, the situation is finely scaled. For instance, every color combination is accepted for the flags, where the symbolic meaning prevails. Moreover, there are "colors going with" every other color. This fact is well known for natural scenes, where greens are finely intra-categorically modulated in space and time [17], and every pairing with flower colors is highly appreciated, whatever it is [16]. It has been suggested [18] that the colors of the missing XII basic category "go with" every other color. Probably we are (cognitively) "adapted to them, since they are frequent at most in our natural and man-made environments..
At last, let us recall that some of the basic color categories are displayed to test the individual preferences, in an abstract sense. But the judgement becomes finely scaled and very critical when pairing an intra-categorical color to a given object (a car, a dress, etc.).

2. OUR EXPERIMENT

2.1 Balance versus averaging, for a pair of juxtaposed samples

The early literature on visual harmony, when referred to the visual balance as one of its ingredients, or related to the primary after-image, and similar, was often referred to the sensation which one would report when the two paired images would be "hypothetically" mixed. Some early authors referred exclusively to the case where the samples were complementary, so that their mixture would be achromatic. Later, this concept has been extended to non-complementary pairs of colors. Now,the position above has been strongly criticized [19], by considering that one cannot refer to a non-exixting situation: in practice, the two displayed paired colors, are juxtaposed, in two distinct spatial locations, respectively.

However, having confidence in the power of the intuition of our ancestors, we started elucubrating about their suggestion.

On one side, we had been meeting a painter (also visual scientist) who asserted that she used to spread the colors on a canvas without strict reference to the represented scene, because "color sensations may be mixed by the brain". From the stand point of conventional colorimetry it sounds paradoxical. But, from the stand point of cognition it might sound as an extreme acceptable position. In fact, computer science accepts the possibility that during a process started in a spatial realm, at a given stage, it might continue being transferred to a temporal realm (and viceversa).

A counterpart of it is probably found in the visual literature. When a physically uniform field is invested by intermittent illumination (producing a patent sensation of flicker), the appearance of the field is other than uniform, because of numerous fluctuating fuzzy spots.. It is suggested that "the brain converts the temporal modulation into spatial modulation". Another example is found in the literature on visual balance. Munsell's inverse area ratio law, A1 (V1 C1) = A2 (V2 C2) relates a physical quantity as the Area is, to psychophysical data such as Value and Chroma . The balance, intended as a match of the visual weights of two juxtaposed samples, implies that, at a given stage of the visual process, the effects produced by the various attributes (size, brightness , hue-and -saturation) are interchangeable.

The experiment here described aims at speculating about the above quoted possibilities: average through higher level mixture and various interchangeabilities.

2.2 Materials and Method

The target consists of two paired (cotton) samples: a white reference, a colored test. They are presented in a light-proof booth, on a vertical display, at a viewing distance of 59 cm, lit by an incandescent source. The luminance of the white reference sample is fixed at 15 cd/sq.m, that of the colored sample depends on its reflectance factor, so that the intra-pair luminance contrast may vary, when passing from one to another sample. We performed two experiments.

In the former experiment the paired samples are applied on a circular cardboard (13 cm radius), fitted on the face of a desk ventilator, driven at 1500 rpm. On the disk, a pair of samples is presented four times, in the four quadrants. When the disk rotates, a fused image is seen. Obviously, its whiteness, Wh (assessed by the match with NCS samples), increases as the ratio S, of the area of the white sector to that of the colored sector, increases. Recall that Wh = 100 – (s + c), where s, the blackness and c, the colorfulness, are both given as "nuance" in the NCS notation of the matching sample.

The second experiment was devoted to assessing the visual balance condition [20]. The target consists now of a rectangle of given height (h = 2°.5), as is shown in the

inset at the top of Figure 2. The (colored) test sample, of area A1, is a square. Let us denote its side by Lc=h= 2°.5. The white reference sample is a rectangle ; its height is h= 2°.5, its length (variable) is denoted by L°w.

For any colored sample, juxtaposed to the white reference one, the spatial (visual) balance was obtained by the constant stimuli method, by varying L°w, and hence the area of A2.

Being A2 brighter than A1, at the balance is L°w > L°c, in obeyance to the Munsell's law.

As a final remark., let us recall that previous research has abundantly shown that the intra-pair luminance contrast is the factor relevant at most, as far as the spatial balance is concerned; on the other hand , also the saturation of the colored samples is very important, but not the hue per sé. For this latter reason, the colorimetric data of the samples we used are not reported here.

2.3 Results and discussion

Figure 1 shows, as expected, that the whiteness Wh increases as the size of the white sector increases, relatively to that of the colored sector. The rate of the increase is the greater, the greater the intra-pair luminance constrat is.

Figure 2 shows the method used to determine the so called "equivalent whiteness" Weq of a balanced sample.For this, we determined the ordinate value of a point B, representing the balance in terms of the log ratio of the two areas, A2 and A1 determined with the variable rectangle shown in the right portion of this same figure.

In other words, if the two (actually steady) paired samples, at the balance, were mixed, their whiteness would be Wh.. Note that Weq is very close to the saturation level of the plots of log Wh versus los S (being S the ratio of the areas of the white-to-colored sectors, in each quadrant of the spinning disk). Now, the greater the intra-pair luminance constrast, the greater the ratio of the areas A2 / A1 (and, hence, the ratio L°w / L°c) at the spatial balance.

In turn, as Figure 3 shows, the equivalent whiteness (concerning the mixture on a spinning disk), at the spatial balance, increases with increasing the intra-pair contrast.

It is in line with the shift to the right of the plots shown in Figure 1, as the luminance contrast of the pair increases.

As recalled above, early investigators believed that the spatial balance in a pair of colors would be somehow referred to their mixture (hypothetically performed by the higher centers). Our data seem to point out that it is not so paradoxical, as it is generally believed. Since Munsell's time ot has been accepted that the effects of factors such as area and brightness may interchangeably contribute to the sensation of visual weight (and hence, of visual balance). As an extension of it, one might accept that the whiteness at the spatial balance is related to that of the mixed samples. In fact, it is the greater, the greater the intra-pair contrast is.

The question arises whether all it may be related to the dichotomy "within Ikeda's RVSI" (recognized visual space of Illuminatin), and "popping-out, outside the RVSI". In Figure 3 we tentatively suggest a borderline, by making reference to the spatial balance situation.

Now. a glance to the literature shows that the reults of various experiments often led to contradictory results. This is a typical situation in visual research, and it is customarily ascribed to the differences in the methodologies adopted by various authors. According to our experience, when comparing two samples so juxtaposed as to represent a simple geometrical shape, the balance condition is easily determined. This is, for instance, the case of a rectangle, or of a single quadrant of a sectored disk. But

this is no longer the case when considering the whole set of four (equal) quadrants together, so as to form a complete circle. A St. Andrew's cross so obtained is intrinsically a stable and well balanced pattern, whatever the relative sizes, brightnesses and colors of the various sectors are. Another example may be a cross, where the test-object is located at the meeting point of its arms, whatever their lenght. Apparently, the perception of a known shape prevails over balance.
Let us consider now a textile related example: in middle age ceremonies and parades, the costums of some vallets often exhibited patent lack of symmetry (e.g. their stockings differed in color), but it did not produce imbalance. Probably, the costum's characteristics were such that it appeared as a self-standing entity, prevailing over the occasional alterations.

2.4 Multicolored, patterned textiles : naming and classification

The samples above considered are uniformly colored, and so flat, that any effect of texture could be neglected.. A further study now in course is devoted to the "patterned samples".Because of the variety of their complexity, it is imperative to subdivide them into groups, by also proposing the appropriate color naming for each of them. Being the topic other-than simple, and to be respectful of the allowed space, this topic cannot be dealt with in the present report.

3. CONCLUSION

The facts, effects and data displayed in the present paper might represent a journey across visual science performed by looking at the textiles. It might be argued that the stylists and fashion experts make use of their fine visual sensitivity, creativity and capability (even if at an unconscious level), to create their own personal schemes and strategies. In turn, the visual scientist quantifies the effects they use, even by rediscovering them by himself, and independently from the artist.
In conclusion, artists and scientists make use of the language of visual functionality as a common tool communication tool, even with different modalities, goals, ingredients (aesthetics, emotion, know-out), by taking profit of the versatility of the shared language itself.

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5. CAPTIONS TO THE FIGURES

Figure 1 – Data obtained by the use of a sectored spinning disk. Abscissae : log of the ratio of the area of the white sector to that of the (colored) test sector. Ordinates: whiteness of the matched NCS (2nd Ed.) sample. Each plot refers to a different value of luminance contrast, c, for each pair of sectors. Dots, c= 23%; crosses, 46%; asterisks, 61%; open circles, 85%; filled squares, black vs white comparison.

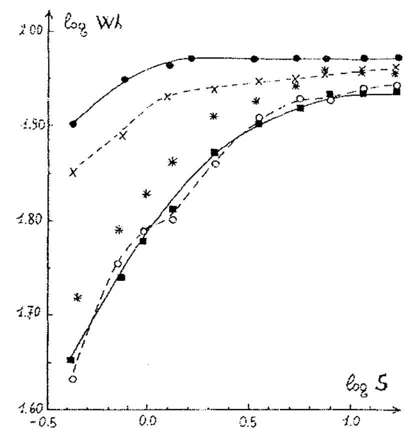

Figure 1: Data obtained by the use of a sectored spinning disk

Figure 2 – *Right:* the target used is shown in the top inset; the bottom plot is an example of a frequency-of-seeing curve; for a given value of the intra-pair luminance contrast . On the abscissae, the variable length of the variable rectangle A2 (reference white) is shown. The ordinate shows the percent probability of getting a response of the type "yes, balance". *Left:* a plot of the kind shown in Figure 1, for a contrast equal to that of the considered pairs. The balance condition, obtained by the Probit Analysis, is transferred, as point B, on the abscissae of this (left) plot. The corresponding ordinate is the "equivalent" whiteness, as determined with the spinning disk.

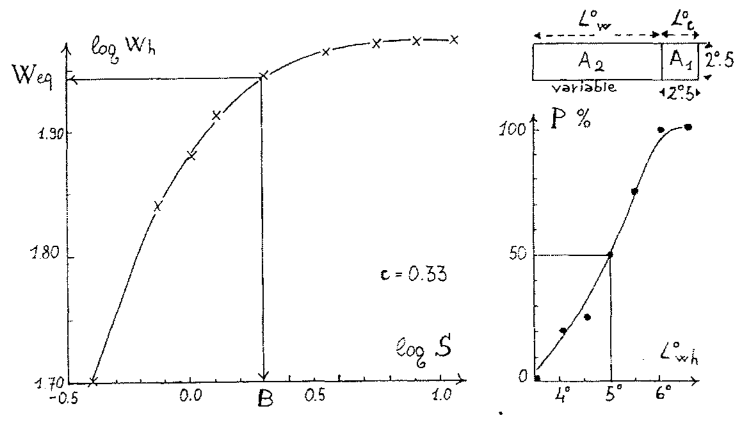

Figure 2

Figure 3 – Abscissae: the spatial balance data, expressed by the ratio of the areas (or, what is the same, the sides) of the white rectangle to that of the colored square. Each point refers to a given value of the intra-pair luminance contrast, c . Ordinates: ratio of the equivalent whiteness of the spinning disk , at fusion, to the whiteness of the colored sample, in the steady state, at the balance.

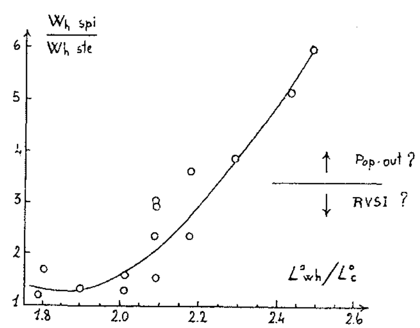

Figure 3

Prof. Lucia Ronchi, Ph. D., Associazione Ottica Italiana 1, Via Suor Maria Celeste, 50125 Florence, Italy. Phone +39 55 223112, Fax: +39 55 222090, E-mail: n.rositani@flashnet.it

PREDICTION OF PERCEIVED COLOR OF LIGHTING IN A COLORED ROOM

Taiichiro Ishida and Naohiro Toda
Department of Architecture and Environmental Design
Graduate School of Engineering, Kyoto University
Kyoto, Japan

Abstract

Colors of the inner surfaces of a room must have significant effects on our perception of color of lighting in the room. The aim of this study is to examine how we perceive the color of lighting in a colored room and develop a method to predict the perceived color of lighting quantitatively. Light filled in a room physically consists of the direct component from illuminants and the indirect component produced by mutual reflections between the inner surfaces. Two small model rooms (test box and matching box) were used for the experiments. The test box had several combinations of the interior colors and the inner surface of the matching-box painted gray. The task of the subjects was to adjust the color of the illuminant of the matching box so that the matching box appeared to be illuminated by the same illuminant of the test-box. It was shown that the subject's judgement of the color of lighting was closely correlated to the sum of direct and indirect components of lighting. Our results suggest that the perceived color of lighting in a colored room can be predicted as the sum of direct and reflected component of the lighting.

Keywords: *color of lighting, interior color, mutual reflection, illuminant perception*

1. INTRODUCTION

Colors of the inner surfaces of a room must have significant effects on our perception of color of lighting in the room [1, 2]. For instance, if a room is colored green and illuminated by a white illuminant, we may perceive the color of lighting as somewhat greenish. It is important to know how the color of lighting would be perceived for designing interior lighting and colors. The aim of this study is to examine how we perceive the color of lighting in a colored room and develop a conventional method to predict the perceived color of lighting quantitatively.

The physical light filled in a room consists of the direct and indirect components. The direct component is the light that is emitted directly from the illuminant, and therefore its color is equivalent to the color of the illuminant. On the other hand, the indirect light components are produced by mutual reflections between inner surfaces, and therefore their color shifts toward the color of the surfaces. The actual light illuminating the room is the sum of these two components. The focus of this study is to test which physical components of the light determine our perception of the color of lighting.

2. METHODS

Two small model rooms were used for the experiments: one is referred as the test box and the other as the matching box. The

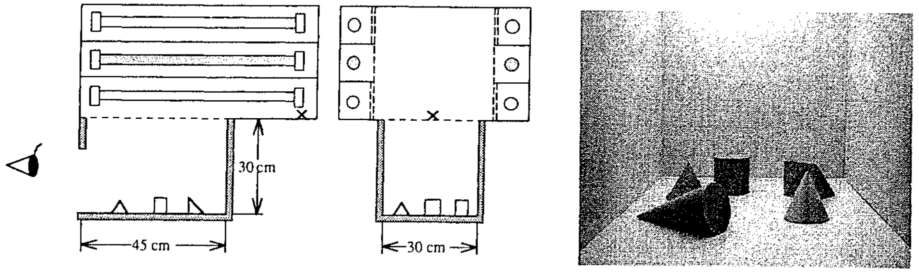

Figure 1: The model box. (a) Side-view, (b) front-view, (c) inside view

two boxes are illuminated separately by three types of fluorescent lamps(R, G, and B) to produce various colors of lighting. The colors of the inner surfaces (walls and floor) of the test box were set to various combinations of nine colors. The color of the inner surfaces of the matching box was gray (N7.4). The task of subjects was to adjust the color of the illuminant of the matching box so that the matching box appeared to be illuminated by the same illuminant of the test box. The perceived color of lighting in the test box, whose interior was colored, would be shifted from the color of the light source. The adjusted color of lighting in the matching box, whose interior was neutral gray, would give subjects' perception of color of lighting in the test box. The configurations of the model box are shown in Figure 1. The interior colors and illluminants conditions are given in Table 1. The chromaticity coordinates of lighting for two boxes are shown in Figure 2.

Five subjects participated in the experiment. The total number of conditions of the test box was 45: 9 interior colors x 5 colors of the illuminant. One session consisted of 15 trials. In each trial the subjects adjusted the color of the illuminant in the matching box so that it appeared equivalent to that of the test box, while he/she was observing the inside of both boxes one at time. Conditions were replicated three times in separate sessions.

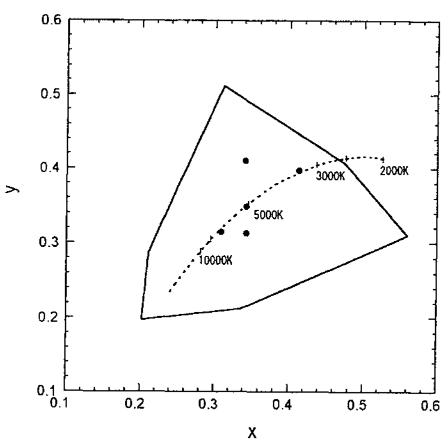

Figure 2: The color of the illuminants of two model boxes. Closed circle; illuminant colors for the test box., Solid line; adjustable range of the illuminant colors for the matching box., Dotted line; Prankian locus.

Table 1: Colors of interiors and illuminants for the model boxes.

	test box	matching box
colors of walls and a floor	N7.4, 8.3Y7.4/2.7, 6.7B7.5/2.3, 9.8B7/7.3, 7.4Y7.4/6, 9.4P7.4/2.1, 10P6.7/4.8, 7.5GY7.6/1.4, 7.3GY7.5/5.7	N7.4
colors of reference items	3.9Y8.8/7.8, 5.2RP7.8/6.7, 0.8P6.8/6.5, 3.1GY7.6/5.3, 0.4PB4.8/9.5	5.1Y9.1/5.4, 0.3R8.3/4.6, 0.7RP5.6/8.5, 5.7GY7.4/7.7, 6.5B7.7/6.1
Chromaticity coordinates of light source (x, y)	(0.34, 0.35), (0.31, 0.32), (0.41, 0.40), (0.34, 0.41), (0.34, 0.31)	Adjustable (see Figure 2)

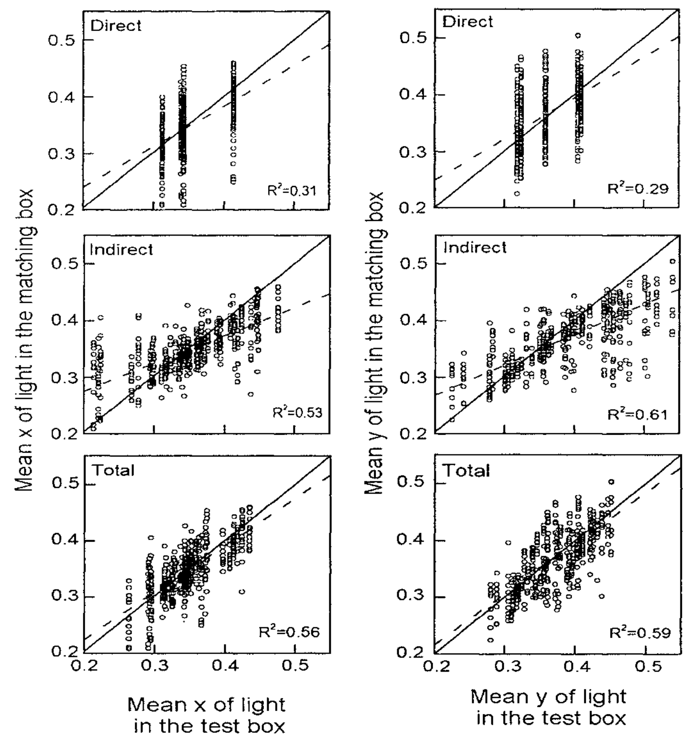

Figure 3: Results of the experiment: Mean chromaticity coordinates of light in the matching box are plotted against those in the test box for each of direct, indirect and total components of light. Left panels present chromaticity x and right panels chromaticity y. Broken lines are liner regression to data. Solid lines have a slope of 45 degree and intersect the origin 0. All matching results of five subjects are plotted together.

3. RESULTS

The main interest of this experiment is to see how the subject's perception of lighting in the test box relates to two physical light components; the direct component emitted from the light source and the indirect component reflected between inner surfaces of the box.

To know quantity and color of indirect component of lighting, we calculated the illuminance distribution in the box produced by interreflections[3]. The enclosing surfaces of the box are divided into several zones, each of which is assumed to have a constant luminance over its area and to be perfectly diffuse reflector. By solving simultaneous flux balance equations for each zone we obtained indirect component of illuminance for each zone. Also we applied this computation to each wavelength with 20 nm intervals and total them to know colors of indirect components.

Figure 3 presents the results of the experiment. All matching results of five subjects are plotted together in this figure. Mean chromaticity coordinates of light in the matching box are plotted against those in the test box for each of direct, indirect and total components of light. Three panels on the left show chromaticity x and those on the right show chromaticity y. Note that colors of light in the matching box would indicate subjects' perceived colors of light in the test box. Thus, if perception of color of illuminant is determined by one of the light components, matching data for that component will fall near the solid line. Colors of direct components, which correspond to light source colors, do not relate directly to the perceived color of lighting. Color of indirect components, which are strongly affected by inner surface colors, correlates to the perceived color of lighting, however, the regression line apparently deviates from the 45 degree line. The total of direct and indirect components of lighting was closely correlated to the colors of lighting in the matching box and data points fall near to the 45 degree line, indicating the subjects understood that the test box was illuminated by a light source whose color is equivalent to the sum of the actual direct and indirect components. In other word, we cannot distinguish the indirect component of lighting from the direct component. The similar results were obtained in our previous study in which the illuminant colors were limited along yellow-blue direction [2].

The results of our present study suggest that the perceived color of lighting in a colored room can be predicted as the sum of direct and reflected components of the lighting. Further study using a real-scaled room may be required to develop a predicting method that takes visual effects in pracitical situations into account.

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Associate Prof. Dr. Taiichiro Ishida, Kyoto University, Graduate School of Engineering, Department of Architecture and Environmental Design, Yoshida-Honmachi, Sakyo-ku, Kyoto, 606-8501, Japan. Phone: +81 75 753 4766, Fax: +81 75 753 4766, E-mail: ishida@archi.kyoto-u.ac.jp
MSc, Mr. Naohiro Toda, Currently at Matsushita Electric Works, Ltd., 234 Togasaki 2-chome, Misato, Saitama, 341-0044, Japan. Phone: +81 48 956 1745, Fax: 81 48 948 1007, E-mail: toda@lpd.mew.co.jp

UNIFORM SCALE OF CHROMATICITY AND HIDDEN GEOMETRICAL STRUCTURE OF THE COLOR OPPONENCIES IN FOVEAL VISION

Claudio Oleari
Università degli Studi di Parma, Dipartimento di Fisica,
Istituto Nazionale di Fisica della Materia, Parma, Italy

Abstract
The coordinates of the Uniform Color System of the Optical Society of America (OSA-UCS) [1, 2] *have been written as logarithmic functions of the tristimulus coordinates in two different ways, related to different geometrical structures, one "evident" and the other "hidden"* [3]. *The hidden structure reveals the role of a particular reference frame in the tristimulus space, named "main" reference frame. Analogously, a uniform scale chromaticity diagram for the foveal vision and based on MacAdam ellipses* [5] *has been written by logarithmic functions of the tristimulus values* [4]. *The geometrical structure of this transformation is "evident", in analogy with the transformations given for the 10° observer. Such a situation induces us to search for a "hidden" geometrical structure for foveal vision. It is shown that a "main" reference frame for the foveal vision exists and that new uniform chromaticity coordinates for the viewing situation of the MacAdam ellipses are obtained by a mixing of the logarithms of the ratios of two pairs of components of the tristimulus vector in the "main" reference frame. Now the analogy between 2° and 10° observers is complete.*

Keywords: *uniform color scale, color opponency*

1. INTRODUCTION

Recently, we have considered the problem of uniformity of scale for the foveal and extra foveal vision and we have proposed solutions for both visual situations. With regard to extra foveal vision, we have shown two different geometrical structures in the Uniform Color System of the Optical Society of America (OSA-UCS) [1, 2], one structure is *evident* and the other *hidden* [3]. In both cases, the $(L_{OSA}; j, g)$ coordinates of the OSA-UCS system are written as logarithmic functions of the (X_{10}, Y_{10}, Z_{10}) tristimulus values. The hidden geometrical structure is simpler and shows higher symmetry and regularity. Particularly, this structure reveals the role of a reference frame in the tristimulus space, that we name *main* reference frame.

With regard to foveal vision, we proposed a chromaticity diagram with uniform coordinates (t, d) [4], based on MacAdam ellipses [5] and obtained from the tristimulus space by logarithmic transformations. The geometrical structure of this transformation is *evident*, in analogy with the transformations given for the 10° observer.

The aim of the present work is to find a *hidden* geometrical structure for the 2° observer based on a *main* reference frame. This structure exists and the uniform chromaticity coordinates are given by a linear mixing of the logarithms of a pair of ratios of tristimulus components in the *main* reference frame.

2. ANALOGIES BETWEEN EVIDENT GEOMETRICAL STRUCTURE OF 2° AND 10° OBSERVERS

The analogies existing between the evident geometrical structure of OSA-UCS system, that hold for the 10° observer, and the structure of the uniform chromaticity coordinates (t, d) derived from the MacAdam ellipses, that hold for the 2° observer, are the following:

1) two neutral lines subdivide the hues into two opponent sets;
2) the chromatic response functions related to the opponent mechanisms are logarithmic functions, whose arguments are ratios of proper tristimulus values;
3) these ratios are in correspondence with angles, therefore in both cases the chromatic discrimination is represented by proper angular variables;
4) the centers of the angles are the deuteranopic and the protanopic confusion points for the two degree observer and two pairs of points close to protanopic and tritanopic confusion points, respectively, for the 10° observer. In this second case the center of the angle jumps from one point to the other of the pair in the changing of the opponent hues. This is the main difference between the two observers.

The many existing analogies induce us to classify as *evident* the geometrical structure of the uniform coordinates (t, d).

3. 2° OBSERVER AND HIDDEN GEOMETRICAL STRUCTURE

In this section, in analogy with the 10° observer, the existence of a hidden geometrical structure for the 2° observer is shown. First, we have to define for the 2° observer, if possible, the main stimuli and the main reference frame, as defined for the 10° observer.

3.1 Main Reference Frame and Main Stimuli

The hidden geometrical structure regards the color opponencies and the lattice, like the OSA-UCS one, facilitates the finding of such a structure. The available empirical data for the 2° observer are mainly constituted by the MacAdam ellipses, and we must derive the geometrical structure of the color opponencies from these ellipses. In the uniform scale chromaticity diagram, the MacAdam ellipses are represented by equal radius circles embedded in a square lattice, therefore the transformation, that alters such a square grid into a grid of equispaced parallel straight lines, alters the equal radius circles in equal ellipses and the directions of the semi axes are the same as a *dilatation* (i.e. a transformation equal to a change of scale). Moreover, in the OSA-UCS system, the hidden geometrical structure is related to the Weber fraction of ratios of tristimulus values in the main reference frame. This induces us to find in the CIE (x, y) diagram, if it exists, two three-component diagrams $\boldsymbol{A_iB_iC_i}$ (i = 1, 2) such that

a) at constant lightness Weber fractions hold

$$\frac{\Delta(A_i/B_i)}{(A_i/B_i)} = k_{A_iB_i} , \qquad (1)$$

with $\Delta(A_i/B_i)$ evaluated as semi-axes of the MacAdam ellipses,

b) MacAdam ellipses, represented on a diagram with two orthogonal coordinates

$$q_i = \ln\left(\frac{A_i}{B_i}\right),\ q_j = \ln\left(\frac{A_j}{B_j}\right), \qquad (2)$$

obtained up to a factor by the integration of the Weber fractions, appear as equal ellipses with parallel axes.

The research for these diagrams is long and tedious, but successful. An iterative technique converges on a set of three points $\boldsymbol{A}$, $\boldsymbol{B}$ and $\boldsymbol{C}$ as follows (In such a process the MacAdam ellipse with center (x = 0.160, y = 0.057) is not considered, as in previous ones [4, 6], because its orientation is in contrast with the general setting of all the other ellipses): a three component diagram $\boldsymbol{ABC}$ exists (Fig. 1)

$$\begin{aligned} \boldsymbol{A} &= (x = 1.002, y = 0.091) \\ \boldsymbol{B} &= (x = 1.513, y = -0.840) \qquad (3) \\ \boldsymbol{C} &= (x = 0.162, y = -0.008), \end{aligned}$$

and any pair of the following quantities

$$q_{AB} = \ln\left(\frac{A}{B}\right),\ q_{BC} = \ln\left(\frac{B}{C}\right),\ q_{CA} = \ln\left(\frac{C}{A}\right) \quad (4)$$

can be considered as orthogonal coordinates, on which the MacAdam ellipses are equal and with parallel semi-axes.

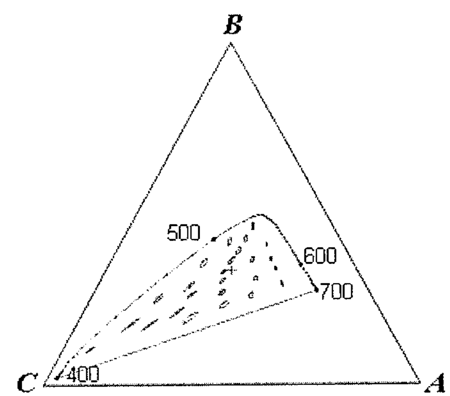

Figure 1: Chromaticity diagram with MacAdam ellipses (enlarged 10 times) in the *main* reference frame.

Stimuli **A**, **B** and **C** with chromaticity (3) are the *main stimuli*, and the reference frame where the main stimuli are the reference stimuli is the *main reference frame*.

3.2 Dilatation and color opponency mixing

In all three diagrams with coordinates (q_{AB}, q_{BC}), (q_{BC}, q_{CA}) and (q_{CA}, q_{AB}), the MacAdam ellipses are equal and equally oriented, therefore these chromaticity diagrams can be transformed by proper dilatations into diagrams where the ellipses are equal radius circles. The directions of dilatation are given by the semi-axes of the ellipses. The dilatation parameters are the reciprocal of the averaged lengths of the long and the short semi-axes, respectively. The final chromaticity diagrams obtained in three different ways are equal but differently oriented. We choose to set these diagrams with the long wavelength part of the spectrum locus parallel to the abscissa axis. Therefore the three diagrams are rotated by proper angles. The complete transformation is linear

$$\begin{pmatrix} -g^* \\ j^* \end{pmatrix} = \mathbf{T}_{ij,kl}\begin{pmatrix} q_{ij} \\ q_{kl} \end{pmatrix} \qquad (5)$$

where

$q_{ij} = q_{AB}$, $q_{kl} = q_{AC}$ for the 1st pair,
$q_{ij} = q_{AC}$, $q_{kl} = q_{BC}$ for the 2nd pair,
$q_{ij} = q_{AB}$, $q_{kl} = q_{BC}$ for the 3rd pair,

and g^* and j^* are the uniform scale coordinates, named in analogy with the OSA-UCS system. The origin of the g^* and j^* coordinates is in the adaptation white C. The three diagrams are exactly equal (Fig. 2) and this is not a surprise, because the three coordinates q's are mutually dependent satisfying the following identity

$$q_{AB} + q_{BC} + q_{CA} =$$

$$= \ln\left(A/B\right) + \ln\left(B/C\right) + \ln\left(C/A\right) = 0 . \qquad (6)$$

The uniformity of scale is good: the mean radius evaluated by 46 radii for each circle is 0.34 jnd's (the expected value is 1/3 of jnd) with an RMS equal to 0.09 for the hidden geometrical structure.
These results hold for the viewing situation of the MacAdam ellipses.

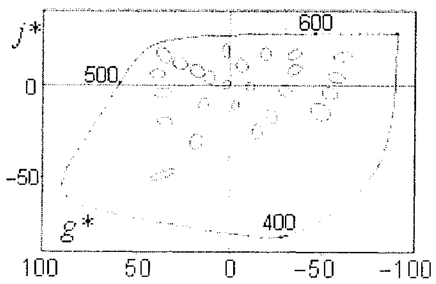

Figure 2: Uniform scale chromaticity diagram related to the hidden geometrical structure. The coordinate origin is in the standard white C and the unit of scale is the just noticeable difference (jnd).

4. CONCLUSIONS

The analysis carried out in this work shows that the analogy between the two and ten degree observers is almost complete. The color opponent mechanisms of both observers have an *evident* and a *hidden* geometrical structure. The hidden geometrical structure is the same for both observers. Only the numerical values are different. In the evident geometrical structures some differences exist, but the main characteristics are equal for the two observers.

The simplicity and the symmetry of the hidden geometrical structure induces us to believe that this structure is more meaningful.

5. ACKNOWLEDGEMENTS

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Claudio Oleari, Università degli Studi di Parma, Dipartimento di Fisica, Istituto Nazionale di Fisica della Materia, Parco Area delle Scienze 7A, 43100 Parma, Italy. Phone: +39 (0) 521 905214, Fax +39 (0)521 905223, E-mail: oleari.claudio@unipr.it

WHAT INFORMATION IS CODED IN HUMAN V4? - NOT ONLY COLOR, BUT ALSO FIGURE-GROUND SEGREGATION -

Ichihara Y.G.[1)4)], Nakadomari S.[2,3)],
Takeuchi H.[3)], Kitahara K.[2)], Miyauchi S.[4)]
Hosen Gakuen College, Tokyo, Japan[1)], Dept. of Ophthalmology, The Jikei University School of Medicine, Tokyo[2)], Japan Kanagawa Rehabilitation Hospital, Kanagawa, Japan [3)], Communications Research Laboratory, Hyogo, Japan[4)].

Abstract
Whether human V4 is a color center or not is still controversial, because a colored stimulus is usually presented with a figure and a ground, and it is difficult to completely separate the color processing from the processing for figure-ground segregation.
This suggest that V4 is not just a color center but also for reading separate figures and the background when reading shapes from colors.
In this study, the stimuli were only the background, and the results indicated that with textured pattern stimuli, with no shape in the figure, V4 does is not active even with colors.
Here we report that V4 can be activated not only by color, but also by figure-ground segregation.

Keywords: *human color vision, fMRI, V4, color picture*

1. INTRODUCTION

Artists have long been adventurous persons in perception, using color and shape to suggest, to strengthen, to destroy, or simply to compose what they assume to be their viewer's traditional associations between color and form. Modern color imaging of current printing techniques and displays are grand benefited by the theory of neo-impressionism by Paul Signac and Georges Seurat. Color imaging which is a collection of pixel dots is essentially different from pre-impressionism paintings that are drawn by following the contours of the object.
The task of drawing color images is different from arranging colors one-dimensionally.
The composition of colors in 2 dimensions requires a totally different logical explanation from looking at single colors in a small vision, such as contrast and assimilation of colors in figures and the background, or categorization of similar colors.
In 1885[1)] and in 1888[2)], Charles Henry, a French psychologist, first proposed that "les lignes"(line), "les couleurs"(color), and "les colours sombres" (shade) each have their own independent role as basic components in a picture, and that these roles are different from roles expressing the concrete object.
Seurat, and later Signac were strongly impressed by this idea. They drew by dividing the image plane with color dots. Bauhaus also inherited this idea, and for the first time, true "Abstract Art" was born. Artists like Mondrian, drew pure abstract paintings by constructing the plane with lines and colors, without representing any particular concrete subject.

The exciting creations by these "Modern Artistic Revolution" painters during the 1910s and 1920s intuitively expressed this localization of colors and shapes in the visual cortex before neuroscientists discovered them.
In the 1960s, Hubel and Wiesel[3] found that neurons in cats' brain react selectively to a transverse line in the visual field, which involves orientation in particular. Livingstone et al.[4][5] showed the reaction of a particular region towards shape, color and movement in the visual cortex of the monkey brain.
In the 1990s, people were finally able to see the human brain non-invasively. Study on V4 was conducted in 1989 by Lueck et al. and in 1991[6] by Zeki et al. using PET. In 1995[7] this was followed by another study by Sakai and in 1997[8] by McKeefry using fMRI. A study using picture stimuli was conducted in 1998[9] by Zeki and Martini, indicating that the more definite objects colored with natural colors would activate more anterior region, V4a. With these study backgrounds our group have also succeeded in projecting V4 activity using fMRI and picture stimuli starting from winter 1999[10][11].

2. METHODS

Exp. 1 [10]: Four subjects without color vision deficiency observed the following three variations of Ishihara plates:

1) A plate composed of Readable-Colored number on a dappled background with a different color (RC).
2) A plate composed of a Non-readable (random dot) Colored pattern on a dappled background with a different color (NC).
3) A plate composed of a Non-readable Monotone pattern on a dappled background with the same achromatic color (NM).

Exp. 2 [11]: Three subjects without color vision deficiency observed the following five pictures composed of 1400 small dots (Fig. 2):
"rand", "kumo", "uzuu", "rect", and "mono". The first four were composed of dots with four different but iso-luminant colors: "rand" is a random pattern; a vague cloud-like pattern was depicted in "kumo"; a whirl in "uzuu"; rectangles in "rect". "mono" were achromatic versions of these four pictures. Data were collected with a clinical MRI system (Siemens Vision, T2* weighted EPI; TR: 5000 msec; TE: 66 msec; FA: 90 degrees; voxel size: 3x3x3 mm). Preprocessing (realign and smooth [6x6x6 mm]) were done using SPM99. Then, we calculated the mean time course of the MR signals in the areas around the collateral (V4) and the calcarine sulcus (V1/V2).

3. RESULTS

In Exp. 1, V1/V2 was activated in both RC-NM and NC-NM subtractions.
However, only the RC-NM subtraction revealed left V4 activation, and there was no significant difference between the NC and NM conditions. In Exp. 2, all the colored pictures ("rand", "kumo", "uzuu", and "rect") activated V4 in comparison with the achromatic pictures ("mono"). In addition, there was a tendency that both "uzuu" and "rect", which had clear figure-ground segregation, showed higher V4 activity than "rand" and "kumo", which had no or vague figure-ground segregation (Fig. 3).

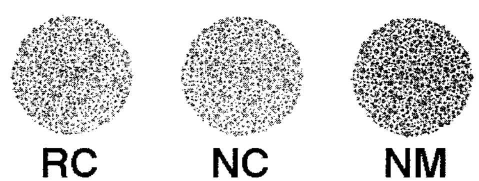

Figure 1: Stimuli employed in Exp. 1

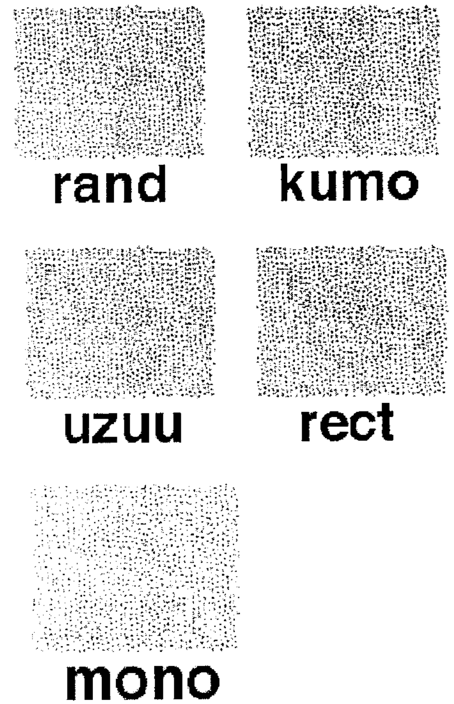

Figure 2: Stimuli employed in Exp. 2

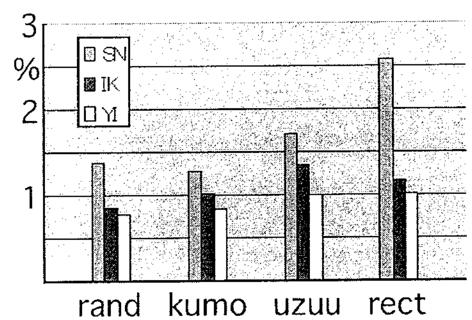

Figure 3: % signal changes in V4 compared with "mono" (control condition) in Exp. 2

4. DISCUSSION

The result of kumo being close to that of random dot stimulus was surprising because kumo has a high proportion of adjacent dots being the same color. This result suggests that the V4 may be activated by color configuration, the block of color dot of certain size. The relationship activity between uzuu and rect was surprising. What is the picture similarity of uzuu and rect?
First of all, when these two stimuli are observed as pictures, they both have a center. A structure that makes you think·· that a "concrete or abstract something" is there seems important in this case. Kumo and rand's similarity is that these two do not have a geometrical figure to be its center and is a decorative pattern. Kumo seems fluffy as its name "cloud" suggests, and rand is random dot, a texture not resembling any particular object.
Currently, some scientists believe that visual information is processed in parallel in 2 modules in the brain[12]. It is assumed that visual working memory assimilates the information from 2 visual information processing streams.
The first is the dorsal "where" stream (processing space, position and motion information) that runs from V1 through the posterior parietal.
The second is the ventral "what" stream (color, shape, face information processing) running from V1 through the inferior part of the temporal lobe, in the confines of the prefrontal cortex.
V4 is located in the ventral stream (color, shape, face information processing). From these data, it is assumed that all of these visual information are inputted in V1 but the texture information may be omitted in V4. In kumo or rand, the same colors and areas of each color were present but they do not possess the "figure" to be its geometric figure or object.
V4 is not highly activated solely by colored dots. Our results indicate that V4 may activate when the construction of dots suggest object characteristics ("what" information processing). Also, it is assumed

that color/shape attribution and texture attribution is separated in V4 or V1/2.
These results suggest that human V4 is not a simple color center. Rather, V4 activity is more associated with figure-ground segregation as a pre-processing for shape and color category comprehension in the higher ventral/what system.

5. CONCLUSION

The human color cognition system is not a single mechanism. The fact that stimuli exist that may or may not activate V4 indicates that the difference between "seeing of color (V1 activity)" and "recognition of color (V4 activity within the process of cognition of colors as an object)". Random dot stimulus or kumo exhibits low V4 activity even though the same colors and the same amount of color are used as uzuu or rect.
These stimuli have camouflage characteristics to blend into the background and may go through the dorsal stream as texture. As a leopard with its spotted pattern can blend into a leaf shade background, the camouflage texture stimuli may activate the movement area (V5) when in motion.

6. ACKNOWLEGEMENT

*Iso luminance with between color and achromatic stimulus was adjusted based on the references[13] and using colorimeter by Mr. Ichiro Kuriki, of NTT communication science laboratories.
**Image-calculator is an analytical program developed by Dr. Atsushi Kandatsu, of Jikei University.
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Associate Prof. Dr. Yasuyo G. Ichihara, Hosen Gakuen College, Department of Art & Design, 2-33-26, Chuo, Nakano-ku, Tokyo Japan, Phone: +81 3 3370 4022, Fax: +81 3 3365 0393, E-mail: ichihara@po2.hosen.ac.jp

PRACTICAL EXPERIENCES WITH THE COLOR CONTOUR TEST

Klára Wenzel*, Ilona Kovács**, And Veronika Böhm*
* Budapest University Of Technology And Economics
* * Rutgers University, Psychology Department

Abstract
The Contour Integration Test consists of small achromatic Gabor signals on an A4 gray paper or on the monitor. The Gabors are placed on the paper with random orientation and distances (noise), but some of them are arranged at the same distance from each other in continuously changing orientation and form a closed loop (contour). The 15 plates of the test are arranged in an increasing order of difficulty, where difficulty is defined by the amount of noise within each card. The Gabors are replaced by disks of variable diameter, luminance and color on the color version of the Contour Integration Test. The contour is defined by red disks, and the background is composed of mixed red and green disks. We conducted examinations on 24 people with normal and on 12 with anomalous color vision. Color vision of the participants was checked with pseudoisochromatic plates and a Heidelberg anomaloscope. We have conducted measurements with both the Contour Integration Test with Gabors and the Color Contour Integration Test. The results of the experiments with the Color Contour Integration Test were in good correlation with Pseudoisochromatic Tests.

***Keywords**: Defective Color Vision, Contour Integration Test ,Color Contour Integration Test, Anomaloscope, Pseudoisochromatic plates*

1. INTRODUCTION

Our goal is to introduce a new test of color vision, the Color-Contour Test, and to present data and practical experiences on people with normal vision and color deficiences.

2. METHODS

Each location in the retinal image is being analyzed by a large number of local cortical detectors that process different aspects of the image. After such an analysis, in order to arrive at a unified percept of any visually perceived object or event, the activity of local cortical analyzers responding to the same object has to be integrated. Visual psychophysics can be applied to reveal visual integration mechanisms. A contour-integration task has been applyed to study the integration of orientation information across the visual field, e.g. [2,6,8,9]. The task involves the detection of spatially extended patterns with continuous paths of Gabor signals and orientation noise. Linking of local Gabor elements in this task requires both local orientation analysis, and lateral interactions among the local analyzers. These relatively low-level interactions are sensitive to factors of global perceptual organization. Superiority of closed paths over open paths has been found in terms of maximal separation between adjacent elements in this task [5,8,10,12] and enhanced local contrast sensitivity within closed contours. The superiority of closure – a classic Gestalt

concept–under these circumstances is striking because the global constraint of closure affects local association rules: adjacent, nearly collinear segments can be linked across larger spatial distances when they belong to a closed contour.

In a series of recent experiments, the development of visual spatial integration and the effect of abnormal visual input has been tested in children and in adults. In addition to significant improvement of performance in children between 5 to 14 years in the contour integration task [3,7], a deficit was found in the performance of adults who had abnormal binocular visual experience during their developmental period [7, 8,]. Test of very young subjects (3-month-old babies) [7, 11] and patient populations with a possibility of perceptual organization problems (schizophrenics [5], agnosic patients [4]) has also been started. In all these studies, a card-test version of the contour integration task is being used. The card test was designed for the purposes of testing children and clinical patient populations.

Ilona Kovacs has developed a new version of the contour card test for the request of the Coloryte Inc., the Color-Contour Test. Instead of using orientted Gabor patches as elements, the cards now contain non-oriented disks of diferent sizes and randomized luminances. The path of the contour is defined by color similarity between the elements (red contour elements, green background elements). The difficiulty level of the card-set is matched to that of the oriented set by adjusting the percentage of red elements in the background noise. The path of the contour can only be found based on hue information. There are no lumnance cues that would help finding the path. The test is composed of 15 cards, in an increasing order of difficulty. The test can be administered by using a computer, and displaying the card, or using a printed oout, hardcopy version of it.

The test is relevant because it goes beyond the other pseudo-isochromatic methods in that it makes it possible not only to isolate normal versus color deficient vision, but to define the depth of color deficiency [2]; and to objectively measure the effectiveness of Coloryte goggles [1, 13].

3. MEASUREMENTS

- **Subjects**

24 people with normal color vision, and 12 color deficent people participated in these measurements. They were all students at the tecvhnical University of Budapest, aged between 20 and 30 years.

- **Color vision tests**

We checked the participants' color vision by the Heidelberg anomaloscope, and pseudoisochromatic plates.
In the anamaloscopy measurements, we defined the range within which a subject could obtain a match between the two halves of the visual field. The experimenter set the R/G values by 5 units, and the subject had to find the Y setting at which the two halves of the visual field appeared equivalent.
We used the Ishihara plates, and Velhagen booklet as pseudoisochromatic plates. Since the two tests have different numbers of plates, and the plates have different numbers of figures, we defined a relative measure of performance, which is the percentage of the correctly identified figure and the total number of figures. Color deficiency was considered anomalous when both tests or at least one showed significant differences from normal performance levels. Normal performance is characterized by R/G=40+/-4 and Y=15 in the Heidelberg anomaloscope. People with normal vision easily identifed all figures in the

pseudoisochromatic plates. We presented the plates under normal daylight conditions.

- **Contour Test and Color-Contour Test**

We printed out the Contour and the Color-Contour test-cards, and covered them with plastic to avoid normal wear. We presented the cards under normal daylight conditions, from about 60 cms distance, in an increasing order of difficulty. Threshold performance was defined by the first not identified card. We run the tests four times on all participants. To avoid familiarity effects, we presented the test-cards by randomly rotating them.

4. RESULTS AND DISCUSSION

The results of the anomaloscopy, the psudoisochromatic Test, Contour Test and Color-Contour Test cards can be found in the Table 1. NCV refers to normal color vision, and ACV refers to anomalous color vision.

We applied an analysis of variance. The level of significance was %95.

Although the four repetitions of the Contour tests would provide an opportunity for double classification and for crosseffect anaylsis, we have not done that because the crossefect was so strong (the Color Contour results of the color deficient people are very different from that of the other participants) that the results can better be analyzed by using single classfication.

5. CONCLUSIONS

- There is a significant difference between the Color-Contour results of NCV and ACV people (single classification, F=53.8, F_{crit}=3.942). Therefore, the test can be applied for the diagnosis of color vision.
- There is no significant difference between the Contour results of NCV and ACV people (single classification, F=0.139, F_{crit}=3.942). There is a significant difference between the Contour and Color-Contour results of ACV people (single classification, F=44.29, F_{crit}=3.942). Therefore, the performance on the Contour Test and on the Color-Contour test is independent from each other.
- Average performance for all observers on the Contour test was 12.45, variance was 1.1, worst performance was 11, and best performance was 15. Average NCV performance on the Colour-Contour test was 12.98, variance was 1.0, worst performance was 11, and best performance was 15. Average ACV performance on the Colour-Contour test was 8.42, variance was 4.1, worst performance was 0, and best performance was 15.
- We investigated the fatigue and practice effects as well. There was no signifcant difference between the results of the four repetitions, therefore there is no fatigue/practice effect in these experiments.
- Diagnosis of color deficiencies is a difficult and tiresome work. There are even controversies in the data, which can be observed in our table also (controversial data are in boldface in the Table 1.). For example the anomaloscopy results of NCV subjcets 13, 19, 20, 21, 23, 24, 30 and 34 are outside of the normal range, at the same time, they show 100% correct performance on the pseudoiso-chromatic plates. We found even greater controversies among ACV people, see e.g. subjects 3 and 9.
- There is a good agreement between the results of the pseudoisochromatic plates and the Color - Contour Test. Whenever there is a 100% correct

Table 1: Measuring data

Color Vision	No.	Male	Anomaoscope	PIC Test, %	Contour Test, No.	Color Contour Test, No.
Anomalous Color Vision	1	M	10/17-30/15	47	11	6
					12	7
					11	5
					11	7
	2	F	44/15-49/15	89	12	11
					12	10
					13	12
					13	12
	3	**M**	**25/20-45/18**	**100**	11	12
					12	12
					12	13
					12	13
	4	M	00/31-73/01	32	11	0
					12	0
					12	0
					11	0
	5	M	00/25-73/01	53	12	6
					13	7
					13	5
					13	6
	6	M	62/07-67/05	74	11	10
					11	11
					12	11
					11	9
Anomalous Color Vision	7	M	50/11-64/07	17	14	6
					15	2
					13	4
					13	4
	8	M	09/17-11/16	79	12	11
					13	12
					12	11
					13	10
	9	**M**	**50/12-52/12**	**100**	12	15
					12	15
					13	15
					13	15
	10	M	19/16-22/16	79	12	8
					13	10
					13	9
					12	10
	11	**F**	**No acceptance**	**100**	13	9
					14	10
					12	10
					13	9
	12	M	10/17-37/14	42	14	6
					15	5
					14	7
					13	6

performance for the pseudo-isochromatic plates, the result of the Color-Contour Test is always in the normal range with a single exeption (subject 11).

- Whenever the result with the pseudoisochromatic plates is below the normal range, the result with the Color-Contour Test will also be below normal.

Color Vision	No.	Male	Anomaoscope	PIC Test, %	Contour Test, No.	Color Contour Test, No.
Normal Color Vision	**13**	**M**	**44/16-46/15**	**100**	14	11
					13	12
					14	12
					14	11
	14	F	40/15-42/15	100	11	12
					11	12
					12	12
					11	13
	15	M	37/16-45/15	100	13	12
					13	12
					13	12
					13	13
	16	M	37/15-42/15	100	11	12
					12	14
					14	13
					13	12
	17	M	35/15-42/14	100	11	12
					12	13
					12	13
					12	13
	18	F	40/15-45/13	100	11	15
					11	15
					11	15
					12	15
	19	**M**	**45/15-46/15**	**100**	14	12
					15	13
					14	13
					14	13
	20	**M**	**42/13-50/13**	**100**	11	13
					12	13
					12	13
					13	13
	21	**M**	**40/16-47/14**	**100**	12	13
					12	13
					13	13
					11	13
	22	M	39/18-45/13	100	13	13
					13	14
					14	13
					14	13
	23	**M**	**45/15-50/14**	**100**	11	13
					12	13
					11	12
					12	13
	24	**M**	**30/11-50/13**	**100**	12	12
					12	12
					11	12
					11	13

Color Vision	No.	Male	Anomaoscope	PIC Test, %	Contour Test, No.	Color Contour Test, No.
Normal Color Vision	25	M	40/16-42/16	100	12	13
					12	13
					12	13
					12	15
	26	M	35/16-45/16	100	14	13
					12	13
					14	13
					14	13
	27	M	39/15-42/15	100	12	15
					14	15
					14	15
					14	15
	28	F	40/15-43/15	100	11	12
					11	12
					12	14
					11	14
	29	M	35/15-42/14	100	12	13
					12	12
					12	11
					12	11
	30	**M**	**39/15-42/13**	**100**	14	13
					14	13
					14	13
					14	13
	31	M	37/13-42/15	100	13	13
					12	14
					13	14
					12	12
	32	F	37/19-47/14	100	14	13
					12	13
					13	13
					13	13
	33	F	37/17-42/15	100	13	13
					12	12
					12	13
					12	12
	34	**M**	**44/12-46/12**	**100**	11	12
					12	12
					11	13
					12	13
	35	M	36/15-41/15	100	11	15
					11	15
					11	15
					11	15
	36	F	38/16-42/14	100	14	13
					14	13
					14	12
					14	12

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Prof. Dr. Klára Wenzel, University of Budapest, Faculty of Mechanical Engineering, Department Precision Mechanics and Optics, Egry Jozsef utca 1, H 1521 Budapest, Hungary. Phone: + (36-1)463 3792, Fax: + (36-1)463 4167, E-mail: wenzel@coloryte.hu

Dr. Ilona Kovács, assotiated professor, Laboratory of Vision Research, Rutgers University, Busch Campus-Psychology Building, Piscataway, NJ 08854, USA. Phone: + 1-732-4456714, Fax: + 1-732-445-6715, E-mail: ikovacs@cyclops.rutgers.edu

Dipl. Ing.Veronika Böhm, University of Budapest, Faculty of Mechanical Engineering, Department Precision Mechanics and Optics, Egry Jozsef utca 1, H 1521 Budapest, Hungary. Phone: + (36-1)463 3792, Fax: + (36-1)463 4167

RATING OF COLORS USED FOR LIVING ENVIRONMENT BY YOUNG AND ELDERLY PEOPLE

Haruyo Ohno, Masami Kono
Otemae university, Itami in Hyogo, Japan

Abstract
When devising a color plan, it is desirable to predict the physical and physiological effects of colors to be used. This paper reports on the results of experiments on the ease of visual perception of colors commonly used for living environments by young and elderly people.

Keywords*: elderly people, interior color, living environment, safety color, young people*

1. INTRODUCTION

The ease of visual perception of colors used for living environments is affected by various factors, whose psychological effects have extensively been studied. A wide variety of objects functioning as visual displays are placed in and out of buildings, including traffic lights, signboards, posters, and advertisements. If we can predict how these colors are perceived in their environments and how people are affected by them psychologically and physiologically[1], then the information would be very useful for color planning.

2. AIM

This paper discusses the ease of visual perception of colors commonly used for living environments. The author has found through investigation that the visual perception of an achromatic color target can be evaluated by three parameters: the target size, illuminance, and contrast with the background. For chromatic color targets, three parameters – the three attributes of colors, Munsell Hue, Munsell Chroma, and Munsell Value in the Munsell renotation system – are added to the above-mentioned three parameters for predicting achromatic color perception. The author has conducted experiments using subjects to grasp the effects of the parameters on the ease of visual perception of chromatic color targets[2)-7)]. As a result, it has been inferred that color planning for easy visual perception of chromatic colors can be achieved to a certain extent for Munsell Value and Munsell Chroma by using the relationship among the three parameters for predicting achromatic colors, excepting Munsell Hue.

It has already been found difficult to quantitatively grasp the tendencies of rating hues, as it widely varies from subject to subject. Also, it is necessary in this aging society to give consideration to aged people as well when investigating the perception of visual displays. It was therefore decided to conduct a questionnaire survey and visual perception experiment in regard to the rating of colors used in living environments by young and elderly subjects. An achromatic background was used for examining the ease of vision of chromatic color targets.

3. METHOD

- Subjects

Tests were conducted on 662 subjects in two groups: a young group consisting of 394 students of Otemae Junior College (for women) and an elderly group consisting of 228 members of Hyogo Inamino Senior Citizens' College, a prefectural college for the elderly. The age of the young group was 19 on average, whereas the average among the elderly was 66. Table 1 gives the age distributions of the groups. Table 2 gives the years of employment of members of the elderly group.

Table 1: Subjects by age and gender

Genera-tion	58 ~ 59	60 ~ 69	70 ~ 79	80	Un-known	Total
Female	9	73	14	0	4	100
Male	2	86	39	1	0	128
Total	11	159	53	1	4	228

Table 2: Length of employment of subjects

Length of emplo-yment	1 ~ 10	11 ~ 20	21 ~ 30	31 ~ 40	41 ~ 50	Un-Kno wn	Tot-al
Female	9	73	14	0	4	34	100
Male	2	86	39	1	0	2	128
Total	11	159	53	1	4	36	228

-Procedure

The questionnaire survey on color taste and visual perception tests were conducted on the same day at a lecture room, the interior of which (ceiling, walls, floor, desks and chairs) was finished in achromatic or nearly achromatic colors. The light source was white fluorescent tubes, with the average illuminance on the desk being 500 lx. The windows were covered with gray black-out curtains. The fifty color targets as given in Table 3 were produced by Japan color research institute. These consisted of 16 colors high in Chroma, 16 colors medium in Chroma, 9 safety colors, and 11 commonly used interior finishes.

The subjects were asked to express the ease of visual perception of color targets in numerical values relative to the reference color target, which was compared with each test color target at the center of a background in N7. The two patches showing the test color target on the left and the reference on the right are located at a visual distance of 30 cm and visual angle of 3.2° × 2.4°. The subjects assumed the ease of vision of the reference on the N7 background to be 100 and then rated the ease of vision of the test color targets on the N7 background in comparison with the vision of the reference color target by numerical values of not less than 0.

Table 3: Color samples used for evaluation

Type	Munsell renotation for each sample
high - chroma	5R4/14,5YR7/14,5Y8/12,5GY7/10 5G5/8,5BG5/8,5B5/8,5PB4/12, 5P4/12,5RP4/12,5R5/10,5YR5/10 5Y5/10,5PB5/10,5P5/10,5RP5/10,
medium - chroma	5R5/6, 5YR5/6, 5Y5/6, 5GY5/6, 5G5/6, 5BG5/6, 5B5/6, 5PB5/6, 5P5/6, 5RP5/6, 5R5/8, 5YR5/8, 5Y5/8, 5PB5/8, 5P5/8, 5RP5/8
Safety colors [8)]	2.5RP4.5/12, 5R4/13, 2.5Y8/12, 2.5YR6/14, 2.5PB5/6, 5G5/6 N9.5, N1.5
Interior finish colors	10YR9/2, 10YR8/2, 10YR8/4, 10YR7/2, 10YR6/2, 10YR6/6, 7.5YR9/2, 7.5YR8/2, 5Y9/2, 2.5G7/3, 5YR6/2

4. RESULTS

4.1 Questionnaire survey

4.1.1 Characteristics of color taste

The subjects were asked to give their preferences for 13 colors: 10 hues and white, gray, and black.

Young age group

As given in Table 4, the colors preferred by the largest percentages of young subjects were white, black, and blue (60-70%), followed by gray, red, and yellow (20-40%). The colors designated as moderate by the largest percentage include yellow-red, yellow-green, and blue-green (50-55%), followed by green, blue-purple, and red-purple (around 40%). The color designated as not preferred by the largest percentage of young subjects was purple (40%). This percentage is the total of those for "not preferred" and "relatively not preferred."

Elderly age group

Tables 5-1, 5-2, and 5-3 give the results of color tastes among the elderly.

The colors preferred by the largest percentage of elderly female subjects were white (80%) followed by green and purple (around 40%). The percentages of preference for other colors ranged between 15 and 25%, showing even distribution. The color disliked by the largest percentage was gray, with more than 40% designating gray as the color they dislike or relatively dislike. Twenty percent of the elderly female subjects selected white as their favorite color, whereas little difference was observed among other colors. As for selection of one color they hate, 40% selected gray followed by yellow-red (13%) and black (12%). The largest percentage of elderly male subjects designated green as preferred (47%) followed by 37% for white. Many other colors were designated as preferred but the percentages were less than 20%. The largest percentage of the elderly male subjects designated black as a color they dislike (25%), while 16% designated gray in the "dislike" category. The colors designated as "slightly dislike" include gray (46%) and black (25%). As for the vote for one favorite color, 35% selected green, while other colors capturing less than 10%. Thirty-five percent of the elderly male subjects selected gray as one color they hate, followed by 25% and 10% selecting black and red-purple, respectively.

These results suggest that, for a color they actually hate, people tend to avoid giving a clear opinion by normal method of asking , instead responding that they "slightly dislike" the color.

For the elderly age group as a whole, the colors they designate as preferred include white and green. Those who "like" and "slightly like" white accounted for 70% of the elderly subjects, while the counterpart for green accounted for 75%. The percentages for "moderate" were highest for red, yellow-red, yellow, blue, blue-purple, and red-purple, ranging between 50 and 45%.

Table 4: Colors preferred by the percentages of young subjects (%)

Sample color	Like	Slightly like	Neutral	Slightly dislike	Dislike
R	31	29	34	5	1
YR	9	15	56	18	2
Y	23	22	39	13	3
GY	5	20	53	19	3
G	17	28	41	11	3
BG	12	21	52	12	3
B	61	24	12	2	1
PB	15	22	39	19	5
P	9	9	36	28	18
RP	9	20	41	23	7
White	76	14	8	2	0
Gray	41	29	21	7	2
Black	69	19	11	1	0

The colors designated in the "dislike" category by the elderly were gray and black, with the percentage being 55% and slightly less than 40%, respectively, including "slightly dislike."

4.1.2 Interest in signboards

Table 6 shows the degrees of interest in signboards. In the young age group, nearly 40% answered that their degree of interest in signboards is "moderate," and 36% "relatively low," suggesting their generally low degrees of interest in signboards. On the other hand, more than half the elderly

group answered that their degree of interest is very high or relatively high.

Table 5.1: Colors preferred by the percentages of elderly female subjects (%)

Sample color	Like	Slightly like	Neutral	Slightly dislike	Dislike
R	27	25	43	3	2
YR	18	20	47	10	5
Y	21	25	44	7	3
GY	26	32	31	8	3
G	43	27	26	2	2
BG	24	27	41	5	3
B	28	18	47	2	5
PB	19	25	41	9	6
P	38	28	28	3	3
RP	19	18	47	9	7
White	77	10	13	0	0
Gray	8	15	33	25	19
Black	24	13	46	6	11

Table 5.2: Colors preferred by the percentages of elderly male subjects (%)

Sample color	Like	Slightly like	Neutral	slightly dislike	Dislike
R	10	17	58	10	5
YR	3	27	51	17	2
Y	11	34	46	6	3
GY	15	34	43	5	3
G	47	30	18	4	1
BG	21	30	44	3	2
B	19	31	43	5	2
PB	6	19	60	13	2
P	15	23	38	17	7
RP	4	16	47	28	5
White	37	20	36	4	3
Gray	2	7	27	46	18
Black	7	8	32	28	25

Table 5.3: Colors preferred by the percentages of elderly whole subjects (%)

Sample color	Like	Slightly like	Neutral	slightly dislike	Dislike
R	17	21	52	6	4
YR	8	31	47	13	1
Y	15	30	45	7	3
GY	20	33	38	6	3
G	46	29	22	1	2
BG	22	29	43	4	2
B	23	25	45	4	3
PB	11	22	48	13	6
P	25	25	34	11	5
RP	10	17	47	20	6
White	54	16	26	2	2
Gray	4	11	30	37	18
Black	15	10	38	18	19

Table 6: Interest in signboards

Subject	Very high	Relatively high	Moderate	Relatively low	Low	Unknown
Young people	2.0	13.9	38.5	36.1	9.5	0
Elder people	13.6	39.5	34.6	3.5	0.9	7.9

4.1.3 Interest in interior colors

Table 7 gives the results of inquiring into the degree of interest in interior colors. Seventy-five percent of the young subjects answered that their degree of interest in interior colors is very high or relatively high, whereas the percentage for the elderly is 58%. Young people are therefore found to be greatly interested in interior colors.

Table 7: Interest in interior colors

Subjects	Very high	Relatively high	Moderate	Relatively low	Low	Unknown
Young people	21.9	53.9	18.8	5.0	0.4	0
Elder people	16.7	42.5	31.1	2.6	0	7.1

4.2 Visual perception tests

4.2.1 Distribution of ratings

Figure ** shows the ratings for ease of visual perception of 50 color targets by all subjects in the 10th, 50th, and 90th percentiles. The solid and broken lines represent those for the young and elderly age groups, respectively. The ratings for color targets high in Chroma are those for hues other than the safety colors with a Munsell Chroma of 10, 12, or 14. The ratings for color targets moderate in Chroma are those for 10 hues with a Munsell Chroma at a Munsell Value of 5.

- Ratings of colors with a high Munsell Chroma

Young age group – The ratings in the 90th percentile for colors with a high Munsell Chroma were significantly higher than the reference. These were particularly high for 5R4/14, 5YR7/14, and 5Y8/12 at nearly twice as high. In the case of a Munsell Chroma of 10, ratings in the 50th percentile were around 0.9 times the reference, despite the high ratings in the 90th percentile. The ratings in the 10th percentile were between 0.3 and 0.5 times the reference.

Elderly age group – The ratings in the 90th percentile for high-chroma color targets were 1.3 to 1.4 times the reference. The ratings in the 50th percentile for such colors were 0.7 to 0.8 times the references. Those in the 10th percentile were 0.3 to 0.5 times the reference, which equal the ratings by young subjects.

- Ratings of colors with a medium Munsell Chroma

Young age group – The ratings for colors with a Munsell Chroma of 8 were higher than those for colors with a Munsell Chroma of 6 with all hues. The ratings in the 90th percentile were 1.2 to 1.3 times the reference. The ratings in the 50th and 10th percentiles were 0.8 times and 0.3 times the reference, respectively.

Elderly age group – The ratings for colors with a Munsell Chroma of 8 or 6 were similar with all hues. Whereas the ratings in the 90th percentile were 1.1 times the references, the ratings in the 50th percentile were low at 0.8 times the references. The ratings in the 10th percentile were 0.3 times the reference in all cases.

When compared with the ratings by the aged, the ratings by the young subjects for colors with high and medium Munsell Chromas were higher in the 90th and 50th percentiles by 10 to 20%, whereas they were nearly the same as those by the elderly subjects in the 10th percentile.

4.2.2 Safety colors

The eight safety color standards specified in the Japan Industrial Standard (JIS) were rated. The eight colors include 2.5Y8/12 for "caution," 5R4/13 for "stop," 2.5YR6/14 for "danger," 2.5RP4.5/12 for "radioactive," 2.5PB5/6 for "attention," 5G5/6 for "safety," and black and white for others.

Young age group – The ratings in the 90th percentile were more than 2 times the reference for "caution", slightly more than 2 times the reference for "stop", 2 times the reference for "danger", and 1.7 times the reference for "radioactive". Those in the 50th percentile were 1.2 times, 1.1 times, 1.2 times, and 1.0 times the reference for the same categories, suggesting that these colors satisfactorily achieve their purposes. However, as for the standard colors for attention and safety, the ratings in the 50th percentile were low between 0.9 and 0.8 times the reference, though the ratings in the 90th percentile were 1.2 times the reference. This poses a problem to be examined in the future, as these colors should preferably be rated higher than the reference by a majority of the subjects.

The test results were re-tabulated for the subjects who named blue, black, and white as their favorite colors and purple as the color they disliked. The solid line in Fig. 1 represents the ratings by all subjects, and the broken lines represents the ratings by those who liked blue (○), black (●), or white (Δ) best and those who hated purple (×). This figure reveals that the tendencies of ratings are the same regardless of the color liking, though the absolute values slightly vary.

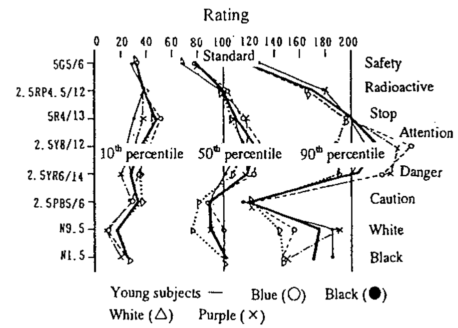

Figure 1: Rating of safety

Elderly age group – The ratings in the 90th percentile for the colors specified to express "caution", "stop", "danger", and "radioactive" are 1.4, 1.3, 1.2, and 1.2 times the reference. For the ratings in the 50th percentile, these ratios were 0.9, 1.0, 0.9, and 0.9 times the reference, suggesting that nearly half the subjects rated the ease of visual perception of these colors lower than the reference. For the colors expressing "attention" and "safety", the ratings in the 90th percentile were 1.1 times those for reference, exceeding the reference by 10%, whereas in the 50th percentile, the ratings were as low as 0.7 times the reference. These colors ought to be rated high by many people. When comparing the ratings by male and female subjects in the elderly age group, no marked difference was observed, though ratings by female subjects were generally higher.

It was therefore found that the ratings for ease of visual perception of the safety colors specified for "attention" and "safety" were low both by young and aged subjects, suggesting that the effect of safety colors may not be fully materialized. The safety colors expressing "attention" and "safety" should be re-examined.

4.2.3 Interior finishes

The visual perception of interior colors of commonly used interior finishes was investigated.

Young age group – In the 90th percentiles, the ratings for 10YR9/2, 7.5YR9/2, and 5Y9/2 were 1.4 times the reference, while those for 10YR8/2, 10YR/8/4, 10YR6/6, and 7.5YR8/2 were 1.2 times the reference. The ratings for other colors were nearly the same as the reference. In the 50th percentiles, the ratings for 10YR9/2, 7.5YR9/2, and 5Y9/2 were 0.8 times the reference, whereas the ratings for 10YR8/2, 10YR8/4, 10YR6/6, and 7.5YR8/2 were 0.7 times the reference. The ratings for other colors were around 0.6 times the reference. In the 10th percentiles, the ratings were around 0.2 times the reference.

Elderly age group – In the 90th percentiles, the ratings for 10YR9/2, 7.5YR9/2, and 5Y9/2 were 1.2 times the reference, while the ratings for 10YR8/2, 10YR8/4, 10YR6/6, and 7.5YR8/2 were 1.1 times the reference. The ratings for other colors were nearly the same as the reference. In the 50th percentiles, the ratings for 10YR9/2, 7.5YR9/2, and 5Y9/2 were 0.7 times the reference, whereas those for other colors were around 0.6 times the reference similarly to the case of young subjects. In the 10th percentiles, the ratings were 0.2 to 0.3 times the reference.

Accordingly, the ratings for interior colors by young subjects were slightly higher than those by elderly subjects in the 90th and 50th percentiles, but slightly lower than those by elderly subjects in the 10th percentile.

4.2.4 Contrast and ratings

Figures 2 and 3 show the relationship between the contrast of color targets and the ratings by subjects (●: 10 percentile, ○: 50 percentile, ×: 90 percentile).

Young age group – In the case of young subjects, different hues led to significant differences in the ratings in the 10th, 50th, and 90th percentiles. The data surrounded by the broken lines are the ratings for color targets with a Munsell Chroma of 10 or higher. This figure reveals that the ratings by young subjects for color targets with a low contrast may be high, if the chroma value is high. However, with a contrast of 0.5 or higher, the ratings for color targets with a high Munsell Chroma may generally be high but can also be low. A high contrast may not necessarily lead to a high rating.

Elderly age group – Though the ratings were lower than those by young subjects, the relationship between the contrasts and ratings of color targets tends to be similar to that of the young group.

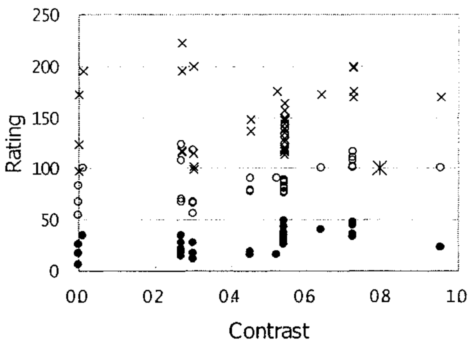

Figure 2: Young group

5. CONCLUSIONS

From the questionaire survey on color taste and visual perception tests, the following results were obtained:

1. Young subjects named white, black, and blue as colors they like and purple as a color they dislike.
2. Elderly female subjects liked white, green, and purple and disliked gray. Elderly male subjects liked green and white and disliked black and gray.
3. Young subjects were much more interested in interior colors than elderly subjects were.
4. Elderly subjects were highly interested in signboards, whereas young subjects were not very much interested in them.
5. The ratings for high-chroma color targets relative to reference color targets by young and elderly subjects were both high. In the 90th and 50th percentiles, the ratings by young subjects were 10 to 20% higher than those by elderly subjects. In the 10th percentile, their ratings were nearly the same.
6. The ratings for medium-chroma color targets relative to reference color targets by young subjects were slightly higher than those by elderly subjects, both being higher than the ratings for the reference, in the 90th percentile. In the 50th and 10th percentiles, their ratings

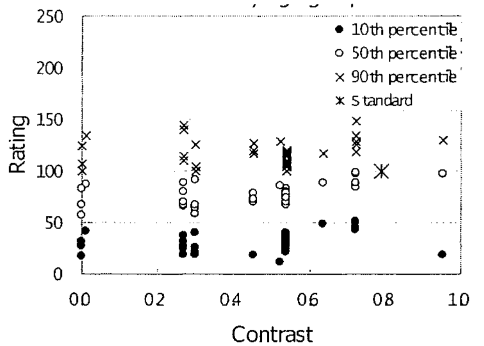

Figure 3: Elderly group

were the same at 0.8 times and 0.3 times the reference, respectively.

7. Among the 8 safety colors, the colors signifying "attention" and "safety" should be subject to re-examination.
8. The ratings for colors used for interior finish were similar by the young and elderly. The higher ratings by the elderly than the young in the 10th percentile may result from the changes in their visual function due to aging.
9. The contrast may not necessarily correlate with the rating.

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Prof. Dr., Haruyo Ohno, Faculty of Socio-cultural studies, Otemae University, 2-2-2,Inano, Itami, Hyogo, Japan 664-0861, E-mail: ohnoh@otemae.ac.jp
Research Associate., M.Eng., Masami kono, Department of life and culture, Otemae Junior College. 2-2-2,Inano, Itami, Hyogo, Japan 664-0861, E-mail: kounou-m@otemae.ac.jp

COLOUR AND LIGHT: ORIENTATION AND WELL-BEING IN HEALTH CARE FACILITIES

Leonhard Oberascher
Psychology of Architecture and Design, Salzburg, Austria

Abstract
Colour and light in health care facilities should not only fulfil architectural or aestehtic criteria, but over all regard specific user requirements. In this paper the concept of freedom of action is used as a framework of criteria to categorize and assess various measures of colour and lightning design.

Keywords: *freedom of action, orientation system, , intensive care unit, personalisation*

1. INTRODUCTION

There is no doubt that colour and light in architecture have a strong influence on physiological and psychological well-being, performance and spatial orientation.
According to Brainard [1], "it is well established that light can regulate physiology both on the body surface (skin or dermis) and internally (circadian and neuroenocrine systems). [...] The intensity and wavelength are important in determining the capacity of a photic stimulus to regulate human physiology. Light has been used successfully for treating SAD winter depression. Claims about the therapeutic effect of colour therapy or chromotherapy - however - are not supported by controlled scientific studies and thus await empirical confirmation."
Bartenbach and Witting from Bartenbach Light Laboratory in Austria [2], have shown in well controlled experimental series how light, natural and artificial, its spectral composition, colour temperature and flicker frequency influences work performance and well-being.
Izsó and Majoros at the University for Technology and Economy in Budapest [3] recently compared the effect of static versus dynamic light. They came to the conclusion that dynamic light is more pleasant, stimulating and activating and therefore also increase the quality of work.
Küller and Mikellides [4] reviewed the research on colour, physiological arousal, thermal comfort and subjective time from 1921 till 1993. Their remarkable experiments with full-scale spaces helped us a lot to clarify the renitent confusion and misconceptions about the physiological and psychological effects of surface colours.
These are just some highlights of the newer findings in this important field of research. But despite all our knowledge about colour and light, the appropriate use of it in modern architecture remains a big challenge.
Colour and light in architecture are always perceived in the context of space, time and movement, material, surface and form, as well as the characteristics and activities of the observer.
In my presentations in Gotenborg [5] and Kyoto [6] I have pointed out that the increasing use of modern materials and artificial light makes it difficult even for an experienced architect to predict accurately the actual appearance, impact of and responses to colour and light in the completed architectural space. For example, recently I was concerned with a new office building in Austria, which had an outstanding innovative glass façade. Unfortunately the employees complained about headache, dizziness and other symptoms. As I could demonstrate after some measurements and analyses, the problem was neither the colour of the glass elements of that façade nor the light itself but the totality of the visual scene determined by the daylight from outside, the artificial lighting of the building, the position and colour of the glass elements and the employee's position/movement in relation to these factors.
Now, while e. g. in office buildings the users are usually (more or less) healthy individuals who spend only part of the day at their working place and therefore are more or less able to cope with such a stressful environment, old, handicapped and disabled people, patients of health care facilities and inmates of psychiatric wards do not have much choices and are therefore even more exposed to the quality and effects of the architectural environment. To be sick, disabled, handicapped or old, usually means a decisive limitation of our freedom to move, to act and to experience. We become dependent not only socially, as we need care, therapy and maintenance, but also spatially, for example when using a wheelchair.
Today there is a growing awareness that besides the measures essential for care and therapy, architectural design is of considerable significance for the purposes and demands of health care facilities. For patients, staff and visitors, the considerations – variously evaluated – are: well-being, minimising of stress factors, gaining control, and participation in the life of the institution, and (inner and outer) orientation by means of clear and readily comprehensible orientation systems. Thus design should not only fulfil architectural or aesthetic criteria but above all regard specific user requirements.

2. COLOUR AND LIGHT IN HEALTH CARE FACILITIES

How can colour and light in the design of health care facilities contribute to achieve these goals?
Before we look at this question in detail we should try to evaluate the potential of colour and light for the design of health care facilities in a broader context.

2.1 A general perspective to environmental design: the person-environment-setting

Environmental Psychology and in particular Transactionalism emphasizes that person and environment are part of one inclusive entity. Neither individuals nor settings can be adequately defined without reference to the other. Under this premise any kind of institution can be understood as an open system consisting of 3 components:

- the (physical) setting
- the socio-cultural script
- the person

The success and efficiency of a health care facility will therefore depend on an optimal relation and interplay of all components.

2.1.1 The concept of "freedom of action" and its importance for the user's environmental satisfaction

Rudolf Welter [7] in his article about therapeutic environments points out that the most important criterion for the user's satisfaction is personal control and participation in the spatial, organizational and social conditions. In health care facilities the opportunities for control and participation by the user are essentially related to the freedom of action available. This consists of the following dimensions:

- freedom of movement

- freedom of relation-forming
- freedom of operation and activation
- freedom of decision and control

The extend of the freedom of action available is determined by:

- architectonic and technical conditions
- organisational and administrative conditions
- attitudes and behaviour

These dimensions and conditions can be related to each other in a matrix of 12 fields. Freedom of movement for example is determined by architectonic and technical conditions like accessibility of rooms, windows, wardrobes, also for patients in wheel chairs (barrier free access), further by organisational and administrative conditions like rules of the house that regulate when and where patients can go, as well as by attitudes and behaviour, for example tolerance of the management and staff that patients visit each other.
If we read the matrix in the other direction it may also serve as a framework of criteria to assess the design of therapeutic environments. Measures to be taken in the field of colour and lighting design as elements of architectonic conditions should be categorized in this framework of criteria and assessed with reference to the latitude mentioned above.
So far, the following questions are of central interest:
How can colour and light in health care facilities support:

- the freedom of movement?
- the freedom of relation-forming?
- the freedom of operation and activation?
- the freedom of decision and control?

To each point I will try to give some general recommendations, with reference to some concrete examples of my work.

2.1.1.1 How can colour and light support the freedom of movement?

A colour concept can form the basis of direction signs and orientation systems, thus contributing to safety, effectiveness, well-being and identification with the place of residence. Colour, or to be more precise, hue, chromaticness, black- and whiteness, lightness, colour combination, contrast and harmony are crucial for the visibility and readability of direction signs and information boards. Of course colour coding does not have to be limited to direction signs and information boards but may also strongly contribute to the understanding and readability of the total physical structure of a building. Striking colours can provide clear spatial, emotional and symbolic points of reference. Contrasting colours and intensities may help to distinguish different spatial functions and elements, to define and separate different areas, indicate directions and floor levels, mark intersections, circulation paths, destinations and information points.
However, when a colour coding scheme is used, it must be logically and consistently and should not conflict with other coloured elements (as for example coloured lines for decoration, indication of technical elements and functions) in order to avoid confusion. Also only a small number of highly contrasting colours should be used because people – especially under stress – would not be able to distinguish and remember subtle nuances. In general coloured lines on the floor or wall are highly preferred by the staff, patients and visitors, but may be very confusing if the ways are too long or if there are too many destinations. A major disadvantage of floor lines is that the paints or materials used are often not very resistant, are covered during renovations and often conflicts with other signs or visual elements (see also Carpman and Grant [8]).

Lighting can significantly influence the overall ambiance of corridors and the effectiveness of a variety of way-finding elements. Circulation areas, corridors, stairways and entrance areas should be illuminated in a way to facilitate safe and comfortable movement. Lighting can be used to signal changes such as the beginning of a ramp, to distinguish circulation paths from other spaces, to break up long corridors into segments, to define areas along a hallway and to highlight meaningful spaces, such as reception and waiting areas or major intersection. The effectiveness of orientation or navigation systems is significantly influenced by lighting. The visibility and readability of direction signs and information boards can be greatly enhanced if they are well illuminated or self-luminant. Coloured lights attract interest and provide strong visual cues. Colour coded lights can be used to distinguish circulation paths from other spaces, mark different areas and to represent destinations (see also Carpman and Grant [8]).
In one of our actual hospital projects in Austria we are installing coloured light bands in the floor as part of the navigation system, using side radiating optical fibre cables. Compared with simple colour codes (e. g. painted lines) these means are much more visible and also resistant to usage. Another advantage is that the hue and intensity of the bands can be changed or even modified dynamically. The combination of colour coding and advanced lighting technologies offers us new possibilities to design effective and flexible navigation aiding systems, that can be adapted to the changing institutional needs and thus support the patient's / visitor's freedom of movement under different organisational conditions (e.g. ambulant treatment during daytime, night or holydays).

2.1.1.2 How can colour and light support the freedom of relation forming?

Freedom of relation forming has to do with the possibility to choose or adjust the level of social, acoustic and visual stimulation. Colour and lighting design should therefore try to create a balance between stimulation and sedation, order and variability, affinity and contrast. It should on the one hand link, create order and convey information; on the other hand it should offer sufficient variety to encourage the observer to interact with his architectonic environment. Modern lighting design and decentralized lighting management offer new technical solutions that allow a maximum of flexibility and the adjustment of light and colour to individual needs. For example, electronically controlled window shields, mirror elements and prisms allow an optimal use of daylight.
A carefully planned arrangement and mix of different light sources together with bus-connected technology make it possible to program and recall different light scenes and light sequences for different needs, activities and times of the day. The fast development of LED technology will soon make it possible to produce colour mixing lamps for a reasonable price that will give the user the freedom to choose his individual colour moods.
As I explained in my presentation at the AIC congress in Kyoto [6], a basic consideration of our work is that human beings have spent the greater part of their social evolution in a natural environment characterized by surfaces of varied texture and subtly variegated colouration. Under this premise my colleague Thomas Nowotny and I have been working now for many years on the development of different painting techniques, which have allowed us to produce, using modern industrial materials, surfaces that are more in accordance with "visual-ecological" requirements. We first applied this concept

in a nursing-home for the elderly and a children's hospital [9]. During the last years we have developed this concept further and applied it in highly sensitive therapeutic areas like Dialysis Centre, Post-operant Observation, Coronary and Intensive Care Units. Intensive care units (ICUs) in particular demand sensitive use of colour and lighting, in order to convey to the patient a sense of comfort, relaxation, recuperation and security.
In ICUs the design of the ceiling is probably the most important design measure, not only because for the patient lying on his back, the ceiling becomes the dominating horizon, but also because in most cases there are no walls or free plains in the room that can be painted or decorated. Room walls or separations are mostly built from glass, in order to enable the staff to monitor the patients, or if they are solid they are hidden behind medical equipment and high-tech instruments. In respect to the design of the ceiling, visually confusing elements must be strictly avoided. Also abstract forms, geometric patterns, strong colour contrasts and glossy surfaces should not be used.
Instead, when using surfaces in accordance with "visual-ecological" requirements as mentioned above, the (visual) ambiguity of the patterns on the one hand and the unobtrusiveness of the colour texture on the other ensure that the observer does not get tired of it after only a short time. According to mood and receptivity, angle of vision and lighting, the ceiling offers stimuli of varying intensity, their interpretation being left to the imagination (see also [6]).
Other important factors are the link with the outside world and with daylight, directing daylight or, if necessary, supplementary artificial light. If artificial light is used, special attention must be paid to the lighting level and the direction and colour of the light. Dazzle from ceiling lights but also from light-sources for examination, night-lights and orientation lighting should be avoided.
Through a combination of these design measures, symptoms of the ICU syndrom – like hallucination, delusions, psychotic episodes, sleep disturbances, disorientation and misjudge of the length of the stay – can be considerably reduced.
Another important aspect of the freedom of relation forming is the possibility to control one's private sphere. Visual privacy can be easily achieved through flexible screens or curtains. Window curtains, due to the large area they cover, can be dominant elements of a room. It is therefore important to find the right relationship between the architectural style of a room and its decorative elements. In general, most people prefer representational motives over abstract ones (see also Carpman and Grant [8]), although usually it is not easy to discover motives suitable for the hospital environment. A further aspect is the partial translucency of the material so that in connection with sun light the colours can become vivid and beautiful.

2.1.1.3 How can colour and light support the freedom of operation and activation ?

Freedom of operation and activation means to be able to decide or influence the content, amount and process of actions and activities. The impression and affordances of spaces and rooms depend to a great extend on their visual design. The materials, surfaces and colours together with the illumination provide clear information about the purpose and usage possibilities of a room. Colour and light of a room can therefore encourage or hinder activities. For example, a room in which everything is painted white can hinder activities because it appears clean and one might be afraid to dirty it. In the same way an abundantly coloured room can also hinder activities because the total

impression is overwhelming and does not leave any freedom for personalisation.
When developing colour schemes for health care facilities, it is important that the selected building materials, their colours and texture are clearly readable in a sense that they communicate their physical properties, the purpose value and usage possibilities in order to stimulate appropriate behaviour. If for example colour, texture and gloss of a floor tile do not communicate solidness and stability it will definitely limit the freedom of operation and activation.

2.1.1.4 How can colour and light support the freedom of decision and control ?

Freedom of decision and control has much to do with the possibility to regulate privacy and to control a personal or group territory. Control over a personal or group territory also means that the owner (or owners) physically or symbolically demarcate and personalize it, for example through signs, personal object or decoration. Where this can not be realised, colour and light can offer some kind of compensation for territorial markers and objects for identification. Wherever possible the user should be incorporated in the planning and decision process, although most of the users do not have design competence. It is therefore essential to find a good compromise between user participation on the one hand and not loosing control over the design process on the other. One possibility of controlled user participation is to offer a limited range of colour choices within a given design concept. For example, the option to choose from different colour schemes for specific staff areas (recreation rooms, changing rooms...), according to our experience significantly increases the staff's identification and satisfaction with the working place. Here colour gives the user a concrete possibility of control as it serves as a powerful symbol for personalisation and territorial marking.

3. CONCLUSIONS

Colour and light in architecture are not qualities that can be easily understood. The impressions of colour and light emerge from the constant flux of changing and overlapping scenes, in themselves the result of a complex combination of various factors. Colour and light are perceived in the context of space, time and movement; material, surface and form as well as the characteristics and activities of the observer.
Especially concerning the (architectural) design of health care facilities – with the purpose to optimally serve the sensitive requirements of patients, medical/ therapeutic staff members and visitors as their users, an integrative approach seems to me necessary: A sensible, technologically flexible/adaptable integration of colour, light, material, information signs, decorative elements and art into the architectural concept enable us to create a more comprehensible environment with positive emotional reference that will support the user's orientation and well-being.
However it is difficult to establish generally prescribed criteria for the design of health care facilities. The design recommendations given in this paper can be taken as suggestions. In order to arrive at the best possible design solution a differentiated and comprehensive analysis of each individual project is inevitable.

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Dr. Leonhard Oberascher, Psychology of Architecture and Design, Kaltnergasse 8, A 5020 Salzburg, Austria. Phone: +43 662 628459, Fax: +43 662 628459 50, E-mail: ecd@leoncolor.com

COLORS OF TEXTILE AS CHROMATIC ALPHABET OF SOCIETY

Lia Luzzatto and Renata Pompas, Milano, Italia

COLOR AS INTERFACE AND DOCUMENT

Historian of dyestuff Franco Brunello describes a prehistoric fabric (dated between 3.000 or 4.000 BC), coming from a lake palafitte of the Zurich Canton, and here stored at the Landesmuseum. This fabric has some small check, stripe and triangle decoration in blue, red, mauve and yellow colors. Brunello supposes that these dyes come respectively from Elder (*Sambucus nigra*) for blue, Orache (*Atriplex hortensis*) for red, Blueberry (*Vaccinum mirtullus*) for mauve and Bearberry (*Arbustus uva ursi*) for yellow.
The textile fragment is the demonstration that colors are expressive values, inseparable from the functional properties of goods, a complex expression of the society, which manufactured them.
In fact observing the colors characterizing the community on the whole, allows to reflect about aesthetic, ideological and commercial orientations which permeate it; so as to analyze the color worn by each person into his individuality, allows understanding his way of telling himself.
Fabric is the preferential support of chromatic subject and, when covering the body, it is the interface among the individual and the group or collectivity.
The survey on colored fabrics usage, as chromatic alphabet of society, can be conducted in different ways: either in a vertical or horizontal manner.

The horizontal manner (spatial – geographical) takes great care of each country morphologic peculiarities and of the natural resources offered by that land, which are the mainstays of future technological and cultural evolutions.
The elements which effect the chromatic range of a specific place are various: all together the colors of the environment, the quality of light, the presence or absence of some coloring substances, the type of fibers available and their dying receptivity. These factors all together specify an aesthetic imprint that settles into tradition, building the local taste and the chromatic typicality of each place.
Instead the vertical manner (temporary – historical) takes care of the chromatic range typologies, as they are in their historical context, and observes their modifications during time, meant as a witness of culture, art, society, economy, and religious expressions. The aim of the vertical survey is to look backwards to understand the present and imagine the future.
Using textile terminology, we could say that when the vertical manner, the warp, meets the horizontal manner, the weft, it generates a interweaving between things and ideas, and the specific historic period when it happens; becoming one of the various expressive peculiarities of that chromatic speech, that humanity is conducting since its origins.

HISTORICAL CHANGING COLORS TASTE

In our studies on colors, published in Italy, we have applied the vertical survey to monitor the evolution of the western society dress color taste. Now we will present you three examples about many different historic periods – the late Latin Empire, the

late Medieval and the eighteenth century – to show how colors can reveal ideological, politic and social tendencies.
A look on the remote period of the Latin Empire decadency reveals a palette of warm tones – yellows, oranges, roses, reds, plums, browns and violas – applied on the best fabrics coming to Rome from all over the known word. From North Europe arrived the weightless woolies, from Greece and Egypt the light linens, from Meddle East the transparent herons, from India the buoyant cottons and from China the most expensive silk. We meet the Mediterranean solar colors, which narrated – exhibiting of social privilege, luxury, extravagance, abundance and excess – the late magnificence of Latin society.
Very different is the palette that we find in the late Medieval, characterized by strong contrasts between warm and cool tones, expressed in their greatest intensity. In that period the light theology, which saw the presence of God in brightness of colors, encouraged aesthetic of full, saturated and bright color. Structuring of various codes – heraldic, liturgical, courtly and devotional – used them in combination of meaning in crests, gonfalons and ensigns, transferring them on textiles of liveries.
If we look instead at the Eighteenth century, we find a chromatic, bright and watery palette, as if it was made of air and light. It was suitable to express the new scientific and social conceptions, deriving from one side from Newton's theory of light diffraction, and from the other from the Enlightenment doctrines. Gentle and tenuous fabrics, nearly transparent, some time iridescent, dyed preferably in blue-grey, mauve, pistachio green, peach rose, ivory white and light blue.

ALIVE AND PERMANENT COLORS

Actually beyond these three examples very synthesized, many have been the historic periods which have marked a radical transformation in the color taste, in relation to deep technical and social mutations. The invention and production of artifical colors before, and of synthetic material after, have provoked a real revolution - technological, economical and social - that completely modified the chromatic scenery.
After Perkin's discovery of the coal tar tinctorial power, with famous mauve creation and following new aniline and synthetic dying – that made the fortune of some giant chemical companies, today known as Bayer, Basf, Hoech – the natural dyestuffs have been completely substituted.
The artificial colors diffusion has provoked an inversion in the symbolism of *status* and value of textiles dying, which still survives.
The dye intensity and solidity - that had been for centuries the quality and economic worth guarantee - have become affordable to everyone, losing its luxury and exclusivity features.
The Sixties have provided fancy and joyfulness qualities to bright and intense colors of plastics and synthetic fabrics; expression of new mass consumption, which was characterized by cheap products with easy, fluent and youthful appeal.
But first of all the substitution of natural colors with synthetic colors has altered chromatic perception and relation with color: the criterions of uniqueness and vitality, qualifying natural colors, were substituted by multiplicity of flat homogeneous tones, never changing, whose permanence and equality, deny the value of time. So those transformations which make natural colors alive - toning and bleaching given by air, water, light and use – have disappeared.
Nowadays because of the permanence of industrial dyeing it has been necessary to replace it quickly, so to fuel consumption. This has provoked an artificial acceleration of aesthetic orientations, with a consequent compression of time perception.

The fashion has constantly requested different chromatic suggestions, first born on catwalks and passed to the street, then created on the street and absorbed by catwalks, and lastly merging in a vortical spiral, with quotes, revivals and contamination.
The market has organized itself with the creation of "Trends forecast offices" and their seasonal "Colors books", specialized on commodity sectors and consumption typologies. To orient color consumption into a convenient number of fixed ranges has become essential to companies, to rationalize coloring substance production. So the consumer's choice is solicited and conditioned, to a number of tones decided by the market, which often he doesn't really find in accordance with his feeling.
It is possible that some particular colors – such as purple in its various shades, or some intense blues, or also more saturated yellows – are absent from the textile market for more seasons.

COLLECTIVE AND INDIVIDUAL CONSUMPTION

Color is at the same time expression of collectivity and individuality: choosing and using it, each person satisfies his aesthetic need, indicates a social membership, and expresses emotions and awareness. Color is an active energy, which affects body and psyche, influencing personal wellness.
Everybody knows that blue light has the power to lower the bilirubin level in baby's blood; commune in Pediatric hospital departments. Perhaps not everybody knows the Medieval use of covering smallpox patients with red fabric.
The interruption of dialogue between body and color and psyche and color, eliminated by our society's mass consumption, by fashion imposition and by mortification of chromatic expression, indicates the devaluation of worthiness as affectivity, emotion and feeling, represented by colors.
The society of image imposes to the body new rules and new borders: on one hand the capacity of integrating itself in proposed models and in the public imagination; and on the other hand denying them, when ever possible, so to affirm uniqueness criteria.
The dress – with its materials, volumes and colors – offers itself as a privileged instrument of "body advertising". And textiles' colors constitute, more than ever, the aesthetic characteristics of body marketing: a variable envelope, which is constantly actualized in accordance to fashion trends imposed by the market, or in accordance to individual attitude, in a mixture of subjectivity and massication, and of "appearing" and "being".
If every historic moment has testified itself also with colors, what could be the chromatic-textile scenery that we suppose for the next future?
The media celebrations for the new millennium pointed out to us the future as a cyber scenery: a life regulated by multimedia electronical note pads, on line jobs and "clever clothes", sensitized by dialoguing microchips.
Instead, the consumption prospecting describes a degree of technology acceptance only when is hidden and not exhibited and when it is subordinated to give a performing surplus to reassuring products, with a natural aspect. This research has registered a considerable orientation towards values of affectivity and intimacy, that one that some trend consultants call *nesting*, wish of nest.
Political uncertainty and worry of outstanding wars cause a wish of assurance, of shelter in what is already well-known and familiar, and of a research for protection.
So textiles become more compact and colors recuperate a double aspect of offence (with red or mixed red tones) and defense (with brown or mixed brown tones).

Nevertheless the present is based on immateriality of digital technology and on a constant opening towards futuristic and cosmic spaces, redefining our roll in the universe.
All these perspectives are present in those luminescent fabrics that seem to have interwoven, together with optical fibers, the violet light of computer displays.
A color passage from the chemistry kingdom to a synthetic light one, which is parallel to that created by screens which brighten our everyday life.

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Mrs. Lia Luzzatto, full professor to Acaddemia di Comunicazione (Milano – Italia), journalist, color consultant, lecturer, writer of essays E-mail: lia.luzzatto@libero.it, www.color-and-colors.it
Mrs. Renata Pompas, full professor to Nuova Acaddemia di Belle Arti (Milano – Italia), journalist, color consultant, lecturer, writer of essays E-mail: renata.pompas@libero.it

COLOUR PREFERENCES OF DESIGN STUDENTS IN RESPECT OF COLOUR HARMONY THEORIES

Nilgün Camgöz
South Bank University, Colour Design Research Centre,
School of Engineering, 103 Borough Road, London SE1 0AA, UK

Abstract
This study is an analysis of colour preferences of design students in respect of colour harmony theories they have encountered in their design courses. Research on colour combinations provides designers with experimental Guilford and Smith [1], Helson and Lansford [2] and experiential Chevreul [3{Itten, 1970 #5]} knowledge gathered from preference responses of people in general and from expert views respectively. Expert views are widely known as colour harmony studies within colour theory. Colour harmony is traditionally referenced in design education, initiating from the very first year of a design student. Within a controlled experiment setup, design students were presented image sets through a computer monitor. Each student viewed and singled out the colour square that they preferred on the presented background colour for each one of the eight background colours. The research hypothesized that there would be a consensus on preferred background-foreground colour combinations and that this consensus would reflect students' prior knowledge on colour harmony. The findings of the experiment favoured only a few harmonious colour combinations recommended by experts. On the other hand, it confirmed most of the results from previous experimental colour preference research. Thus, despite the information that is instructed within the design tradition, there seems to be an inclination towards perceptually based responses for one of the basic themes of design, colour.

Keywords: *Colour Combinations, Colour Preference, Colour Harmony, Colour in Design Education*

1. INTRODUCTION

Research on colour combinations has been two fold. On the one hand there has been research from the fields of physics, psychophysics, and psychology (Guilford and Smith [1], Helson and Lansford [2], etc.). On the other hand, there have been theories developed by experiences of experts (Chevreul [3], Itten [4], etc.). The latter, commonly known as colour harmony studies, is traditionally referred to in design education, initiating from the very first year of a design student. Colour harmony studies are found to be convenient as the formulas provided have been applied and tested before by an expert who has been working with colours for a considerable amount of time.
Experimental research on colour preference provides the designer with knowledge obtained from people in general, while experiential studies provide knowledge gained from people with professional experience. This paper purports to examine within a controlled environment setup, the colour preferences of design students in Ankara, Turkey, who are equipped with both types of knowledge on colour, firstly through their own visual/ perceptual

experience and secondly through expert views instructed in their courses.

The objective pursued through the course of this inquiry was to determine the effect of the three attributes of colour (hue, saturation, brightness) on the preference choices on coloured backgrounds. The results obtained were than examined in respect of previous studies of experimental and experiential nature. Thus, an understanding on the issue of colour in design is tried to be gained from two domains of knowledge: experimental and experiential.

2. PREVIOUS STUDIES ON COLOUR COMBINATIONS

2.1 Experimental research on colour combinations

Washburn and Grose [5], in 1921, observed that making their participants imagining a given colour in combination with another colour changed their affective ratings for that colour. The first systematic attempt to study colour combination effects came from Helson and Lansford [2] in 1970.

Helson and Lansford [2] presented 125 colour chips against 25 coloured backgrounds under five different illumination sources to 10 participants. Participants were shown twelve colour chips on a background and made absolute judgments on a nine-point scale. They found that background colours of either high or low brightness and very low saturation enhanced judged pleasantness of object colours. Brightness was the most important factor for pleasant colour combinations: the greater the brightness contrast, the more likely one was to have a colour combination perceived as good. Independent from background colour and light source, blue, purple-blue, green, blue-green were judged most pleasant. Yellow and purple ranked low.

Reddy and Bennett [6], in 1985, researched colour combinations in a cross-cultural study. They found brightness contrast between background and object colour to be the major factor in pleasantness ratings. The three cultural groups varied slightly only in the hues they disliked. This study implied a similar pleasantness rating for all of the three cultural groups involved.

In the above studies, contrast seems to play an important role in preference. The studies demonstrate that the perceived pleasantness of a colour is changeable and is not an invariant quality of the colour itself. The studies state that brightness contrast is directly related with preference in the sense that as the brightness contrast between background and the stimulus colour is increased, the colour's preference rating also increases. These experiments also demonstrate that colour combinations can be experimentally investigated and their results can serve as a tool by which one may begin to make colour decisions.

2.2 Experiential studies on colour combinations: Colour harmony

Experts extensively studied colour, especially colour combinations, and tried to formulate their own experiences of colour. Sometimes, they also conducted qualitative research based on interviews or observations.

During the Renaissance period, Leonardo da Vinci [7], in his *A Treatise on Painting*, reflected his experience as:

> "Of different colours equally perfect, that will appear most excellent is seen near its direct contrary: a pale colour against red; a black upon white [. . .] blue near yellow; green near red: because each colour is more distinctly seen, when opposed to its contrary, than to any other similar to it"

In the eighteenth century, Sir Isaac Newton [8] suggested that harmony of colours was related to their "vibrations" (wavelengths):

> "May not the harmony and discord of Colours arise from the proportions of the Vibrations propagated through the Fibres of the optick Nerves into the Brain, as the harmony and discord of Sounds arise from the proportions of the Vibrations of the Air? For some Colours, if they be view'd together, are agreeable to one another, as those of Gold and Indigo, and others disagree." (pg. 346)

Colour circles are established to study the relationship of colours with each other and to understand harmony of colours. They generally present colour samples in the sequence of spectral hues, as found in a rainbow. A colour circle is completed by inserting the nonspectral hues (purples and purplish reds) between violet and red.

Colours selected to form a colour circle are arranged in a geometrical manner, such that pairs of complementary colours (additive or afterimage complementary pairs) are directly opposite to each other (Agoston [9]: 45).

It was not until the nineteenth century that explanatory studies on colour harmony were undertaken. One of the earliest studies on colour harmony or "good" colour combinations dates back to 1854 with Chevreul [3]. He set forth definite principles of colour harmony, which have been included in teachings of basic colour education for years ever since. He differentiated colour harmony into two harmony of analogous colours and harmony of complementary colours.

In the colour circle that Chevreul [3] used, red, yellow and blue were stated as primaries, where orange, green, violet were secondaries, and red-orange, yellow-orange, red-violet, etc. were intermediate hues (Fig. 1). Harmony of analogous colours was the colours that lie next to each other on this colour circle. For example, red with red-orange, orange, red-violet, or violet would be a harmonious analogous colour combination. Harmonies of complements would be colours facing each other on the colour circle. For example, red with green, yellow with violet, orange with blue, etc. Harmonies of split-complement would be a colour with the two colours that lie on the sides of its direct complement.

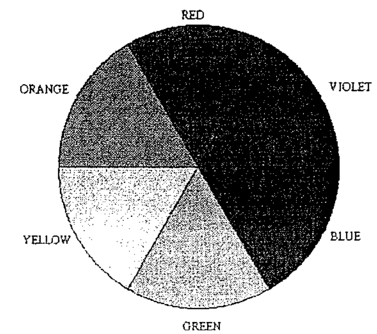

Figure 1: Chevreul [3]'s Colour Circle.

Examples would be red with yellow-green and blue-green, blue with red-orange and yellow-orange, etc. The list of Chevreul [3] extends to harmonies of triads (combinations with three colours), harmonies of tetrads (combinations with four colours), etc.

Chevreul [3] suggests that all hues are harmonious within dual combinations, which further suggests a control over the other two attributes (brightness and saturation) of colours (App. Table 1). Chevreul [3] does not present any information on how brightness/ saturation should be to obtain harmonious colour combinations.

Being a chemist and working with dyes, Chevreul [3] was well-aware of scientific methods of his time andindicated that:

> "I do not pretend to establish rules based upon scientific principles, but to enounce general propositions, which express my own peculiar ideas" (pg. 81)

Despite the lack of scientific data, Chevreul [3] had full confidence in his principles of harmony that he wrote:

"I hope that many classes of artists, particularly dressmakers, decorators of all kinds, designers of patterns for textiles fabrics, paper-hangings, &c., will derive some benefit from consulting them" (pg. 179)

Munsell [10], the inventor of one of the most widely used system of colour notation, also worked on colour harmony (App. Table 2). Some of Munsell's principles on colour harmony are (Birren [11], pp. 63-64): "

1. Value (brightness) used in combined colours should always have the middle (5) of 9 grey steps as a balancing point. A combination of 1,5,9 (black, medium grey, white) or 3,5,7 or 4,5,6 provides harmonious combinations of value according to Munsell [10].
2. Monochromatic harmonies should be solved with the above principle. For example, a colour of medium 5 value and medium 5 chroma (saturation) can be combined with a 3 or 7 or 4 or 6 value of the same hue. It can also be combined with 3 or 7 or 2 or 8 chromas of the same hue.
3. Complementary colours are considered to be harmonious, but within certain rules. A red of 5 value can be combined with blue-green of 5 value. Or a chroma 5 red can be combined with a chroma 5 blue-green, and so on.
4. Neighbouring hues can be combined with split-complements but should be balanced according to 5."

Itten [12] introduced a twelve-part colour circle to build his theories on colour harmony. His colour circle begins with the three primary colours: yellow, blue and red. The secondary colours are orange, violet, and green. He arranged his colour circle so that two diametrically opposed colours were complementary (Fig. 2). Itten [12] referred complementary colours as harmonious pairs: red/green, blue/orange, yellow/violet were such harmonious pairs.

The only requirement of Itten [4] to obtain harmonious pairs was that the two colours be symmetrical with respect to the centre of the sphere (App. Table 3).

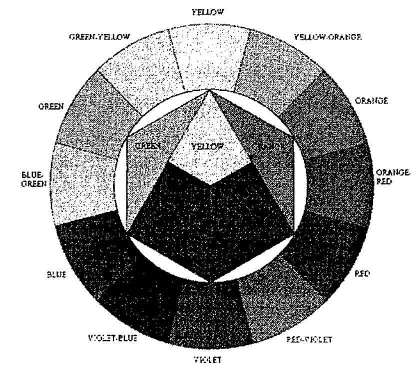

Figure 2: Itten [4]'s Colour Circle.

The colour circles developed in order to study colour harmony are most of the time geometrical arrangements, which reflect expert's individual experiences.

3. IMPLICATIONS ON HARMONIOUS / PREFERRED COLOUR COMBINATIONS FROM PREVIOUS STUDIES

Colour harmony/preference is not simply a question of personal taste. There is some consensus on colour preferences among individual viewers and on colour harmony among experts.

3.1 Outcomes of experimental research:

1. Blue appears to be a preferred colour, while yellow is not Camgöz, N. [13] (sec. 2.1).
2. Brightness has a direct relationship with pleasantness of colours in isolation Camgöz, N. [13].
3. Saturation has a direct relationship with pleasantness of colours in isolation Camgöz, N. [13].

4. Brightness contrast seems to have an effect on perceived pleasantness of foreground-background colour relationships Camgöz, N, Yener and Güvenç [14] (sec. 2.1).

3.2 Outcomes from experiential studies:

1. Complementary colours are thought to be harmonious Chevreul [3, Itten [4, Munsell [10, Itten [12] (sec. 2.2).
2. Hue combinations to be harmonious when brightness/saturation is kept the same. (Munsell [10] suggests this only for complementary colours. Chevreul [3] does not mention brightness/saturation, but suggests colour harmony for every possible hue combination. One way of achieving this is to keep brightness/ saturation the same.)

4. THE EXPERIMENT

4.1 The controlled environment setup and the participant group

The experiment setup consisted of a computer monitor located in a windowless room, illuminated with cove lighting. Standard Philips TL 54 fluorescent, having 6200 colour temperature (CT) and 72 colour rendering index (CRI) was used for lighting in the room (Camgöz, N. [13]).

The experiment verbally asked the participants the question, "which colour square would you prefer on the background colour on the screen?"

Each image consisted of a coloured background and 63 colour squares of differing hues, saturations, and brightnesses. Each participant viewed and answered the experiment questions for eight background colours. These eight background colours were shown successively, starting with 0^0 (red) on the HSB colour circle, continuing with 45^0 distances, ending at 315^0 (magenta) (Fig. 3).

A total of 123 participants took part in the experiment. All the participants were students at Bilkent University, Faculty of Art, Design, and Architecture, located in Ankara, Turkey. The majority of the participants were between 20-24 in age (78%), second year students (55%) in the Department of Interior Architecture and Environmental Design (81%).

The participants were asked if they had any courses or training related to colour during their university education. 28% said they had intense courses on colour with the electives they have chosen, 65% said they had courses which mentioned colour design issues, but not with much depth, and 7% said they could not recall any colour design issues addressed in any of their courses. The participants were also asked if they were interested in colour design. Most of them (68%) had a general interest in colour within the scope of the school curriculum, while some (26%) have extended their interest into colour related hobbies. 6% said they were not interested in the subject at all. (Camgöz, N. [13])

4.2 The image set

Adobe Photoshop software was used to create the image set. The image set consisted of 8 images representing 8 backgrounds. All of the background colours had 100% saturation and 100% brightness. Thus, they were fully saturated and bright. Hues were selected from the standard colour circle starting with red 0^0, continuing with 45^0 intervals, ending at magenta 315^0 (Fig. 3).

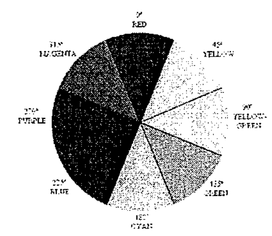

Figure 3: Colour Circle Used.

On every background colour, all the hues (excluding the background hue itself) were represented in 7 separate rows. Each hue row was then divided into 9 columns, where the hue was represented with varying brightness and saturation levels.

5. DISCUSSION

Results of this study (Camgöz, N. [13, Camgöz, N, Yener and Güvenç [14]) are as follows:

1. Brightness 100%-Saturation 100% is significantly preferred the most.
2. Blue is preferred the most.
3. Green, yellow, yellow-green are the least preferred.
4. Harmony of neither analogous nor complementary colours has been observed.

The brightness 100%-saturation 100% range is preferred the most by the participants (p-value between 0.0001-0.0200, Camgöz, N, Yener and Güvenç [14]). Therefore, colour squares that are most saturated and brightest are preferred on backgrounds of most saturated and brightest colours. Washburn and Grose [5], Reddy and Bennett [6] demonstrated that in the judgments of participants, as the brightness contrast increased, a more preferred colour combination was obtained. Among the experts dealing with colour harmony, only Munsell [10] was cautious concerning brightness and saturation levels. He promoted brightness difference with the middle (5) of 9 grey steps as a balancing point if the hue was kept the same. Munsell [10] also suggested complementary hues to be harmonious if their brightness/saturation were kept the same. There is no brightness contrast between the background and foreground colours in the preferences of participants in the Camgöz, N. [13] study.

Regardless of the background colours they viewed, the participants preferred blue the most (p-value 0.0001, Camgöz, N, Yener and Güvenç [14]). This corresponds with various findings of previous experimental research. Washburn and Grose [5] also found that blue was the most preferred colour regardless of its background. Data gathered in this inquiry demonstrated that green, yellow, yellow-green and non-colours of white and black were the hues that were preferred the least (Camgöz, N, Yener and Güvenç [14]). Washburn and Grose [5] also stated yellow as the least preferred hue.

Blue is preferred on the background colours of red, cyan, and magenta (App. Table 4) (Camgöz, N, Yener and Güvenç [14]). Chevreul [3] also suggested red to be harmonious with blue. On the other hand, Vinci [7], Newton [8] and Itten [4, [12] suggested other colours to be harmonious with blue.

Magenta is preferred the most on the purple background (App. Table 4) (Camgöz, N, Yener and Güvenç [14]). Chevreul [3] might have approved this combination as harmonious, but it is not included in the suggestions by Munsell [10] or Itten [4, [12].

Yellow and blue were background colours where it was hard to determine any agreement on preference. For the yellow background, although there was a scattered distribution of preferences, there was a significant inclination towards preferring blue and red (App. Table 4) (Camgöz, N, Yener and Güvenç [14]). Vinci [7], Newton [8] and Chevreul [3] also stated blue to be harmonious with yellow. Chevreul [3] also would have approved yellow-red combination. Munsell [10] and Itten [4, [12], on the other hand would suggest purple-blue, purple to be used with yellow, which the participants did not incline to prefer.

A similar difficulty in deciding on preferences was found for the blue background (App. Table 4) (Camgöz, N,

Yener and Güvenç [14]). Red, purple and magenta were preferred over other hues on this background. Contradicting to any of the preferences stated by participants, Vinci [7] and Newton [8] would prefer yellow on blue. Purple and red are preferred hues on blue background, which are also suggested by Chevreul [3] as harmonious combinations.

The participants did not have statistically significant hue preferences on the yellow-green and green backgrounds (App. Table 4) (Camgöz, N, Yener and Güvenç [14]).

6. CONCLUSION

Analyses of data demonstrated that all three attributes of colour (hue, saturation, and brightness) were important in preferences. Colours having maximum brightness and maximum saturation levels ranked higher than any other brightness-saturation combination on backgrounds of most saturated and brightest colours (Camgöz, N, Yener and Güvenç [14]). Experimental findings of past research suggest that in the judgments of participants, as the brightness contrast increased, a more preferred colour combination was obtained (sec. 2.1). On the other hand, experiential studies suggest either a brightness/saturation difference or keeping the brightness/saturation the same while hue is changing (sec. 2.2). There is no brightness/saturation contrast in the preferences of participants of this study. This does not agree with experimental research, but agrees to some extent to experiential studies.

No matter what the background was, blue was preferred the most. This corresponds with various findings of previous experimental research. There seems to be an inclination towards preferring blue regardless of its presented medium (Wijk [15]et al.; Saito [16]; Guilford and Smith [1]; Washburn and Grose [5]). This finding contradicted with experiential studies on colour combinations.

The foreground-background preferred colour combinations of the Camgöz, N. [13] study (App. Table 4) do not fully confirm the views of Chevreul [3], Munsell [10] and Itten [4, [12]. There does not seem to be a systematic harmony of either analogous or complementary colours in preference judgments.

The participants were second year design students (55%) within the conventional design education in Turkey. They were mainly equipped with the colour harmony knowledge from experts like Chevreul [3, Itten [4, Munsell [10, Birren [11, Itten [12], but not with the experimental research knowledge on colour.

The colour combinations preferred by the participants lacked reference to taught colour harmony combinations. One explanation may be that being only in the second year of their design education, students might not be visually experienced enough to make colour judgments combining their perceptual and instructed theoretical knowledge on the issue.

Another explanation may be that within the given setup, the colour combination problem was solved mainly with perceptual appeal, not giving much credit to the instructed theoretical knowledge. This might further suggest a choice of preferring one domain of knowledge above another, rather than integrating them. It is not suggested here that instructed knowledge should be thoroughly followed by design students, but rather that experiences of experts could be integrated while making final decisions.

One other explanation could be that colour combinations were not emphasized enough within the design studio. Thus, students could only make perceptual preference judgments without the use of the wide range of possible harmonious colour combinations available to them. If that should be the case, it is essential to re-evaluate design education to include colour which is an inseparable and inherent component of design decisions.

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8. APPENDIX: TABLES

Table 1: Colour harmony chart for Chevreul [3].

Chevreul's Colour Harmony			
Colour	Analogous	Complementary	Split-Complementary
Red	Orange, Purple	Green	Yellow, Blue
Orange	Yellow, Red	Blue	Green, Purple
Yellow	Green, Orange	Purple	Blue, Red
Green	Blue, Yellow	Red	Purple, Orange
[illegible]	Purple, Green	Orange	Red, Yellow
Purple	Red, Blue	Yellow	Orange, Green

Table 2: Colour harmony chart for Munsell [10]

Munsell's Colour Harmony	
Colour	Complementary
[illegible]	Cyan
[illegible]	Blue
Yellow	Purple-Blue
Yellow-Green	Purple
Green	Magenta
Cyan	Red
[illegible]	Orange
Purple	Yellow-Green
Magenta	Green

Table 3: Colour harmony chart for Itten [4, [12].

Itten's Colour Harmony	
Colour	Complementary
	Green
	Blue
Yellow	Purple
Green	Red
	Orange
Purple	Yellow

Table 4: Hues that are most preferred on specified backgrounds in the Camgöz, N. [13, Camgöz, N, Yener and Güvenç [14] experiment.

Camgöz Experiment	
Colour	Preference
	Blue (35%)
Yellow	Blue (23%) Red (17%)
Yellow-Green*	Blue (19%)
Green*	Blue (21%)
Cyan	Blue (44%)
	Red (22%) Purple (21%) Magenta (20%)
Purple	Magenta (36%)
Magenta	Blue (43%)

* No statistically significant hues were differentiated for these backgrounds, thus inclinations from response distributions have been included.

Dr. Nilgün Camgöz, South Bank University, Colour Design Research Centre, School of Engineering, 103 Borough Road, London SE1 0AA, UK. Tel: +44(0) 20-7815-7013, Fax: +44(0) 20-7815-7699, E-mail: ncamgoz@hotmail.com, camgozn@sbu.ac.uk

TEXTILE DESIGN BASED ON BUILT ENVIRONMENT AND END-USERS SPECIFICITIES

Re-scaling a classroom with colored patterns on textile curtains

Jean-Luc Capron & Marie-Hélène Huysmans
Hic et nunC asbl, Rixensart, Belgium

Abstract
For a classroom with large windows on south and north façades, generating pupils' discomfort due to overheat and glare, the authors designed and printed curtains. Aims of the design is to provide a solution combining the necessity of a solar protection, with the need for a spatial balance between the scale of the group of pupils and a personal anchoring for each child. By taking in account space and user specificities, the nature, graphic delineation, size and colors of the pattern are defined to reach the objective of visually rescaling the classroom. The entire composition is made of vertical and horizontal stripes of a unique abstracted floral pattern, colorfully silkscreen printed on a translucent (non-opaque) unbleached textile.
The paper discusses in detail: (1) The entire process, which is of a type evaluation-design-evaluation, with on site and full-scale test of the pattern, scale and colors, as well as the global composition. (2) The results of a three years assessment program achieved by the authors, based on a post-occupancy evaluation approach and a survey focusing on three topics: general preferences (colors, shapes and patterns), perception of space (depth and anchoring) and users' feeling (comfort and quality). (3) The proposed guidelines for similar designs.

Keywords: *built environment, colored patterns, children, perception, behavior*

1. DESIGN PROCESS

In a classroom of the Athénée Royal de Rixensart, an elementary school located nearby Brussels (Belgium), large windows on south and north façades generate discomfort of pupils due to overheat and glare [1]. In 1999, Jean-Luc Capron (Dr. Eng. Architect) and Marie-Hélène Huysmans (silkscreen artist), were asked to design and print about 70 m² of curtains. This task was part of a larger process, including a previous consultancy for the choice of appropriate colors for new individual desks and chairs, and a post-occupancy evaluation assessing the impact of the printed curtains on pupils' behavior and well-being in this classroom.

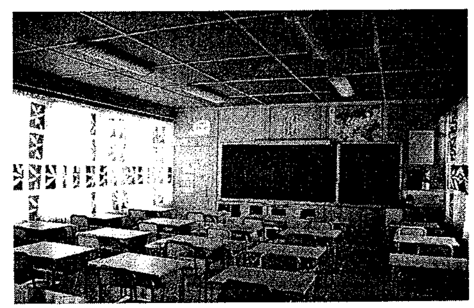

Figure 1: Interior view of the classroom, with the printed curtains of south façade on the left and the one of the north on the right.

1.1 Design Context

The classroom is located within a prefabricated building made of a wooden structure with a span of 1.2 m between posts. The room is about 8.4 m long (7 spans) by 6 m wide (5 spans) and 3 m high. On the opposite side to the entrance door, the blackboard hangs on the west wall, so that natural light mainly reaches the pupils from left. The south façade presents windows on the full length, while on the north side the two spans close to the entrance door are opaque.

As it is a key point of our design approach, it is important to analyze how the classroom is used. The basic features with an impact on the use of the classroom are the colored individual desks that allow for more flexibility in the classroom. The sitting layout is function of the number of pupils to be hosted in a classroom, as well as with the pedagogical preferences of the teacher and the use of related devices, such as computers.

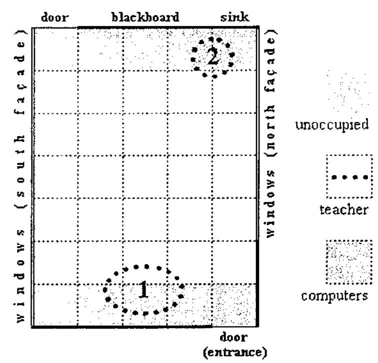

Figure 2: Plan of the classroom, with the two locations of the teacher's desk and the computers area.

Most of the pupils hosted in the classroom are 10-11 years old, about 1.40 m tall when standing and 1.15 m seated, with the eye level at about 1 m.

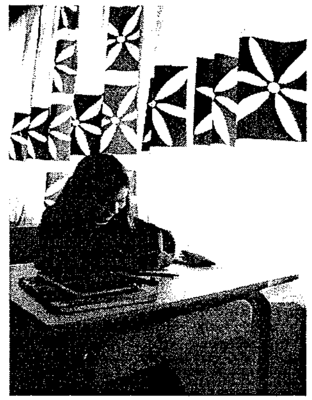

Figure 3: The horizontal stripe made of printed patterns is re-scaling the classroom height according to the one of a seated child.

The colors of the seats and individual desks were chosen among the restricted color chart provided by the furniture factory. The nearest NCS notations of the three chosen colors are 1070-R20B (tele magenta), 0040-R90B (pale blue) and 2060-B20G (turquoise blue).The selection of furniture colors was made several months before we made the curtains design, and therefore influenced the colors printed on the curtains.

1.2 Design Aims

The basic requirement for our design was to provide a solar protection, but also a visual screen between the classroom and the street nearby, in order to reduce the disturbance generated by the automotive and pedestrian traffic. We took also the opportunity to design a solution combining the initial requirements with the need for a spatial balance between the scale of the group of pupils and a personal anchoring for each child.

The textile-curtain solution was chosen for the low cost of their production and maintenance, and for an easy manipulation by children. The tactile dimension of

colored patterns silkscreen printed on textile has been discussed elsewhere [2].

Figure 4: On site, full-scale test to define the adequate high of the horizontal stripe made of juxtaposed *blue* patterns.

The pattern is an abstracted flower materialized by the unprinted surfaces that appear within a squared surface of about 32 cm by 35 cm printed in three different colors. Both pattern and layout design took advantage of a prior cross-cultural experiment based on black and white juxtaposed squares, randomly or not [3].

The patterns layout on the curtains has for support a tartan like rectangular grid, based on the span of the building structure. A rhythm occurs from a random like arrangement of the vertical stripes, by combining hues and interval.

1.3 Design Materialization

The curtains are made out of two meters high hangings pieces of unbleached serge cotton, with the bottom at about 70 cm from the floor and the top at 30 cm of the ceiling. As the printed colors are backlit, their perception varies with the sunlight color temperature and illuminance. Moreover, those factors differ between the south and the north side. For that reason, the three printed colors are called here: *red* for a S1070-R20B "fuchsia", *green* for a S2050-B40G "turquoise", and *blue* for a S2565-R80B "periwinkle"; the NCS references are mentioned as if the textile was laid on an opaque surface, thus with the printed surface illuminated. Therefore, in order to avoid confusion with the three colors when used as general color concept or preferences, the three printed colors are written in italics as *red*, *green* and *blue*.

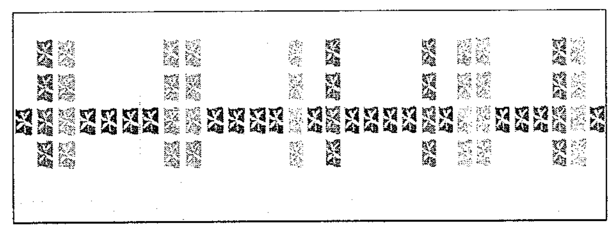

Figure 5: View of the interior side of the south façade showing the rhythm generated by the vertical stripes made of *red* (medium grey) and *green* (light grey) patterns and the horizontal *blue* patterns (dark grey) on the printed curtains.

2. DESIGN ASSESSMENT

Assessment by users is part of our design approach based on a continuum of assessment-design-assessment. The results of such a survey are important because of a lack of data about the influence of colors and textile on people behaviors in the built environment.

The survey is divided into six parts, each devoted to a specific topic — colors, shapes, patterns, space, comfort and

feeling — and is based on a set of questions answered in the classroom by each child sitting at his/her actual location. It was conducted during the academic years 1999-2002, with 51 children who filled the questionnaire on a sunny day, with the curtains drawn when the pupils answered questions about.
Designing the questionnaire, we pay a special attention to make the questions easily understandable and answerable by children. For example, in order to make the answers to questions related to sitting location easier, the survey form includes plans of the classroom with the division of the ceiling into thirty-five squares used as a reference grid. Each square is referenced by a letter and a number. The origin of the axes of reference is the south-west corner, on the top left corner of the plan. The use of the ceiling grid as reference, instead of the precise location of each pupil, allows taking in account the above described variations of the sitting layout in the classroom, which occurred during this three years survey. The plan is used both in the test, for the questions about the location of the occupied seats and the (dis)liked locations in the classroom, as well as for the graphic analysis of the processed statistical data, with a three steps grayscale.
The feedback we got from both the pupils and the teacher is very positive. Most of the pupils expressed a deep interest about the questions and clearly understood what are the purposes of the survey, as well as the aims of our design. In addition, the teacher asked to be informed about the results and was particularly interested by the location preference test.
The purpose of a design is to be enjoyed by most of the end-users, boys and girls. This includes color, shape and size of patterns as well as the global layout. Everyone knows about the differences between boys and girls of the age of the concerned pupils. Therefore, a special attention is paid in this survey to the gender of the subjects. In addition, the results show how specificities of gender tastes diverge from clichés, such as pink as the girls' favorite color.

3. RESULTS AND DISCUSSION

This paper focuses on the aspects of the survey related to color in relation to space perception and use.

3.2 Color Preferences

The first set of questions of the survey deals with color preferences. The pupils are first asked to select three colors they prefer and three colors they dislike, among twelve colors named as: white, red, orange, yellow, green, turquoise, blue, violet, pink, brown, grey and black. As half of the proposed colors have to be selected, the non-selected colors are called "neutral" in this paper. The results show that blue is, by far, the preferred color by most of the pupils (76%), but a closer analysis shows that blue is indeed preferred by a majority of the girls (88%), while boys are not as keen of blue color (60%). Males subjects are more attracted by red (83%), while this color is mainly "neutral" for female subjects (79%).

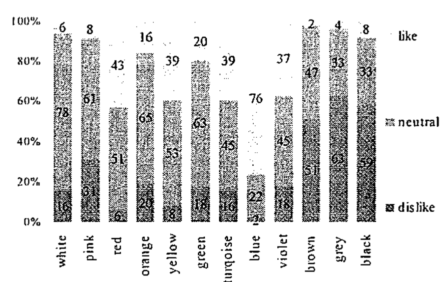

Figure 6: General color preferences by boys and girls, 1999-2002.

The combination of boys and girls preferences makes several colors to be "neutral": white, red, orange, yellow, green, turquoise, violet and pink. Surprisingly, girls seem to be as less attracted by pink as boys are. This seems to contradict a gender a-priory, caricaturized by the pink color over-related to the Barbie doll. Pink becomes therefore a kind of affectively "neutral" hue for most of those children. Most of them seem indifferent to white (78%), but they generally reject dark colors, such as brown, grey and black.
A detailed analysis of the general color preference test shows only few variations of the results during three academic years. They can be summarized as slight accentuations of preferences, without any inversion of tendency. Therefore, results of the general color preferences test might be expected to be relevant for several years.

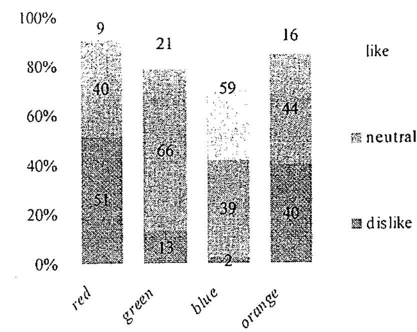

Figure 7: Boys and girls' printed curtains color preferences, 1999-2002.

A second set of questions is about both the colors of the pupils' chairs and desks and the similar colors of the printed patterns on the curtains. Both answers were similar, showing again a strong preference for the *blue*, a slightly negative response to *red* and a global indifference for *green* color.

3.2 Pattern Size

From the survey, we can assume that the designed pattern is not perceived as too large or too small, but merely of a "medium" scale. As the colored patterns are backlit, they seem to be smaller due to the irradiation effect and larger due to their apparent brightness — brightness which is different on each windowed side due to their respective orientation. This can help to give answer to both the general perception of the motive as "medium" and the asymmetry of the spatial distribution of similar perception.

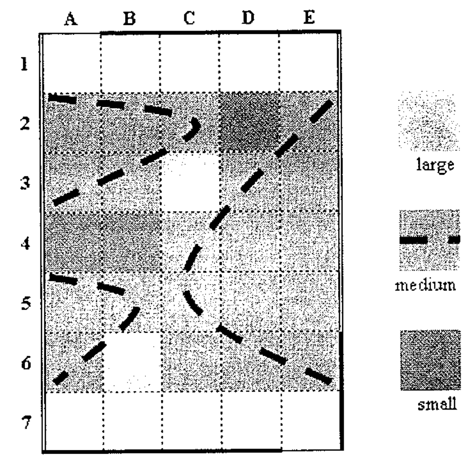

Figure 8: Perceived size of printed patterns.

3.3 Color Depth

The data collected from the survey about the perception of depth for each of the printed colors are of a special interest in relation with our aim of rescaling the classroom by means of colored patterns printed on the curtains. Among the factors that can help to understand the perception of *blue* patterns as nearer (45%) and the *red* as farer (40%) is the importance of lightness in the phenomenon of advancing and receding colors [4]. The respective position of the printed colored patterns on the textile support and the orientation of curtain towards the sun — high luminance of the sunlight coming from the south versus low luminance coming from the north — are also acting on the perception process of depth. The relation between the viewer and the patterns is a factor providing helpful information about the quite "indeterminate" depth feature of the *green* patterns.

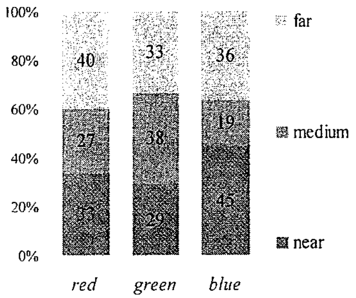

Figure 9: Perceived depth of printed colors.

Quite unsurprisingly, most of the pupils who associate the *green* patterns with the "near" attribute are sitting close to the curtains, and those sitting more in the center perceive the *green* patterns as "far". The *red* patterns are perceived as having no specific depth attribute by the pupils located near the south curtains, but they seem to be more distant for those sitting closer to the north curtains. In addition, the *red* patterns are perceived as "near" by most of the pupils sitting around the central area of the classroom. The *blue* patterns are perceived as "far" by the pupils close to the colored patterns, and more especially by those close to the north curtains, with the exception of those sitting in the center of the classroom. On the contrary, the children sitting between the two-mentioned areas perceive as "far" the *blue* patterns.

As some distortions in the perception of depth might come from the fact that some subjects can look to the curtains located on the north or on the south side. Further survey should be conducted in order to make clearer which of the curtains are taken as reference by the pupils answering the question about the feeling of depth associated with the printed colors.

Nevertheless, at this level of analysis and as expressed on the graphic synthesis, we could already note that the perception of distance associated with the *red* colored patterns is reverse to the perception of the *blue* and *green* colors. This opposition in the assessment of distance between a *red* pattern and *green-blue* patterns may refer to the perception of depth of *red* and *blue* colors.

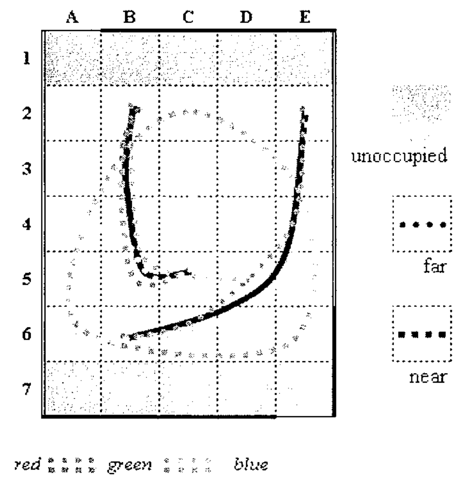

Figure 10: Synthesis of perceived depth of the printed colors.

3.4 Classroom size

The goal of our design is to modify the global perception of the classroom and a global analysis of data shows that the classroom is perceived as smaller with the curtains drawn, by only a small amount of pupils (19%), while a short majority (51%) perceives it as bigger. Unsurprisingly, the length is mainly perceived as increased (64%) and so is the width (43%), while the height is perceived as unchanged (45%) or even perceived as lower (31%). The perception of the vertical dimension is of a special interest for the assessment of one of the design goals: to create a "virtual ceiling" lowering the high of the classroom. The distribution of data reported on the plan of the classroom shows how perceptions of spatial features as increased are organized along a diagonal axis. The direction of this axis is partly related to the orientation of the curtains and their backlit colored printed patterns. This is confirmed by the decreased dimensional feature perceived by pupils sitting in the south-west corner of the classroom. In addition, it is worth to mention that children sitting at the back of the classroom perceive the space as lower, thus revealing how space might be rescale to a more human dimension.

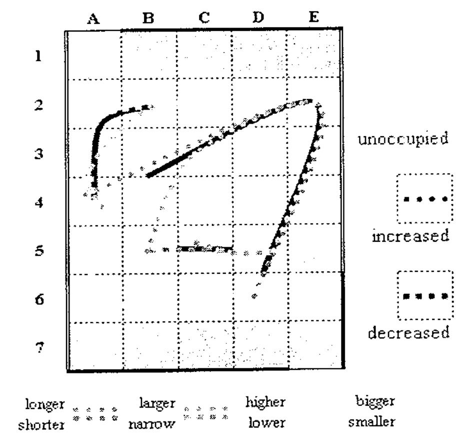

Figure 11: Synthesis of the perceived spatial features of the classroom.

3.5 Classroom Appropriation

The last point of the survey to be analyzed here is the general improvement of the end-users well-being, by means of the feeling of "being in my classroom". Globally, the answers to this question are positive (46%), with only few children (17%) having more difficulties to "feel at home" in the classroom when the curtains are drawn. The relationship between the location of the pupils and the type of answer show that improvements due to the curtains, their design layout and colored printed patterns, mainly occur for pupils sitting at the back and along the aisles of the classroom. The lack of improvement for those sitting at the very back of the classroom tends to show the limits of interaction between pupils and teacher, resulting for instance from the acoustic properties of the room. Data, like those collected by Sommer [5], about the participation rate of pupils in similar straight-row classrooms show how pupils sitting at same position have difficulties in interacting with the teacher and take part to pedagogical activities. The comparison of both set of data, by means of the pupils' sitting locations in the classroom, shows a correlation between improvements of the pupils' well-being and better participation to pedagogical activities. Therefore, the enhancement of the feeling of "being in my classroom" for the children sitting at the back and along the aisles of the classroom would make more pupils feeling to be a member of the group. This feeling allows the teacher to be more devoted to pedagogical activities, which not only helps those precise children, but all the pupils in the classroom.

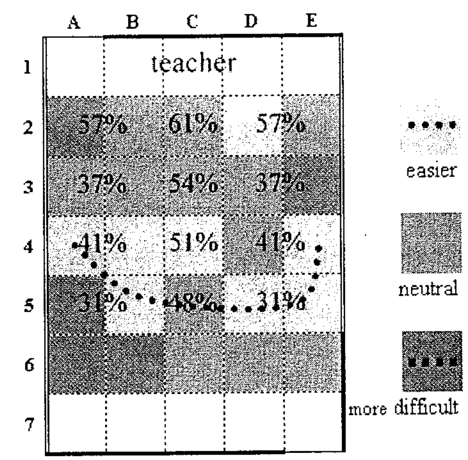

Figure 12: Feeling of "being in my classroom" compared with Sommer's data about pupils' participation in straight-row classrooms [5].

4. DESIGN GUIDELINES

As a conclusion, we could state that large printed textile surfaces, such as curtains in a classroom, designed with concern for both, the scale of the room and the scale of the end-users require looking for:
- The perceptive dynamic generated by the composition of the colored patterns, providing a balance between the scale of the group and the one of the child.
- Territorial anchorage and appropriation of the space achieved by the association of a textile support and the colorful patterns, laid out according to a horizontal segmentation and vertical rhythmic.
- Colors, pattern, composition — and the interaction between those perceptual factors — rescaling the classroom dimensional characteristics to a perceived size, in accordance to pupils' scale, individually sitting.
- Patterns, colors and textile supports acting on a semantic dimension, as a mean of personalization.

We therefore would like to propose some guidelines that could enhance the well-being of children in a classroom by the use of colors on textile surfaces.

-Textile fabrics: by its textural characteristics, it adds a tactile dimension to the visual perception of printed colors.

Printed colors: by their ability to be perceived as advancing or receding, they can modify the perception of depth of the surrounding surfaces enclosing a room.

Patterns layout: by the composition and position on vertical surfaces, it rescales rooms, thus helping for spatial anchoring and concentration on the performed activity.

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Dr. Jean-Luc Capron, Hic et nunC asbl - human factors and built environment, Beau Site 2° Avenue 3, B-1330 Rixensart, Belgium, Phone: + 32 2 653 66 12, E-mail: hic_et_nunc@belgacom.net, Web: http://users.belgacom.net/hic_et_nunc
Ass. Prof., Institut Supérieur d'Architecture Bruxelles, Brussels, Belgium.
Lecturer, Faculté Polytechnique de Mons, Service d'Architecture Civile, Mons, Belgium.
Silkscreen Artist Marie-Hélène Huysmans, Hic et nunC asbl.

INFLUENCE OF THREAD FINENESS AND WARP AND WEFT DENSITY ON COLOUR VALUES OF WOVEN SURFACES

Helena Gabrijelčič & Krste Dimitrovski
Faculty for Natural Sciences and Technology, Department of Textiles, Ljubljana, Slovenia

Abstract

Multicolour jacquard fabrics are mostly structurally multi-layer fabrics with patterns of various shapes and sizes, which are made of differently coloured areas. The colour in particular parts of pattern depends upon the number of differently coloured threads that interlace in the top layer of the fabric and their colour characteristics as well as upon the fabric constructional parameters – thread fineness, warp and weft threads density and weave. In practice it happens very frequently that a yarn of defined fineness is replaced by a yarn of slightly lower or higher fineness with identical colour values and with an unchanged or adequately corrected thread density. Of course this reflects in colour values of those parts of the fabric where these threads appear on surface. The colour effect of surface changes particularly in relation with other effects in the patterns.

Prior to introduction of numerical evaluation of colours and equipment for optical measuring of their values it was impossible to objectively estimate colour deviations resulting from the changed yarn fineness or changed warp and weft threads density. Even today it is practically impossible to carry out a systematic research of this influence on real fabrics because it is impossible to weave such a big number of referential patterns (different types of yarn, different ranges of fineness and densities). CAD systems enable relatively quick and cost-effective preparation of simulations of colour surfaces of multicolour patterns. They even enable changing of certain parameters within the ranges, which can be hardly or cannot be achieved at all in practice. By the measurements carried out on these simulations colour deviations due to the changed yarn fineness or warp and weft density can be estimated in a wider interval. It has to be emphasized that there is a difference between the measurements carried out on colour simulations and on real fabrics. However, the aim of the research is to determine the principles and above all to estimate quantitatively the influence of the changed yarn fineness and warp and weft density on colour values of a fabric simulation. In further researches it would be possible to prepare only a defined number of real fabrics and to compare the results on simulations.

The paper presents the simulations of a defined number of fabrics of different fineness, the results of their colour values measurements and the analysis of their differences.

Keywords: *fabric simulation, thread fineness, thread density, colour values measurements*

1. INTRODUCTION AND AIMS

The properties of Jacquard fabrics, which are made of differently coloured threads significantly differ from the properties of piece dyed or printed fabrics. By piece dyeing only single-colour fabrics can be produced, whereas multicolour printed fabrics have some advantages and some disadvantages in relation to the fabrics made of differently coloured threads. The advantages are relatively sharp outlines of patterns and the colours of the highest saturation. The disadvantages are different look and quality of the fabric's face and back side, different stability of the look, different permeability properties in particular parts of a pattern and different possibility of care. In view of these disadvantages of printed fabrics, the fabrics made of differently coloured threads distinguish by numerous applicability values. They can be used as double face fabrics, they have better permeability properties, care (washing, dry cleaning) is easier and with less frequent damages of the colour surfaces.

As regards the colour, printed fabrics and the fabrics made of differently coloured threads differ by colour values in individual pattern effects. In the case of the fabrics made of differently coloured threads, these values depend as well upon the constructional parameters of the fabric. Thus, with a certain number of differently coloured threads, it is possible to produce a limited, but a relatively large number of different colours on a fabric surface.

The following questions frequently arise in practice, but so far they have not been answered satisfactorily:

- To which extent does the colour on a fabric surface change if the weft density or the yarn fineness decreases/increases by a certain percentage?
- Is a changed colour still acceptable for the customer?
- In which way to perceive, measure, define a desired colour?
- How objective the measuring method is?
- Is it possible and in which way to make a correction, which would provide acceptable colour on a fabric surface despite changed values?

In this paper, we would try to answer these questions. Although the answers should not be considered absolute and final, they will certainly clarify and more precisely identify this issue. A basic problem in answering these questions is that in practice it is impossible to make such a large number of differently woven patterns within the entire range of possible colour combinations, which would give reliable answers on the basis of spectrophotometrical measurements. Thus, we decided to use an analytical, calculating method and the measurements on the printouts of the fabric's computer simulations. However, it has to be emphasised that the measurements on printouts differ from those on real fabrics, because they have all colour surfaces in one level (in real fabrics individual colour surfaces are differently distributed by depth/thickness of a fabric). Nevertheless, this method has some other advantages. It enables relatively quick and cost-effective preparation of a required range of patterns in various colour combinations and simulation of woven fabrics, which could hardly be made or used in reality. The examples of these fabrics are fabrics with extremely high density and maximum surface coverage, which could not be produced without special devices (stentering of weft by the entire fabric width) or fabrics with too low density, which would lack stability of structure during usage.

The fact that only the first question can be relatively quickly and simply answered by means of spectrophotometrical measurements indicates how complex the answers to the above questions are. Other questions can be answered only provided that certain criteria defining the unit of measure for colour deviations, the standard as a basis of comparison and the objective measurement error are set. Likewise in dyeing and printing, the CIE L*a*b* colour system is used in our experiments. The unit

ΔE^*_{ab} from this system is taken as a unit of measure for colour deviations. A fabric structure with almost 100% surface coverage in which the foundation reflectance effect is the lowest is taken as a reference fabric. How objective these measurements are or to which extent they may deviate from real values and what are still acceptable values of colour deviations of surfaces is not known and depends upon the customer.

The last question, however, cannot be answered without an analytical approach by which other constructional parameters or colour values of the threads to be used for correcting colour differences are defined by calculation.

1.1 CIE L*a*b* Colour System and Colour Deviations

The CIE L*a*b* colour system indicates the values of colour deviations through the values ΔE^*_{ab}. Their relation with the L*, a* and b* colour values is presented in Equations *(1)* and *(2)* [1].

$$\Delta E^*_{ab} = \sqrt{(\Delta a^*)^2 + (\Delta b^*)^2 + (\Delta L^*)^2} \qquad (1)$$

$$\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta C_{ab}^*)^2 + (\Delta H_{ab}^*)^2} \qquad (2)$$

Where:

Δa* is the difference in the a* (red – green) value between the pattern and the standard;

Δb* is the difference in the b* (yellow – blue) value between the pattern and the standard;

ΔL* is the difference in the L* (lightness) value between the pattern and the standard;

ΔC^*_{ab} is the difference in the C^*_{ab} (chroma) value between the pattern and the standard and $C^*_{ab} = ((a^*)^2 + (b^*)^2)^{1/2}$;

ΔH^*_{ab} is the difference in the H^*_{ab} (hue) value between the pattern and the standard where $\Delta H^*_{ab} = C^*_{ab}\ \Delta h_{ab}\ (\pi/180)$, h_{ab}= arc tg $(^{b^*}/_{a^*})$;

ΔE^*_{ab} is the colour difference between the pattern and the standard.

Colour deviation in the mentioned system means the shortest distance in the CIE L*a*b* co-ordinate space from the position of a certain colour to the position of a standard colour which it is compared with. In practice the comparison is normally made between the achieved colour and the colour required and evaluated through colour values by the customer.

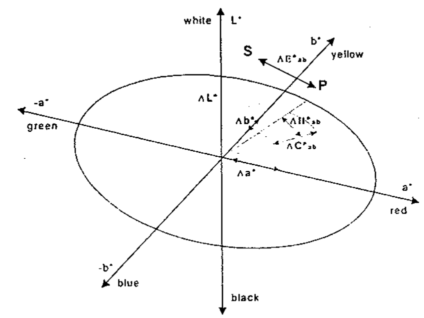

Figure 1: CIE L*a*b* colour space and colour difference between colour P and standard colour S.

1.2 Theoretical Calculation of Colour Values of Woven Surfaces

Colour values of a fabric surface are made up of three areas in the warp and weft interlacing point. These areas are the surface of the warp thread, the surface of the weft thread and the space between the threads. Colour values of a weave repeat and a colour repeat are calculated in accordance with geometrical participation of the mentioned areas and colour values of the warp and weft threads that make these areas. The method of calculation [2] is based upon the geometrical scheme of a fabric as shown in Figure 2 from which the shares of individual colour components are calculated.

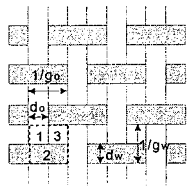

Figure 2: Schematic presentation of a fabric and an interlacing point.

On the Figure 2 the interlacing point is made up of three colour components where 1 is the warp thread, 2 is the weft thread and 3 is the foundation colour.

So far the size of the surface of individual warp and weft points has been calculated by using Equation (3):

$$p_{o,w} = \frac{1}{g_o} \cdot \frac{1}{g_w} \qquad (3)$$

where g_o and g_w is the density of the warp and the weft threads, while the colour content of i component in a repeat unit is:

$$U_i = \frac{n_{oi} + n_{wi}}{n} \qquad (4)$$

where n_{oi} and n_{wi} is the number of the warp and the weft points of i colour and n the total number of points in a colour repeat.

If a warp interlacing point is considered as a colour surface made up of three components, the content of individual colour components in a colour repeat of a fabric will be calculated by using the following Equations *(5)*, *(6)* and *(7)*:

$$p_{1o} = d_o \cdot \frac{1}{g_w} \qquad (5)$$

$$p_{2o} = d_w \cdot \left(\frac{1}{g_o} - d_o\right) \qquad (6)$$

$$p_{3o} = \left(\frac{1}{g_o} - d_o\right) \cdot \left(\frac{1}{g_w} - d_w\right) \qquad (7)$$

Where:

d_o, d_w is the diameter of the warp, the weft threads;

g_o, g_w is the density of the warp, the weft threads;

p_{1o} is the surface of the warp thread in the warp interlacing point;

p_{2o} is the surface of the weft thread in the warp interlacing point and

p_{3o} is the foundation reflectance surface in the warp, the weft interlacing point.

Index $_o$ applies to the warp interlacing point. Index $_1$ applies to the surface of warp thread in the interlacing point, index $_2$ to the surface of weft thread in the interlacing point and $_3$ to the surface between threads. The contents of individual surfaces in warp interlacing point are calculated from the ratio between equation *(5)* and *(3)*, *(6)* and *(3)* and *(7)* and *(3)*. Equation *(5)* and *(6)* for the surfaces 1-warp and 2-weft in weft interlacing point are accordingly adjusted. The rest is the same as in a case of warp interlacing point.

On the basis of the diameter of the thread (d_o, d_w), the threads density (g_o, g_w) and the weave the contents of individual colour threads in the pattern are calculated by using the following Equation *(8)*.

$$U_i = \frac{(u_{on,ot} + u_{on,wt}) \cdot n_{oi} + (u_{wn,ot} + u_{wn,wt}) \cdot n_{wi}}{n} \qquad (8)$$

Where:

n is the number of all points in a colour repeat;

$u_{on,ot}$ is the content of the warp thread colour in the warp interlacing point;

$n_{ot,oi}$ is the number of the warp points on i colour warp threads;

$u_{on,wt}$ is the content of the warp thread colour in the weft interlacing point;

$n_{wt,oi}$ is the number of the weft points on i colour warp threads;

n_{oi} is the sum of the warp and the weft points on i colour warp threads = $n_{ot,oi}+n_{wt,oi}$;

$u_{wn,ot}$ is the content of the weft thread colour in the warp interlacing point;

$n_{ot,wi}$ is the number of the warp points on i colour;

$u_{wn,wt}$ is the content of the weft thread colour in the weft interlacing point;

$n_{wt,wi}$ is the number of the weft points on i colour wefts;

n_{wi} is the number of the warp and the weft points on i colour wefts = $n_{ot,wi}+n_{wt,wi}$.

Colour differences are calculated by using the following Equation *(9)* [3].

$$\Delta E^*_{ab} = \sqrt{\left(\sum_{i=1}^{n}(a^*_i U_i) - a^*_s\right)^2 + \left(\sum_{i=1}^{n}(b^*_i U_i) - b^*_s\right)^2 + \left(\sum_{i=1}^{n}(L^*_i U_i) - L^*_s\right)^2} \qquad (9)$$

Where:

a^*_s, b^*_s and **L^*_s** are the colour values of the standard fabric;

a^*_i, b^*_i and **L^*_i** are the colour values of i component;

U_i is the content of i component in a colour repeat.

2. METHODS AND RESULTS

The simulations of bicolour fabrics in plain weave with varying fineness and density of the warp and weft threads are prepared with CAD system Arahne [4]. All basic saturated colours (red, yellow, blue, green) are combined. Since the space is limited and the obtained curves have similar shapes and differ only in values, the results of the combination of red colour in the warp and yellow colour in the weft are going to be presented.

Colour values of the simulations are measured with a spectrophotometer Spectrolino SpectroScan by GretagMacbeth (D65). The measured colour values of the printed simulations have the following values:

- red: $L^* = 16.79$, $a^* = 57.51$, $b^* = 16.59$
- yellow: $L^* = 84.4$, $a^* = 7.59$, $b^* = 68.54$.

The variations of constructional parameters take place in two ways. In the first case the colour values of the computer simulations are calculated and measured for a fabric in which the warp and weft threads density varies from initial 30 threads per cm to final 15 threads per cm at constant warp and weft threads fineness 30 tex. In the second case the warp and weft threads fineness varies from initial 30 tex to final 15 tex at constant warp and weft density 30 threads per cm.

Colour differences ΔE^*_{ab} in Tables 1 to 2 are calculated in view of standard-reference fabric having the warp and weft threads density 30 threads per cm and in Tables 3 and 4, where the reference fabric has warp and weft threads fineness 30 tex. These fabrics are chosen due to minimum influence of foundation reflectance – the colour of the space between threads.

2.1 Influence of Density

The calculated values of the influence of density upon the change of colour values at constant warp and weft fineness 30 tex are shown in Table 1 and graphically represented in Figure 3, and the measured values in Table 2 and Figure 4.

Table 1: Calculated dependence of colour deviation ΔE^*_{ab} upon changed warp-g_o (threads/cm) and weft-g_w (threads/cm) density.

ΔE^*_{ab}						
g_w \ g_o	30	27	24	21	18	15
30	0.00	4.25	8.49	12.74	16.99	21.24
27	4.11	1.18	4.90	9.21	13.56	17.92
24	8.23	4.28	3.16	6.52	10.77	15.18
21	12.34	8.30	5.47	5.94	9.22	13.38
18	16.46	12.38	9.16	7.94	9.52	12.91
15	20.57	16.46	13.12	11.23	11.54	13.91

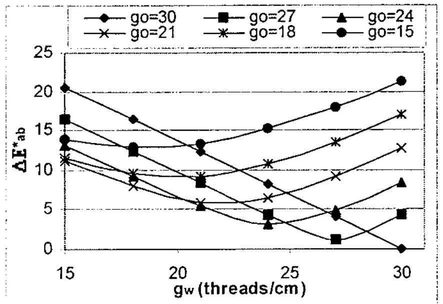

Figure 3: Calculated dependence of colour deviation ΔE^*_{ab} upon changed warp-g_o and weft-g_W density.

Table 2: Measured dependence of colour deviation ΔE^*_{ab} upon changed warp-g_o and weft $-g_w$ (threads/cm) density.

	ΔE^*_{ab}					
g_w | g_o	30	27	24	21	18	15
30	0.00	5.21	11.04	17.41	24.43	28.97
27	2.88	2.15	7.83	13.25	21.24	25.71
24	6.32	2.80	4.55	11.09	17.18	23.08
21	9.69	6.75	4.68	9.20	15.09	21.36
18	13.93	11.78	7.21	9.99	14.83	21.35
15	16.46	13.92	11.99	11.60	17.00	22.26

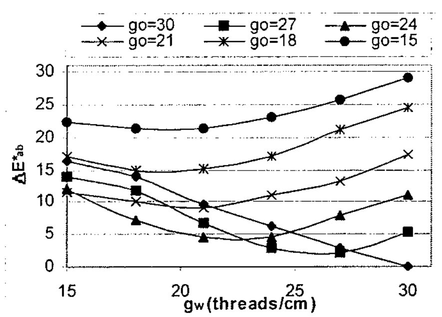

Figure 4: Measured dependence of colour deviation ΔE^*_{ab} upon changed warp-g_o and weft $-g_w$ density.

2.2 Influence of Fineness

The calculated results of the influence of the yarn fineness on the change of colour values at constant warp and weft threads density 30 threads per cm are shown in Table 3 and graphically represented in Figure 5, and the measured results in Table 4 and Figure 6.

Table 3: Calculated dependence of colour deviation ΔE^*_{ab} upon changed warp-Tt_o (tex) and weft-Tt_w (tex) threads fineness.

	ΔE^*_{ab}					
Tt_w | Tt_o	30	27	24	21	18	15
30	0.00	2.48	5.28	8.09	11.23	14.69
27	2.38	0.69	3.15	5.98	9.15	12.67
24	5.08	2.78	1.82	3.99	7.09	10.62
21	7.78	5.43	3.35	3.31	5.63	8.99
18	10.79	8.43	6.11	4.77	5.39	7.98
15	14.13	11.75	9.35	7.57	6.93	8.22

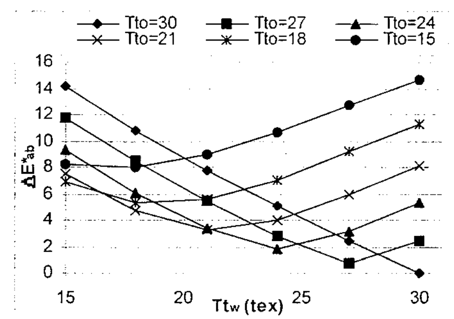

Figure 5: Calculated dependence of colour deviation ΔE^*_{ab} upon changed warp-Tt_o and weft-Tt_w threads fineness.

Table 4: Measured dependence of colour deviation ΔE^*_{ab} upon changed warp-Tt_o (tex) and weft-Tt_w (tex) threads fineness.

	ΔE^*_{ab}					
Tt_w | Tt_o	30	27	24	21	18	15
30	0.00	2.61	4.56	7.91	10.60	13.49
27	0.80	0.51	2.77	5.29	8.48	11.83
24	3.78	2.91	1.13	2.55	6.14	9.09
21	6.05	4.07	3.65	0.91	4.41	7.83
18	8.94	7.46	5.12	2.04	2.34	5.25
15	12.74	10.46	7.68	5.77	4.53	7.85

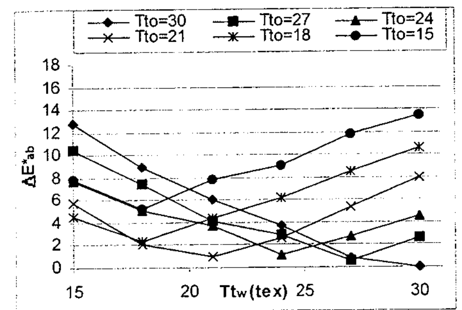

Figure 6: Measured dependence of colour deviation ΔE^*_{ab} upon changed warp-Tt_o and weft-Tt_w thread fineness.

3. DISCUSSION

The warp and weft threads fineness and density are chosen as constructional parameters because they directly influence on the shares of individual colour components in a colour repeat. There is a significant difference between these two parameters, namely, with the variation (decrease) of density, the surface of a colour repeat increases, whilst with the variation of fineness, this surface remains constant. Both, however, influence the change of the colour components share, which in turn depends upon the extent of individual changes. In our experiments the variations of both parameters are 10% of initial, starting values. However, the variations in the diameter of the threads are lower at the changed fineness, because the diameter of the thread taken into account both in calculations and computer simulations is a root function of the threads fineness. Therefore, on principle all changes of the value ΔE^*_{ab} in the case of the changed fineness are absolutely lower than in the case of adequate changes of density (Tables 1 to 4).

The curves in Figures 3 to 6 have similar shape, but different values ΔE^*_{ab}. If a variation of a parameter takes place in one system only (the warp or the weft), the curve that describes the change of the colour deviation is a straight line with a certain angle of inclination. Other curves are virtually similar to parabolas with the lowest point corresponding to the fabric square construction. If the zero point was displaced and other type of fabric was selected for comparison (e.g. density/fineness 27/27), the deviations would take place on this straight line either in the case of decrease or in the case of increase of the mentioned parameters. The variation of one constructional parameter only, results in higher values of colour deviations than the variation of the same parameter in both systems at the same time. Thus, with the changed weft density and the unchanged warp density the value of colour deviation is 20.57, and with the changed warp density and the unchanged weft density 21.24. But if both parameters are changed at the same time, this value is only 13.91 (Table 1). The reason is changed shares of individual colour components in a colour repeat. When only one parameter is changed, the share of one colour component and that of reflectance increase on account of the share of the other component. As already mentioned, colour deviations are lower when the yarn fineness is changed; in this case the values are by one third inferior to the values obtained when the density is changed (Table 3, 4).

There are differences between the calculated and the measured values of colour deviations. These differences can be attributed particularly to the selection of individual colours and to the threads shading which gives more plastic, three-dimensional appearance of simulation. The calculation of colour values, which takes into account an identical and unchanged diameter of threads – like in simulation, no such factor appears and no eventual errors in printouts and spectrophotometrical measurements occur. So, these differences are maximally pronounced in the measured values of colour deviations due to the changed threads density (Table 3). In this case colour deviations at the minimum weft density and the maximum warp density (minimum share of yellow colour) are lower than theoretically calculated for the value ΔE^*_{ab} cca. 4, and at the maximum weft density and the minimum warp density (maximum share of yellow colour) higher for the value ΔE^*_{ab} cca. 7.5.

Colour deviations between the patterns with the most similar constructional parameters are important for practical use. In patterns 30/27, 27/27 and 27/27 these deviations in view of the pattern 30/30 range from 4.25 (27/30) max. to 1.18 (27/27) min. at the calculated changes of density, and from 2.48 (27/30) max. to 0.69 min. at the calculated changes of fineness. The deviations are slightly higher at the measured values. Thus, max. measured values of the change of density are 5.21 (27/30) and min. values 2.15 (27/27), and max. measured values of the change of fineness are 2.61 (27/30) and min. values 0.51 (27/27).

We estimate that both the calculated and the measured colour deviations are among the highest possible deviations because the shares of colour components contributed by differently coloured threads and their colour values (considerable differences in values a* and b*) are of such nature and because the variation of constructional parameters is high – 10%. In the case of more akin colours, with lower variations of constructional parameters and with a fabric construction having a higher share of reflectance than the standard fabric, the changes of colour values would certainly be lower than those presented in this paper.

4. CONCLUSIONS

Trying to answer the questions raised in the introductory part, we can summarise the following:

The value ΔE^*_{ab} from the CIE L*a*b* colour system is taken as a unit of measure for evaluating colour deviations. A square fabric construction with minimum foundation reflectance is selected as a reference, standard fabric. On the basis of theoretical calculations and measurements carried out on printed simulations, the following conclusions have been made:

- The changes of colour values are linear depending upon the extent of the variation of constructional parameters. Therefore, they can be predicted by calculation.
- Colour deviations are bigger if the variations take place in one thread system only.
- Colour deviations at changed fineness are by about one third inferior at the same percentage of changes (the diameter of the yarn is a root function of the fineness).
- The calculated and the measured colour deviations are among the highest. In most other cases they would be lower.

It should be emphasised that these findings have to be verified on real fabrics. The findings show that the measured and the calculated colour deviations are in good accordance and that the analytical calculating method can be used for correction of individual colour values due to projected constructional changes. The variations of other constructional parameters and the colour values of individual threads in order to obtain satisfactory colour deviations can be calculated.

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Doc. Krste Dimitrovski, University of Ljubljana, Faculty for Natural Sciences and Technology, Department of Textiles, Snežniška 5, SI-1000, Ljubljana, Slovenia. Phone: +386 1 200 3 217, Fax: +386 1 4253 175, E-mail: krste.dimitrovski@ntftex.uni-lj.si

OPTICAL COLOUR MIXING OF TWO OR MORE COLOURS ON THE WOVEN FABRIC'S SURFACE

Tanja Nuša Kočevar
University of Ljubljana, Faculty of Natural Sciences and Engineering,
Department of Textiles Ljubljana, Slovenia

Abstract
A woven fabric's surface can be either in one, two or in more colours. On the surface of a two- or more- coloured woven fabric, individual colour surfaces, respectively surfaces of yarn floats, can be very small. In addition, distances between them can be very short too. If the colour surfaces are so small and close together that they cannot be distinguished with the naked eye, they mix together into a new colour sensation. Sometimes colours optically completely fuse into a new, uniform colour shade. However, colour constituents usually can still be defined, but their mutual influences in a great deal change the visual appearance of individual colour surfaces. Optical colour mixing is creatively used by woven fabrics designers to reproduce various shades of colour on the surface of colourful woven fabrics and to express their ideas in textile medium. Alteration of parameters of a woven fabric's composition influences the size of individual colour surfaces and distances between them, as well as other fabric's surface characteristics. That all influences a perceived colour of a fabric's surface.
The paper presents the optical colour mixing on the fabric's surface. Besides, the influences of some parameters of a woven fabric's composition on the optical colour mixing and on fabric's appearance are presented.

Keywords: *Optical colour mixing, weave, fabric's set, yarn thickness, design*

1. INTRODUCTION

The colour impression of a woven fabric is the result of interactive relations between colours of yarns, which float on a fabric's surface. The visual appearance of yarn floats, their length and positions depend on chosen yarns, fabric set, a weave and on other technological factors. That influences contrasts between colours which are presented on a fabric's surface and thus the colour of the fabric. If the yarn floats are small and they are placed closely together an optical mixing of colour can occur. This is the process when the original colours become indiscernible and replaced by an optical colour mixing. Colours of yarns which were chosen and woven into a fabric sometimes therefore change their appearance to a great extent, when they confront each other in various positions and proportions on a fabric's surface. Besides the colours' characteristics, all the factors of a fabric's composition and construction influence the fabric's colour. Because of that a woven fabric's designer has to possess the knowledge on interactive influence of colours and on the influence of the fabric composition on the fabric's appearance in order to create an attractive appearance of a fabric.

2. OPTICAL COLOUR MIXING

When designing a fabric, all the colours' characteristics and dimensions which are placed on its surface should be considered, and their mutual relationships should be foreseen. E.H. Gombrich [1] explains the difficulties at the perception of absolute colour's characteristics: "While form is absolute, so that you can say at the moment you draw any line that it is either right or wrong, colour is wholly relative. Every hue throughout your work is altered by every touch that you add in other places; so that what was warm a minute ago, becomes cold when you put a hotter colour in another place, and what was in harmony when you left it, becomes discordant as you set other colours beside it; so that every touch must be laid, not with the view to its effect at the time, but with a view to its effect in futurity, the result upon it of all that is afterwards to be done being previously considered".
Every colour thus should be placed cautiously, considering the impression which it is going to create with other colours. The appearance of a colour namely changes depending on surrounding colours. The same colour looks differently on different backgrounds. Between colours various contrasts appear, which depend on the colours' characteristics and the size of shapes which they occupy.
When the colour surfaces and distances between them get smaller the optical colour mixing occurs and the fusion of colours into a new colour shade appears. This phenomenon puts in appearance when the combination of a viewing distance and sizes of various coloured surfaces is of such a kind that the human eye cannot distinguish individual colour elements which create a new colour.
The phenomenon of optical colour mixing is applied in various areas of colour forming and very often in the visual art too. Before the colour surfaces visually fuse into a new, uniform colour, the eye sometimes distinguishes individual colour surfaces and sometimes one uniform colour. This mutual influence between colours gives the coloured surface a visual brilliance and liveliness, which cannot be achieved by uniform colours [2].
Observing the woven fabrics where the optical colour mixing is in the presence, lively colour activities can also be noticed. Especially when fabrics revive on a moving body or in various drapes, for example in an interior. That gives products made of woven fabrics their uniqueness and attractiveness.

3. DESIGNING A COLOUR ON A FABRIC'S SURFACE

3.1 Fabrics in one colour

The colour of a woven fabric is designed in various stages of its production. We choose the type and the count of a yarn, which is in one, two or more colours. With a chosen yarn we define the colours which will be presented on the fabric's surface. All the same, the yarn characteristics influence the texture, the lustre, the voluminosity and other visual characteristics of a fabric's surface. Not only the colour of the yarn influences the colour of the fabric. Almost all factors of the fabric's composition have influence on a fabric's surface appearance, such as a warp and a weft pattern, a set of a fabric, and especially the weave.
After the fabric is produced, its colour can be altered applying various finishing, such as dyeing, printing, etc.
The surface of a thread which floats on the fabric's surface, is a colour surface which is the elementary part of the fabric's colour. If the warp and the weft are in the same shade, all the colour elements are the same and the fabric's surface is in one colour. Its appearance is influenced by the texture of the fabric, which is a result of fabric's

technological factors. If, for example, we use the yarn with expressive lustre, such as e.g. silk, and use the satin weave, which also emphasizes the lustre, the colour will appear more lively and lighter.

3.2 Two- or more-coloured fabrics

Using two or more coloured yarns, the possibilities of creating various patterns and colour shades on a fabric's surface increase. Various colour surfaces can be arranged into various patterns, depending on chosen factors of fabric's composition, such as warp and weft pattern, weave, set, and others. If the individual colour surfaces are small enough and if their mutual distance is short, the optical colour mixing on the fabric's surface occurs and colours can optically fuse into new colour shades. The colour surfaces are the smallest for instance in plain weave and their interacting distance is very short when the fabric set is very high and when the pores between the threads in a fabric are small.

Sometimes colours optically completely fuse into a new, uniform colour shade. But sometimes colour constituents still can be defined. However their mutual influence changes the visual appearance of individual colour surfaces, while colours optically affect each other when they are placed close to each other. They optically tend to assimilate according to their lightness, hue and saturation. In some cases therefore it is difficult to estimate the colour of a yarn when it is not interlaced with another one. If we focus our view on individual floating threads, we notice that its colour appearance strongly depends on the colour composition in which it is placed.

4. THE RESEARCH OF OPTICAL MIXTURES ON A FABRIC'S SURFACE

Five colours of yarns and their variations on two- and three-coloured fabrics were researched, regarding their optical mixtures. The used colours of yarns are red, magenta, blue, green and yellow. The counts of used yarns vary a little, besides, the fabrics were woven by hand and therefore their weft set vary a little as well, which all has an impact on the fabrics' colours. They were measured by spectrophotometer and visually estimated.

4.1 Optical mixing of two colours on a fabric's surface

Five fabrics and their colour pairs were observed when researching the optical mixing of two colours on a fabric's surface. These pairs are:

- Red and magenta,
- Red and blue,
- Red and green,
- Red and yellow (figure 1),
- Magenta and green.

The fabrics are in plain weave. The warp is in one and the weft in another colour. In figure 1, the measured yarns' and fabrics' colours are presented in the CIE Lab diagram.

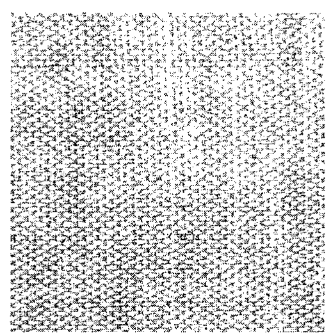

Figure 1: Two-coloured fabric. The warp is red, the weft is yellow.

The results are as follows:

Red and magenta: The hue difference between both colours is not very big. The difference in lightness is small but the red is more saturated. The colour of the fabric is a rather saturated red, whose lightness is similar to the lightness of both colour components. On the colour wheel it is closer to the magenta, which shows that the influence of the magenta colour is bigger than the influence of red. That is the result of the bigger set of the magenta weft.

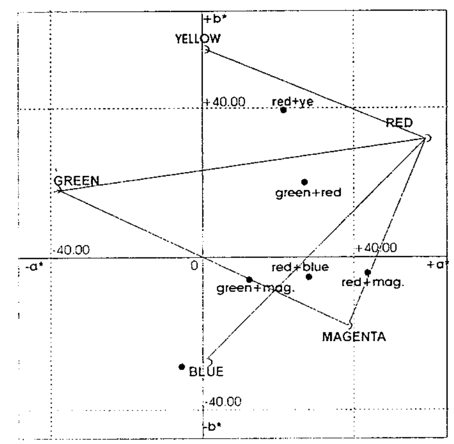

Figure 2: CIE Lab – colour diagram, on which the yarns' colours and the two-coloured fabrics' colours are presented.

Red and blue: The difference between hues is bigger than in the colour pair above. The red is lighter and more saturated than blue. The colour optically mixes into a slightly violet colour, which is less saturated than red and a little more than blue. It is lighter than blue and darker than red. On the colour wheel it lies very close to the connecting line between both colours.

Red and green: The hue difference is big. The green is lighter and the red is more saturated. The colour of the fabric is greyish and its saturation is smaller than the saturation of both components. The colour is also darker than both colours.

Red and yellow: The yellow is lighter but less saturated than the red. The hue difference is not big. The colour of the fabric is orange, whose saturation is smaller than the saturation of both colours and it is lighter than red and darker than yellow.

Magenta and green: The colours are complementary. The green is slightly lighter than magenta, their saturations are very similar. The colour of the fabric is greyish, unsaturated, and lies close to the centre of the colour wheel, closer to magenta, which implies that its influence on the fabric's colour is bigger.

The colour characteristics of two coloured fabrics depend on the yarn colours' characteristics as follows:

a) *Hue:* The hue of a fabric depends on the hues of yarns. If we connect the hues of the yarns, indicated on the CIELAB diagram, with a straight line, we can see that the hue of a fabric lies somewhere around that connecting line.

b) *Saturation:* The colour of a fabric is usually less saturated than the saturation of both yarn colours, respectively it is less saturated than one which is saturated more than another. When the hue difference between yarn colours is big (the biggest is between complementary colours), and the connecting line between two colours runs close to the unsaturated centre of the CIE Lab diagram, the saturation of a fabric's colour will be smaller and the colour will be greyish. This is very obvious in the pair green and magenta, where the connecting line runs almost through the centre. When the hue difference between two colours is smaller (blue and magenta or magenta and red), the saturation of the colour is bigger, and having two similar hues on the fabric's surface, a saturated colour can be achieved.

c) *Lightness:* It depends on the lightness of both components as well as on their hue difference. When the colours are complementary (e.g. magenta and green) the lightness can be smaller than the lightness of both colours. The texture of the fabric with its shadows can also influence the lightness of the fabric's colour. If the colours are not complementary, the colour of the fabric is approximately half of the sum of the lightness values of both colours.

4.2 Optical mixing of three colours on a fabric's surface

The following two combinations of colours were observed on fabrics' surface:

- Red (warp) + magenta + yellow (weft).
- Blue (warp) + magenta + yellow (weft) (figure 3).

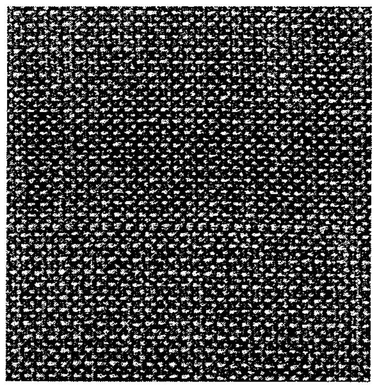

Figure 3: Three-coloured fabric. Blue warp, magenta and yellow weft.

The warp pattern is 1A and the weft pattern is 1b, 1c, therefore the warp colour has a bigger influence on the fabrics' colour, correspondingly the colour surfaces on the fabrics face are not in the equal quantity ratio.

The combination of red, magenta and yellow does not contain a complementary pair. The biggest hue difference is between magenta and yellow. The yellow is the lightest, therefore it is very obvious. Red and magenta optically fuse because they have similar hue and lightness. It is very obvious, that the red warp changes its colour depending on with which colour it is interlaced. It looks more orange and warm with the yellow, but cooler and more violet with magenta. The measured colour of the fabric is medium saturated, rather light and the hue is similar to the hue of the red.

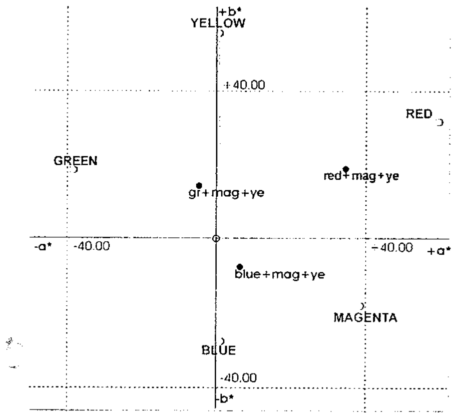

Figure 4: CIE Lab – colour diagram, on which the yarns' colours and the three-coloured fabrics' colours are presented.

The combination of blue, magenta and yellow contains a complementary colour pair, which is blue and yellow. A fabric colour therefore looks greyish. The yellow floats are very obvious because of their lightness. The magenta is lighter than blue, therefore the magenta floats step out visually too. The colours optically do not fuse, but their influence is rather visible. The hues of yellow and magenta are slightly cooler. On the colour wheel the measured colour of the fabric lies close to its centre. The colour has low saturation, it is darker than yellow and magenta and lighter than blue. The hue angle is bigger that the hue angle of the blue colour but smaller than the hue angle of the magenta.

The combination of green, magenta and yellow: The green and the magenta are complementary colours, consequently the fabric looks greyish. The yellow is warm and light and therefore visually stands out. Nevertheless it loses a part of its saturation and also looks more grey. The hue angle of the fabric's colour is similar to the one of magenta.

We can conclude as follows:

If on a fabric's surface three colours optically mix, the hue of a fabric's colour lay in a triangle whose sides are the lines which connect the yarns' colours, regarding the CIE Lab diagram. In all three cases it is obvious that the fabric's hue is similar to the hue of a colour which is between the other two, regarding the centre of the colour wheel. The saturation of a colour depends on the yarns' colour hues and their saturations. The fabric's colour saturation will be smaller if two out of three colours are complementary. The lightness of a fabric's colour is smaller than the lightness of all colour components, especially if there is a complementary pair in the composition [3].

5. THE INFLUENCE OF FABRIC'S COMPOSITION PARAMETERS ON OPTICAL COLOUR MIXING ON ITS SURFACE

As mentioned before, the interacting influence of colours changes by alteration of the largeness of the colour surfaces and by changing their mutual distances. The change of the technological factors of the fabric influences the appearance and the largeness of yarn floats and correspondingly colour surfaces on the fabric's surface. That influences the optical colour mixing and the colour of a fabric. The influence of the following factors on a fabric's appearance were observed in the research:

- The weave,
- The yarn thickness,
- The fabric set.

5.1 The influence of weave on fabric's colour

The chosen weave influences the size of the yarn floats, their order and their interactive quantity proportion. All that influences the apparent pattern on the fabric's surface and the perceived optical mixture of colours.

a) Ratio between colours on a fabric's surface: Depending on weaves, the ratios between warp and weft floats are as follows: plain weave 1:1, hopsack and 2/2 twill 2:2, 7/1 satin 7:1 and 1/ sateen 1:7 (the warp and the weft set and the thickness of warp and weft yarns should be the same). These ratios have the biggest influence on optical colour mixing on a fabric's surface.

b) The pattern: The weave also affect the length and arrangement of yarn floats, which creates various patterns. At plain weave, the individual yarn floats are separated from each other and small dots are visible if the warp and weft are in different colours. At hopsack weave, floats compose bigger squares, which attract and retain the eye. At the 2/2 twill, floats compose diagonal lines, which are also more obvious and guide the eye by the fabric's surface. The satin and sateen weaves are more even and regular because yarn floats do not tend to compose more obvious shapes, although sometimes isolated dots on their surfaces also have the power to catch the eye or if the fabric set is big they can visually even form diagonal twill lines. The appearance of colours' surfaces on a two- or more- coloured fabric vary depends on the ratio between colours as well as on the absolute largeness of colour surfaces, which influences the colour of a fabric. E.g.: Colour surfaces on hopsack weave look slightly different than on plain weave because the colour surfaces compose larger squares whose colours do not assimilate as in plain weave.

c) The texture: In a fabric the warp and the weft threads interlace according to the weave. The thread is illuminated if it lies above another thread. At the same time it covers the thread lying beneath and shades it. The result of thread interlacing in a fabric are also interspaces, whose largeness and shape depend on a weave, fabric set and other factors. If the interspaces are large, the background colour can shine through and affect the fabric's colour. If they are small and shaded it has an influence on the fabric's colour as well. Depending on the weaves, therefore various textures can be created, which also influence the colour of the fabric by the various arrangements of shadow and light. According to the fabric's texture and arrangement of floating threads on a fabric's surface, weaves can be divided into the following groups [3]:

- *Weaves which create a granular surface*

The weaves such as plain weave, crepe or broken twill with small repeat, create a granular fabric's surface. The light reflected from such a surface is rather diffused and there are no distinctive shaded or illuminated surfaces.

- *Weaves which create various simple patterns*

Such weaves create for instance lines (weft or warp rib), diagonal lines (various twill weaves), square blocks (hopsack or basket). The patterns are bigger and therefore more obvious. Thus an optical fusion of colours occurs with a bigger viewing distance.

- *Weaves which create bigger surfaces with equally orientated threads*

Such weaves are satin and sateen. The surface of a fabric can have a great lustre what influences the perceived colour.

- *Weaves which create distinctive texture*

Some weaves, such as honeycomb, create very distinctive textures, with bigger differences between illuminated and shaded surfaces, which influences the colour of a fabric.

5.2 The influence of yarn thickness on fabric's colour

If the yarns are thicker, the colour surfaces are bigger and the mutual influence of colours on a fabric's surface is smaller, which influences the fabric's colour. Using thicker yarns, the weave structure and consequently the texture of a fabric is more pronounced. Decreasing the yarn thickness means that colour surfaces on the fabric's surface become smaller and therefore the optical colour mixing is more pronounced. The yarn count also influences the size of pores between threads. Using finer yarns, at the given set of the fabric, the pores between threads become larger. The fabric therefore can be translucent and the perceiving colour of the fabric is influenced by the background's colour.

5.3 The influence of the fabric set on its colour

Changing a fabric set means changing the distances between threads and consequently means changing distances between colour surfaces on a fabric's face. The mutual influence of colours therefore varies with a different fabric set and consequently a fabric's colour. Therefore at a certain set, an optical colour mixing can occur. The fabric set also affects the fabric's colour with the size of pores between threads. At a smaller fabric set the pores between threads are bigger and the background colour can influence the fabric's colour. This also emphasizes the texture of a fabric, which is coarser at a smaller set, when shaded and illuminated surfaces are bigger. At a smaller set the texture of yarns are more obvious too. In that case the floats are bigger and the threads are not so tensed and compressed as if the fabric's set is bigger.

6. CONCLUSION

Designers want to interpret and reproduce different ideas on fabrics' surfaces. Various

colourful artworks and photographs are an inexhaustive source of inspiration. Despite the restrictions set by the weaving technique, it is the optical colour mixing which enables creation of a rather extensive colour gamut on a fabric's surface. The knowledge which was acquired through the research presented above, can be of great assistance to predict the outcoming colour on a colourful fabric's surface.

Possessing the knowledge on visual art and the understanding of influence of a fabric's composition parameters on its colour and texture, an attractive appearance of a fabric can be created. Notwithstanding we are over and over again surprised by the influence of chosen parameters on the final result – the appearance of a fabric, which makes a designer's work attractive. All together it is just an additional motive for us to persistently explore the possibilities of translating visual ideas using the complexity of expression resources offered by interlacing of warp and weft threads.

Nevertheless, designing a fabric, the mutual relationships should be studied and observed further. Observing a fabric's face from a short distance, a composition of various floats – small coloured surfaces can be seen, where every shade's appearance depends on another and influences it back. Increasing the viewing distance, coloured surfaces optically blend together into new colours and patterns, which is the result of the optical colour-mixing phenomenon. Bigger colour surfaces influence each other again. We should not forget the texture of a fabric, which is its unique quality and as such can enhance its colour and vice-versa. Yet, an installation of a fabric into an interior or on a body shows it in a new, different scale and correlation. The fabric, as a whole, influences the space around it by its colour, texture, pattern, and inversely, the environment affects it by the illumination and its own colour, texture and pattern. A fabric's smallest part therefore should be considered in all expected relationships and also in its ultimate – to its extended environment.

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Dr. Tanja Nuša Kočevar, University of Ljubljana, Faculty of Natural Sciences and Engineering, Department of Textiles, Snežniška 5, SI-1000 Ljubljana, Slovenia. Phone: +386 1 200 3249, Fax: +386 1 425 3175, E-mail: tanja.kocevar@ntftex.uni-lj.si

TEACHING COLORIMETRY

Schanda, János
University of Veszprém
Veszprém, Hungary

Abstract
Colorimetry becomes an important subject in many areas of life. Traditionally a subject for specialized arts and crafts students, now a day it is penetrating areas of science, techniques and arts.

The basics of colour are usually taught by the art teacher, who has a very special relation to colour: for him it is a vehicle to express his/her mood. The child will learn about colour harmony, the meaning of different colours in its cultural environment, will perhaps experiment with subtractive colour mixing using paints, but will not hear anything about how to use colour when he is confronted with a computer and experiences the possibilities of producing coloured text and graphics on the monitor.

Colorimetry should be dealt with in computer studies, at the time the students get introduction to make their layouts on the computer.

The paper will show an outline of such a colour course that can be implemented into the normal school system, where the students can experiment with colour matching on the computer, learn the differences between additive and subtractive colour mixing, where colour harmony, assimilation and contrast can be shown by examples and where the students are lead to understand the proper use of colours in their everyday life.

Keywords: *Colorimetry, teaching colour, using colour on compute and, in printing, graphic arts*

1. INTRODUCTION

The application of colour becomes more and more important, as the possibilities of using colour in almost all areas of life becomes possible. Now a days our morning newspaper greets us with coloured pictures (of some horrible scenes of terror), large coloured posters are seen in our streets as we go to work, our main communication gadget, our desktop computer greets us with a coloured screen. We use colour to identify objects of work, to highlight subjects, to organize items, etc. We use colour often subconsciously almost in every daily occupation. At the evening ours, when we watch television, it is almost unbelievable that a few decades ago these equipment delivered only monochrome pictures.

While since ancient times mankind used colours, the ability to deal with colours so freely is very recent. Therefore it is understandable that the teaching of the proper use of colours is not that widespread as it should be.

Children learn about colours (actually paints) during their courses of drawing and later arts. This is, however, restricted to a very limited area of colour application, and confined – more or less – to traditional painting and drawing.

It is seldom to see that in a normal school curriculum the teacher would let the children to experiment with the use of colours on computers. There are many educative computer toys (beside the much greater variety of non-educative, or even

demoralizing computer games), where the creativity of the child can enfold, but there are very few that would tap on the colour issue. This is not quite understandable, as the computer lends itself to experiment with colour.

Based on above experience we would like to suggest that a more scientific approach to colour should be part of the computer education. At the time the child learns about producing his or her WEB page, communicate with its friends using coloured pictures, etc. one can easily point out the interrelations between different hues, etc.

In the following we would like to present an outline, how at an early age children's affinity to colours can be increased.

2. COMPLEX APPROACH TO COLOUR

Professor Wright, the father of modern colorimetry, once wrote a very nice pamphlet on teaching colour. This was still in the pre-computer age, and he envisioned the co-operation of the physics teacher (explaining the fundamentals of optical radiation), of the chemistry teacher, who should build on the physics and explain why different materials have different colours, then the biology teacher could build on these getting the student acquainted with the colours of nature, and how these interrelate with biological functions – ending up with the explanation of colour vision. Naturally one should not forget the art-teacher, who will introduce the aesthetic side of colour and can – perhaps – make even the less interested young girls interested in selecting the best colour for their make-up.

In our present age of television and computers children find additive colour mixing natural. One has only to show them the screen of a CRT monitor and it will be clear for them that different hues can be built up by changing the intensity of three basic hues. One can then continue to the concept of colour matching, build up the system of the description of colour stimuli, the CIE system of colour stimulus description.

As a next step more advanced colour stimulus description can be introduced, alternative descriptions explained and demonstrated.

Finally the aesthetic value of colour can be shown and the correct use of colour demonstrated.

3. A TUTORIAL ON COLOUR

We have developed at our university a colour tutorial – for the use of informatics students, that can be, however, easily stripped down for the use in computer high-school courses. Our contains a number of interactive animations that make the use of it more entertaining and enjoyable. In the following some highlights shall be shown.

3.1 Introducing additive colour mixing

Showing the screen of a CRT monitor through a simple magifying glass will make the mixing of colours clear for the student. As a next step one can simulate on the screen the additive colour mixing experiment, usually shown using three slide projectors, but relatively difficult to set up in a class-room, as one needs three projectors properly adjusted, has to use intensity regulation and has to darken the room for properly seeing the experiment. On the screen one can simulate this as shown in Figure 1.

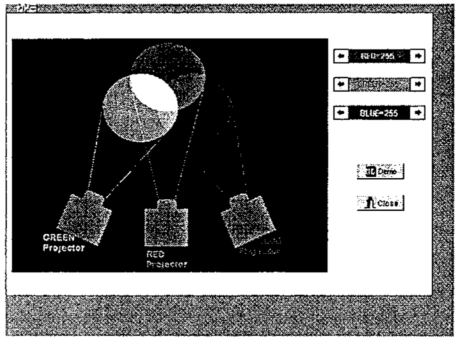

Figure 1: Simulating additive colour mixture.

By the help of the three coloured bars on the right of the picture one can adjust the intensity of the three simulated projectors and as a result the overlapping "illuminated fields" will change their colour. The student can experiment, how the intensity change of one of the basic colour stimuli changes the the appearance of the colour patch alone, how it changes if mixed with on of the other basic hues and what the effect of the field, where all three coloured beams illuminate the virtual screen.

As a next step the student can be confronted with the concept of colour matching. Figure 2. shows the screen image, where on the left side a coloured field is seen, which is produced by a random generator. On the right side first a grey field is seen, and the experimenter has to change the hue and brightness by

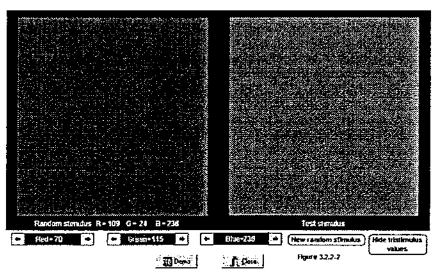

Figure 2: Screen image of the colour matching experiment.

adjusting the three bars seen below the fields. Within these bars numbers show the set R, G, B values (we have not re-calculated the monitor's R, G, B values into X, Y, Z or any other colour space values, as in this experiment the task is only learn how the intensity adjustment of the three basic hues will influence the colour appearance of the field. When the student thinks that the colour match is good enough, he/she can click on a button and the R, G, B values of the left hand side field will be shown and the student can compare whether the adjustment was correct or not. A built in demo program will make the colour match automatically. By clicking on a further button a new test colour will be displayed, or by clicking onto the "close" button the experiment can be terminated.

A number of further "experiments" will make the student familiar with more complex phenomena, where on of the is of great importance showing the additive and multiplicative nature of colour stimuli, and by the help of this producing the foundation of CIE colorimetry (this might be too complicated for high-school students, they just have then to accept that the additive mixture of monochromatic stimuli can be matched with the sum of the fundamental stimuli used for the matching of the single monochromatic components).

3.2 Colour spaces and advanced colorimetry

Computer provides good opportunity to demonstrate colour spaces as well. From the simple display of the gamut volume, to interactive virtual reality representations of the colour space and to hands-on experiments to get better understanding of the meaning of the different descriptors used in colour space and colour atlas descriptions, the computer simulation provides a variety of possibilities. Figure 3.

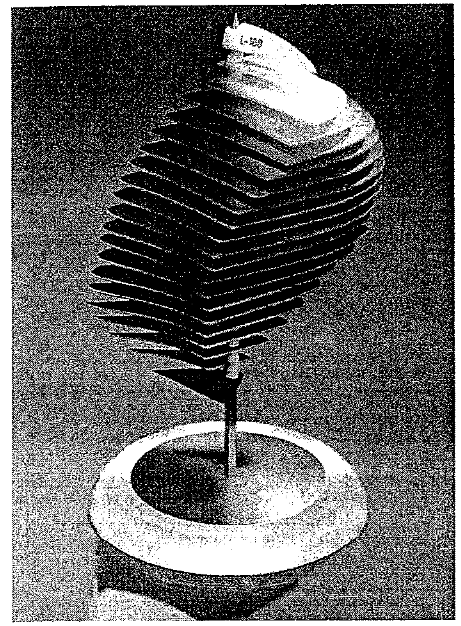

Figure 3: CIELAB colour space shown in a screen image.

shows the CIELAB colour solid, as an example.
Similar picures of other colour solids can help to understand the similarities and differences between them.

Figure 4. shows a snap-shot from an interactive excercise to teach Musnell chroma and value.

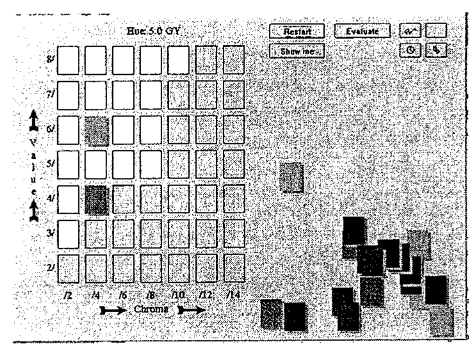

Figure 4: Interactive exercise to teach Munsell chroma and value.

The student has to pick with the mouse pointer a sample and place it into the Musell leave. When he/she finished, the program will evaluate his/her performance, and show – if necessary – the correct setting.

The computer can be used also to teach more advanced colour subjects, like chromatic adaptation. Remember Dr. Hunt's famous yellow pillow, or see e.g. Dr. Bodrogi's colour memory experiment, Figure 5.). The appear part of Figure 5. shows a photo, where the observer had to memorize the colour of the skin tone of the forehead. Then the observer has seen the colour patches reproduced in the lower part of Figure 5. The task was to select the patch that resembled best the skin tone seen in the previous figure. Such experiments give a good feeling how reproducible, or rather irreproducible our colour memory is. Many further experiments can teach colour appearance models.

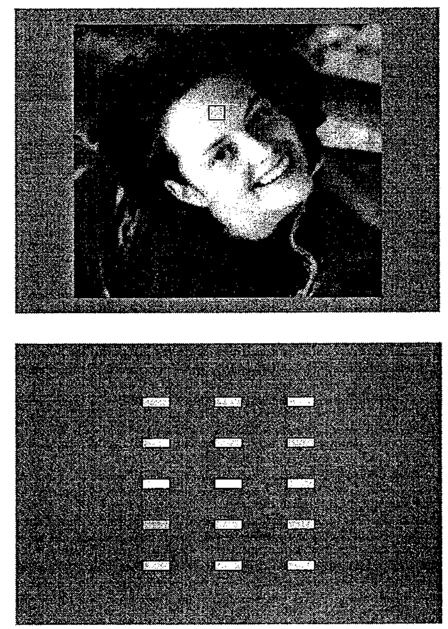

Figure 5: Colour memory experiment.

3.3 Using colour and the aesthetic aspects of colour

The picture of teaching colour would not be complete without pointing out the practical application and give some tast of good colour handling. The easy reproduction of coloured images in computer graphics provides an extremely easy way to show good (and bad) practice.

Not speaking about the possibilities computers offer for virtual picture galleries, enabling the art teacher to show master works in the class-room, or even enable the students to experience those pictures at their own pace and for their own pleasure.

In the colour tutorial we draw the attention also on colour harmony issues, on the use of colour good legibility, etc. For students of informatics and computer science this is then coupled to computer graphics questions, but even high-school students can learn from good and bad examples how they should use colour e.g. in their home-page preparation.

4. PRINTING AND COLOUR MANAGEMENT

It is often frustrating to see the big difference between the hues on the screen and reproduced – on often cheap – ink-jet printers. The tutorial explains on some examples why colours reproduce differently in different media – but this is an item that needs some technological knowledge, for the general high-school tutorial we would stop by just telling that there are differences, and show some examples.

5. COLOUR VISION AND COLOUR DEFICIENCY

Students probably come for their biology studies with some knwoledge of colour vision. This can be recapitulated, showing pictures of retina, images that are confused by colour abnormals, and even colour vision tests can be run to screen the students.

6. SUMMARY

Colour is a fascinating subject that certainly interest students. The computer course at high-school level provides good opportunity to show students the possibilities computer can provide in showing, but also understanding colours and colorimetry.

It is hoped that if students get inflicted with the understanding of colour during their studies, the next generation will not go anymore via more loud and vibrating colours, but will consider the aesthetics as well, and will know how to apply colurs, not only in their work with computers, but also in everyday life.

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Dr. János Schanda, Profesor Emeritus University of Veszprém, Laboratory for Colour and Multimedia, Egyetem u. 10. H-8200 Veszprém Hungary, e-mail: schanda@ella.hu

COLOUR EDUCATION AND TRAINING FOR TEXTILE ENGINEERING AND DESIGN

Robert Hirschler and Jennifer Gay

SENAI/CETIQT, Rio de Janeiro, Brazil

Abstract

Teaching colour is a fascinating battle: you have to fight with yourself all the time, trying to contain the flood of ideas, reducing the material to a fraction of what you originally intended to tell your students - only to discover halfway through the course that you barely covered a quarter of the topics you were supposed to. Looking back to the first colorimetry/colour science course one of us (RH) gave nearly 30 years ago to a group of interested (and, in retrospect, we must add very patient) engineers and physicists it looks simply horrible. Over the years the course material has lost about 80% of its "scientific" content and became – we sincerely hope – so much the better for it.

Colour education and training has a special importance at SENAI/CETIQT, a textile educational and technology centre in Rio de Janeiro, having a full 5-years textile engineering, a 1½ (soon to be 3) years textile design and a 3 years higher education level fashion design course. All of these include at one point or another "colour studies" and we are trying to give each side a reasonable insight into the other world: engineers learn about colour order and colour harmony, and designers have some simple colour physics and psychophysics.

We are convinced that the key to successful colour education and training is trying not to overwhelm the students (be they technically or artistically inclined) by the complexity of the subject, and cram all the information - that may or may not be important - into the available number of hours, but to show them the beauty and the intellectual challenge of the subject. To capture the students' interest our courses are highly visual, with lots of demonstrations showing additive, subtractive and "partitive" mixing, the spectrum and how it is modified through selective absorption, the effect of illumination, adaptation, contrast and those visual illusions which every designer (and engineer) should be fully aware of.

For the more technical courses we use a fully interactive classroom equipped with 16 industrial colour measuring and formulation systems, while the designers can play around with complete sets of NCS and Munsell student kits, and get familiar with all the well-known colour order systems and colour collections. For those wishing to learn more than the material given in the courses, a library is available with over 300 books and all the major journals on the technical and artistic aspects of colour. Integrating the services of the only accredited colorimetry laboratory in the country with the facilities of the SENAI/CETIQT Design Institute, a new Colour Institute is foreseen to be established in 2003, offering the full spectrum of colour education and training for engineering and design students as well as for technical, design and other professionals throughout Brazil.

***Keywords**: colour education, colour in design, colour science*

1. INTRODUCTION

SENAI/CETIQT was established over 50 years ago as a school for teaching textile technology at the skilled operator, foreman and technician level. Then it became also a technology centre, and in 1997 launched a full-fledged 5-year Industrial Textile Engineering course, followed by a 1½ year Textile Design, and in 2002 a superior level 3 year Fashion Design course.
To answer demands from industry the Applied Colorimetry Laboratory was established in 1989 which, by 2001, became the best-equipped industrial colorimetry laboratory in South America with accreditation in reflectance and transmittance measurement and calibration services.
The Applied Colorimetry Laboratory and professionals of other units of CETIQT (the Institute of Design, the Faculty SENAI/ CETIQT, the weaving, knitting and finishing pilot plants and the Information Technology Unit) involved in one way or another in the colour field are now being integrated into the SENAI/CETIQT Colour Institute, which will offer a series of colour courses at different levels.

2. THE COLOUR COURSES

2.1 How much should be left out?

Claudio de Moura Castro, a well-known economist and essayist wrote an interesting article [1] on the main problem of the Brazilian educational system: the excess of information thrown at the students without considering their capacity of absorbing it. He compares it to the well-known story of the Vasa ship, built on orders of the Swedish king, Gustavus Adolphus, to be invincible. They had put so much armour and weaponry on the ship that it sunk on its maiden voyage in 1628. "Our educators and authors of didactic books are creating invincible curricula" concludes Castro, and asks: "do we want to continue having a population which has heard of all the theories but is incapable of applying any one of them?"
The great temptation for any educator is to tell the students everything he knows, maybe even more. For colour educators the temptation is even worse. As Paul Green-Armytage [2] explained "Because I find the whole topic so fascinating I have made the mistake in the past of planning my courses around what I want to teach rather than basing it on what students need to learn... When you are clear about what they need to learn, then it is easier to evaluate all the components of the course to see what might be left out and what is missing."
This, of course, is the crucial point, easy to accept the principle but extremely difficult to put into practice. No matter how short or how long a course is, there is always too little time. The last time we gave "Colour Studies" in 12 hours for a group of 25 students in textile design we decided to keep only the absolutely essential parts – and yet, in the evaluation of the course the most frequent complaint was that it was interesting, but far too much information crammed into far too little time. On the other hand all the students answered in the questionnaire that there were a number of topics which ought to have been described in much more detail, and the topics mentioned included colour physics, colorant mixtures, NCS exercises, visual aspects, and one of the student simply said: everything!
We also asked the students which part(s) they considered excessive or unnecessary. Only one of them mentioned "colour physics" (which many of the others wanted to hear more about), and all the other (15) respondents answered "none".
As for the subject matter, in this relatively homogeneous group some complained about "too much colour physics" which others found too little, some thought the

demonstration of mixing colour light were fascinating while one of the students interrupted the demonstration with a "don't talk about light, talk about pigments". Nearly all of the students wanted more exercises, particularly "tests with dyes and pigments".
What is it then, that we think the students need (and what do they don't need) to learn in "Colour Studies" or "Colorimetry"?

2.2 Newton or Goethe?

The mistrust - or even animosity - between those looking at the spectrum in the dark and those looking through the prism at daylight has been strong ever since Goethe declared that "if the Newtonian doctrine was easily learnt, insurmountable difficulties presented themselves in its application" [3]. Goethe's latter-day followers are putting it in even stronger words: "If we reflect on the nature of the light – and are not tempted to cling to the Newtonian fallacy but observe things without prejudice..." [4]. On the other hand, those who "cling to the Newtonian fallacy" (and these include the overwhelming majority of physicists, engineers and other technically minded colour scientists) simply tend to ignore Goethe – and everything his school of thought represents – as if he had never ventured beyond Faust and The Sorrows of Young Werther.
Maybe the fiercest battles in this war between the two sides are fought in the field of colour order, particularly between advocates of the Munsell and those of the Ostwald (or more recently the NCS) systems. For a number of reasons the engineering types (my earlier incarnation included) always seem to prefer the former, while designers, artist and architects) seem to adopt the Natural Colour System.
It has taken quite some time for us to discover that there is no need (what's more, there is no possibility) to decide between one or the other, both have to be taught for everybody involved in colour, because we are talking about two ways of looking at the same three-dimensional colour space.
In colour education there are some excellent examples of trying to build "a bridge between art and science" [5], to fight the "xenophobia" between the two cultures [6], by – for instance – teaching applied colour science for art and design students [7].
We are in the enviable position of teaching engineering and design students within the same, relatively small institution. Size in this case is important, because in a large university it is possible (alas, probable) that design and engineering students are completely isolated.
Our colorimetry (read: more technically centred) courses have for quite some time now included the description and some exercises on the best-known colour order systems: Ostwald, NCS and Munsell, this latter discussed in more detail both as a basis of the CIELAB space and as a visual system widely used in industry also in textile-specific versions such as Pantone or ScotDic. Its usefulness in finding or defining harmonious colour combinations is also mentioned. However, in these courses we have, until now, managed to include very little of the "other" aspects of colour – always excusing ourselves by referring to lack of time.
Our efforts in the design-related courses have been too physics-heavy (in our own evaluation as well), due to our engineering background and the relatively short time since these courses have been given. SENAI/CETIQT is making a major effort now to correct these shortcomings. By creating the SENAI/CETIQT Colour Institute a group of engineers will be joined by a group of designers / architects to reformulate all the current course material, and develop new courses using a new, integrated approach.
The structure of the courses for designers and that for engineers are fairly similar,

with significant differences only in the depth of treatment of the different modules.

2.3 Colour Studies for Textile and Fashion Designers

Our designer-oriented courses are based on four modules, making maximum use of the available demonstration and exercise material.

1. *Basic Concepts*

What is colour; major schools of thought (antiquity, Middle Ages, Newton and Goethe, Impressionism and Post-Impressionism, Bauhaus, contemporary art)

2. *Colour Order Systems*

Munsell, Ostwald, NCS and RAL. **Exercises** with Munsell and NCS student kits. Colour collections based on Munsell: Pantone and ScotDic.

3. *The Physics and Psychophysics of Colour*

Demonstrations: the effect of the illumination, object and observer in the formation of colours. Additive and partitive mixing, the basics of the CIE system. Selective absorption, spectral transmittance and reflectance curves, simple and complex subtractive mixing. **Exercises:** combination of filters, pigment mixing. Basics of colour management.

4. *Visual Aspects of colour*

Demonstrations and experiments: Metamerism. Colour combinations, relative colours, visual illusions (simultaneous contrast, adaptation, coloured shadows, crispening, spreading). Design considerations, colour harmony.

2.4 Colorimetry for Textile Engineers

The colorimetry courses also utilize the demonstrations and – in a much more limited way – the exercises used in the design courses.

1. Visual Aspects of Colour

Colour order systems (exercises with Munsell), colour harmony. Colour collections (Pantone, ScotDic, RAL, Colorcurve).

2. Colour Physics - Experiments

Additive colour mixing, the composition of light, the spectrum. The interaction of colours: greys, coloured shadows. Sources and illuminants, adaptation. Selective absorption, transmittance and reflectance. Simple and complex subtractive colour mixing.

3. Colour Physics – Exercises

Spectral reflectance curves, spectrophotometers. Measurement of Munsell Hue, Value and Chroma series, interpretation of the curves.

4. Psychophysics, the CIE system

Demonstration of the spectral tristimulus values. XYZ, the xy diagram and their limitations. Exercises of the calculation of XYZ and xy.

5. The Psychometrics of Colour

CIELAB and MUNSELL. Visual interpretation and calculation of $L^*a^*b^*$, $L^*C^*h^o$, DE* and its components (exercises). Tolerances, the CMC and the CIEDE2000 formulae. How to establish industrial tolerance limits. Shade sorting and tapering.

6. Colorant Formulation

The Lambert-Beer and the Kubelka-Munk formula, calculations of colorant mixing. The theory and practice of recipe formulation .

7. Spectrophotometry and Colorimetry in Process Control

Factors influencing the colour of textile substrates. Spectral reflectance or transmittance, K/S(□), $L^*a^*b^*$, ΔE^*_{ab}, $\Delta L^*\Delta a^*\Delta b^*$, $\Delta L^*\Delta C^*\Delta H^*$, or ΔE_{CMC} – which one to use in controlling which process parameter.

3. THE TEACHING ENVIRONMENT

To implement practice-oriented colour education SENAI/CETIQT has invested heavily in special classrooms,

demonstration and exercise material and – maybe most important of all - in literature.

3.1 Books and periodicals

In addition to a fairly complete collection of the current literature on all aspects of colour, the Alexandre Figueira Rodrigues Library of SENAI/CETIQT has managed to collect most of the important out-of-print titles as well.

It's impossible to list even a brief selection of the books considered indispensable or just plainly useful in building the course material. The AIC Study Group on Colour Education [8] is compiling a list on literature and references used in colour education, Caivano [9] is building up an interactive bibliographical database and Osborne [10] published a list of 900 books on colour.

It's difficult to point out only a few of the many excellent books consulted in the preparation of our course material, but some deserve special mention for having exactly the right balance of theory and practice, useful for (obviously among many other professionals) textile and fashion designers.

- Long, J. and Luke, J. T.: *The New Munsell Student Color Set*, 2^{nd} ed.
  The booklet, accompanying the actual sample set (which will be briefly discussed later) is a superb course guide, of just the right amount of detail, and giving exercises fitting perfectly into the course material.
- Feisner, E.A.: *Color Studies*
  A beautifully produced recent addition to everybody's shortest list of "must have" books, may also be adopted as the course material (in which case it comes with an Instructor's Guide).
- *LAMBERT, P., STAEPELAERE, B. and FRY, M.: Color and Fiber*
  Unique in having most of the illustrations as photos of actual textile samples, and containing a wealth of suggestions for the practicing textile designer.

For the engineering / colour science courses the recommendation depends a good deal on the actual field, there are special textbooks available on computer graphics, food colorimetry, graphic arts, museum objects, pigments etc. We have found Roy Berns' *Billmeyer and Saltzman's Principles of Color Technology*; Hunt's *Measuring Colour* and McDonald's *Colour Physics for Industry* maybe the most directly applicable books for our purposes.

Finally we must mention Zollinger's recently published book: *Color - A Multi-disciplinary Approach*, which is all about what we are trying to implement in our courses.

3.2 Demonstration and exercise material

Talking about colour is not very amusing, and it is certainly not an efficient way of raising interest in the subject. We try to make all of our courses, be they theoretical or practical, artistic or technical/scientific more bearable by interlacing lecturing (i.e. showing some - preferably pretty – images and explaining whatever they represent) with demonstrations and exercises.

Practically all of our courses start – after a brief introduction of the basic concepts – with exercises of the Munsell and the NCS colour order systems. Depending on the course this may take anything from an hour to 8-10 hours. We have found no difficulty in working with both, in fact one of the exercises of the NCS kit leads "naturally" to the concepts of Value and Chroma – and thus to Munsell.

Colour mixing (additive and subtractive) and the composition of light, are demonstrated using slide and overhead projectors, a grating and special filters, while selective absorption, transmittance and reflectance are demonstrated both in the spectral mode (projecting a spectrum and showing the effect of filters) and by

projecting coloured rays of light through slightly turbid water (to trace the rays) which may be coloured by dyes, or into which coloured filters are inserted.
The effects of illumination and metamerism are demonstrated using light booths, the D&H Color Rule and other metameric samples. One of the most surprising demonstrations, which even the most bored student finds somewhat interesting, is a reproduction of Hunt's famous "yellow pillow" slide, showing the effect of adaptation. We are using a high quality OH transparency photo of a fruit basket, first projecting it covered with a magenta filter. In spite of the strong colour cast the characteristic colours of the fruits are quite recognizable, and the students are called to name them: the grapes are green, the lemon yellow, tomatoes are red, the table cover blue and the bananas yellow with a green stem. The filter is then removed, showing everything in their original colours except for the bananas which are still covered by a small piece of the same magenta filter cut out in banana form. It takes quite some convincing for the students to accept that what appeared yellow and green, and now is undoubtedly magenta, is, in fact, exactly the same physical stimulus.
The interaction of colours is first shown on slides using selected examples of simultaneous contrast, spreading (assimilation), crispening, after-images, illusion of transparency etc. Experimenting these effect using coloured paper samples (Munsell, NCS, ColorAid, or just cuttings of pictures from magazines) is much simpler than trying to make exercises with coloured pencils or paints. Most of the design students, however, are asking for exercises using their usual medium, and one of our current worries is to prepare meaningful exercises using paint, aquarelle and also combinations of textile fibres, yarns and fabrics.

To make the link between the visual concepts "hue" "lightness" and "chroma" and the shape of the reflectance curves engineering students measure H, V and C series from the Munsell Color File, and have to explain what they find.
It is considered important for the these students also to perform the basic colour calculations "manually" (in fact they have to prepare Excel spreadsheets), so that they really understand what lies behind the formulae. It's simply not enough to show the students how the software (of whichever commercial system) calculates XYZ or L*a*b* for the required illuminant-observer combination, they have to look up the data in the CIE or ASTM standard, find the right tables and constant, and go through the details. One of the most difficult concepts seems to be that of the 2^{o} and 10^{o} observers, particularly for students who have already had some experience in measuring samples. "But my instrument measures at 8^{o} (or 45^{o})" – is the usual source of misunderstanding.

3.3 Classrooms

In order to make the course "flowing", there should ideally be a classroom with "everything": a high quality video projector, possibility to completely darken the room (for the spectral demonstrations), three, preferably identical slide projectors, OH projector, light booths, daylight illumination and tables large enough for the exercises, and – for the engineering and other technical courses - computers with spectrophotometers, colorimetry software and a spreadsheet program.
When CETIQT launched the textile engineering course (5 years ago) all the classrooms were equipped with multimedia computers and projectors, and a special classroom (called *SATE)* was created for teaching computer applications, among them colorimetry. *SATE* is equipped with 16 small desktop spectrophotometers, each

connected to computers with industrial colour measurement and colour matching software.
Most part of the colorimetry courses can be held in *SATE,* but we need to use another room for the spectral demonstrations. For the design courses we have to use alternately a classroom with projection possibilities and another one where the exercises may be done. CETIQT is now preparing the *Visual Classroom*, which will permit the interlacing of presentations, demonstrations and exercises – a colour educators dream to come true.

4. THE SENAI / CETIQT COLOUR INSTITUTE

SENAI/CETIQT is a technology centre active in education, training, research and consultancy services primarily related to textile manufacturing (from spinning through weaving, knitting, dyeing-printing-finishing to garment manufacturing) and to textile and fashion design.
Colour is an important issue in each and every one of these fields, and in order to improve the cooperation between the different departments the SENAI/CETIQT Colour Institute has been created.
The Colour Institute will integrate all colour-related activities at CETIQT without reallocating professionals from their current departments. We are forming three teams, one each in the fields of colour metrology, colour management and design.
All the professionals of the Applied Colorimetry Laboratory will participate in the *Colour Metrology Team* together with faculty members of the textile engineering course and professionals of the weaving, knitting and the dyeing-printing-finishing pilot plants. Their first task will be to increase the range of the current services of the ACL (measurement and calibration services for industry, industrial colorimetry courses and the *Applied Colorimetry in the Textile Industry* course given to the engineering students) and to offer new courses in the field of industrial colour measurement. Members of this team will also teach in the graduate and post-graduate level courses (textile engineering, MS).
The *Colour Management Team* will have members from the Information Technology Unit, the Design Institute and the weaving, knitting and printing pilot plants, integrating the experience in computer graphics and textile CAD/CAM. Within a year they should be offering training and consultancy in the field, and contribute to the development of new course material for short industrial courses as well as for the colour content of the regular engineering and design courses.
Teachers from the Design Institute (textile design) and from the School of Fashion Design make up the *Visual Aspects and Design Team*. They are offering this term a 40-hours *Colour Studies* course for the Fashion Design students, and will play a prominent role in the development of new courses.
The first week of August 2002 a Master of Science course in Industrial Colour Metrology was launched, in cooperation with PUC-Rio, the Pontifical Catholic University of Rio de Janeiro. This is the first such course in Brazil, and one of very few in the world. For the time being it is a special field within the Industrial Metrology course of PUC, but the students will get a massive dose of colorimetry (90 hours) and prepare their thesis in this field. Within a year or two this MS course will offer – in addition to *Fundamentals* and *Advanced Colorimetry* - a number of special subjects, such as *Colorimetry of Dyes and Pigments, Colour Management, Spectroradiometry.*
Developing a postgraduate, possibly MA level course *Colour for Designers* is among the immediate plans of the Colour Institute.
We hope that the SENAI/CETIQT Colour Institute will contribute to "spreading the

light" not only in Brazil, but wherever people want to know more about this fascinating subject taught for engineers and designers, scientist and artist – colour.

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Dr. Robert Hirschler and Ms. Jennifer Gay, SENAI/CETIQT, Rua dr. Manuel Cotrim, 195, Rio de Janeiro, Brazil, 20961-040. Phone: +55-21-2582-1029, Fax : +55-21-2241-0495, E-mail: rhirschler@unido.org , jgay@cetiqt.senai.br

NCS AND ITS APPLICATION IN THE LIVING ENVIRONMENT AND IN THE INDUSTRY

Janko Milev, Technical University, Varna, Bulgaria

Todor Kehlibarov, Bulgarian Academy of Sciences, Sofia, Bulgaria

Abstract

The paper is a summarized review of the authors' experience with NCS means for visual colour analysis in the sphere of the living environment and the industry. It is necessary to expand NCS means potential for teaching and industrial purposes.

***Keywords**: Natural Colour System (NCS), visual colour system, colour*

History of NCS:

- 1611 A. S. Forsius lays the foundations of NCS
- 1874 E. Hering makes his contributions
- 1946 The Scandinavian Colour Institute (SCI) was founded
- 1952 S. Hasselgren's Colour Atlas was published
- 1978 SCI AB received its present name
- 1995 2nd edition of NCS with 1750 colour samples
- 1998 NCS is given ISO 9002 (No. 17888) and the standard opened the way for a wide application in the sphere of environment and industry

What NCS visual means can we use for the purpose of teaching and industrial application? These are: NCS Index, NCS Block, NCS Box, NCS Atlas, NCS Sheets in different sizes, NCS Palette for computerized design, NCS Colour Meter, NCS Brilliant Samples, etc.

The NCS samples collection with 19 exercises was found to be very useful, and so were all other above-mentioned NCS means.

NCS provides for an easier colour assessment than the other known colour systems like Munsel, DIN etc. Therefore, leading colour experts and scientists from Europe and America are using NCS means ever more widely for research, teaching and industrial applications.

During the 90ies, Bulgarian producers of textiles, paints, building materials, printed matter, etc. were also greatly assisted by these means. This was as well felt abroad, not only by the world's largest producers but also by small businesses.

It is a well known fact, that architects and designers have used NCS means for a long time to obtain the primary formulae of desired colour mixtures. However, presently NCS means enable colourists in the sphere of industry to achieve the same. And this means considerable saving of costs for dyes and pigments. The application of NCS notations will lead to a rapid closing of the circle: – producer (design, lab, technology, quality control, salesman) – customer, to the benefit of both. NCS provides for better chances to make selections of colours that can be reproduced. The NCS colour codes make it possible to develop new colours and to reproduce old ones. It is necessary to combine a high quality Light-Box (Viewing-Box) with the NCS evaluation, and take into consideration the CIE document (CIE 116-1995 Industrial Colour Difference Evaluation), as well as the specified visual evaluation conditions. In order to achieve progress in NCS industrial application, it is desirable that SCI should develop a set of new NCS teaching exercises, and to implement the most important part of the existing ones. The above mentioned suggestion is based on our summarized experience in colour projects, teaching courses in universities, colleges and in the sphere of industry.

The question is, whether the introduction of NCS means after 1978 and more precisely after the 90ies, which was going on simultaneously with the other colour systems like Munsel, DIN etc., has not led to the point where ISO should definitively make its choice and select one unified colour system?

The authors would like to thank SCI and SCF for their support which contributed for a more comprehensive understanding of this modern colour system. We are ready to provide any further information and thereby promote the wider implementation of NCS in industry and education.

Assoc. Prof. Dr. Janko Milev, Technical University Varna, 1 Studentska St., BG-9000 Varna, Bulgaria, Phone: + 35952 302 457; e-mail: jmilev@abv.bg
Assoc. Prof. Dr. Todor Kehlibarov, BG-1000 Sofia, POB 1089, Bulgaria, e-mail: tk_color@mail.bg

GAMUT EFFECT IN THE PROJECTED IMAGE BY LIQUID CRYSTAL PROJECTOR

Hirohisa Yaguchi, Masaaki Toraiwa and Satoshi Shioiri
Department of Information and Image Sciences, Chiba University, Chiba, Japan

Abstract
We examine if the gamut effect is observed when we see images projected by a liquid crystal projector in a dark room and in an illuminating room. Two degrees square test color patch surrounded by a uniform gray background or a multicolored pattern with the same space-averaged luminance and the same chromaticity as the gray. The test images were projected by a liquid crystal projector in two types of room lighting conditions, a dark room and in an illuminating room where the illuminance at the observer was 280 lx. Projected light from the projector was set two intensity levels with a neutral density filter. We used 156 colors as test stimuli. In order to evaluate color appearance of test stimuli, we employed the categorical color naming, where subjects were asked to see each test stimulus and give a color name of it. Color names were restricted to eleven basic color names. Color appearance of test color patches did not change much in spite of changing the colorimetric purity according to the room lighting condition. This type of color constancy was observed in both of the gray uniform background and the multicolored background. Comparing the experimental results from two different surrounds in a dark room, we found that the area of neutral color such as white and gray increased at the multicolored surround. This result is consistent with the gamut effect.

Keywords: *gamut effect, color appearance, categorical color naming, liquid crystal projector*

1. INTRODUCTION

Liquid crystal projectors have been commonly used for a digital image display. Since the liquid crystal projector is usually equipped with a high intensity light source and is operated interactively with a personal computer, the projected images are often viewed in a bright room illuminated with room lamps. In such a case, each color of the image is determined by not only light projected by the projector but also the light from room lamps. Projected color in a lit room looks less saturated than those in a dark room, because color stimuli projected in a lit room consist of white light from room lamps as well as three primary color, red, green and blue provided by the projector.

On the other hand, the perceived color at each point in an image is not merely determined by the colorimetric value of the point. It depends on various factors such as the chromatic adaptation of the visual system and the simultaneous color contrast effect. Brown and MacLeod [1] found that objects appear more vivid and richly colored against low-contrast, gray surrounds than against high-contrast, multicolored surrounds. It tends to normalize the gamut of perceived colors in each visual scene. This phenomenon is called gamut effect.

Thus, the color appearance of images projected by the liquid crystal projector in a lit room could be affected by both the physical de-saturating effect and the perceptual gamut effect. In the present study, we examine if the gamut effect is observed when we see images projected by a liquid crystal projector in a dark room and in an illuminated room.

2. EXPERIMENT

Color appearance of the test stimulus on a screen projected by a liquid crystal projector was evaluated by the categorical color naming method.

2.1 Method

The test image was projected on a screen by a liquid crystal projector in two types of room lighting conditions, a dark room and in an illuminating room where the illuminance at the observer was 280 lx. The luminance at the screen illuminated by room lamps was 33.6 cd/m^2. The projected light from the projector was set two intensity levels, high and low, with a neutral density filter inserted in front of the projector lens. The maximum luminance on the screen was 345 cd/m^2 and 20.5 cd/m^2 at the high-and low-intensity projection respectively. Two degrees square test color patch surrounded by a uniform gray background or a multicolored pattern with the same space-averaged luminance and the same chromaticity as the gray. Test patterns are in Figure 1. A whole stimulus size was 10° by 10°. Totally, eight experimental conditions shown in Table 1 were examined. We used 156 colors distributing at about 15 ΔE^*_{ab} step in the CIELAB space as test stimuli. They included three different L^* levels. Figure 2 shows the test color in the a^*-b^* diagram.

In order to evaluate color appearance of test stimuli, we employed the method of categorical color naming, where subjects were asked to see each test stimulus and give a color name of it. Color names were restricted to eleven basic color names determined by Berlin and Kay [2]. Color naming was repeated three times for each experimental condition in a separate session.

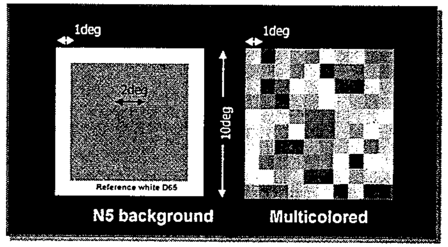


Figure 1: Two types of test patterns; a neutral background and multicolored surround.

Table 1: Experimental conditions

room	Projector	surround
dark	High	gray
		muticolored
	Low	gray
		muticolored
bright	High	gray
		muticolored
	Low	gray
		muticolored

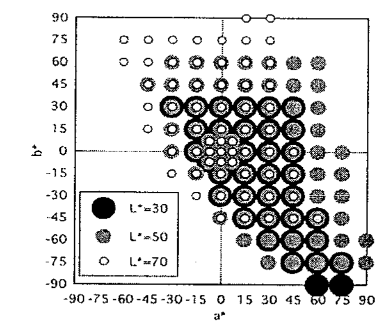
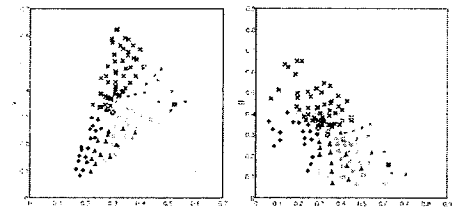


Figure 2: Test stimuli in the a^*-b^* diagram.

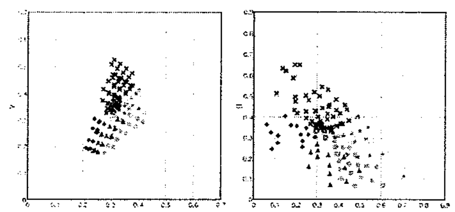
2.1 Results

We selected test color named constantly with the same color in all three sessions for each subject. Figure 3 shows color name regions for test patterns with a neutral background for high-intensity projection in a dark room, in two types of the chromaticity diagram. The (x, y) chromaticity diagram (a) presents colorimetric values obtained from both the projected light and the illuminated light by room lamps. On the other hand, the (r, g) diagram (b) presents colorimetric values obtained only from the projected light. A similar result was obtained for a low-intensity projection in a dark room.



(a) (b)

Figure 3: Color name regions of test pattern with a neutral background by high-intensity projection in a dark room.

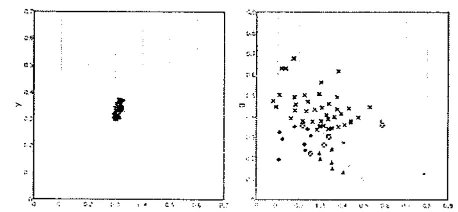


(a) (b)

Figure 4: Same as Figure 3 but in an illuminated bright room.

Chromaticity diagrams of color name regions obtained for the same test patterns of Figure 3 but presented in an illuminated room are shown in Figure 4. Color name regions in the (r, g) diagram for two different room illumination conditions were almost same. It means that the projected color itself shows a kind of color constancy in spite of illumination.

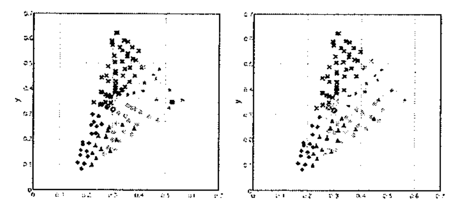
The gamut of the test color stimuli projected by the low-intensity projector in a bright room is shrunk as shown in Figure 5 (a). Although the number of test stimuli which were constantly named with same color, the effect of illumination-independent color constancy is still observed as shown in Figure 5 (b).



(a) (b)

Figure 5: Color name regions of test pattern with a neutral background by low-intensity projection in a bright room.

Figures 6 and 7 show the comparison of two different surrounds; a neutral surround and a multicolored surround. In the case of a dark room, the area of neutral color names such as white and gray increased at the multicolored surround as shown in Figure 6. It is consistent with the gamut effect reported by Brown and MacLeod [1].



N5 Multicolored

Figure 6: Comparison of color name regions of different surrounds with high-intensity projection in a dark room.

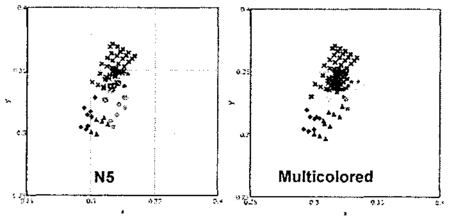


Figure 7: Comparison of color name regions of different surrounds with low-intensity projection in a bright room.

The reverse effect, that is the area of neutral color is expanded in a neutral background condition, however, was observed in a bright room condition as shown in Figure 7.

3. SAMMURIES

There was no difference between color appearance of image with a high-intensity projector and those with a low-intensity projector in a dark room. Furthermore, color appearance of test color patches did not change much in spite of changing the colorimetric purity according to the room lighting condition. This type of color constancy was observed in the both surround conditions, the gray uniform background and the multicolored background. Comparing the experimental results of two different surrounds in the dark room condition, we found that the area of neutral color such as white and gray increased at the multicolored surround. This result is consistent with the gamut effect. But, the reverse gamut effect was observed in a bright room condition.

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Prof. Dr. Hirohisa Yaguchi, Mr. Masaaki Toraiwa and Associate Prof. Dr. Satoshi Shioiri, Chiba University, Faculty of Engineering, Department of Information and Image Sciences, 1-31 Yayoicho, Inage-ku, Chiba, 263-8522, Japan. Phone:+81 43 290 3472, Fax +81 43 290 3490, E-mail: yaguchi@image.tp.chiba-u.ac.jp

PROPAGATION OF DETECTOR-BASED PHOTOMETRIC AND COLOR SCALES USING A SPECTRALLY TUNABLE LED-SOURCE

George P. Eppeldauer and Steven W. Brown
National Institute of Standards and Technology
Optical Technology Division
Gaithersburg, MD 20899

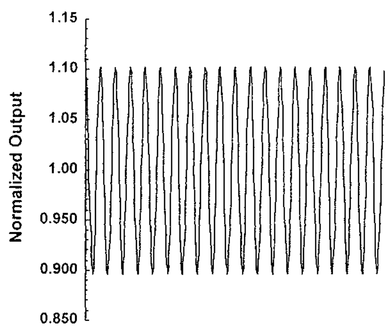
Abstract

Improved accuracy photometric and tristimulus color scales are being developed at NIST utilizing the very low uncertainty of novel spectral responsivity determinations [1]. In order to transfer the scales with minimal uncertainty increase from the NIST standard to field-level photo/colorimeters, a transfer source has been developed with a spectral distribution equal to the distribution of the test source to be measured. The design and characterization of the tunable output LED transfer-source is described here that can satisfy the increased accuracy requirements of photometric and colorimetric scale transfers. In this prototype source, 40 LEDs with 10 different spectral distributions are mounted onto an integrating sphere source. A voltage-to-current control circuit was designed and implemented, enabling independent control of the current feeding each set of 4 LED's. The effect of LED seasoning for luminance and chromaticity was studied. Also, the luminance, chromaticity, and spectral distribution changes versus LED drive current were analyzed for representative red, green, and blue LEDs. The tunable source can simulate standard sources as well. Target uncertainties for the calibration of test artifacts are less than 1 % in luminance and 0.002 in chromaticity for any source distribution.

1. INTRODUCTION

A stable, spectrally tunable, radiometric source is needed for a variety of photometric, colorimetric and radiometric programs. For example, commercial integrating sphere sources typically utilize broad-band sources such as incandescent lamps or Xe-arc sources with fixed spectral distributions. Colorimeters can be calibrated against these sources with minimal errors, on the order of 0.001 in chromaticity (x,y) and 1 % in luminance (Y). However, errors in measurements of artifacts with different spectral distributions - such as colored samples, displays - using these colorimeters can be an order of magnitude larger. Development of a spectrally tunable source would enable rapid evaluation of the operation of these colorimeters when measuring different spectral distributions. Additional applications include evaluation of material properties under differing illumination conditions, characterization of reflective materials and displays, and calibrations of instruments that would benefit from a non-standard spectral distribution. A spectrally tunable source using a conventional lamp and monochromator with a multi-element liquid crystal filter is currently under development [1].

Recent advances in materials and manufacture have resulted in the commercial availability of light emitting diodes (LED's) with narrow spectral distributions and dominant wavelengths spanning the entire visible spectrum [2]. The radiometric and photometric properties of a variety of LED's have been measured [3], and they are being further evaluated as possible standard sources [4,5]. By equipping an integrating sphere with a number of LED's having different spectral distributions and varying the radiometric output of the various LED's, the sphere radiance can be tuned from the blue to the red, as well as tuned to approximate CIE-defined standard source distributions (e.g. Illuminant A or D65), enabling calibrations of colorimeters and spectroradiometers against different spectral distributions. Detector-based photometric and tristimulus color scales have been worked out on filtered trap-detectors where spectral corrections were introduced to perform high accuracy illuminance and color measurements of sources with widely varying spectral distributions [6]. The high accuracy scales can be transferred from the NIST standard [7] to field level meters utilizing the tunable LED source and adjusting its spectral distribution to approximate that of a specific test source.



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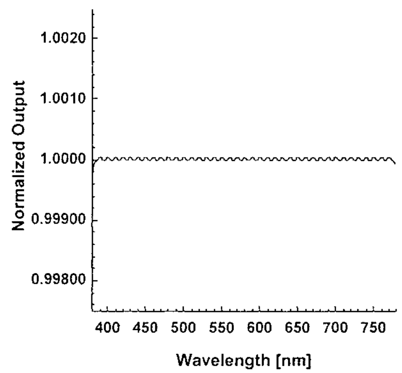

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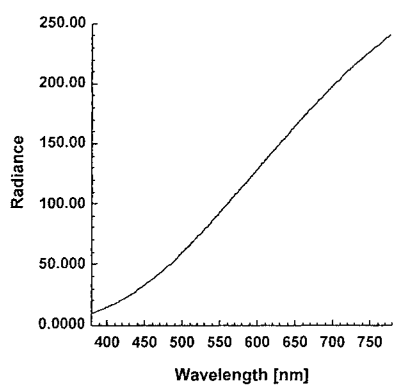

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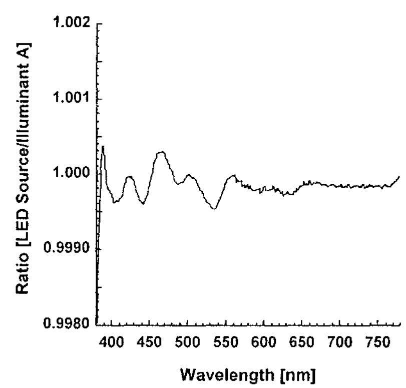

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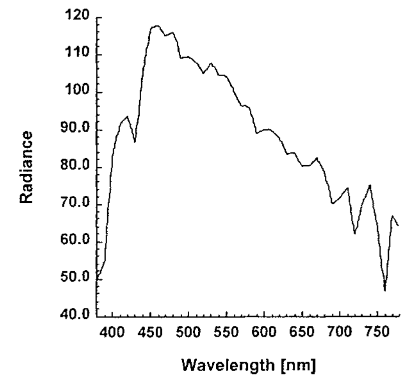

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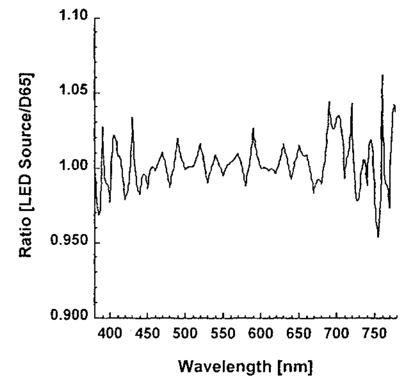


(f)

Figure 1: Simulations of colored source approximations for equi-energy source distribution for (a) 20 LED's and (b) 40 LED's over the spectral range from 380 nm to 780 nm; (c) Spectral distribution of CIE Standard Illuminant A over the range from 380 nm to 780 nm; (d) Ratio of simulated LED source distribution with 40 LED's to Illuminant A; (e) Spectral distribution of CIE Standard Illuminant D65 over the range from 380 nm to 780 nm; (f) Ratio of simulated LED source distribution with 40 LED's to D65.

In Figure 1, we show the results of simulations of an idealized LED source with 20 and 40 LED distributions spanning the colorimetric spectral range from 380 nm to 780 nm. The simulations demonstrate that incorporation of 40 LED's with different spectral distributions into a single unified source could enable sufficient reproduction of standard illuminant sources and common display phosphor distributions.

We recently developed a prototype source to evaluate the potential development of LED-based tunable integrating sphere sources for photometric, colorimetric and radiometric applications. The prototype ISS described in this work is equipped with a total of 40 LED's, 4 LED's each with 10 different spectral distributions. We describe the design and characterization of the electronic circuit as well as aging studies of typical red, green and blue LED's used in the source.

2. ISS DESIGN AND LAYOUT

A schematic diagram of the LED source is shown in Fig. 2. A 10-channel electronic control box determines the current sent to each set of 4 LED's. Twenty LED's are included in each of two source modules that mount on either side of a commercial integrating sphere. Two LED's in each module are connected in series and controlled with one channel in the electronic control box. The source is designed to be stable, but, because of its tunability, it is not a standard calibrated source. Instead, two monitor detectors: a single channel photopic detector and a diode array spectroradiometer, are used to determine the real-time photometric and spectral radiometric output of the ISS. A computer logs the photometric or radiometric output of the monitor detector and can turn the LED's on or off.

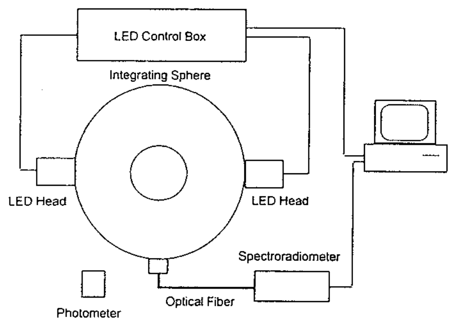


Figure 2: The schematic diagram of the LED source

2.1 Electronic control box

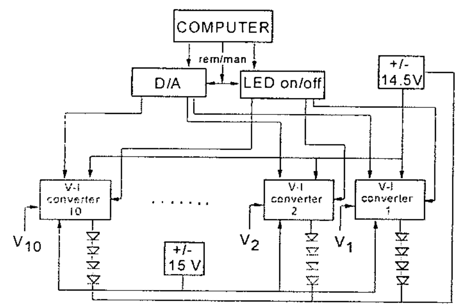


Figure 3: Schematic diagram of the electronic control box

A simplified schematic diagram of the electronic control-box is shown in Fig. 3.

Ten voltage-to-current (V-I) converter circuits provide a constant current to ten sets of four LED's. The current of each LED drive circuit can be switched on and off in either manual or remote control mode. Also, the input voltages, V_I to V_{10}, of the V-I converters can be controlled in both operational modes (local or remote). Two power supplies are used. A +/- 14.5 V reference voltage source feeds the power stages of the V-I converters, while the other circuits are operated from a +/- 15 V power supply.

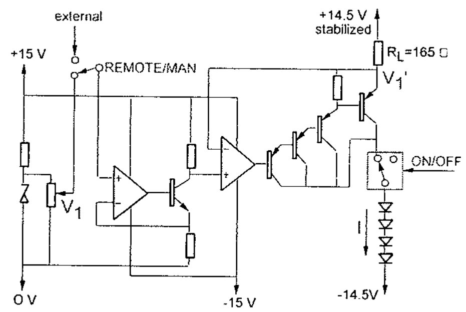


Figure 4: Circuit diagram of the voltage-to-current converter

The circuit diagram of a V-I converter is shown in detail in Fig. 4. The input voltage V_I is attenuated from a Zener diode by a 10-turn potentiometer equipped with a reading dial. Alternatively, the output voltage of a D/A converter can be used in remote control mode. The input voltage V_I controls the output voltage V_I' through a two stage amplifier. The first stage is an inverting voltage amplifier. The second stage is a voltage follower for the load resistor that works as a current source for the serially connected LED's. Both stages utilize analog control loops (using negative feedback from the output back to the input) to obtain high signal gain accuracy and stability. The highly stable supply-voltage of the output current source is 0.5 V lower than the +15 V power supply of the second-stage control circuit. Consequently, V_I' does not have to be higher than 14.5 V. The 0.5 V difference makes it possible that V_I' can follow the output voltage of the first stage with a high accuracy even for very small LED current selections. The current of the LED's can be easily switched on and off using reed relays. The TTL input of the reed relays can be controlled in both manual and remote modes. The LED current is determined by the load resistor R_L and the voltage difference between its terminals:

$$I = \frac{14.5V - V_I'}{R_L} \qquad (1)$$

The LED current will be stable if the (14.5 V - V_I') difference and the load resistance remain constant. A high wattage resistor with a small temperature coefficient was selected for R_L.

2.2 Optical Head Design

The LED source module was designed to fit onto existing ports in a commercial integrating sphere. The source module was designed to enable rapid change of a particular set of LED's within a module, or for the entire module to be easily changed. Two sets of source modules were fabricated. One set of source modules was equipped with LED's having spectral distributions ranging from the blue to the red. The spectral distribution and chromaticity coordinates of a number of LED's have been measured [2]. Their chromaticity coordinates are shown in Fig. 5. From these LED's, 10 sets of 4 LED's with chromaticity coordinates varying from the blue to the red were mounted in the source module. Their chromaticity coordinates are also shown in Fig. 5.

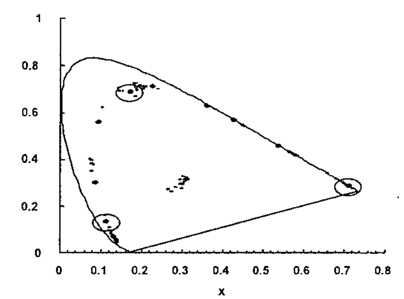


Figure 5: Chromaticity coordinate diagram with the chromaticity coordinates of a variety of LED's. Close diamonds represent chromaticity coordinates of LED's installed in the source. Circled symbols are chromaticity coordinates of red, green and blue LED's discussed in the text.

2.3 Monitor Detectors

The source has one detector port. There are two interchangeable monitor detectors, a single element silicon detector with a photopic filter for monitoring the photometric output of the source and a commercial fiber-coupled diode-array spectroradiometer for continuously monitoring the spectral output of the source over the range from 350 nm to 860 nm.

3. SOURCE CHARACTERIZATION

The electrical and optical properties of the LED source have been characterized. Each is discussed in detail below.

3.1 Electronic Characterization

The range of the control voltages V_I and V_I' for a load resistor of about 200 Ω is shown in Fig. 6. As the graph shows, the relation between the LED current and the control voltages is linear. The LED current can be regulated from 0 to 50 mA with a precision of approximately 0.01 mA. Figure 7 shows the results of the stability test of the voltage-to-current converter. The output current to the selected LED's was stable to better than 0.03 % of the set point (in this case 35 mA) over 14 hours. Similar studies have been extended to 100 hours with similar stability. No long term drifts in the current have been observed over a total operational time of 500 hours.

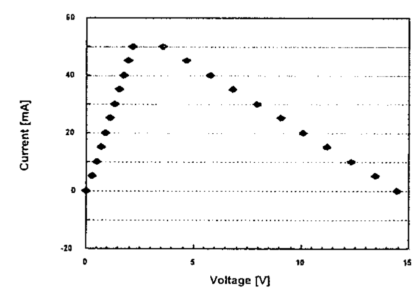


Figure 6: Range of the control voltages of the V-I converter versus LED current.

3.2 Optical characterization

The optical characteristics of representative red, green and blue LED's used in the source are presented. The chromaticity coordinates of these LED's are circled in Fig. 5. Each set of 4 LED's was aged for 100 hours, and their chromaticity and luminance monitored for the next 50 hours of operation. For each set, the chromaticity was stable to within 0.001 in *x* and *y*, well within our target chromaticity uncertainty of 0.002.

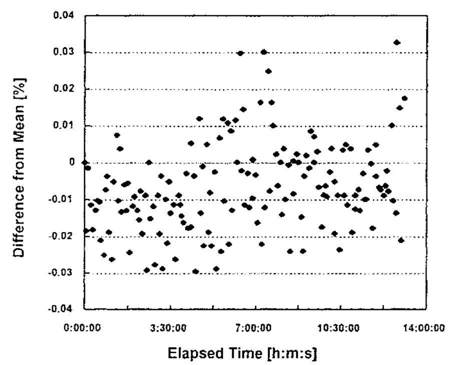


Figure 7: Stability of the output current of the V-I converter to a set of LED's.

The measured luminance from the green and blue LED's was stable to within 0.5 %, also well within our target uncertainty of 2 %, while the red luminance changed by 4 %. Further aging studies of the red LED's are currently under way to establish the longer term stability of those LED's. The source is stable to better than 0.2 % in all cases over the duration of several hours, the typical duration for a calibration.

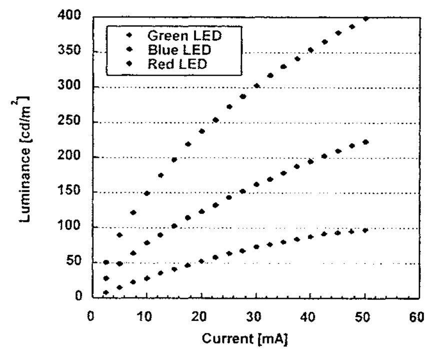
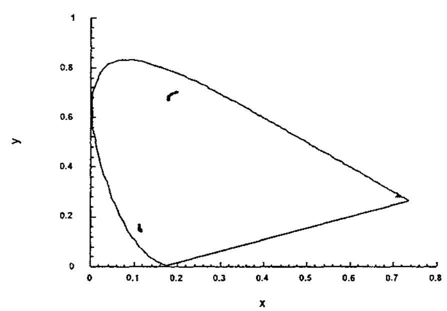


Figure 8: The relationship between the luminance and the drive current of a representative set of red, green, and blue LED's (circled chromaticity coordinates in Fig. 5).



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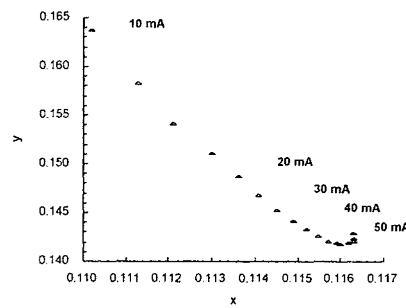

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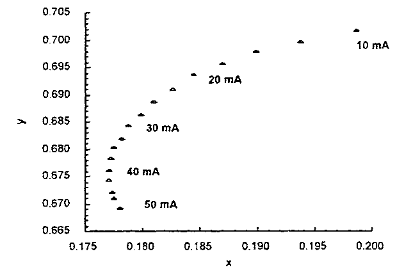

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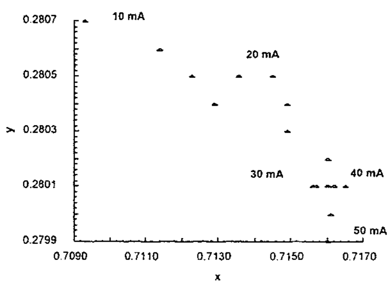

(d)

Figure 9: (a) The chromaticity coordinates of red, green, and blue LED's as a function of drive current. Expanded view of (b) blue, (c) green and (d) red LED chromaticity coordinates as a function of drive current.

The relationship between the luminance and the drive current of each set of LED's was established, as shown in Fig. 8. The normalized relationship was very similar for the three sets of LED's. The luminance of each set of LED's approaches the luminance of a CRT display set to saturated red, green, and blue colors. With 50 mA sent to all ten sets of LED's, the source luminance was 1000 cd/m2 and its radiance was 600 μW/cm2/sr. The radiometric and photometric output of the source is comparable to that of a conventional lamp-illuminated integrating sphere integrated over the visible spectral region. However, the LED source has negligible output in the infrared spectral region while the output from a lamp-illuminated integrating sphere with a color temperature of 3000 K peaks in the infrared at 1000 nm and has significant radiometric flux to 2500 nm.

The chromaticity was a strong function of drive current, as shown in Fig. 9. These changes arise from shifts in the spectral distribution of the LED with drive current. In developing the algorithm to mimic a specific source distribution, the spectral dependence of each set of LED's must be measured and included in the model.

4. SUMMARY

We have developed a prototype spectrally tunable source utilizing 40 LED's with 10 different spectral distributions. A voltage-to-current control circuit was designed and implemented, enabling independent control of the current sent to each set of LED's. The LED's have been characterized for stability and dependence on drive current. The prototype source demonstrates the feasibility of development of a spectrally tunable LED source with up to 40 different LED's. Simulations demonstrate that such a source would be able to approximate standard illuminant distributions over the visible spectral range – from 380 nm to 780 nm – with an uncertainty on the order of 1 % in luminance and 0.001 in chromaticity. The tunable LED source will be used to propagate high accuracy detector-based photometric and colorimetric scales from reference meters to field-level instruments with a minimum increase in uncertainty when special test sources are measured.

5. ACKNOWLEDGEMENTS

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Dr. George P. Eppeldauer, Optical Technology Division, Gaithersburg, USA, National Institute of Standards and Technology NIST. 100 Bureau Drive, Gaithersburg, Maryland 20899-8441, USA. E-mail:geppeldauer@nist.gov, tel: 301-975-2338, fax: 301-869-5700
Dr. Steven W. Brown, Optical Technology Division, Gaithersburg, USA, National Institute of Standards and Technology NIST. 100 Bureau Drive, Gaithersburg, Maryland 20899-8441, USA. E-mail:steven.brown@nist.gov, tel: 301-975-5167, fax: 301-869-5700

APPLYING DIGITAL CAMERAS FOR MEASURING COLOURS

M. R. Luo, G. H. Cui, C. Li, W. Ji and J. Dakin*
Colour & Imaging Institute, University of Derby, UK; *VeriVide Limited, Leciester, UK

Abstract
This paper first describes the technologies for characterising digital cameras by transforming a camera's RGB signals to CIE tristimulus values and methods for generating spectral reflectance functions corresponding to sets of RGB values.
An imaging system called DigiEye developed by the University of Derby and VeriVide Limited for measuring colour and appearance of objects is then introduced. It overcomes many of the problems associated with the use of conventional colour measuring instruments. They are not capable of measuring ultra-small, non-uniform and curved surfaces, nor can the different colours in a multi-coloured object be measured at the same time. The hardware and software of the system will be introduced together with its performance in terms of accuracy and precision.

Keywords: *CIE colorimetry, characterisation of digital camera*

1. INTRODUCTION

Digital cameras are becoming commonplace not only for consumer electronics but also for industrial applications such as digital photography and industrial inspection. The performance of cameras with respect to colour fidelity and image quality has been rapidly progressed. It is expected that they will be applied to much wider areas in the near future.
This paper describes an imaging system based upon a digital camera for capturing high quality images and accurate measurement colours of objects. It is named DigiEye and is mainly used for specifying the total appearance of objects. The captured images can be easily processed, duplicated, modified or transmitted via electronic networks. The colour of each pixel can be accurately expressed in term of *Commission Internationale de l'Eclairage* (CIE) colorimetric values [1] or spectral reflectance functions.

Conventionally, instruments such as tristimulus colorimeters and spectrophotometers are used for colour measurement. The results are reported in terms of tristimulus values and spectral reflectance functions respectively. Although they are widely used, they are incapable of measuring three dimensional, non-uniform or ultra-small samples. Most importantly, increasing numbers of applications in product design require the specification of 'total appearance' including not only colour but also texture and gloss information. DigiEye product was developed to solve these problems.

This paper first describes different techniques for camera characterisation and reflectance generation. Subsequently, the DigiEye system will be introduced. Its performances in terms of colour accuracy and precision together with the quality of the predicted reflectance functions are reported.

2. TECHNIQUES FOR CHARACTER ISING DIGITAL CAMERAS

The CIE system [1] is a colour specification system and describes the three elements for viewing colours: light source, sample and observer. Each element is defined as spectral distribution across the visible spectrum ranged around 400 to 700 *nm*. Each colour is described by *X, Y* and *Z* tristimulus values are calculated using equation (1).

$$\begin{aligned} X &= \int_{400nm}^{700nm} S(\lambda) r(\lambda) \bar{x}(\lambda) d\lambda \\ Y &= \int_{400nm}^{700nm} S(\lambda) r(\lambda) \bar{y}(\lambda) d\lambda \\ Z &= \int_{400nm}^{700nm} S(\lambda) r(\lambda) \bar{z}(\lambda) d\lambda \end{aligned} \qquad (1)$$

where $S(\lambda)$ describes the spectral power distribution (SPD) of a given source for illuminating the object and $r(\lambda)$ is the spectral reflectance of an object. The $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, and $\bar{z}(\lambda)$ refer to the CIE standard colorimetric observer. If two stimuli have the same tristimulus values, they match each other under the specified viewing conditions.

The *RGB* colour signal of a digital camera can be expressed by equation (2).

$$\begin{aligned} R &= \int_{400nm}^{700nm} S(\lambda) r(\lambda) \bar{r}(\lambda) d\lambda \\ G &= \int_{400nm}^{700nm} S(\lambda) r(\lambda) \bar{g}(\lambda) d\lambda \\ B &= \int_{400nm}^{700} S(\lambda) r(\lambda) \bar{b}(\lambda) d\lambda \end{aligned} \qquad (2)$$

where $S(\lambda)$ and $r(\lambda)$ are already defined in equation (1). The $\bar{r}(\lambda)$, $\bar{g}(\lambda)$ and $\bar{b}(\lambda)$ are camera's spectral sensitivities representing three types of spectral sensors. The colour signals produced by a digital camera are associated with sensor spectral sensitivity, which means the *RGB* signals generated by a camera are *device dependent*, i.e. each different camera has its own different sensor characteristics. This is opposite to the tristimulus values in equation (1) which are *device independent*.

It is clear from equations (1) and (2) that camera *RGB* values are not the same as the CIE *XYZ* values because the camera sensors do not have the same spectral sensitivities as the CIE standard observer. In order to measure the colours of an object in terms which are device independent using a digital camera, there is a need to correlate the *RGB* signals and *XYZ* values. This procedure is known as *camera characterisation*.

The most common technique for digital camera characterisation is known as *Colorimetric Based Camera Characterisation.* It consists of presenting the camera with a series of colour patches in a standardised reference chart with known *XYZ* values, and recording the averaged *RGB* signals for each patch. The frequently used reference charts include Macbeth ColorChecker [2], ColorChecker Digital Chart (DC) [3] and IT8 [4]. Various methods have been derived to relate *RGB* to *XYZ*. Alternatively, *Spectral Based Camera Characterisation* can be used.

2.1 Colorimetrically Based Camera Characterisation

There are three methods for colorimetrically characterising a camera, namely least-squares fitting using linear or non-linear transformation [5,6], look-up table with interpolation [7,8] and Neural Network [9]. An example of a camera characterisation model based on ninth-order polynomial is given in equation (3)

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} a_{1,1} & a_{1,2} & \cdots & a_{1,9} \\ a_{2,1} & a_{2,2} & \cdots & a_{2,9} \\ a_{3,1} & a_{3,2} & \cdots & a_{3,9} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \\ R^2 \\ G^2 \\ B^2 \\ RG \\ GB \\ RB \end{bmatrix} \qquad (3)$$

where *R, G* and *B* refer to the camera's signals and *X, Y* and *Z* are the CIE tristimulus values. The $a_{i,j}$ coefficients are optimised between the sets of *RGB* and *XYZ* values from the samples in a particular reference chart [2-4]. The important parameters to be considered for obtaining $a_{i,j}$ coefficients are: the material of the test chart, the number of colours in the chart used for deriving the transform coefficients and their distribution throughout colour space, and the measure used to determine the prediction error between the measured and predicted tristimulus values. In principle, the higher the order of polynomial which is used, the more accurate the colour space transformation.

2.2 Spectral Based Camera Characterisation

Spectral based camera characterisation can be further divided into two steps: *determining the spectral sensitivities* and *predicting the surface reflectance*. The former step is to directly measure the camera spectral sensitivities $\bar{r}(\lambda)$, $\bar{g}(\lambda)$ and $\bar{b}(\lambda)$ using monochromatic light sources, say at a 10 nm-interval. Each mono-chromatic light is measured by the camera in question. By scanning the wavelength output of the monochromatic light sources across the visible spectrum and recording the camera *RGB* signals at each wavelength, the camera's responses can be measured directly. The details of this method can be found in reference [3].

Once the sensitivities of the camera and spectral power distribution of the light source are known, the surface reflectance can be predicted for given a *RGB* response of the camera at a pixel. Normally this is based on numerical integration and equation (2), which is replaced by the following matrix equation:

$$W^T r = b \qquad (4)$$

Here *W* is a 3 by *n* matrix, which is the weighting function, products of the camera's spectral sensitivities and the spectral power distribution of lighting source. Vector *r* consists of $r(\lambda_i)$, $i = 1,2,\cdots,n$ and *b* consists of the camera's response R,G, B.

In order to recover the vector *r*, one approach is to use the basis functions to reduce its dimensionality. Typically, a representative set of reflectance functions is used. The singular value decomposition (SVD) method or the principle component analysis (PCA) method are then used to obtain the orthogonal basis vectors: $r^{(1)}, r^{(2)}, \dots, r^{(n)}$. The first basis vector corresponds to the largest singular value and the second basis vector corresponds to the second largest singular value, and so on. Any spectral reflectance vector *r* can be a linear combination of the basis vectors, i.e.

$$r = \sum_{i=1}^{n} c_i r^{(i)} .$$

Here the c_i coefficients are uniquely determined by vector *r*. Several researchers found that the majority of the spectral reflectance functions of the world's objects are highly constrained with a great smoothness, and can be well represented by only a few basis vectors, say the first *k* basis vectors, i.e.

$$r \approx \sum_{i=1}^{k} c_i r^{(i)} .$$

By setting $B_k = (r^{(1)}, r^{(2)}, \dots, r^{(k)})$, an *N* by *k* matrix and $c^T = (c_1, c_2, \dots, c_k)$, the coefficient vector, the reflectance vector *r* can be calculated if vector *c* is known.

$$r = B_k c \qquad (5)$$

Equation (4) can be written by replacing *r* by equation (5).

$$b = W^T B_k c \qquad (6)$$

Thus, the coefficient vector *c* can be obtained by solving equation (6), and the reflectance vector *r* can be computed using equation (5). Note that if $k=3$, then the coefficient vector c can be uniquely determined from equation (6). If k is greater than 3, there is more than one vector c satisfying equation (6).

A number of researchers have used this method [10-14] to predict spectral reflectance. The results are summarised as follows:

- As the dimension of the linear model increases, the approximation improves.
- A linear model with only three proper basis functions can reasonably well approximate the surface reflectance of a set of samples used to optimise the model.
- A linear model that best describes any particular class of surfaces will be the data set that accounts for the greatest proportion of variance in the collection of surface reflectance functions.
- A linear model with about 7 basis functions can account for over 99% of the variance in the data and the mean reconstruction errors by the linear models are less than one ΔE^*_{ab}.

In general, if too many basis functions are used the spectral reflectance functions generated will be far from smooth and too rugged to be realistic. Methods for overcoming this phenomenon have been only partially successful. A model with three basis functions will give a reflectance function with some adequate smoothness , but the reflectance function cannot be guaranteed to be within the desired range (less then one and greater than 0).

Alternatively, other methods can also be used to predict spectral reflectance functions, Examples are those based on smoothness [15] and the use of a colour inconstancy index [16]. The DigiEye system applies these two measures to predict the spectral reflectance functions. The smoothness approach aims to minimise the difference between the values at adjacent wavelengths in a reflectance function. The colour inconstancy index (CON) is added to ensure that the predicted reflectance function corresponds to a high degree of colour constancy. This ensures constant colour appearance across different illuminants. The combined method is described in detail in reference [17].

3. DIGIEYE SYSTEM

Using the methodologies outlined above the DigiEye imaging system based upon the use of a digital camera was developed [18]. The system as shown in Figure 1 includes a digital camera 1, a computer 2, a colour sensor 3 and an illumination box 4. The computer software includes four functions: camera characterisation, colour measurement, monitor characterisation, and texture profiling.

The digital cameras used are different for different applications. For example, a lower resolution camera may be sufficient for measuring colours, but a high-resolution camera will be needed for capturing high quality images with fine details and textures. The computer is mainly used to operate the system and includes software and a driver to capture images from the digital camera. The system also includes a colour sensor used for measuring CRT colours. This ensures the display of high colour fidelity colours on the screen.

The illumination box containing typically a D65 simulator, provides a stable illumination environment. The sample is illuminated by two sets of lamps at 45° to the sample. For colour measurements both lamps are used but for texture measurements the sample is illuminated from one side only. This produces higher contrast. The illumination box used is critical for achieving accurate colour images because it provides a highly stable illumination environment.

The computer software includes several important functions:

- *Camera characterisation* for transforming camera *RGB* signals to CIE specifications by means of a reference chart;
- *Colour measurement* for capturing colour images and for measuring the colour of each pixel or a group of pixels in the captured images – these are reported in terms of colorimetric values and spectral reflectance function;
- *Monitor characterisation* for calibrating displays to ensure high colour fidelity images displayed on the monitor;
- *Texture profiling* for building an image database to simulate the effect of applying different colours onto a given texture and for applying colours onto a pre-defined texture profile.

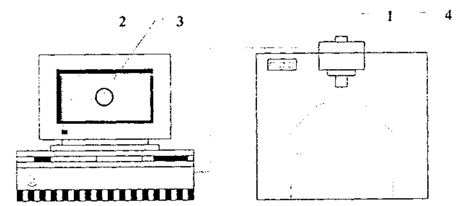

Figure 1: The DigiEye system.

4. SYSTEM PERFORMANCE

The DigiEye system has been evaluated in terms of accuracy and precision. Both the measured colorimetric values and the predicted spectral reflectance functions calculated by a DigiEye system were compared with those measured using a bench top spectrophotometer with a d/8 viewing and illumination geometry.

4.1 Performance of the System Accuracy and Precision

The Macbeth ColorChecker DC target [3] including 240 colours was used to characterise the digital camera. These colours are evenly distributed in colour space. These were also used to test the system performance in terms of accuracy and precision. The image was captured 10 times in a day. A characterisation model similar to equation (3) was developed each time and each colour in the chart was predicted. For each colour, the ΔE^*_{00} value between the 'original' values, measured by the spectrophotometer, and those captured by the DigEye system was calculated. The ΔE^*_{00} is the colour difference calculated by the CIE 2000 colour difference formula, CIEDE2000 [19]. It agrees better with visual colour differences for small to medium colour differences than other formulae. Finally, the mean ΔE^*_{00} values for all 240 colours were averaged. For evaluating the precision of the DigiEye system, the predicted colorimetric values from the previous 10 measurements were first averaged. The ΔE^*_{00} value was again calculated between the mean results and each individual measurement. These were averaged to represent the precision.

The results are 1.6 and 0.5 mean ΔE^*_{00} values representing accuracy and precision respectively, with maximum values of 6.2 and 2.1. This performance is considered to be highly satisfactory.

Note that for DigiEye applications, images are captured at different periods with different settings of camera and illumination box. However, there is always a reference chart image captured under the same conditions as the test image . Hence, although the above test only used the same 240 testing colours in a reference chart, the results represent the typical performance of the system.

4.2 The Quality of the Predicted Spectral Reflectance Functions

The spectral reflectance function is predicted based upon the colorimetric measurements as described above. As mentioned earlier, both a smoothness function and a colour inconstancy index (CON) are applied when predicting the

reflectance functions. This method is evaluated using three comprehensive data sets: Munsell, NCS and a textile set with 1560, 1750 and 705 samples, respectively. Each set includes a large number of reflectance functions. The first test was carried out to measure the degree of colour inconstancy in ΔE^*_{00} unit. It measures the change of colour appearance for a colour sample when changing from illuminant D65 to illuminants A and F11. For a perfectly colour constant sample (same colour appearance under all illuminants), the ΔE^*_{00} value should be zero. A larger value indicates a larger degree of colour inconstancy. (Note that the CON used here is not the same as reference [16]. The CMC 2000 chromatic adaptation transform, CMCCAT2000 [20] was used here instead of CMCCAT97 [21] because the former is a simplified version and more accurate transform than the latter.)
Three data sets were used to test the performance of the system. They were all measured using the same spectro-photometer as before. The results are summarised in Table 1. It can be seen that the 'predicted' reflectance functions are slightly more constant than those of 'original', especially under illuminant F11. In practice, it is typical to have a close spectral match between a 'standard' and a 'batch'. Hence, it is important to have a colour constant 'standard', otherwise all batches would be colour inconstant and will be rejected by customers.

Table 1: Performance of DigiEye system in terms of Colour Inconstancy Index

Data	No. of	Original		Predicted	
set	samples	A	F11	A	F11
Munsell	1560	2.8	2.4	2.7	2.0
NCS	1750	2.4	2.6	2.3	2.0
Textile	705	2.3	2.2	2.0	1.9

The same data sets were used for testing the agreement of the predicted reflectances with the 'original'. The metamerism index (MI) in ΔE^*_{00} units is used to indicate the colour difference between the tristimulus values computed from the 'original' and 'predicted' reflectance functions under illuminants A and F11. (Each pair has a zero colour difference under illuminant D65.) If two reflectance functions are identical, the MI value will be zero. The results are listed in Table 2. It can be seen that the MI is very small with about 1.5 ΔE^*_{00} values under both illuminants.

Table 2: Performance of DigiEye system in terms of Metamerism Index (MI)

Data	No. of	MI	
set	samples	A	F11
Munsell	1560	1.3	1.6
NCS	1750	1.3	1.5
Textile	705	1.5	1.3

5. CONCLUSIONS

DigiEye is an imaging system based upon a digital camera for capturing high quality images and for measuring the colours of an object accurately and precisely. The theory behind the product is described and together with its hardware components and software functions. Finally, its performance is also reported. The system is capable of measuring the total appearance of an object.

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Prof. M. Ronnier Luo, Dr. Guihua Cui, Dr. Changjun Li, Mr. Wei Ji, Colour & Imaging Institute, University of Derby, Kingsway House, Derby, DE22 3HL, UK. Phone: +44 (0)1332 593100, Fax: +44 (0)1332 593103, E-mail: M.R.Luo@Derby.ac.uk

INTEGRATION OF UNIFORM COLOR SPACE AND COLOR APPEARANCE MODEL

Yasuhisa Nakano, Naoki Obayashi, Ken-ichiro Suehara, Jiro Kohda, Takuo Yano
Dept. of Information Machines and Interfaces, Hiroshima City University, Hiroshima, Japan

Abstract
We developed a new color appearance model based on the uniform color space proposed previously (AIC Proceedings, 2001, pp.291-294). The model can predict experimental data of Bezold-Brücke effect, corresponding colors under different illuminants, Hunt effect, Stevens effect, and Helson-Judd effect. The model integrates uniform color space and color appearance model into one model.

Keywords: *Uniform Color Space, Color Appearance Model, Chromatic Adaptation*

1. INTRODUCTION

Purpose of colorimetry is to quantify color, but there are several ways to do it. In such case as one wants to evaluate how two colors are different, one might use uniform color space such as CIELUV or CIELAB, or might use color difference formula such as CIE2000. In another case as one wants to evaluate how the target color looks like under different lighting conditions, one might use color appearance model such as CIECAM97s. It is very valuable if these color spaces were integrated into one model.

We proposed a new uniform color space based on color vision mechanisms in 2001 [1]. This uniform color space improved uniformity of small color differences such as MacAdam ellipses and that of large color differences such as Munsell grids simultaneously. This model utilizes non-linear input-output function for cone photoreceptors and for successive post-receptor mechanisms. We thought this uniform color space might be applicable to color appearance model by introducing chromatic adaptation into the non-linear input-output function in the model. Then we can integrate uniform color space and color appearance model into one.

Purpose of this study is to propose such an integrated color space model by introducing chromatic adaptation into our uniform color space.

2. METHODS

2.1 The Uniform Color Space

Three-dimensional coordinates in our uniform color space are calculated from XYZ tristimulus values as follows.

First, CIE 1931 *X, Y, Z* tristimulus values are converted into cone tristimulus values using the matrix in Equation (1) which is based on Smith and Pokorny cone fundamentals [2] but slightly modified so that responses of L, M and S cones were equalized for D65 daylight source and that Judd-Vos modification would be accounted for.

$$\begin{pmatrix} l \\ m \\ s \end{pmatrix} = \begin{pmatrix} 0.23036 & 0.83167 & -0.03938 \\ -0.43744 & 1.31887 & 0.10225 \\ -0.00020 & 0.00055 & 0.92331 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \quad (1)$$

Here, a unit of *Y* should be consistent with cd/m^2.

Then, responses of cone photoreceptors are calculated by Equation (2).

$$\begin{aligned} l_C &= 0.6250\{f(l,\ 10000)+4\}, \\ m_C &= 0.3125\{f(m,\ 10000)+4\}, \\ s_C &= 0.0625\{f(s,\ 10000)+4\}, \end{aligned} \quad (2)$$

where $f(x, \sigma)$ is a non-linear input-output function defined as Equation (3).

$$f(x, \sigma) = \frac{\sigma}{114}\left[\left\{342\left(\frac{x}{\sigma}\right)+1\right\}^{\frac{1}{3}} - 1\right] \quad (3)$$

Saturation constant σ=10000 in this case, and a values 4 is added to the output as a constant noise. Coefficient multiplied to each response corresponds to a proportion of each cone type. We assumed L:M:S = 10:5:1.

Finally, three-dimensional coordinates of the uniform color space, (L^*, t^*, s^*) are calculated by Equation (4).

$$\begin{aligned} L^* &= 40 f(l+m,\ 100) \\ t^* &= 1500\left\{f\left(\frac{l_C - m_C + s_C}{l_C + m_C + s_C}, 30\right) - f(0.3750,\ 30)\right\} \\ s^* &= 1500\left\{f(0.0625,\ 10) - f\left(\frac{s_C}{l_C + m_C + s_C}, 10\right)\right\} \end{aligned} \quad (4)$$

The same non-linear input-output function was used as Equation (3) but with different saturation constants. Origins of t^* and s^* were shifted so that D65 daylight source would be located at origin.

2.2 Chromatic Adaptation

We introduced chromatic adaptation into the uniform color space described above. When eyes are adapted in different illuminants, the non-linear input-output function of Equation (3) will change its property accordingly. We, therefore, modified it to Equation (5).

$$f(x, \sigma, a, \beta) = \frac{a^{\beta}\sigma}{114}\left[\left\{342\left(\frac{x}{a\sigma}\right)+1\right\}^{\frac{1}{3}} - 1\right] \quad (5)$$

Additional parameters a and β were introduced here. The parameter a represents adaptation coefficient, and the β represents incomplete adaptation index. Adaptation coefficient a is determined by

$$a = \frac{x_{N5T}}{x_{N5R}}, \quad (6)$$

where x_{N5T} and x_{N5R} represent input values for neutral gray (N5) when it is illuminated by a test illuminant and by a reference illuminant, respectively. Incomplete adaptation index β was a function of x_{N5T} for cone photoreceptors and a constant for post-receptor mechanisms. Complete adaptation will occur when β=0, and it will be incomplete as the value of β increases within the range between 0 and 1.

The adaptation coefficient for L cone response in Equation (2), for example, becomes

$$a = \frac{l_{N5T}}{l_{N5R}}, \quad (7)$$

and incomplete adaptation index becomes

$$\beta = \frac{2}{f(l_{N5T},\ 10000)+4}. \quad (8)$$

Then Equation (5) is substituted for Equation (3) for calculating l_C in Equation (2). The same procedure follows for calculating m_C and s_C.

For post-receptor stage formulated by Equation (4), adaptation coefficient is calculated by Equation (6) in the same way as the cone photoreceptor stage. Adaptation coefficient for t^*, for example, is calculated as a ratio between $(l_C - m_C + s_C)/(l_C + m_C + s_C)$ for N5 illuminated by the test illuminant and by the reference illuminant. L-cone response for N5 illuminated by the test is l_C=0.6250{$f(l_{N5T}$, 10000, a, β)+4}, where a and β are determined by Equations (7) and (8), and that illuminated by the reference is

l_C=0.6250{$f(l_{N5R}$, 10000)+4}. Responses of other cones are calculated in the same way. Incomplete adaptation index, on the other hand, is constant, that is,

$$\beta = 0.05\,, \tag{9}$$

for all the post-receptor mechanisms. Offset values for shifting origins, f(0.3750,30) and f(0.0625,10), stay as it is with or without adaptation.

3. RESULTS

3.1 Bezold-Brücke Effect

The present model applies compressive non-linear input-output function for both cone photoreceptor stage and post-receptor stage. Bezold-Brücke effect is naturally explained by their non-linearity. We predicted hue shifts of monochromatic lights between two retinal illuminance levels of 100Td and 1000Td by assuming that straight lines from origin in t^*- s^* plane correspond to constant hue loci. Retinal illuminance was converted into luminance by assuming certain pupil diameter, resulted in 15 cd/m^2 and 150 cd/m^2, respectively. Figure 1 shows the prediction of the hue shifts by the model (dashed line) compared with the experimental data by Purdy (1931) [3] (solid line).

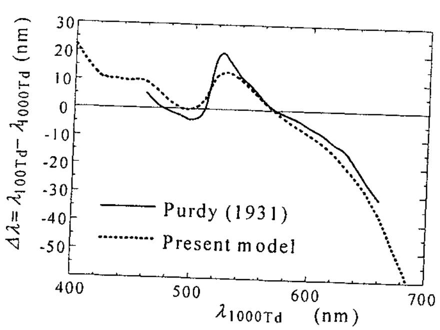

Figure 1: Bezold-Brücke effect predicted by the present model

Though some systematic deviation between the experimental data and the prediction was observed, basic trend is consistent. This supports that the uniform color space we proposed is applicable to specify color appearance of a stimulus.

3.2 Corresponding Colors

To see the applicability of the model to chromatic adaptation phenomenon, we predicted corresponding colors under different illuminant sources. We used experimental data collected by a research committee under the Color Science Association of Japan (CSAJ) [4], and it is distributed via the Internet [5]. The data had been collected by haploscopic color matching technique. A test patch was presented to one eye under test illuminant A and a subject searched for a Munsell color chip having the same color appearance as the test patch using the other eye under reference illuminant D65. Illuminances of D65 and A were 1000 lx for both.

Figure 2 shows comparison between reference patches and test patches plotted in t^* - s^* plane. (t^*, s^*) coordinates for the reference patches (filled circles) were calculated using Equations (1), (2), (3) and (4). To convert luminance factor based tristimulus values into luminance based tristimulus values, factor of $E/100\pi$ was multiplied to the CSAJ tristimulus data, where E represents illuminance, assuming that color patches had Lambert surface. For the test patches, chromatic adaptation was taking into account as described in section 2.2, and then (t^*, s^*) coordinates were calculated (open circles). Corresponding colors are close to each other on the t^* - s^* plane, and this means that our model can predict color appearance under different illuminants by taking account of chromatic adaptation.

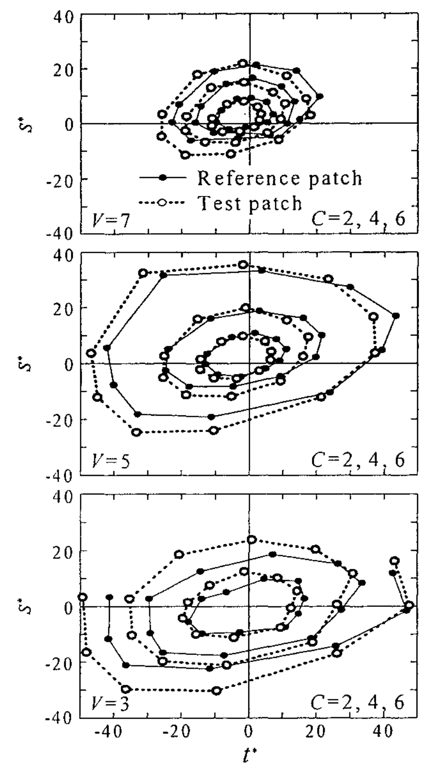

Figure 2: Corresponding colors under different illuminants, D65 and A, collected by CSAJ plotted in t^* - s^* plane

Reference patches under D65 were plotted without adaptation process and corresponding test patches under A were plotted with adaptation process by the model. Three panels are for different Munsell values and three curves of each symbol in each panel are for different Munsell chroma as indicated in each panel.

3.3 Hunt Effect

Hunt effect is the effect that apparent saturation of colored chip increases as illuminance increases. This effect can be measured by haploscopic color matching technique using different illuminance levels for left eye and for right eye. CSAJ also conducted such experiment and the electronic data is available from the same source as corresponding color data. Illuminants used here were D65 for both reference and test fields. Illuminances of D65 were 200 lx for the reference field and 10, 50, 1000 and 3000 lx for the test field. Five test color chips having value 5 and chroma 6 were tested.

Figure 3 shows comparison between reference patches and test patches plotted in t^* - s^* plane. Procedure of plotting data is the same as the one described in section 3.2. It is clear from the tendency of the reference patches that subject perceives the test patches more saturated as illuminance of the test field increases, and the model correctly predicts this tendency by taking account of adaptation process for test patches.

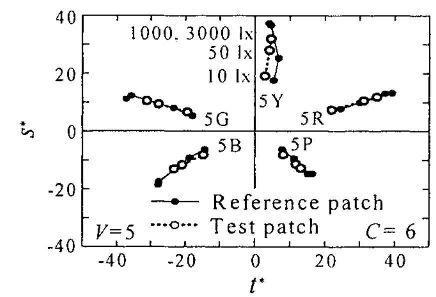

Figure 3: CSAJ data of Hunt effect plotted in t^* - s^* plane

Reference patches and test patches were illuminated by the same illuminant, D65, but with different illuminance levels. Procedure for plotting data was the same as Figure 2.

3.4 Stevens Effect

Stevens effect concerns with perceived lightness of a test patch when illuminated with different illuminance levels. Original Stevens' data showed that apparent lightness of lighter gray than N5 increases as illuminance increases, and that of darker gray than N5 decreases as illuminance increases [6]. CSAJ conducted this experiment using the same technique described above and reproduced the former phenomenon, but did not reproduce the latter phenomenon. This inconsistency may be because of different viewing conditions, white surround vs. gray surround, and different techniques for evaluating apparent lightness, magnitude estimation vs. haploscopic matching. Anyway, our model predicted CSAJ data fairly well as shown in Figure 4, in that L^* was calculated using Equation (4) without adaptation process for every reference patch, and with adaptation process for every test patch.

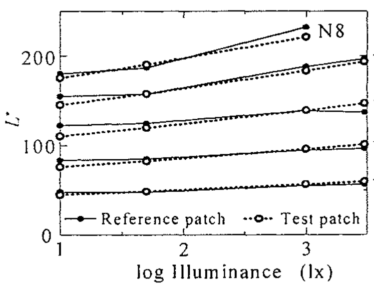

Figure 4: CSAJ data of Stevens effect

Various gray indicated right hand side were observed in different illuminance levels and apparent lightness was evaluated by haploscopic matching in reference illuminance of 200 lx. L^* calculated by Equation (4) was plotted as a function of log test illuminance. Adaptation process was applied when calculating L^* for every test patch.

3.5 Helson-Judd Effect

When the color of illuminant is not neutral, light gray under the illuminant is perceived as colored with the same hue as illuminant, and dark gray is perceived as colored with the opposite hue of the illuminant. This is called Helson-Judd effect. CSAJ conducted this experiment, too, but electronic data is not available via the Internet. So we simulated the experiment using our model. Figure 5 shows the results. Gray patches from N1 to N9 were illuminated by four colored illuminants with 200 lx. Its *xy*-chromaticity coordinates are indicated in each panel. For every gray patch, (t^*, s^*) coordinates were calculated in the same way as described above with adaptation process, and plotted in t^* - s^* plane. These graphs clearly show that lighter grays, from N5 to N9, shift toward the illuminant color and darker grays, from N1 to N4, shift toward opposite direction. That is, our model reproduced Helson-Judd effect.

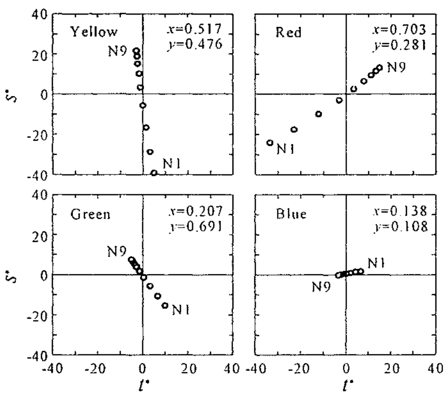

Figure 5: Simulation of Helson-Judd effect.

Gray patches were illuminated by colored illuminant having *xy*-chromaticity coordinates indicated in each panel with 200 lx. (t^*, s^*) coordinates of each patch was calculated using our model with adaptation.

4. DISCUSSION

Color appearance models had been proposed by many researchers [7, 8, 9, 10], and CIE (International Commission on Illumination) published a technical report to recommend a single color appearance model to be used in practical applications [11]. The recommended model is called "the CIE 1997 interim color appearance model (simple version) CIECAM97s." Advantage of the CIECAM97s is that it concentrates on practical applications and comprehensive field test had been done. The calculation process, however, is rather complicated and difficult to imagine the underlying mechanisms. Another disadvantage of the CIECAM97s is that it is not related to uniform color space. On the other hand, concept of the present model is simple and underlying mechanisms are clear. Further advantage of our model is that it forms a uniform color space. This feature will be helpful for practical applications, but comprehensive field test will be necessary before the model is applied to the practical applications.

5. CONCLUSIONS

We proposed a color appearance model based on our uniform color space previously proposed. That is, uniform color space and color appearance model were integrated into one model. This model explains many color perception phenomena such as Bezold-Brücke effect, corresponding colors under different illuminants, Hunt effect, Stevens effect, and Helson-Judd effect.

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Associate Prof. Dr. Yasuhisa Nakano, Mr. Naoki Obayashi, Dr. Ken-ichiro Suehara, Mr. Jiro Kohda, Prof. Dr. Takuo Yano, Hiroshima City University, Faculty of Information Sciences, Department of Information Machines & Interfaces, 3-4-1 Ozukahigashi, Asaminami-ku, Hiroshima 731-3194, Japan. Phone: +81 82 830 1605, Fax: +81 82 830 1605, E-mail: ynakano@bio.im.hiroshima-cu.ac.jp

A COMPUTATIONAL ANALYSIS OF COLOR COMBINATIONS IN "KASANE-IROME," JAPANESE ANCIENT COURT COSTUME

Kobayasi Mituo[1], Takahashi Minori[1], Suzuki Takuzi[2]
[1]The University of Electro-Communications, Tokyo, Japan
[2]National Museum of Japanese History, Chiba, Japan

Abstract
"Kasane" attire is the dress style of the women of the Heian-period (794-1185) aristocracy in Japan, who wore unlined kimono one over the other, taking great care to match and contrast the colors of each layer, which were visible at the neck, sleeves ends and lower skirt. The essential element of this style was the layering of garments to display set combinations of colors collectively known as "kasane-irome" (set of layered colors).
The aim of this study is to analyze features of color combinations in "kasane-irome" computationally.
Color samples of "kasane-irome" made of dyed silk cloths have been published by researchers of Japanese traditional textiles. We performed colorimetric measurements of such color samples. Utilizing our software system, especially designed for multilateral color analysis, the colors used in "kasane-irome" are displayed and visualized in Munsell and NCS color spaces.
The essential features and aesthetic aspect of Japanese traditional color combinations in "kasane-irome" are revealed by colorimetric and computational analysis. A new scientific approach to the study of color in culture is proposed.

Keywords: *"kasane", traditional Japanese colors, color combination, computational analysis*

1. INTRODUCTION

The Japanese aristocracy of the Heian-period (794-1185) expressed their profound sensitivity to the transient beauty of the four seasons by highly refined color arrangement of their garments. The variation of color combinations became standardized and called "kasane-irome," literally layered colors.

There are two types of "kasane-irome:" (a) double-layered kasane; a combination of two colors of a double-weave Japanese kimono called "uchiki" (inner robe), and (b) multi-layered kasane; a set of color combination of several "uchiki" worn in layers one over the other. Variations of "kasane-irome" were described and preserved in historical references in terms of color names of layered robes. A variation of "kasane-irome" is identified by a poetic name referring to natural phenomena, particularly flowers, such as "sakura" (cherry blossom), "tutuzi" (azalea) and "kiku" (chrysanthemum).

Figure 1 is an illustration of "kasane-shôzoku" (layered dress), a court costume of the women of the Heian-period aristocracy. The essential element of this style is the color combination of "kasane-irome", or layered garments, which are visible at the neck, sleeves ends and hemlines. Table 1 is examples of color combination of two types of "kasane-irome".

Figure 1: "Kasane-syôzoku"

Table 1: Examples of color combination in "kasane-irome"

(a) Double-layered kasane
"Sakura" (Cherry blossom)

Sides	Color
Right side	White
Reverse side	Carmine

(b) Multi-layered kasane
"Murasaki-no nioi" (Purple gradation)

	Abr.	Name of robe	Color
Inner	h	Hitoe (Undergarment)	Carmine
▲	I5	Itutuginu (Inner robe)	Pale purple
	I4	Itutuginu	Light purple
	I3	Itutuginu	Purple
	I2	Itutuginu	Purple
	I1	Itutuginu	Purple
▼	u	Uwagi (Outer robe)	Yellow
Outer	k	Koutiki (Outer jacket)	Spring green

2. SOURCES FOR ANALYSIS

In an attempt to reproduce traditional Japanese colors based on the historical references on traditional dying methods, some researchers of Japanese textiles have recently published color samples of traditional Japanese colors made of dyed silk cloths. It will be ideal if the colors of dyed cloths could be preserved for historical references, the original colors, unfortunately, will fade. Digital archiving is one of the methods to preserve color information, which is quite useful for research and application.

In order to record traditional Japanese colors for preservation and for quantitative analysis, we measured spectral reflectance of numbers of such color samples. Utilizing our software system [1], especially designed for multilateral color analysis, the recorded spectral reflectance values are first converted into CIEXYZ values and then transformed into Munsell and NCS color values for further analysis.

The data obtained were stored in our computer system to establish a "Database for Japanese Traditional Colors Reproduced in Dyed Cloths [2]."

Colorimetric data of dyed cloths measured from the four documents [3, 4, 5, and 6] regarding "kasane-irome" are included in the database, to which we applied computational analysis of color combination.

In this study, the source for analysis is the data obtained from document [3]. Color samples of "kasane-irome" contained in the document are:

- Arrangement of 2 colors: 120 variations (240 color samples in total),
- Arrangement of 3 colors: 6 variations (18 color samples in total),
- Arrangement of layered colors: 92 variations (624 color samples in total).

There are 882 color samples in grand total.

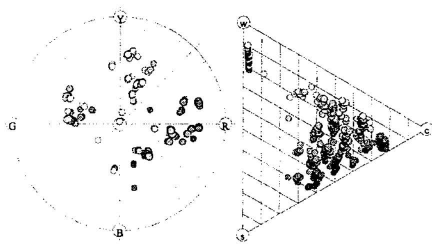
3. ANALYSIS AND RESULTS

3.1 Color distribution

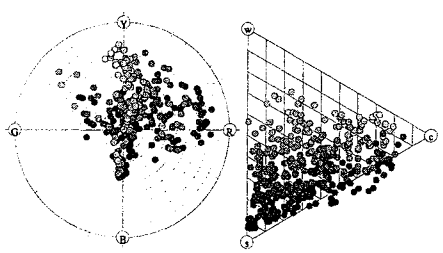
Color distribution of all of the color samples (882 in total) in the NCS color spaces are shown in Figure 2a. Variations of colors mainly used in terms of hue are yellow, orange, red, purple and green. Blue has only a few variations.

Observation of nuance triangle tells most colors except white have large chromaticness with small whiteness and blackness (c= 30~80, w = 0~50, s=10~60).

For comparison, color distribution of 401 colors [7] in Edo-period (1603~1868) is shown in Figure 2(b). It can be seen that unlike the colors in "kasane-irome", there are many colors with small whiteness. It is often said people in Edo-period preferred shaded colors.



(a) Kasane-irome



(b) Edo-color

Figure 2: Color distribution of kasane-irome and Edo-color

3.2 Classification of color combination

Color combinations of "kasane-irome" were classified by our new mathematical method for classification of color combinations based on fuzzy color zones [8].

A color is roughly identified by its name, and a color combination is distinguished by a combination of color names. A color name, however, cannot define a "crisp" region in a color space. A color space can be divided into several regions according to color names, whose boundaries are "fuzzy." The method uses the fuzzy set theory. Munsell color space is divided into a chromatic zone and an achromatic zone. The chromatic zone is subdivided into six hue zones: red(R), orange (O), yellow (Y), green (G), blue (B) and purple (P). The achromatic zone is subdivided into three lightness zones: white (W), gray (N) and black (K). A selection of a set of zone names out of all zone names makes one color combination pattern.

Figure 3 shows the top 10 color combination patterns of double-layered kasane (120 variations) and the ratio of each color combination pattern. G (green), R (red) and W (white) are the hues frequently used.

Almost half (56%) of the 92 variations of multi-layered kasane are classified into seven variations of color combination patterns shown in Figure 4. Conforming to the double-layered kasane, G (green), R (red) and W (white) are the hues frequently used. Especially combinations with G and R are characteristic.

It is interesting to note that the combination of complementary pair B (blue) and Y (yellow) is very few in kasane-irome, especially in multi-layered kasane.

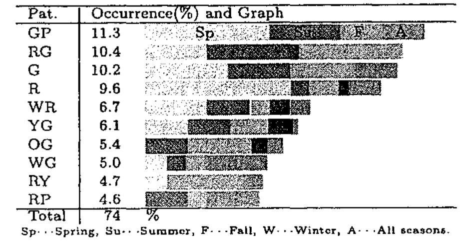


Figure 3: Top 10 color combination patterns of double-layered kasane

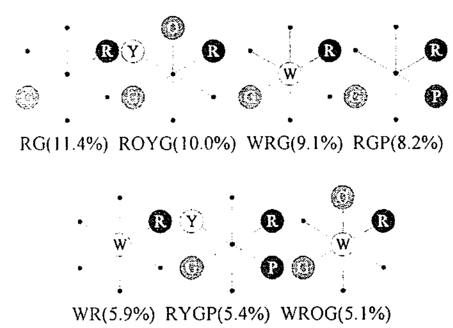


Figure 4: Top 7 color combinations of multi-layered kasane

3.3 Color arrangement of multi-layered robes

In multi-layered kasane, the arrangement of the layered robes, or sequence of colors as well as the color of each robe creates harmonious color combination.

Every color in a set of layered kasane is plotted and illustrated in NCS color circle and in nuance triangle to observe the features of color arrangement.

Layered kasane are categorized into several patterns according to the arrangement of colors. Color sequences of three typical patterns; "nioi" (gradation), "usuyo" (white and gradation) and "iroiro" (variation of hue) will be shown in table 2 and Figure 5.

In the Figures, a triangle indicates "hitoe," several squares indicate "itutuginu," a reverse triangle indicates "uwagi" and a circle indicates "koutiki." The line shows the sequence of the robes.

Table 2: Color values in three typical multi-layered kasane

(a) Yamabuki-no nioi

Abbr.	Munsell	NCS
H	5.0G 4.8/6.2	3845-G04Y
i5	2.7Y 7.5/6.7	1942-Y10R
i4	3.0Y 7.4/9.8	1566-Y07R
i3	2.8Y 7.6/9.4	1462-Y08R
i2	9.9YR 7.6/5.6	1831-Y24R
i1	8.7YR 7.3/7.3	1843-Y26R
U	8.1GY 5.3/6.5	3155-G30Y
K	1.2R 3.6/8.1	3852-R12B

(b) Murasaki-no usuyô

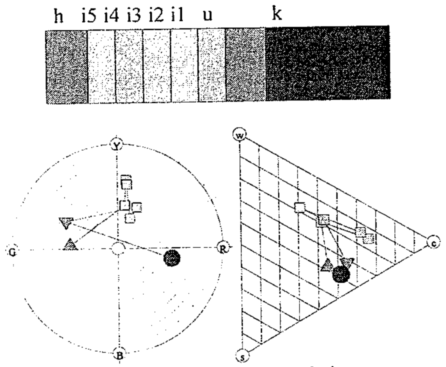
Abbr.	Munsell	NCS
H	5.9Y 8.0/0.7	2103-Y06R
i5	7.0Y 8.5/0.5	1503-Y02R
i4	6.6Y 8.5/0.5	1503-Y04R
i3	5.6P 5.1/7.2	3239-R53B
i2	6.9P 3.6/6.4	4839-R51B
i1	5.8P 3.0/5.9	5140-R53B
U	8.2GY 5.5/6.8	2956-G31Y
K	9.9RP 5.6/8.8	2149-R11B

(c) Iroiro itutu

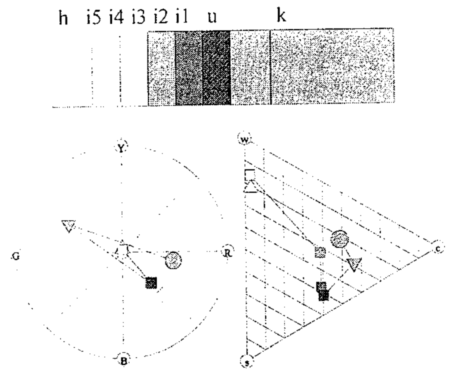
Abbr.	Munsell	NCS
H	3.9R 4.0/12.2	1975-R02B
i5	8.8YR 6.9/7.0	2243-Y26R
i4	1.3R 3.4/7.5	4249-R12B
i3	8.1GY 5.3/6.5	3255-G31Y
i2	0.7R 5.2/8.5	2649-R09B
i1	5.4P 5.1/7.5	3141-R53B
U	9.9RP 5.2/8.8	2550-R12B
K	8.3GY 5.6/6.8	2856-G30Y

(a) Yamabuki-no nioi (gradation of golden yellow)

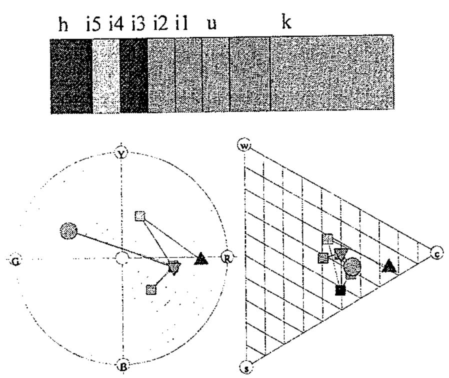
The sequence of the hues is green, yellow, green and red. Strong contrast of hue between green and red. The nuance triangle shows variations of yellow have equal blackness. Two variations of green and red are similar in nuance, which gives uniformity.



(a) Yamabuki-no nioi



(b) Murasaki-no usuyô



(c) Iroiro itutu

Figure 5: Transition of colors in three typical multi-layered kasane

(b) Murasaki-no usuyô (combination of white and purple)

The hues in sequence are white, purple, green and red. Effective contrast between white and purple, purple and green, and green and red. As illustrated in the nuance triangle, variations of purple are uniform in chromaticness. Red and whites have equal blackness.

(c) Iroiro itutu (various colors)

Unlike (a) and (b), this set of kasane does not contain gradation of colors. Hues are arranged in strong contrasts, but all the colors are concentrated on the nuance triangle. Contrasts of hues express variety, while consistency in nuance gives uniformity to the color arrangement.

To summarize, combination of contrast in hue and uniformity in nuance is one of the characteristics of color arrangement of multi-layered kasane.

3.4 Quantitative verification

In the previous analysis, one of the features of layered-kasane, combination of contrast and uniformity, was revealed by observation of the color spaces. In this section, the result of the analysis will be examined quantitatively.

Degree of contrast or uniformity, in other words, similarity or difference between a pair of juxtaposed colors can be measured by color difference between these two colors. Hue difference in Munsell color space(*dH*), difference in whiteness(*dw*), difference in blackness(*ds*), difference in chromaticness (*dc*) and the minimum of these three color differences (min *dn*) in NCS color space are computed:

$$dH = \left\{2C_1C_2\left[1-\cos\frac{2\pi}{100}(H_1-H_2)\right]\right\}^{1/2},$$

$$dw = |w_1 - w_2|, ds = |s_1 - s_2|, dc = |c_1 - c_2|,$$

$$\min dn = \{dw, ds, dc\}.$$

Results of the computation for the three examples "yamabuki-no nioi," "murasaki-no usuyô" and "iroiro itutu" introduced in the previous section are listed in table 3 and illustrated in Figure 6. In the Figures, the horizontal axis indicates the sequence of layered robes, "hitoe" (h), "itutuginu"(i5, i4, i3, i2, i1), "uwagi"(u) and "koutiki" (k), and the vertical axis indicates the degree of *dH* or *dw, ds, dc* and min *dn*.

(a) Yamabuki-no nioi

It is shown in Table 3(a) and Figure 6(a) that from i5 to i1, the *dH* values are very small, while some of the *dw, ds* and *dc* values are large, representing the gradation of yellow robes.

dH is the highest (13.3) between u-k, indicating the strong contrast of hue between "uwagi" (GY) and "koutiki" (RP). *dw, ds* and *dc* for u-k, however, are rather small presenting uniformity in nuance.

(b) Murasaki-no usuyô

Figure 6(b) shows there is a large nuance difference between i4 and i3, illustrating the distinction between the white robes (h~i4) and the purple robes (i3~i1).

i1-u and u-k have large *dH* values, while their min *dn* are small as presented in Table 3(b) and Figure 6(b), indicating that even the hue contrast is strong, at least one of the nuance variation is small, which gives conformity to the color combination.

(c) Iroiro Itutu

Table 3(c) shows *dH* values are constantly high (the hues are R, YR, R, GY, R, P, RP and GY in sequence), however, the values of min *dn* are small for every pair of juxtaposed robes, which is clearly illustrated in Figure 6(c). A well refined color combination of contrast in hue and uniformity in nuance.

To summarize, the relationship between min *dn* and *dH* is illustrated in Table 4 and Figure 7. It clearly shows that when *dH* is large min *dn* is small, in other words, even the hue contrast is strong, there is at least one small component of nuance variation, which gives uniformity.

Table 3: Color difference between a pair of juxtaposed colors

(a) Yamabuki-no nioi

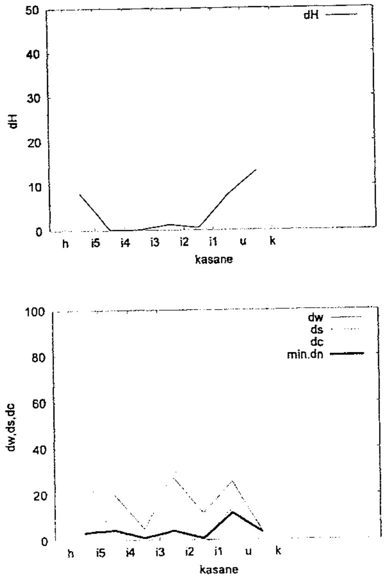
A pair of juxtaposed robes	Color difference				
	dH	*dw*	*ds*	*dc*	min *dn*
h-i5	8.3	21.9	18.7	3.2	3.2
i5-i4	0.1	20.0	4.3	24.3	4.3
i4-i3	0.1	5.0	0.9	4.1	0.9
i3-i2	1.3	27.1	3.9	31.1	3.9
i2-i1	0.5	11.7	0.5	12.2	0.5
i1-u	7.9	25.6	13.8	11.8	11.8
u-k	13.3	3.7	6.9	3.2	3.2

(b) Murasaki-no usuyô

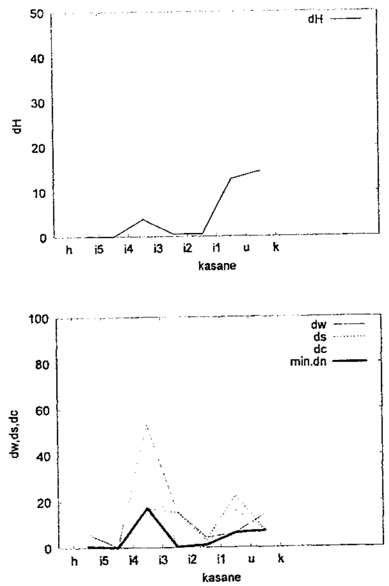
A pair of juxtaposed robes	Color difference				
	dH	*dw*	*ds*	*dc*	min *dn*
h-i5	0.0	6.2	5.7	0.5	0.5
i5-i4	0.0	0.3	0.2	0.0	0.0
i4-i3	3.8	53.1	17.1	36.0	17.1
i3-i2	0.5	15.7	15.3	0.4	0.4
i2-i1	0.4	4.4	3.3	1.1	1.1
i1-u	12.7	6.3	22.3	16.0	6.3
u-k	14.4	14.5	7.1	7.4	7.1

(c) Iroiro itutu

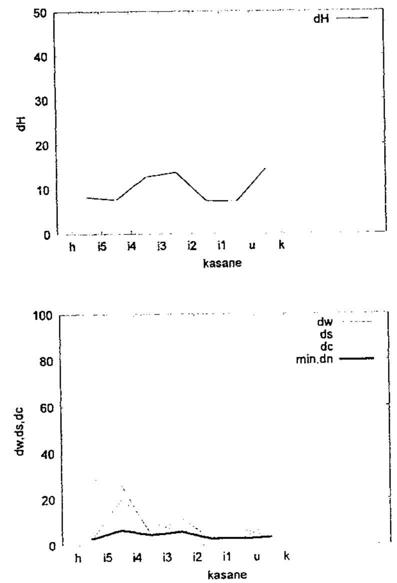
A pair of juxtaposed robes	Color difference				
	dH	*dw*	*ds*	*dc*	min *dn*
h-i5	8.3	29.2	2.9	32.1	2.9
i5-i4	7.6	26.3	19.8	6.5	6.5
i4-i3	12.8	4.5	10.0	5.4	4.5
i3-i2	13.7	11.8	6.0	5.8	5.8
i2-i1	7.4	2.7	5.8	8.5	2.7
i1-u	7.2	2.6	6.8	9.4	2.6
u-k	14.5	9.1	3.3	5.8	3.3



(a) Yamabuki-no nioi



(b) Murasaki-no usuyô



(c) Iroiro itutu

Figure 6: Graphs of color differences between a pair of juxtaposed colors

Table 4: Frequency(%) of color difference (min *dn* and *dH*)

dH	min *dn* 0-5	5 -10	10 -15	15 - 20	20 -25	25 -30	30 -35
0-5	66.5	2.8	1.9	1.7	0.9	1.3	1.2
5-10	5.5	0.9	0.4				
10-15	7.3	4.5	2.1				
15-20	0.8	1.5	1.7				

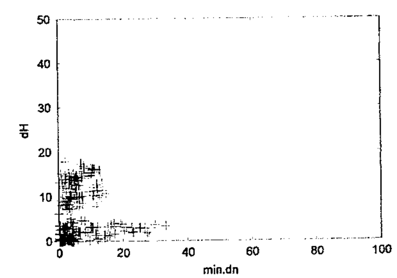


Figure 7: Relationship between min *dn* and *dH*

4. CONCLUSION

The essential features and aesthetic aspect of Japanese traditional color combinations in "kasane-irome" were revealed by colorimetric and computational analysis.

- Features of colors used in "kasane-irome" were illustrated by the color distribution in the NCS color circle and nuance triangle.
- Color combinations of "kasane-irome" were well classified by our mathematical method based on fuzzy color zones.
- Essential features of color arrangement of multi-layered kasane were revealed by illustration in NCS color spaces.
- The features of color arrangement of multi-layered kasane were verified quantitatively.

The quantitative methods introduced in this study have broad possibilities of application.

5. ACKNOWLEDGEMENT

Many thanks to our student, Ms. OKABE Megumi who made the illustration in Figure 1.

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Prof. Dr. Kobayasi Mituo, The University of Electro-Communications, Department of Information Communication Engineering, 1-5-1, Chofu-gaoka, Chofu-shi, Tokyo, 182-8585 Japan. Phone: +81 424 43 5324, Fax: +81 424 43 5334, E-mail: kobayasi@ice.uec.ac.jp
Takahashi Minori, c/o Prof. Dr. Kobayasi Mituo, The University of Electro-Communications, Department of Information Communication Engineering, 1-5-1, Chofu-gaoka, Chofu-shi, Tokyo, 182-8585 Japan. Phone: +81 424 43 5324, Fax: +81 424 43 5334, E-mail: kobayasi@ice.uec.ac.jp
Suzuki Takuzi, Research Associate, Museum Science Department, National Museum of Japanese History, 117 Jonai-cho, Sakura-shi, Chiba, 285-8502 Japan. Phone: +81 43 486 0123, ext.409, Fax: +81 43 486 4299, E-mail: suzuki@namazu.rekihaku.ac.jp

APPLYING DIGITAL CAMERAS FOR GRADING TEXTILE FASTNESS

M. R. Luo, G. H. Cui, J. Dakin* and J. Morris**
Colour & Imaging Institute, University of Derby
*VeriVide Limited
**TechniCare, Leicester

Abstract
Textile fastness test include the assessments of colour change and staining by experienced colourists. It is a slow, subjective and expensive process. Although instrumental methods were introduced, they are not widely used due to the limitation of conventional colour measuring instruments such as the difficulties of measuring very small-sized and sometimes non-uniform test samples. A new system is introduced based on digital cameras. It performs as accurately as a panel of 87 observers.

***Keywords**: fastness test, grey scales, colour change, staining*

1. INTRODUCTION

Fastness is an important property for textile materials. It is evaluated via visual assessments against a grey scale by the experienced operators. Two types of assessments are considered here: one considering how much a colour has changed during a process such as washing, the other the degree of stain on an adjacent fabric. Two grey scales are recommended by ISO 105: A02 [1] and Part A03 [2], respectively. Each of two grey scales consists of five pairs of grey scale samples arranged as shown in Figure 1. The number below each pair is the Grade number. For each pair, the left-hand sample is identical to the right-hand sample denoted 5. Pair 5 thus has a zero colour difference due to the same colour being used for both samples. The contrast between the pairs increases from Grade 5 to Grade 1. The right hand sample in Part A02 is progressively lighter the lower grade, while in Part A03 scale it is the opposite, with a white sample as the left-hand sample.

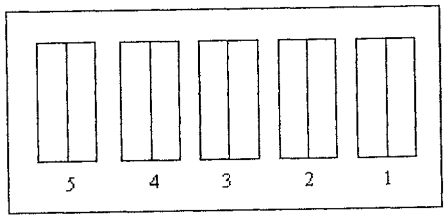

Figure 1: ISO Part A02 or A03 grey scales for assessing colour change or staining.

The assessment is recommended to be carried out under an illuminance level of 600 lux with a 45/0 viewing geometry using a daylight simulator representing north sky light. Grey masks should be used to mask all other colours except the pair in question and the test pair. Grade 5 of each scale is specified by CIE Y tristimulus value, i.e. Y of 12 ±1 and Y ≥85 for the A02 and A03 scales respectively. Increasing use is made of nine-step grey scales, in which four additional intermediate half grades (1-2, 2-3 etc) are added to the original five full grades. The colour difference [3] for each grade is given in Table 1 together with its tolerance.

Table 1: Colour differences of each pair for ISO Part A02 and A03 scales.

Grade	ISO 105: A02		ISO 105: A03	
	ΔE^*_{ab}	Tolerance	ΔE^*_{ab}	Tolerance
5	0	+0.2	0	+0.2
4-5	0.8	±0.2	2.2	±0.3
4	1.7	±0.3	4.3	±0.3
3-4	2.5	±0.35	6.0	±0.4
3	3.4	±0.4	8.5	±0.5
2-3	4.8	±0.5	12.0	±0.7
2	6.8	±0.6	16.9	±1.0
1-2	9.6	±0.7	24.0	±1.5
1	13.6	±1.0	34.1	±2.0

The assessment process is highly subjective and very expensive due to the involvement of experienced workers and the length of time. In a ring test carried out by the ISO/TC38/SC1 committee, it was found that there were large variations between results from different laboratories across different countries. At a later stage, this committee added two instrumental methods to the ISO 105 standard series; Part A04 [4] and Part A05 [5] for staining and colour change respectively. Both are based upon modifications of CIELAB [3] colour space. However, these methods are alternatives to the corresponding visual methods (Parts A02 and A03) rather than replacements for the visual methods.
These instrumental methods have not been widely used due to the limitations of spectrophotometers such as the difficulties for measuring very small-sized test samples, particularly for the multi-fibre test strips for assessing staining specimens (see Figure 3). Many of the specimens tested also have coloured patterns or are non-uniformly stained. Most importantly, considerable time is required to measure these samples in comparison with the visual assessments. This paper describes a new technique developed for this purpose based upon the use of a digital camera system.

2. DIGIEYE SYSTEM

A system called DigiEye was developed by the University of Derby and VeriVide Limited for measuring the colour and appearance of objects [6]. The system as shown in Figure 2 includes a digital camera 1, a computer 2, a colour sensor 3 and an illumination box 4. The computer software includes four functions: camera characterisation, colour measurement, monitor characterisation, and texture profiling.

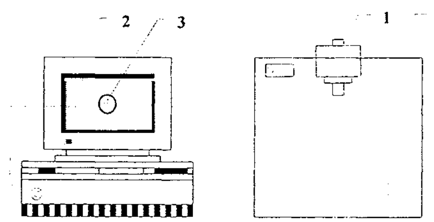

Figure 2: DigiEye system

The digital camera is used to capture the image of an object that is placed in the illumination box. The digital cameras used are different for different applications. For example, a lower resolution camera may be sufficient for measuring colours, but a high-resolution camera will be needed for capturing high quality images with fine details and textures. The computer is mainly used to operate the system and includes software and a driver to capture images from the digital camera. The system also includes a colour sensor used for measuring CRT colours. This ensures the display of high colour fidelity colours on the screen.

The illumination box containing typically a D65 simulator, provides a stable illumination environment. The sample is illuminated by two sets of lamps at 45° to the sample. For colour measurements both lamps are used but for texture measurements the sample is illuminated from one side only. This produces higher contrast. The illumination box used is critical for achieving accurate colour images because it provides a highly stable illumination environment.

The computer software includes several important functions:

- *Camera characterisation* for transforming camera *RGB* signals to CIE specifications by means of a reference chart;
- *Colour measurement* for capturing colour images and for measuring the colour of each pixel or a group of pixels in the captured images – these are reported in terms of colorimetric values and spectral reflectance function;
- *Monitor characterisation* for calibrating displays to ensure high colour fidelity images displayed on the monitor;
- *Texture profiling* for building an image database to simulate the effect of applying different colours onto a given texture and for applying colours onto a pre-defined texture profile.

3. FASTNESS GRADING USING DIGIEYE SYSTEM

Figure 3 shows a captured image including a pair of test samples and the multi-strip samples before and after a standard laundering process. (The multi-fibre test strips include 6 different materials: Dicel, Cotton, Nylon, Polyester, Acrylic and wool.) Operators first select either the colour change or staining function in the 'Staining /Fastness Grading' window. By adjusting the image to a suitable size, operators then select one or a group of pixels as 'standard' and 'batch' samples. The tristimulus values of the selected pixels are then automatically computed. Subsequently, the ISO 105 A03 and A04 formulae are used to calculated colour change or staining grade.

The advantages of using this method are to:

- capture the whole test image at one time, unlike the conventional instrumental method using a spectrophotometer to measure each colour separately,
- be able to select the desired pixels to be measured. For example, many multi-fibre strip colours are not quite uniform; for these the most uniform part can be selected.
- select colours from part of a pattern. The example in Figure 3 shows a striped sample. For assessing colour change, several areas from the dark stripe can be selected and the results averaged. The same applies to the light stripe.

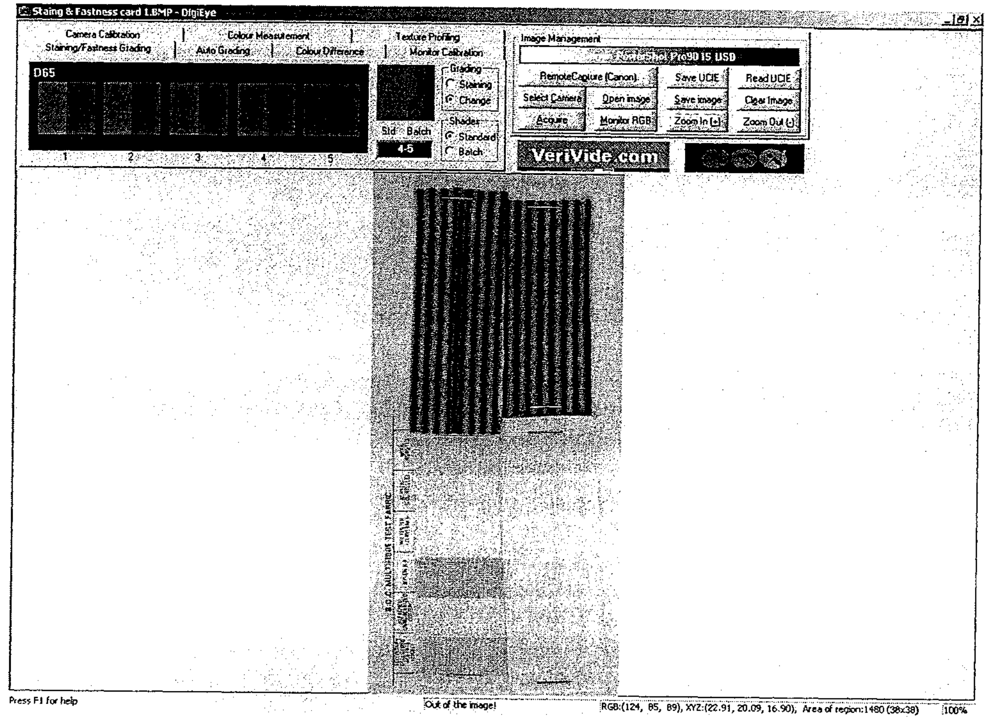

Figure 3: Staining/Fastness Grading control panel with shade change scale and rating.

4. SYSTEM PERFORMANCE

An initial test was carried out to investigate the variation of visual assessments between different professional colourists and between different laboratories. Most importantly, the results were then used to compare the performance of the instrumental method using the DigiEye system. Four textile specimens displayed on a white card and included a pair of test samples and multi-strip samples before and after a standard laundering process were prepared (one of them is displayed in Figure 3). In total, five and 24 pairs were assessed for colour change and staining respectively. (The colour change samples included a 2-coloured sample as shown in Figure 3 together with the other 3 solid colours.) These pairs were assessed by 87 colourists from 33 different laboratories using the 9 step scales.

The visual results from all colourists were first averaged to represent the panel results. The results are given in Table 2 together with those predicted by the DigiEye system. The results are also plotted in Figure 4. The root-mean-square (RMS) is used to measure the errors of predictions. It was found that the RMS difference between the visual and instrumental results was 0.35. This degree of accuracy is considered to be satisfactory, i.e. considerably less than half grade.

The observer accuracy was also calculated to indicate the agreement between the panel and each individual's results. The results showed a mean value of 0.35 with a range of 0.22 and 0.41 RMS units. This

Table 2: A summary of experimental results

Sample No.	Method	Colour Change	Staining					
			Dicel	Cotton	Nylon	Polyester	Acrylic	Wool
1	DigiEye	4.5/3.5	2.50	4.50	2.50	4.50	5.00	**4.5**
	Visual	4.27/3.97	2.63	4.02	2.21	4.43	4.60	**3.69**
2	DigiEye	4.50	1.50	3.50	1.50	2.50	4.00	3
	Visual	4.44	1.37	3.19	1.64	2.37	3.86	2.80
3	DigiEye	5.00	2.50	4.00	2.50	**4.00**	4.50	3.5
	Visual	4.49	2.36	3.54	2.39	**3.37**	4.08	3.15
4	DigiEye	4.50	2.00	**4.50**	2.00	3.50	4.50	3.5
	Visual	4.58	2.10	**3.82**	2.07	3.43	4.18	3.14

implies that the predictions from DigiEye system are as accurate as the visual assessments from the panel of 87 colourists.
The final data analysis was carried out to investigate the variations between the 13 different laboratories, in which more than two colourists took part in this experiment. The mean grades for each pair were used to represent each lab's results. The differences between each lab and the overall mean for each sample averaged 0.24 RMS units with a range of 0.13 and 0.35 RMS units. This indicates that the mean results from each lab agree well with the overall panel results. Finally, the results from every lab were inter-compared to investigate the between-lab variations. The results show a very large variations, i.e. 0.24 to 0.65 RMS units. The visual results from the two most deviate labs are plotted in Figure 5. It can be seen that for samples with grades more than 2, one lab. gave consistently one grade higher than the other.
Further experiments are carried out to include more samples for testing the system performance.

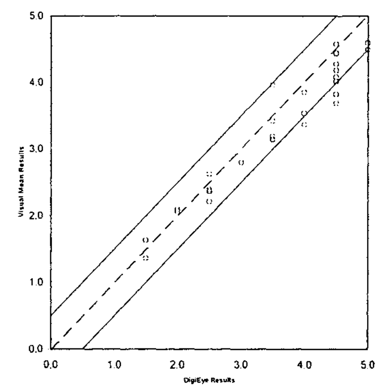

Figure 4: The visual results plotted against DigiEye results.

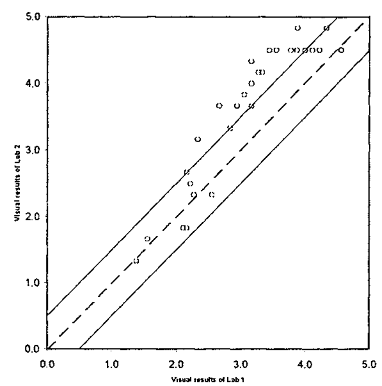

Figure 5: The two labs.' results showing the largest degree of discrepancy.

5. CONCLUSIONS

An imaging system based on digital cameras, DigiEye, was developed for measuring appearance of an object including colour, gloss and texture. One of the functions is to grade fastness for colour change and staining. It performs as accurately as individuals from a panel of 87 observers.

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Prof. M. Ronnier Luo, Dr. Guihua Cui, Colour & Imaging Institute, University of Derby, Kingsway House, Derby, DE22 3HL, UK. Phone: +44 (0)1332 593100, Fax: +44 (0)1332 593103, E-mail: M.R.Luo@Derby.ac.uk

A NEW APPROACH TO DEPTH ASSESSMENT

C J Hawkyard, A Haque and M Kelly*, Department of Textiles, UMIST, PO Box 88, Manchester, M60 1QD, UK.
*Current address, Marks and Spencer plc, Baker St., London.

Abstract
Depth is a term used to describe a subjectively defined property of colour. Yet it is of great importance both in fastness testing and standardisation of dyes. The printed versions of the Standard Depths (BS 1006, AO1) were measured and found to vary both in hue within a supposedly single shade and in the position of the 1/1 depth relative to the point of maximum chroma.
Analysis of a data for a large number of single dyes in databases from the four major European dye manufacturers resulted in a new method of determining 1/1 Standard Depth for each angle round the hue circle. The definition holds whether the colour is dull or bright in shade. After allowance is made for the colour of the substrate the lightness at the point of maximum chroma (L^* at C^*_{max}) has been found to be remarkably constant for a specified hue. An equation relating L^* at C^*_{max} to hue angle round the hue circle has been obtained, and is suggested as the basis of a method of defining 1/1 Standard Depth. Further work with two-dye mixtures supports the initial results with single dyes.

Keywords: *depth, assessment, lightness, maximum chroma*

1. INTRODUCTION

Depth is a visual characteristic produced by colorant strength. The two attributes are directly related, the connection is such that colorant strength is considered the cause and depth the effect. For example a 'strong' colorant produces a 'deep' or 'full' shade, whilst a 'weak' colorant applied under the same conditions will produce a less 'deep' or 'thinner' shade. Absolute strength of a dyestuff is defined by molar concentration present on or in the substrate, whilst depth is evaluated by subjective means. In all uses of colour depth, a comparison is made between that of the shade under observation and a standard of agreed depth.

The Standard Depth reference samples

The original Standard Depths, known as the Hilfstypen standards, were produced on woollen fabric by the Swiss and German dye manufacturers in the early 1930s [1]. These are a series of 18 Standard Depth shades, representing a selection of common hues, at various levels of perceived equal depth; 2/1 (twice standard depth), 1/1 (standard depth) 1/3, 1/6, 1/12, 1/25 (much paler than standard depth). More recently these coloured fabrics have been substituted by representations printed on white card. In use a subjective visual comparison is made between the sample and the closest standard. In this research only standard depth was considered.

Variation of lightness, hue and chroma with colorant concentration

When a white textile is dyed with increasing concentrations of a colorant the depth of the colour will increase, and its lightness, measured by CIELAB L*, will decrease. Although it might be expected that the hue would remain constant this is rarely the case, yellows turning redder as concentration increases, for instance (see Figure 1). The undyed substrate is at the centre of the set of curves.

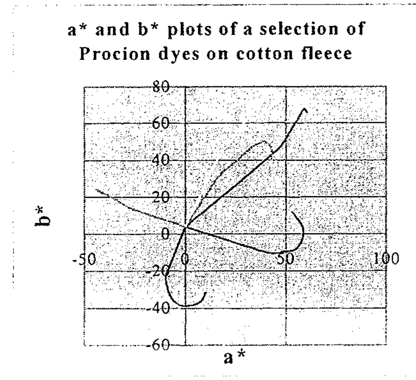

Figure 1: Most dyes turn redder as concentration increases

Chroma naturally increases as more dye is added, but, with the possible exception of yellows, reaches a maximum, after which it decreases with increasing concentration. Theoretically the colour would reach black if sufficient dye were introduced, but the dye sites in the fabric become saturated before this stage occurs. The change of lightness and chroma with increasing concentration for a series of Procion reactive dyes is illustrated in Figure 2. The undyed substrate is at the top left.

The current standard depth patterns

The standard depth illustrations in every day use are those supplied on printed card according to British Standard 1006:1978, A01: 1978 [2]. Besides being inconsistent between one set of cards and another, as reported by Schmitz [3], they are also at variance with the woollen standards, as shown in Table 1.

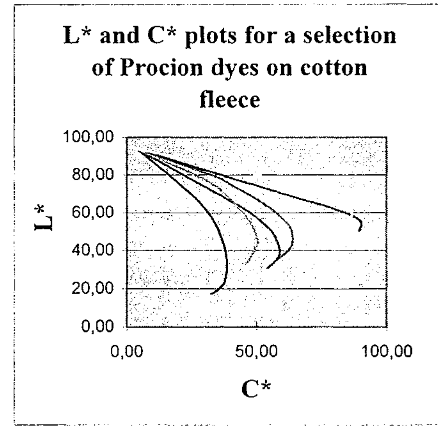

Figure 2: Lightness versus chroma as concentration increases for reactive dyes

Table 1: Colour differences - printed card versus woollen fabrics

	Delta E CMC(2:1)		
REF.	SD(2:1)	SD(1:1)	SD(1:3)
A	3	2.14	1.6
B	6.33	6.43	3.12
C	3.56	3.26	3.28
D	4.77	2.64	1.55
E	5.11	1.91	1.39
F	8.48	5.3	4.03
G	10.21	8.25	3.25
H	8.2	4.52	3.24
I	7.05	4.66	8.58
J	7.37	4.74	2.63
K	6.69	5.39	3.75
L	6.58	4.04	2.3
M	4.11	6.29	2.88
N	6.48	3.11	3.7
O	6.72	4.65	3.42
P	7.6	5.71	4.8
Q	7.65	4.08	3.61
R	5.52	3.72	4.41
MEAN	6	4.49	3.42

The colour differences are much too large to be acceptable commercially, and the major component is often a hue difference.

More recently Christ [4] proposed a formula for Standard Depth based on colour measurement, which was eventually recommended by the ISO in 1995. This is has been incorporated into ISO 105 A06 [5], a method for the *'instrumental determination of 1/1 Standard Depth'*, but the equation is not applicable to other depth series and there still remains a strong need for a more accurate formula. Another method, more useful for mixture shades, is the 'Integ' method devised by Garland [6], used extensively by ICI [7] and its successors. The Integ formula, equation 1, sums the function over all wavelengths, which is preferred in cases where more than one coloured species is present.

$$D = k\, \Sigma (K/S)_\lambda\, E_\lambda\, (\bar{x}_\lambda + \bar{y}_\lambda + \bar{z}_\lambda) \quad ..... (1)$$

Weighting the Kubelka-Munk function, K/S, by the illuminant energy E_λ and the sum of the colour matching functions ($\bar{x}_\lambda + \bar{y}_\lambda + \bar{z}_\lambda$) at each wavelength λ is a purely arbitrary procedure which was found to work in practice.

A similar formula, but excluding the illuminant energy, was proposed by 6 leading dyestuff manufacturers [8].

Lightness/chroma profiles for individual dyes

The relationship between lightness and chroma for a large number of dyes was studied by Hawkyard and Kelly [9]. They obtained 16 databases containing build-up data for more than a thousand dyes on various substrates. A database consists of reflectance data for the substrate dyed with a blank dyebath and with increasing concentrations of each dye in the range. The software then allows tristimulus values, X,Y,Z and CIELAB values L*, a*, b*, C* and h° to be determined. Dyes were selected from the databases so as to cover the full range of hue angles, h°, from 0° to 360°, using the hue angle at maximum chroma as the determining hue. In all 304 dyes were included in the study, and chroma versus lightness profiles were determined for each of them. Since the colour of the substrates varied from one database to another it was decided to allow for this in terms of lightness by shifting the lightness of the substrate up to L* = 100 using equation 2.

$$L^*_{corr} = L^*_{sample} + 100 - L^*_{sub} \quad ...... (2)$$

where the subscripts 'corr' and 'sub' refer to the corrected and substrate values respectively.

The results for the 304 dyes were plotted in two ways; hue versus maximum chroma and hue versus lightness at maximum chroma, adjusted as above. Naturally, since dyes of a similar hue vary considerably in brightness, the chroma for a paricular hue angle varied from one dye to another, depending on its class, structure and the substrate. The results for dyes of a hue angle of 265 are shown below (Figure 3). Although the chromas varied, the lightness at maximum chroma were all in the region of 40-45.

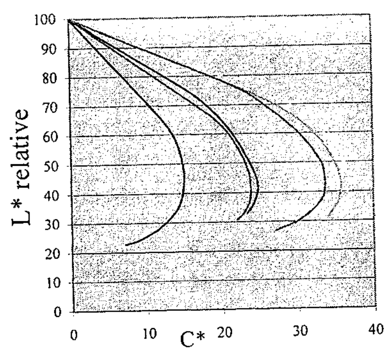

Figure 3: C^*_{max} relative to L* for h° = 265

The relationship between L* at maximum chroma with hue angle was very interesting, however, and is shown in Figure 4. Kelly [9] fitted a polynomial to the curve, but it would probably be best to split it into several hue zones, as was done for the ISO Standard [5].

In their paper Kelly and Hawkyard [9] proposed that the expression for lightness at maximum chroma should be used as the basis for a new method of determining standard depth. This would be based on data for a large number of dyes applied to a range of substrates. Unfortunately, the data have some gaps in them (see Figure 4) where no dyes were available. The largest of these was in the green region, as there are very few commercial green dyes available. Most green shades are achieved with mixtures of blue and yellow dyes. Consequently it was decided to investigate 2-dye combinations to see whether they fitted into the pattern observed with single dyes.

Dye combination for green shades

Two reactive dyes intended for exhaustion dyeing of cellulosic fabrics, Procion Turquoise HE-XL and Procion Yellow HE-6G, were selected for this study. Woven cotton which had been scoured, bleached and mercerised was dyed in the laboratory with various combinations of these dyes (see Table 2) at 80°C in accordance with the method recommended by the dye manufacturer (Dystar). After washing off and drying the colour of the samples was measured using a Spectraflash 600 spectrophotometer and the hue angle determined via the DataMatch© software. In addition the software allows manual input of dye concentrations and predicts the colour of the mixtures, so this was done for all 12 blue/yellow combinations. Although the colours of the substrates were not identical they were sufficiently close for comparative purposes, and so colour differences were obtained between the physically dyed samples and the predictions. The results are given in Table 2. The overall average for the CMC(2:1) colour differences was 1.67.

Table 2: Hue angle of green shades and colour difference between dyed and predicted colours.

REF	Turq HE-XL (%)	Yell HE-6G (%)	h° Measured	ΔE CMC(2:1)
A	0.03	0.97	126.1	3.79
B	0.05	0.95	126.5	0.61
C	0.07	0.93	132.3	0.92
D	0.1	0.9	136.6	0.31
E	0.05	0.05	170.7	2.39
F	0.1	0.1	172.4	1.55
G	0.25	0.25	172.7	1.04
H	0.5	0.5	170.8	0.88
I	1	1	169.8	2.2
J	1.5	1.5	167	2.44
K	2	2	167	2.27
L	2.5	2.5	163.5	1.64
AV.				1.67

Only shades A-D fell within the target range of 95°-150°, but the colour differences were sufficiently small to encourage the use of predictions rather than physical dyeings for the remainder of the investigation.

A series of predictions was then made using 1% total concentration mixtures, as follows (Table 3).

Table 3: Series of predicted hue angles for mixtures

Turquoise (%)	Yellow (%)	Hue angle (h°)
0.001	0.999	98.51
0.002	0.998	100.15
:	:	:
0.249	0.744	152.13
0.250	0.750	152.21

Ten of the series in Table 3 were selected as shown in Table 4 and for each one the ratio of the two dyes was kept constant while the overall concentration was stepped up as shown for Sample 8 in Table 5.

Table 4: Concentration ratios of selected samples

Sample No.	Turq. HE-XL	Yell. HE-6G	Hue at C*max
1	0.001	0.999	96.33
2	0.011	0.989	114.28
3	0.02	0.98	120.93
4	0.031	0.969	125.72
5	0.045	0.955	130.13
6	0.063	0.937	133
7	0.087	0.913	137.13
8	0.118	0.882	141.14
9	0.128	0.872	142.21
10	0.211	0.789	149.01

Table 5: L/C Profile for Sample 8

Total Concentration (%)	C*	L*
0.2	32.9	84.01
0.5	45.26	77.85
1	54.1	72.1
2	61.09	66.14
3	63.91	62.42
4	65.26	59.69
5	65.77	57.47
6	65.81	55.62
7	65.76	54.09
8	65.72	52.8
9	65.63	51.05
10	65.55	50.72

This data is plotted in Figure 5.
The maximum chroma is achieved at 6% concentration for this sample, although the chroma does not decrease very much at higher concentrations. The profiles of all 10 selected mixtures are given in Table 6.

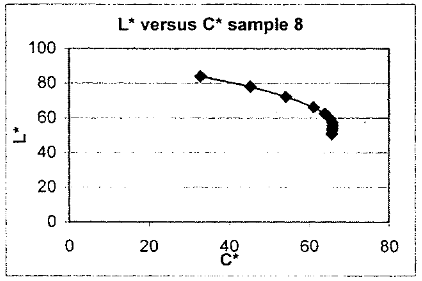

Figure 5: L*/C* Profile for sample 8

Table 6: Profiles of 10 selected mixture shades

Sample	h°	C*	L*
1	96.33	88.5	86.22
2	114.28	75.7	75.8
3	120.93	72.61	71.79
4	125.72	70.65	68.86
5	130.13	69.11	66.17
6	133.00	67.85	66.36
7	137.13	66.76	65.8
8	141.14	65.81	61.63
9	142.21	65.58	61.01
10	149.01	64.06	57.23

The data in Table 6 was added to the data for single dyes and it is clear that the resulting points fit into the projected curve very well (see Figure 6).

2. CONCLUSIONS

The facility within the DataMatch match prediction software has enabled accurate predictions of the colour of mixtures to be made. In addition the feature which allowed concentrations of mixtures to be entered manually was very useful, as it obviated the necesity of carrying out multiple physical dyeings.
The technique described above enqabled the gap in the green region for the L* at maximum C* data, previously obtained for single dyes, to be filled. There is no reason why this technique should not be applied on a larger scale to obtain a large bank of such data covering the full hue circle. A more accurate equation, or set of equations, could then be calcualted for the relationship between L* at C^*_{max} and hue angle. This would form the basis of a new way to define Standard Depth, based on a large amount of data for commercially available dyes and substrates.

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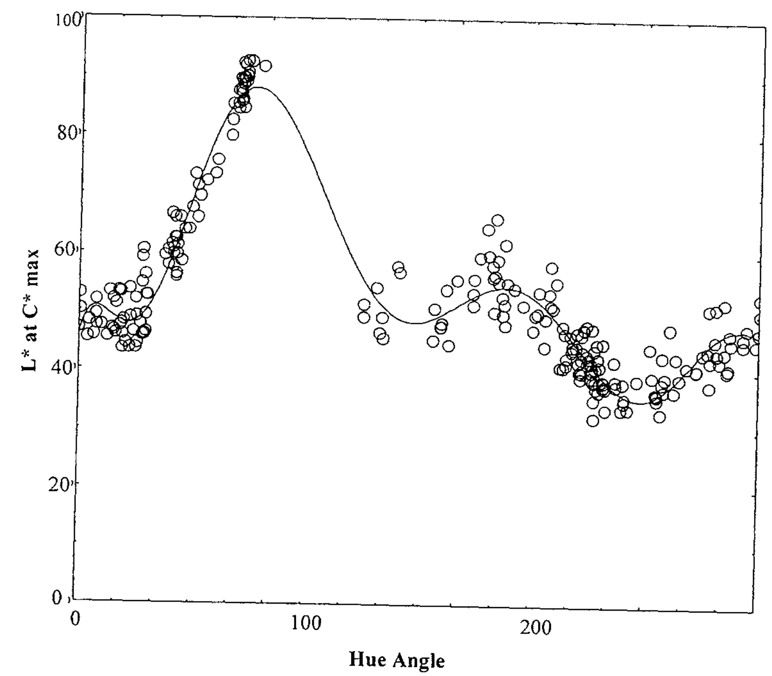

Figure 4: Variation of L^* at C^* maximum with Hue Angle

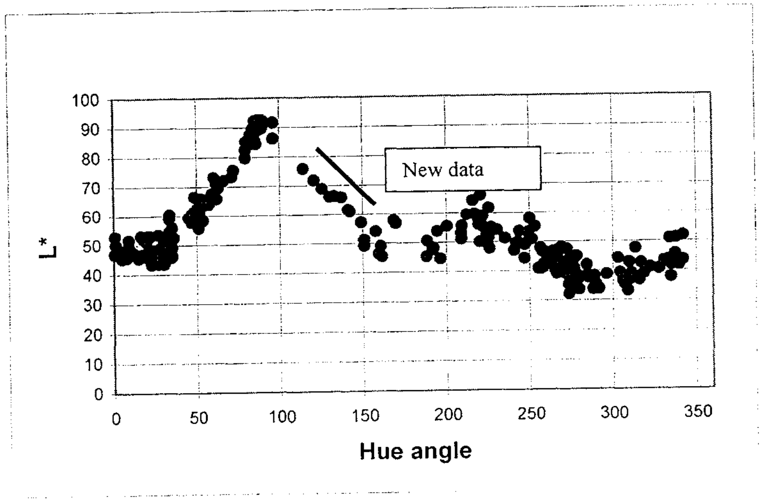

Figure 6: L* @ Cmax versus hue angle

Dr. C.J. Hawkyard, UMIST, Department of Textiles, PO Box 88, Manchester, UK. Phone: +161 200 4132, Fax: +161 955 8161, E-mail: chris.Hawkyard@umist.ac.uk

THE DETERMINATION OF A SURFACE OF EQUAL VISUAL DEPTH IN L*a*b* COLOUR SPACE

Chao-Chi Chen and Roger H Wardman, School of Textiles, Heriot-Watt University, Galashiels, Scotland, TD1 3HF, UK
Ken J Smith, Color Consultancy, Worsley, Manchester, M28 3BP, UK

Abstract
Independent visual assessments of depth by a panel of four professional colourists were made on dyeings prepared along each of eight hue directions in CIELAB colour space. The surface originated from the point L^* = 34.1 on the neutral grey axis, corresponding to an Integ value of 16. From the assessments made the variation of lightness (L^*) with chroma (C^*) for dyeings of uniform depth was mapped along the hue directions. An algorithm was developed that enabled the determination of the L^* value on the surface for any colour of given C^* and h values. Whilst direct comparison with the surface defined by the Christ formula for 1/1 standard depth was not possible, it was found that qualitatively the shapes of the two surfaces were very similar. However the Christ formula defined greater increases in L^* with C^* in the yellow and lime-green regions than the surface obtained in this work. This difference may be due to an inconsistency of depth of the 1/1 standard depth samples in this region, as indicated by other depth formulae.

Keywords: *Dyeing, Depth, Visual assessment*

1. INTRODUCTION AND AIMS

Standard depths were originally developed and agreed by the German and Swiss dye manufacturers in the 1920's. A series of 18 standard shades, representing various hues and possessing what was considered equal visual depth, were produced on woollen fabric. The series defined what was termed 1/1 standard depth. Additionally, other sets were produced at the ratios 2/1 (stronger) and 1/2, 1/6, 1/12 and 1/25 (weaker). In deciding whether a sample corresponds to one of the Standard Depths, it is necessary to assess visually its depth against the standard that is closest in shade to it. However, the method is not accurate because visual assessments are subjective and significant differences between assessors can result. Further, the standards themselves are not entirely consistent as equi-depth series.

An instrumental method is required for the specification of depth. Smith [1] has detailed the various methods that have been developed to evaluate depth. Broadly the methods can be classified into those that are based on spectroscopic methods and those that are based on colour order systems. Of the spectroscopic methods, probably the most useful formula is the Integ formula (Eqn 1):

$$I = \sum E_\lambda \left(K/S\right)_\lambda \left(\bar{x}_\lambda + \bar{y}_\lambda + \bar{z}_\lambda\right) \quad \text{Eqn 1}$$

A similar formula to Integ, but one that excluded the E_λ term, was also used by some dyestuff manufacturers.

The methods based on colour-order systems include those of Godlove [2], Rabe and Koch [3] and Gall and Riedel [4].

These methods attempt, *inter alia*, to define 1/1 Standard Depth. An algorithm was developed by Christ [5] to correspond as closely as possible with the 1/1 physical samples. The algorithm defines eight planar subsurfaces, each occupying a unique sector in the a* b* diagram and all meeting at a* = b* = 0. The algorithm yields the value of L* a colour should have it is of 1/1 Standard Depth. Because the samples are not entirely consistent as an equi-depth series, the Christ algorithm, which is probably the best optimised algorithm available, gives an extent of disagreement [1], E, of ±20%. The Christ algorithm has been incorporated into ISO 105 A06 "Instrumental Determination of 1/1 Standard Depth"[6].

Sato [7] has developed a formula so that a value for depth could be calculated directly from CIELAB coordinates, the resulting formula being:

$$D = (100 - L^*) + \left(0.1 + \frac{\Delta h_{290}}{360}\right) \times \left(1 - \frac{\Delta h_{290}}{360}\right) \times C^* \quad \text{Eqn 2}$$

where L^* is the CIELAB metric lightness
C^* is the CIELAB metric chroma
Δh_{290} is the hue angle difference from h = 290, moving in the hue direction such that $\Delta h_{290} < 180^0$.

More recently, Hawkyard [8] has proposed a method for defining standard depth that is based on an equation that relates the lightness (L^*) of dyeings, applied at increasing depths of shade, to maximum chroma (C^*) reached. However this method has not been substantiated by visual assessment and does not allow for the established variation of L^* with C^* at a given hue angle, for colours of constant depth.

The aim of the work reported in this paper was to map surfaces of constant visual depth throughout the L^* a^* b^* colour space. The results reported here are those for the first surface to be mapped. The results can be used to assess the accuracy of formulae developed for the measurement of depth. When further constant depth surfaces have been defined by a continuation of the work reported here, they will also provide a basis for an improved numerical specification of standard depths. Further, they will enable the conversion of the colorimetric values of ΔL^*, ΔC^* and ΔH^* into the dyers perceived variables of depth, brightness and hue.

2. METHODS

Experimental

A neutral grey sample was dyed as the initial starting point and samples were dyed at points approximately 5 CIELAB units of chroma away from it along each of the eight hue directions at 45^0 intervals round the hue "circle". These samples were dyed so that they had approximately the same depth as the neutral grey, using the Integ value as a guide to depth. At each of these new points, depth ranges of five samples were dyed, at 90, 95, 100, 105 and 110% of the concentration indicated by the Integ formula to yield equal depth. The average of the decisions of a panel of four assessors was used to determine which sample of the depth range had the same visual depth as the neutral grey "standard". The sample selected then became the "standard" for the next depth range of samples prepared a further 5 CIELAB units of chroma along the hue line. This process was repeated, along each of the hue lines, until the maximum chroma possible with the dyes available was reached.

In order to reduce the time lost whilst waiting for the samples to be posted round the panel of assessors, a different methodology was later adopted. For a given hue direction, the depth range samples (90, 95, 100, 105, 110%) were prepared at each of (up to) four chroma increments. For example, in the case of hue direction 0^0, for

which assessments had already been completed to C^* = 15, depth range samples were prepared at C^* = 20, 25, 30 and 35. To allow for the possibility of assessors selecting a sample from the depth range at an extreme of those given (e.g. the 90% depth sample) at C^* = 20, it was necessary that a wider range of depth samples at C^* = 25 was provided, and so on. Hence, as the chroma increased, the number of depth range samples provided was increased. In carrying out the assessments, the assessors were asked to use the sample selected at C^* = 20 (90, 95, 100, 105 or 110%) as the standard against which to compare the dyeings at C^* = 25. Then, the sample selected as having equal visual depth at C^* = 25 (85, 90, 95, 100, 105, 110 or 115%) became the standard against which to compare the dyeings at C^* = 30, and so on. Once the maximum chroma had been reached along each of the eight hue directions, samples were prepared (in the same way as described above) at increments of approximately 5 CIELAB units of colour difference around the hue 'circle' between the points of maximum chroma reached in neighbouring hue directions. The target locations of all the samples prepared are shown in Figure 1.

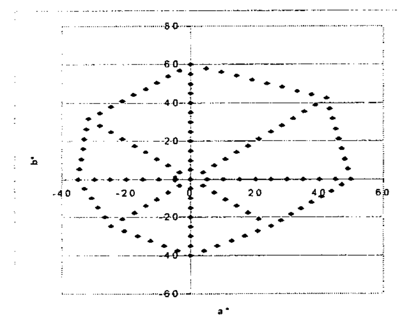

Figure 1: Target locations of samples

Preparation of the samples

The material used was 100% cotton twill (115 x 94 yarns per inch), bleached and mercerised, ready for dyeing. The cloth was cut into samples measuring approximately 18 x 12 cm and weighing 4.000 ± 0.001 g. All samples were dyed using trichromatic combinations of the Procion reactive dyes: Yellow HE-6G, Yellow H-EXL, Orange H-EXL, Red H-EXL, Blue H-EXL, Blue HE-GN, Turquoise H-EXL and Emerald H-EXL. After dyeing, soaping and drying, the samples were conditioned in the open laboratory prior to making colour measurements.

For visual assessment, the samples were folded double and stapled at the two loose corners to give a stable structure measuring approximately 9 x 12 cm. When making their assessments, it was left to the assessors individually to adopt the procedure that best enabled them to make a confident decision. Some assessors placed together the folded edges of the standard and the sample being compared and some compared the fabrics by placing one half-way over the top of the other.

Assessment of samples

A panel of four assessors, all employees of dye manufacturing companies in the UK, and all having extensive experience in the assessment of relative depth, conducted the assessments. They made their assessments independently on their own company premises, using the light cabinet (artificial daylight source) they routinely used for visual judgements during the normal course of their work. On some occasions, the authors visited the assessors in person with the samples. The majority of the samples were posted to the assessors however. None of the assessors had any knowledge of the results given by any of the other assessors.

3. RESULTS AND DISCUSSION

Trends in variation of lightness with chroma at constant visual depth

The variation of L^* values of the samples determined from the visual assessments as having the same visual depth for each hue direction, at increments of 5 CIELAB units

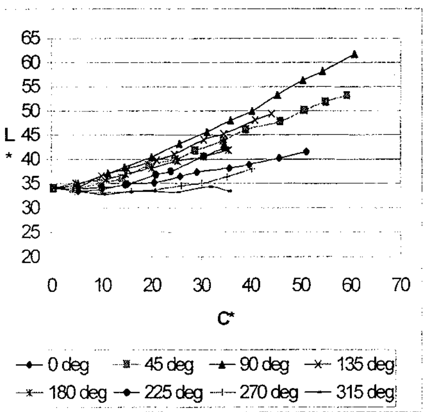

Figure 2: Variation of L^* with C^* for samples of constant visual depth at 8 hue directions.

of chroma, are shown in Figure 2. At each of the hue angles, there was an increase in lightness with chroma. The rate of increase in lightness varied with hue angle however, being the greatest along hue direction 90^0 and least along hue direction 315^0. The variation of lightness around the hue circle for the samples prepared between the points of maximum chroma reached in adjacent hue directions, is shown in Figure 4. These trends were found to be very consistent with those obtained along the individual hue directions.

Defining the surface of constant visual depth

In order to map the surface of constant visual depth, it was necessary to establish first the relationships between L^* and C^* along each of the eight hue directions. It was considered desirable that there existed a continuity of the curve profiles across opposite hue directions at the neutral point. Thus ideally, a continuous curve should be fitted to the L^* versus C^* values for each of the combined opposing hue directions: $0^0 - 180^0$, $45^0 - 225^0$, $90^0 - 270^0$ and $135^0 - 315^0$.

It was decided that the optimised curves should pass through a common value on the L^* axis at $C^* = 0$ and the value of 34.10 was selected, a value close to the value of 34.14 for the neutral grey sample used at $C^* = 0.45$. Inspection of the trends of L^* Vs C^* in Figure 2 suggested that either a quadratic (Eqn 3) or a cubic function (Eqn 4):

$$L^* = k_0 + k_1C^* + k_2C^{*2} \quad \text{Eqn 3}$$

$$L^* = k_0 + k_1C^* + k_2C^{*2} + k_3C^{*3} \quad \text{Eqn 4}$$

would provide good agreement. When the k_i values of these functions were optimised across the opposite hue directions in this way, the error values were significant higher than when fitted to one hue direction individually. For this reason it was decided to employ the general formula that describes the conic sections of circles, ellipses, parabolas and hyperbolas:

$$k_1L^{*2} + k_2C^{*2} + k_3L^* + k_4L^*C^* + k_5C^* + k_6 = 0 \quad \text{Eqn 5}$$

Eqn 5 can be rewritten as a quadratic in L^*:

$$k_1L^{*2} + (k_3 + k_4C^*)L^* + (k_2C^{*2} + k_5C^* + k_6) = 0 \quad \text{Eqn 6}$$

This formula can be solved using:

$$L^* = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad \text{Eqn 7}$$

where $a = k_1$

$b = k_3 + k_4C^*$

$c = k_2C^{*2} + k_5C^* + k_6$

In fitting the conic formula to the results, it was only the positive value of the square-root term, that is $+\sqrt{(b^2 - 4ac)}$ that was required. A least-squares curve-fitting procedure was written to determine the optimum values of the constants k_i in

Equation 6 by minimising the term:

$$Error = \sqrt{\frac{\sum (L^*_{calc} - L^*_{exp})^2}{n}} \quad \text{Eqn 8}$$

where L^*_{calc} is the value of L^* computed using Eqn 6

L^*_{exp} is the experimentally determined value of L^*

n is the number of chroma levels along a given hue direction

The results of the optimisations produced error values (in units of L^*) less than 0.5, which was considered a satisfactory level of fit to the results.

The next stage of the analysis was to develop the algorithm so that the relationship between L^* and C^* could be determined for any hue angle. This required the establishment of the relationships between each of the constants, k_i, of the conic formula and hue angle, h. It was found that a formula of the general structure:

$$k_i = l_0 + l_1\cos(h + m_1) + l_2\cos(2h + m_2) + l_3\cos(3h + m_3) + l_4\cos(4h + m_4) + l_5\cos(5h + m_5) \quad \text{Eqn 9}$$

where i = 1 to 6, was most appropriate.

The constant k_1 was found to be invariant with hue angle, with a value of 0.026. Also, the value of k_3 was set to –1.0 for all hue angles. Thus, it was only necessary to establish the relationships with hue angle for k_2, k_4, k_5 and k_6. The constants were selected also so that at $C^* = 0$, the curves would yield a value for L^* of 34.10. The optimisations were achieved by minimising the function:

$$Error = \sqrt{\frac{\sum (k_{i,calc} - k_{i,actual})^2}{n}} \quad \text{Eqn 10}$$

where n = 8 (the number of hue directions investigated)

i = 2, 4, 5 or 6

Not all of the *l* and *m* terms of equation 14 were required in establishing the optimum relationships. The equations established were:

$k_1 = 0.026$

$k_2 = -5.5\times10^{-3} - 2.1\times10^{-3}\cos(2h - 105) + 3.0\times10^{-4}\cos(4h)$

$k_3 = -1.0$

$k_4 = 7.8\times10^{-3}\cos(h + 32) - 2.3\times10^{-4}\cos(2h + 17) - 2.95\times10^{-3}\cos(3h + 45) - 3.4\times10^{-4}\cos(4h + 87) - 6.8\times10^{-4}\cos(5h - 35)$

$k_5 = 0.191\cos(h) + 9.3\times10^{-2}\cos(3h + 40) + 0.035\cos(5h - 46)$

$k_6 = 3.889 - 0.0437\cos(2h - 13) - 0.01125\cos(4h)$

Eqn 11

where h = hue angle.

Equations 11 can now be combined with equation 7 to define the surface of constant visual depth determined in this work. Firstly the constants for the conic formula ($k_1 - k_6$) are determined for a selected hue angle, h, using the equations 11. Then, for a selected value of chroma, C^*, these constants are used in a equation 7 to obtain the L^* value that the colour of the selected C^*, h values will have if it lies on the equi-depth surface.

In order to verify the proposed method, the values of L^* were calculated for the samples of constant visual depth obtained round the hue circle between the various hue directions at maximum chroma. The results of the calculations, together with the L^* values of the actual samples, are shown in Figure 4.

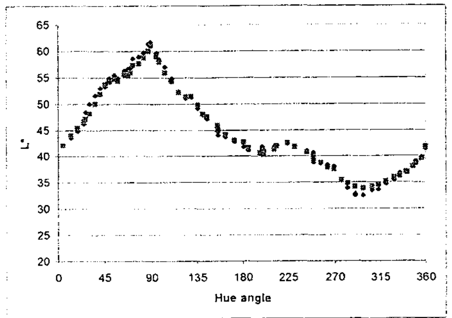

Figure 4: Comparison of L^* values of actual samples at maximum C^* with those computed using equations 7 and 11

The average error of the calculations, as expressed by the formula:

$$Error = \sqrt{\frac{\sum \left(L^*_{i,calc} - L^*_{i,actual}\right)^2}{n}} \qquad \text{Eqn 12}$$

where n = total number of samples round the hue circle, was 0.63.

The accuracy of the L^* values computed using Equations 7 and 11 were also be compared with the actual L^* values at other levels of chroma around the hue circle. Figure 5 shows the trend lines of L^* values with hue angle predicted at the four levels of chroma: C^* = 15, 30, 45 and 60 respectively.

The L^* values of actual samples with values of chroma close to these are also shown. It was not possible to prepare samples at high values of chroma at all hue angles, so for this reason, a complete comparison is not possible. Also the trend lines have been computed for the precise four values of chroma indicated in Figure 5. The actual samples did not possess exactly the same values of chroma, so small differences between the L^* values of the predictions and the actual samples occurred. Nevertheless, Figure 5 shows the generally broad agreement between the L^* values predicted by Equations 7 and 11 with those of the actual samples.

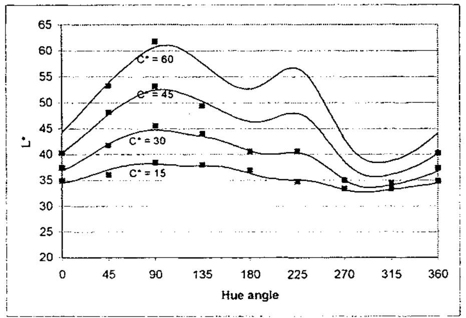

Figure 5: Variation of L^* with hue angle, at C^* values indicated, predicted by Eqns 7 & 11. ■ = actual values

Performance of other formulae for quantifying depth with the results.

The level of correspondence of depth values provided by equations 4 – 8 were evaluated with the results obtained in this work. Since samples have been prepared that have equal visual depth, the equations should yield the same values for all the samples. However, because of the differences in the way in which the various formulae compute a value for depth, the values yielded by the two formulae will not be the same as each other. The values produced (Table 1) show that Integ method

Table 1: Consistency of depth values given by Eqns 1 and 2 for equi-depth surface determined in this work.

Integ (Eqn 1)		Sato (Eqn 2)	
mean	σ	mean	σ
15.16	0.83	66.77	8.17

(Eqn 1) agreed well with the results, although it can give erroneous values when metameric colours are involved[10]. Sato's formula (Eqn 2) agreed with the results less well. With the exception of hue directions 0^0 and 315^0, it tended to yield slightly lower values for depth at higher values of chroma. The decrease in depth value with chroma was particularly large at direction 90^0.

A direct comparison between the results of this work and the values for depth computed using Christ's formula is not possible. The latter formula yields a value for L^* that a colour should have if it lies on the 1/1 standard depth surface. The surface established in this work was at an overall slightly higher level of lightness; at C^* = 0, the value of L^* obtained using Christ's formula is 26.40, whilst the value of L^* obtained using Eqns 7 and 11 is 34.10.

To facilitate an approximate comparison between the surface defined in this work with the surface for 1/1 standard depth defined by Christ's algorithm, it is necessary to lower (in L^* value) the surface defined in this work, so that at C^* = 0, it gives a value for L^* of 26.40, equal to that of the Christ surface at this point. Differences between the two surfaces can then be established by comparing the L^* values at various values of hue angle and chroma throughout colour space. The most straightforward method to compare the shapes of the surfaces is to map the variation of L^* values with C^* along each of the eight hue directions investigated in this work. The difference in the L^* values at C^* = 0 between the two surfaces is 7.7, so the L^* values of the surface determined in this work were reduced by this amount.

Comparisons of the (L^* - 7.7) values with L^*_{SD} values given by the Christ formula, at increasing chroma along four of the hue directions, are shown in Table 2. Generally the Christ formula yields higher values of L^*. As expected the differences are small at low values of chroma, and become greater at higher values of chroma, especially along the hue directions 0^0 and 90^0.

However, the trends show a remarkable degree of consistency in that the various rates of increase of L^* with C^* for the eight hue angles are in very much the same order.

Table 2: Differences between L^* values computed by Christ formula and L^*_{exp}-7.7

Hue angle	Ave diff	Difference at C^*_{max}
	$L^*_{Ch} - L^*_{exp\text{-}7.7}$	$L^*_{Ch} - L^*_{exp\text{-}7.7}$
0^0	2.07	3.65
45^0	0.50	1.05
90^0	5.51	9.51
135^0	3.19	5.92
180^0	1.48	3.18
225^0	0.84	0.02
270^0	2.07	2.09
315^0	1.71	3.00

Thus both surfaces agree that the rate of increase is highest at hue direction 90^0, then at 135^0, with the lowest rate in each case is at hue direction 315^0, followed by hue direction 270^0, then direction 0^0.

4. CONCLUSIONS

A surface of uniform visual depth has been mapped in CIE $L^*a^*b^*$ space and an algorithm developed to define the surface. The algorithm involves a two stage process. The constants of the general conic formula are first determined for the hue angle of the colour of interest. Using these constants and the value of C^* of the colour, the L^* value that the colour should have if it lies on the surface established is computed.

The surface mapped was at an overall higher value of lightness than the 1/1 standard depth samples. A comparison of the shape of the surface with that defined for the 1/1 Standard Depth samples by the Christ formula showed broad similarities. However, the Christ formula defined a surface where L^*_{SD} increased at a greater rate along hue directions 90^0 and 135^0 than that mapped in this work. This discrepancy may arise because the Christ formula has been optimised to fit the 1/1 Standard Depth samples. Samples 1 and 2 of this set (bright yellow and bright greenish yellow) have, according to the Integ formula (Eqn

1) and the Sato formula (Eqn 2), significantly lower depth values than the remainder of the series. There is also a good measure of agreement amongst visual colourists that these two samples are anomalous in depth with respect to the other samples in the series.

Equal depth surfaces at other depth levels are to be mapped to determine whether the shape of the surface mapped in the work reported here is generally applicable. Accordingly, further work is in progress to map other surfaces. It will be possible to produce an algorithm that defines all depth surfaces, and allows re-definition of all values of Standard Depth. It will also be possible to develop an algorithm for the conversion of differences in the metric quantities of lightness, chroma and hue into the dyer's perceived variables of depth, brightness and hue.

5. ACKNOWLEDGMENT

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Dr. Roger H Wardman, Heriot-Watt University, School of Textiles, Netherdale, Galashiels, Scotland TD1 3HF, Scotland, UK. Tel: ++44 1986 892140, E-mail r.h.wardman@hw.ac.uk
Dr Chao-Chi Chen, Taiwan Textile Federation, 13F TTF Building, 22 Aikuo East Road, Taipei 100, Taiwan, R.O.C. Tel: (8862) 2341 7251 ext 2585,
E-mail: n835@www.textiles.org.tw
Prof. Ken J Smith, Colour Consultancy, 38 Ladybridge Avenue, Worsley, Manchester, M26 3BP, UK. Tel: ++44 161 799 0555, E-mail: colconsult@compuserve.com

THE USE OF THE ARTIFICIAL NEURAL NETWORK IN TEXTILE PRINTING

Darko Golob[1], Jure Zupan[2]
[1]University of Maribor, [2]National Institute of Chemistry Slovenia, Ljubljana

Abstract
The Kubelka – Munk theory is unsuitable for the computer match prediction of dye concentration for printing paste, therefore research is oriented towards the use of artificial neural network. It provides the opportunity learning on the basis of numerous samples and predicts unknown targets.
This present paper shows an example of using artificial neural network for the prediction of dye concentration in textile printing paste preparation. An existing collection of printed samples was used for neural network training. The reflectance value served as input data and the known concentrations of each sample were the targets. Some variations of neural network were tested as well as various numbers of neurons in the hidden layer. In addition the influence of the training set organisation was examined together with the number of learning epochs on the success of learning.

Keywords: *Neural network, Colorimetry, Computer match prediction, Textile printing*

1. INTRODUCTION

Colour determination and colour recipe formulation for textile printing base on colour cards i.e. an extensive collection of printed colour samples with known recipes. Samples are printed in various combinations of dyes and different concentrations to comprise complete colour space. To define a new recipe for the demanded colour we first search the colour card and define the samples closest to the required colour and then interpolate the recipe to adjust the colour. If test prints are not good enough we have to correct the recipe and repeat the test print. We try to improve the procedure by using computer, because this is a time and money consuming method.
The classical way of computer recipe prediction based on the Kubelka-Munk theory of radiation transfer is unsuitable for textile printing, therefore other methods are investigated. One of them is the use of an artificial neural network, which is able to perform mappings between colour spaces and concentration spaces. Once the neural network is sufficiently trained with sets of known input and output data, it can predict the output for an unknown set of input data.

2. ARTIFICIAL NEURAL NETWORK

Inspired by biological neurons, artificial neural networks simulate the way human brains are learned. Basic unit is neuron shown in figure 1.

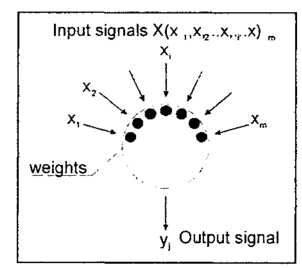

Figure 1: Model of artificial neuron

Each signal coming into a neuron is weighted and summed together. Output depends on the sum of all weighted inputs. Output functions vary but the sigmoid function is the most widely used. It limits the output to one regardless of the values of the input signals. One special input called bias can be added to improve characteristics of a neuron. Bias has a fixed value of 1, but its weight can be adjusted just as any other weight.
Although the mathematics of a neuron is very simple, the true power of neural network is the number of neurons and connectivity.
Neurons are organised in layers. The input layer has as many neurons as the input signals (i.e. input data) and the output layer as many as output data. Multilayer networks can have one or more hidden layers with arbitrary number of neurons. The output signal from each neuron in one layer goes to each neuron in the next layer and each connection has its own weight.
Figure 2 shows a model of an artificial neural network with 16 inputs, 4 outputs and one hidden layer.

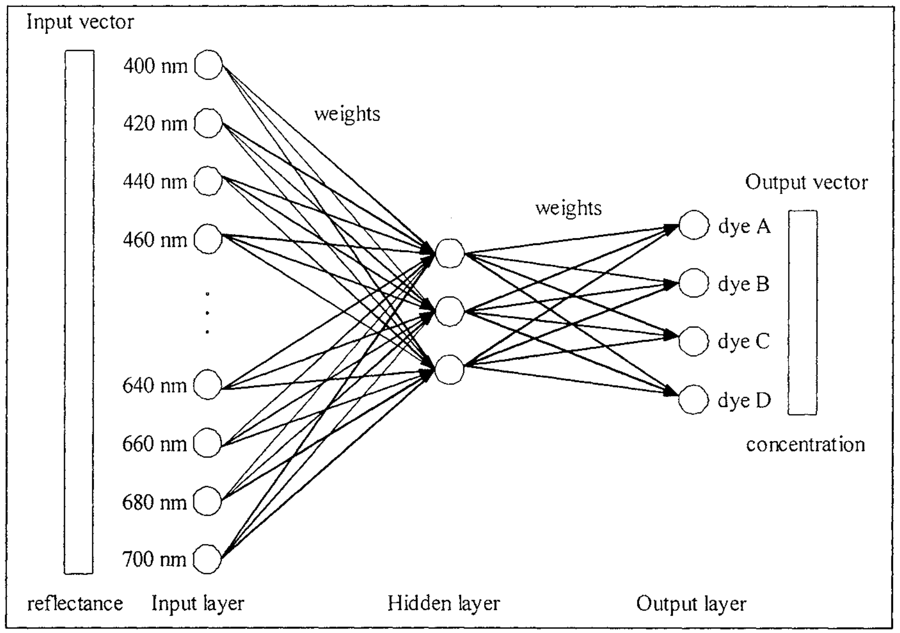

Figure 2: Model of artificial neural network

Error-back propagation is one of the methods for neural network training. Differences between target and predicted data are used for adjusting the weights on the output layer, then the weights on the hidden layer are adjusted and so backward to input layer. This operation is repeated for each data set. When all data in the training set are processed one learning epoch is finished. The difference between target and predicted values is calculated in the form of root mean square error (RMS). Learning process is finished after a given number of epochs or when the RMS is small enough. We also include some coefficients like learning rate and momentum term for better performance.

3. LEARNING DATA

A colour card with more than 4000 samples printed with combinations of one or two dyes out of 19, served as the base for the learning data. Samples were printed in different concentrations (100%, 50%, 25%, 10%, 8%, 4%, 2% and 1% of the maximum amount, recommended by the producer) and the ratios between each dye were 1:9, 3:7, 5:5, 7:3, 9:1 as well as both single dyes. Printed samples were cut in the form of small chips and collected in a colour book, organized by colour shades. Each group of data, dyed with combinations of two dyes, contains 46 samples. Figure 3 shows the positions of the samples dyed with red and blue dyes in a*-b* plane of CIELAB colour space.

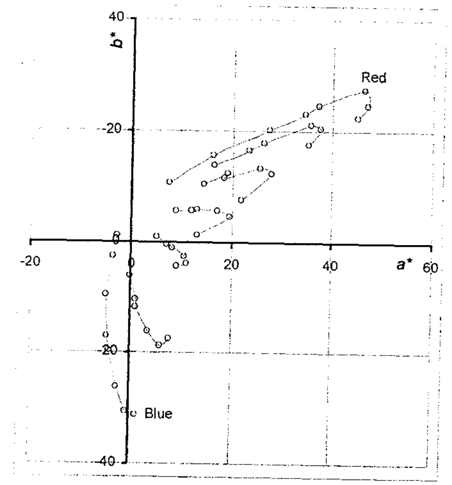

Figure 3: Position of colours in a*-b* plane

For testing purposes 14 additional samples were printed using the same dyes and same technological procedure. The positions of the learning and testing data are shown in figure 4.

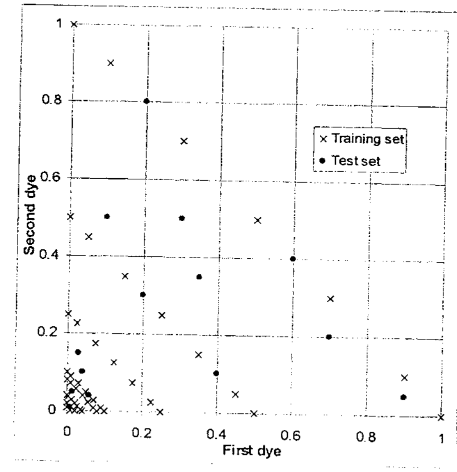

Figure 4: Concentration of training and test set

Producers prescribe different maximum amounts of dye in the printing paste for each dye. We normalised concentrations into a range between 0 and 1 for easier calculation.
Sixteen reflectance values from 400 to 700 nm in 20 nm steps served as input data and normalized concentrations as output values.
Figures 5-8 show the reflectance values of some samples.

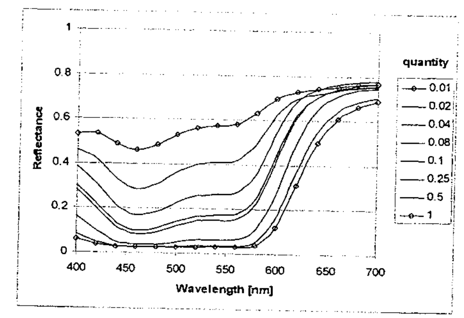

Figure 5: Reflectance values of red dye in different concentration

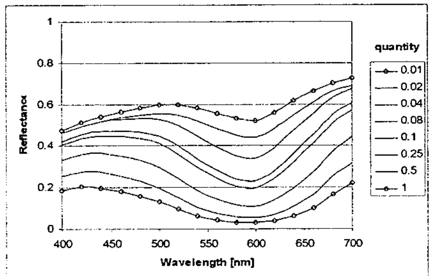

Figure 6: Reflectance values of blue dye in different concentration

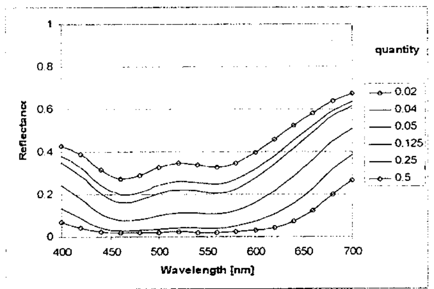

Figure 7: Reflectance values of mixture 5:5 in different concentration

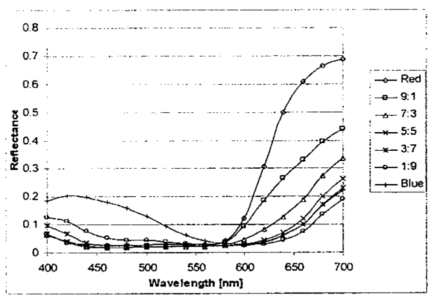

Figure 8: Reflectance values of mixture in different ratios

We tried to reduce the number of input data because of the limited number of samples in the training set. Our network has 16 input neuron and two output neuron. Using 3 neurons in the hidden layer we have 16x3 plus 3x2 = 54 weights and only 46 training records. When the number of weights exceeds the number of training data so-called over-fitting occur. Network is very well trained for known data, but the prediction of unknown input is very bad. Therefore we also tried tristimulus values X, Y, Z as well as CIELAB values L*, a*, b*. Using only 3 input neurons we can vary the number of neuron in the hidden layer by up to 9.

The number of neurons in the hidden layer was changed during the training as well as number of learning epochs, learning rate and momentum term. Inverse mapping was also performed and reflectance values for known concentrations were predicted.

4. RESULTS

Some results are presented in the following figures. An up to 100.000 learning epoch was tried but 10.000 was usually sufficient. The learning rate and momentum term did not significantly influence the result.

Reflectance values as input are unsuitable because too many weights need to be adjusted and we usually don't have enough samples to train the network. We tried to reduce the number of input values so we picked only 5, 7 or 11 reflectance values but the results did not improve. Better result was achieved with CIELAB data L*, a* b* as input among tristimulus and CIELAB data. Figure 9 shows the influence of the number of epochs on the total error RMS.

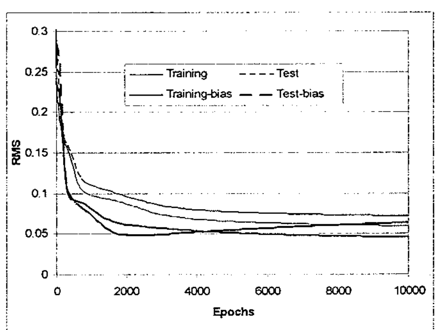

Figure 9: Influence of the number of learning epochs on the RMS for 3 neurons in the hidden layer

Minimum RMS for test data was achieved at 2200 epochs. The next figure shows the influence of the number of neurons in the hidden layer.

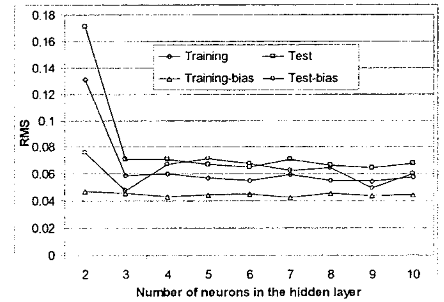

Figure 10: Influence of the number of neurons in the hidden layer on the RMS

The best result for the test data was achieved with 3 neurons and bias. Figure 11 shows the actual layout of the neural network.

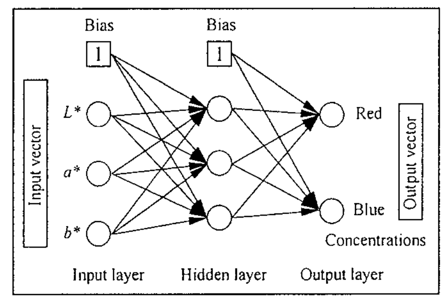

Figure 11: Actual layout of critical neural network

The learning rate and momentum term were varied from 0.1 to 0.9 but it showed that they have a small influence on final result. After recalculation with optimal parameter we obtained the predicted concentration for each dye in the combination. Figure 12 shows target concentrations (printed as solid dots) and predicted concentrations (printed as hollow circles).

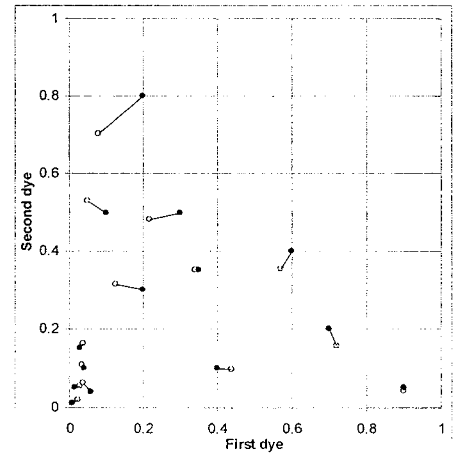

Figure 12: Position of target (red) and predicted (blue) concentration

Some predictions were very close to actual concentrations but the overall results are not good enough. In the next phase we will try to improve the predictions by increasing the number of learning data or rearrange the data in learning data set. One possibility is to add data from combinations with other dyes and extract only that data relevant to the investigated combination.

5. CONCLUSION

Artificial neural networks promise new ways of solving problems like recipe prediction for textile printing. The advantage of this method is the fact that we don't have to be familiar with relationships between input and output data. The disadvantage is the demand for numerous data describing those relationships and time wasting search for optimal learning parameters.

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M. Sc. Darko Golob, University of Maribor, Faculty of Mechanical Engineering, Textile Department, Smetanova 17, SI-2000 Maribor, Slovenia. Phone: +386 2 220 7895, Fax: +386 2 220 7990, E-mail: darko.golob@uni-mb.si

DYING IN SUPERCRITICAL CO_2

Eckhard Schollmeyer, E. Bach, E. Cleve
Deutsches Textilforschungszentrum Nord-West e.V. (DTNW)
Adlerstraße 1, 47798 Krefeld (Germany)

Abstract
A new expanded calibration model is presented to predict dye concentrations for oligochrome dyeing of poly(ethylene terephthalate) (PETP) in supercritical carbon dioxide. The model has been verified by monochrome as well as oligochrome dyeing experiments and shows a good agreement between the measured and predicted values.

1. INTRODUCTION

Up to now only few dyeing results of PETP carried out in supercritical CO_2 are published using more than one dye [1,2]. In these experiments it was found that changes in the temperature and pressure result in significant colour differences concerning the colour yield and the hue. During dyeing, the dyes seem to compete for accessible locations where the dye with the lowest molecular weight has the highest mobility, resulting in the highest dye uptake in relation to the dyes with a higher molecular weight [2]. The additive behaviour which was found by other authors [1] for trichrome dyeing in supercritical CO_2 seems to be a very special case. Based on our own experience, this is not valid for most of the dyes tested [3]. This can also be seen by a comparison of the dyeing results obtained in water and in carbon dioxide. According to the different behaviour of disperse dyes in both media caused by the influence of special auxiliaries in water dyeing, the hues, and in some cases the colour yields, can vary significantly. Therefore, existing water dyeing colour matching systems which are based on additive behaviour of the dye uptake for the prediction of new dyeing recipes are not suitable for carbon dioxide dyeing. At the moment, new systems are under development [3].

2. MATERIALS AND METHODS

For the calibration of the colour matching system 20 monochrome concentration-dependent CO_2-dyeing experiments on PETP were carried out by using four different disperse dyes named Blue 1, Yellow 1, Red 1 and Orange 1 which were purchased from Ciba Specialty Chemicals Basle, (Switzerland). The PETP-fabric (warp 40/2 Nm, weft 20/1 Nm, 18 warp threads/cm, 15 weft threads/cm, mass per unit area 182 g/m^2) was provided by ADO Gardinenwerke GmbH & Co., Aschendorf, (Germany). The PETP was dyed isothermally in the UHDE CO_2-pilot plant at dye concentrations of 0.5%, 1%, 2%, 4% and 6% relative to the fabric weight at 280 bar and 130 °C for 60 min. After dyeing the reflectance values of the fabrics were measured on a spectrophotometer (Spectrophotometer 3890 Datacolor Marl, (Germany) by using illuminant D 65 under an observation angle of 10 °.

3. RESULTS AND DISCUSSION

The aim of the colour formulation by colour measurement is to calculate the amount of dye needed for rematching of the same shade of a dyed fabric. This requires at first the recording of the reflectance curve but also knowledge of the influence of the dye concentration on the reflectance values. For conventional computer-match prediction in water dyeing the Kubelka-Munk and the Lambert-Beer equations are used according to equation (1):

$$\frac{K}{S_\lambda} = \frac{(1-R_\lambda)^2}{2 \cdot R_\lambda} - \frac{K_t}{S_\lambda} = A_\lambda \cdot c, \qquad (1)$$

containing the light reflectance R, the light absorption K, the light scattering S, the self-absorption of the undyed fabric K_t/S_λ, the dye concentration c and the wavelength-dependent absorption coefficient A_λ which relates to S_λ. A_λ is determined by VIS-spectroscopy of the concentration-dependent dyed PETP-fabrics in the absorption maximum at the fixed wavelength λ. Figure 1 shows the K/S-values which were calculated from the reflectance data by equation (1) of the dyed PETP with Blue 1, Yellow 1, Red 1 and Orange 1 at a concentration of 1 % relative to the fabric weight dependent on the wavelength.

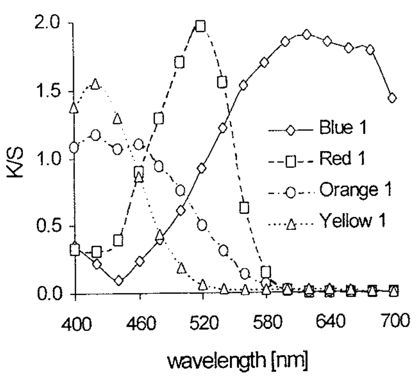

Figure 1 : Wavelength-dependent K/S values calculated after equation (1) of monochrome dyed PETP-fabrics (1 %) in CO_2

In Figure 2 the K/S-values of the concentration-dependent dyed PETP-fabrics in the absorption maximum of the dyes are presented. For all dyes tested a straight line is obtained. This means that there is a linear relationship between the dye concentration and the dye uptake of PETP in CO_2 under the dyeing conditions tested. By using these calibration curves for monochrome dyeing the dye concentration can be predicted. (1)

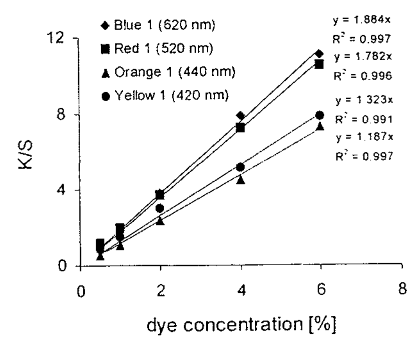

Figure 2 : Dye concentration-dependent calculated K/S-calibration curves of the PETP-fabrics after monochrome dyeing in supercritical CO_2

For realizing a multitude of different shades in the textile finishing industry normally more than one dye has to be used. For three dyes e.g. in water dyeing, the K/S-value at the fixed wavelength λ is obtained by addition of the K/S-values of the monochrome dyed fabrics at the dye concentrations c_1, c_2 and c_3 according to equation (2)

$$\frac{K}{S_\lambda} = \frac{(1-R_\lambda)^2}{2 \cdot R_\lambda} - \frac{K_t}{S_\lambda} = A_{\lambda 1} \cdot c_1 + A_{\lambda 2} \cdot c_2 + A_{\lambda 3} \cdot c_3 \qquad (2)$$

To prove if equation (2) is also valid for CO_2, dyeing experiments were carried out with the dyes Blue 1, Yellow 1, Red 1 and Orange 1 alone and in mixture of all four at a dye concentration of 0.5 % respectively. In Figure 3 the K/S-spectra of the

monochrome and oligochrome dyed fabrics but also the K/S-addition spectrum according to equation (2) of the monochrome dyed PETP are shown. Mainly in the wavelength region between 400 and 600 nm the K/S-values of the oligochrome dyed PETP are significantly lower than the added K/S-values of the monochrome dyed fabrics. This means that a prediction of dye recipes based on monochrome calibration sets is not possible for CO_2 dyeing.

This was also tested by using a colour matching system for water dyeing processes. In this special case after calibration with the monochrome CO_2-dyed samples, the dye concentrations for dyeing PETP in a grey shade were calculated as follows: 0.34 % Blue 1, 0.05 % Red 1 and 0.37 % Orange 1 relative to the fabric weight.

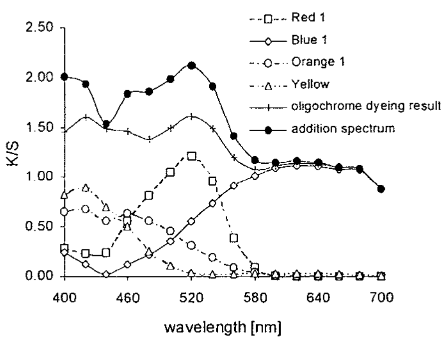

Figure 3 : K/S-spectra of mono- and oligochrome CO_2-dyed PETP-fabrics for testing the validity of the Kubelka-Munk-equation (2) for oligochrome dyeing in CO_2

The CIELab colour difference values between both dyed samples are summarized in Table 1. As expected, a comparison of the original grey sample with the CO_2 dyed resulted in significant deviations in the red and blue colour region (less red and blue).

Table 1 : CIELab colour difference values of PETP between the original and the CO_2-dyed sample after prediction of the dye concentrations by a water colour matching system

Illuminant	D65/10
DE*	6,311
DL*	-2,438
Da*	-2,339
Db*	5,330
DC*	-3,867
DH*	-4,351

Due to the incompatibility, an attempt was made to calculate the dye concentrations for CO_2-dyeing under consideration of non-linear behaviour of the system according to equation (3):

$$\frac{K}{S_\lambda} = \frac{(1-R_\lambda)^2}{2 \cdot R_\lambda} - \frac{K_t}{S_\lambda} = b_0 + A_{\lambda 1} \cdot c_1^{r_1} + A_{\lambda 2} \cdot c_2^{r_2} + A_{\lambda 3} \cdot c_3^{r_3} \qquad (3)$$

in which the coefficient b_0 describes the background absorbance of the dyed fabric and the coefficients (r_1 to r_i, $0 \le r_i \le 1$) the deviations from the linearity caused by non additive behaviour of the monochrome K/S-values.

After measuring the K/S-values at p wavelengths (p = 16 in this example) between 400 and 700 nm and placing the coefficient b_0 to the variables A_{11} and A_{1p} respectively, equation (3) can be written by the matrix equation (4):

$$\begin{pmatrix} \frac{K}{S_{11}} & \frac{K}{S_{12}} & \cdots & \frac{K}{S_{1p}} \end{pmatrix} = \begin{pmatrix} 1 & c^{r_1}{}_{11} & \cdots & c^{r_i}{}_{1i} \end{pmatrix} \cdot \begin{pmatrix} A_{11} & \cdots & \cdots & A_{1p} \\ A_{21} & A_{22} & \cdots & A_{2p} \\ \vdots & & & \vdots \\ A_{i+11} & A_{i+12} & \cdots & A_{i+1p} \end{pmatrix} \qquad (4)$$

When n different oligochrome dyeing experiments with the dyes at the concentrations c_i are carried out and the K/S-values of the dyed fabrics are measured at p wavelengths, the matrix equation (5) can be written as:

$$\begin{pmatrix} \frac{K}{S}_{11} & \cdots & \frac{K}{S}_{1p} \\ \vdots & & \vdots \\ \frac{K}{S}_{n1} & \cdots & \frac{K}{S}_{np} \end{pmatrix} = \begin{pmatrix} 1 & c^r_{11} & \cdots & c^r_{1i} \\ \vdots & & & \vdots \\ 1 & c^r_{n1} & \cdots & c^r_{ni} \end{pmatrix} \cdot \begin{pmatrix} A_{11} & \cdots & \cdots & A_{1p} \\ A_{21} & A_{22} & \cdots & A_{2p} \\ \vdots & & & \vdots \\ A_{i+11} & A_{i+12} & \cdots & A_{i+1p} \end{pmatrix} \quad (5)$$

For clear arrangement reasons the matrix is applied in the following in shorthand form:

$$\underline{\underline{K}} = \underline{\underline{c}}^r \cdot \underline{\underline{b}}, \quad (6)$$

where $\underline{\underline{K}}$ = n * p is the matrix of the K/S-values, $\underline{\underline{c}}$ = n * (i+1) the matrix of the dye concentrations, $\underline{\underline{b}}$ = (i+1) * p the matrix of the absorption coefficients, n = number of the dyed fabrics, i = number of the different dyes, p = number of the wavelengths and r = the coefficients ($0 \le r_i \le 1$) which consider the deviation from the linear dyeing behaviour of each dye on PETP.

Based on the calibration set of the dyed fabrics with known concentrations, the absorption coefficients can be determined by calculation of the $\underline{\underline{b}}$ - matrix after the so called general regression solution:

$$\underline{\underline{b}} = \left(\underline{\underline{c}}^{r\,T} \cdot \underline{\underline{c}}^r\right)^{-1} \cdot \underline{\underline{c}}^{r\,T} \cdot \underline{\underline{K}}, \quad (7)$$

with T = transposed and (-1) = inverse matrix.

After calculation of the matrix of the absorption coefficients $\underline{\underline{b}}$ from the calibration data, the K/S-values and thus the dye concentrations can be calculated from the reflectance data of the dyed fabrics after equation (8):

$$\underline{\underline{c}}^{prediction} = \underline{\underline{K}} \cdot \underline{\underline{b}}^T (\underline{\underline{b}} \cdot \underline{\underline{b}}^T)^{-1} \quad (8)$$

The coefficients r_i are calculated by minimization of the residual variance (QS_R) according to equation (9) by using the Newton iteration method of 2nd order:

$$QS_R(r_1 \cdots r_i) = \frac{\sum_{a=1}^{i}\sum_{b=1}^{n}\left(c_{ab} - c_{ab}^{prediction}\right)^2}{n-(i+1)} = \text{minimum} \quad (9)$$

with the requirement that the number of the dyed fabrics for calibration (n) must be higher than the number of dyes (i+1). (5)

The expanded calibration model was first verified for the presumption of monochrome dye concentrations under consideration of the spectral range between 400 and 700 nm as shown in Figure 4.

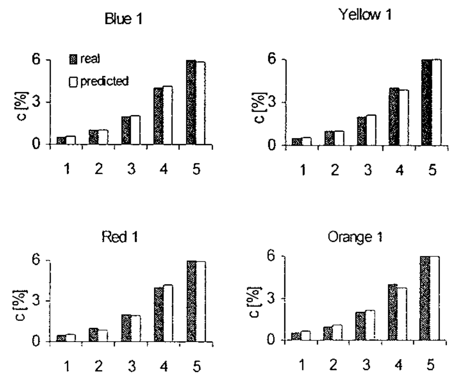

Figure 4 : Comparison of the real and predicted monochrome dye concentrations after a multiple regression evaluation for dyeing of PETP

The values of the calibration set and the predicted ones which are calculated by the reflectance data after a multiple regression analysis are in good agreement for all dyes tested. This can also be seen by the fit of the coefficients (r_i) after minimization of the residual variance according to equation (9) as presented in Table 2. (7)

Table 2 : Calculated coefficients (r_i) and the residual variance QS_R after minimization of QS_R (8)

	Blue 1	Red 1	Yellow 1	Orange 1
r	0,995	0,998	1	0,979
QS_{Rr}	0,0031	0,0083	0,0080	0,0191

(9)

4. CONCLUSION

Due to the fact that the r_i values are all very close to 1, the dye uptake after monochrome CO_2 dyeing of PETP can be calculated according to the conventional Kubelka-Munk equation (2). This is not valid for the prediction of oligochrome dyeing recipes. In this case the calibration set can not only be based on monochrome dyed fabrics but has to be expanded by additional oligochrome dyeing experiments to consider the deviations from linearity (Figure 3).

5. ACKNOWLEDGEMENT

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Prof. Dr. Eckhard Schollmeyer, Deutsches Textillforschungs-zentrum, Nord-West e.V. (DTNW), Adlerstraße 1, 47798 Krefeld, Germany. E-mail: info@dtnw.de

TESTING THE COLOUR MATCH PREDICTION NOVELTIES DEVELOPED AT THE UNIVERSITY OF MARIBOR

Boris Sluban and Olivera Šauperl,
University of Maribor, Maribor, Slovenia

Abstract
The article presents the results of laboratory tests of the least metameric recipe prediction method. These results are used as the starting point for the discussion about the accuracy of dyeing. The main question of the research was: Can the predicted sensitivity of the recipe colour to the colorant concentration errors assist in the selection of the most repeatable recipe(s)? The exhaustive dyeing of polyacrylic with basic dyes under laboratory conditions was examined. Both the biggest scattering of colour in groups of repeated dyeings and the biggest predicted recipe sensitivity to the colorant concentration errors were observed in the cases of light, less saturated target colours. Some light, less saturated target colours were selected and per each target 8 recipes with different sensitivities were tested. The less sensitive recipes generally produced lower scattering of colour in groups of 20 repeated dyeings than the more sensitive recipes did, although some exceptions were noticed. In the majority of cases a weak but still statistically significant correlation between the predicted sensitivity of recipe colour and the observed repeatability of the recipe colour was found.

Keywords: *recipe prediction, metamerism, colorant concentration errors, repeatability of the recipe colour*

1. INTRODUCTION

Many laboratory experiments have been carried out with the aim to test the performance of two theoretical concepts in recipe formulation. The first concept was the minimisation of the metamerism of the recipe colour, and the second concept was the concept of the sensitivity of the recipe colour to random concentration errors.

The reduction of metamerism of the recipe colour is based on the following idea: Let us relax the usual requirement for an exact colour match under the primary illuminant, and we can improve the match for some further illuminants in turn. If the metamerism of the recipe colour produced by the usual single-illuminant strategy is not too high, in this way a more acceptable recipe can be obtained by the same combination of colorants. If the metamerism of the recipe produced by the usual single-illuminant strategy is higher, the balancing of the colour differences (by the multi-illuminant strategy) cannot bring all the colour differences under the tolerance level, but the metamerism can still be diminished. The algorithm following this idea for the case of CIELAB colour difference was published in 1993 [1]. The adaptation of this algorithm for the case of the CMC(2:1) colour difference was briefly mentioned in [2].

The second theoretical concept, which performance was tested in this research, was the sensitivity of the recipe colour to colorant concentration errors. Simple numerical estimates (see [2]) enable to predict and mutually compare the sensitivities of various recipes to colorant

concentration errors at the time of computer recipe formulation. A few attempts were made to answer the following important question: is a lower sensitivity a prospect for a better repeatability of the recipe colour?

2. REDUCING THE METAMERISM OF THE RECIPE COLOUR

First, the effect of the single-illuminant and the multi-illuminant strategy were compared in laboratory dyeing of polyester fabric with disperse dyes. In Table 1 the colorimetric data of samples obtained after subsequent corrections according to either strategy are presented. For each of 12 target colours the Recipe 1 is obtained according to single-illuminant strategy forcing ΔE_{D65} to zero, and the Recipe 2 according to the multi-illuminant strategy, which tends to produce more balanced colour differences under several different illuminants.

It can be seen, that neither the colour difference ΔE_{D65} for the samples prepared according to the single-illuminant strategy Recipe 1 was zero, nor the colour differences ΔE_{D65} and ΔE_A for the samples prepared according to multi-illuminant strategy Recipe 2 were perfectly balanced. This is due to small random inaccuracies and variations in the dyeing process, which prevent to achieve or reproduce the desired colour exactly. Despite these problems the subsequent corrections succeeded to achieve that:

- the sample prepared according to the single-illuminant strategy Recipe 1 regularly had smaller colour difference ΔE_{D65} against target than sample according to the multi-illuminant strategy Recipe 2
- the sample according to Recipe 2 had lower $\max\{\Delta E_{D65}, \Delta E_A, \Delta E_{WWF}\}$ of colour differences under three illuminants than the sample according to Recipe 1. Therefore, the multi-illuminant strategy regularly produced lower metamerism than the single-illuminant strategy.

If the tolerance is set e.g. on the value ΔE_{TOL} = 1.0 and this tolerance level is equal for all the illuminants involved in consideration then the outcome of the above experiment is as follows. In three cases (of 12) the unacceptable metamerism of Recipe 1 was brought within tolerances 1.0 unit of colour difference under all three illuminants considered. In further three cases the $\max\{\Delta E_{D65}, \Delta E_A, \Delta E_{WWF}\}$ was brought under 1.1 unit of colour difference – close to tolerance. In the rest six cases the metamerism was either slightly or substantially reduced.

We can conclude: The multi-illuminant matching strategy produces the recipes with more balanced predicted colour differences under several different illuminants than the usual single-illuminant strategy does. If the metamerism of the single-illuminant recipe is not too high, the multi-illuminant strategy and correction procedure applied on the same dye combination can reduce the metamerism of the recipe colour to an acceptable level or, at least, reduce the metamerism.

The difficulties in the above correction process raised the following questions: how accurate is the dyeing process, and, how big is the experimental noise in our tests? Some partial answers for the case of laboratory dyeing of polyacrilic with basic dyes will be given in the next section.

Table 1: The CMC(2:1) colour differences ΔE against a given standard, exhibited by two matches. The first of them was prepared according to the usual single-illuminant-strategy – Recipe 1 in each particular block, and the second one according to the multi-illuminant strategy – Recipe 2 in each particular block of the table. In recipes there are the abbreviations of colorant names followed by their concentrations in percentages.

				ΔE(CMC(2:1))		
Standard 1	**L*=65.90**	**C*=13.52**	**h= 56.85** (ill. D65)	**D65**	A	**WWF**
Recipe 1	RED 0.0413	YEL 0.0939	BL2 0.0218	0.40	1.34	0.82
Recipe 2	RED 0.0397	YEL 0.0935	BL2 0.0222	1.20	0.69	0.22
Standard 2	**L*=63.62**	**C*=52.05**	**h= 61.94** (ill. D65)	**D65**	A	**WWF**
Recipe 1	BL1 0.0067	RED 0.1116	YEL 0.5828	0.26	3.00	2.73
Recipe 2	BL1 0.0100	RED 0.1033	YEL 0.5604	1.97	2.02	1.23
Standard 3	**L*=62.06**	**C*=11.82**	**h= 84.58** (ill. D65)	**D65**	A	**WWF**
Recipe 1	RED 0.0376	YEL 0.1394	BL2 0.0404	0.30	2.33	1.53
Recipe 2	RED 0.0346	YEL 0.1419	BL2 0.0380	1.38	1.09	0.93
Standard 4	**L*=65.56**	**C*=13.06**	**h=197.47** (ill. D65)	**D65**	A	**WWF**
Recipe 1	DB 0.0206	BL1 0.1085	YEL 0.0323	0.30	1.34	1.22
Recipe 2	DB 0.0170	BL1 0.1156	YEL 0.0349	0.86	0.80	0.61
Standard 5	**L*=42.87**	**C*=25.04**	**h= 73.40** (ill. D65)	**D65**	A	**WWF**
Recipe 1	RED 0.2318	YEL 1.0735	BL2 0.1463	0.35	1.22	0.64
Recipe 2	RED 0.2069	YEL 0.9826	BL2 0.1335	0.86	0.82	0.29
Standard 6	**L*=44.57**	**C*=21.03**	**h=103.84** (ill. D65)	**D65**	A	**WWF**
Recipe 1	RED 0.0907	YEL 0.7966	BL2 0.1800	0.11	2.04	1.37
Recipe 2	RED 0.0814	YEL 0.7979	BL2 0.1820	1.10	1.04	0.87
Standard 7	**L*=47.81**	**C*=25.14**	**h=130.80** (ill. D65)	**D65**	A	**WWF**
Recipe 1	DB 0.1423	BL1 0.2854	YEL 0.5262	0.31	1.96	1.60
Recipe 2	DB 0.1569	BL1 0.2553	YEL 0.5007	0.42	1.28	1.09
Standard 8	**L*=44.63**	**C*=22.41**	**h=250.05** (ill. D65)	**D65**	A	**WWF**
Recipe 1	BL1 0.2878	YEL 0.0828	BL2 0.2274	0.16	1.11	1.36
Recipe 2	BL1 0.3654	YEL 0.0791	BL2 0.1986	0.60	0.85	0.87
Standard 9	**L*=44.50**	**C*=19.84**	**h=284.78** (ill. D65)	**D65**	A	**WWF**
Recipe 1	RED 0.0881	YEL 0.0574	BL2 0.2272	0.18	2.05	1.59
Recipe 2	RED 0.0799	YEL 0.0604	BL2 0.2399	0.88	1.39	1.17
Standard 10	**L*=41.30**	**C*=22.57**	**h=317.23** (ill. D65)	**D65**	A	**WWF**
Recipe 1	DB 0.0920	BL1 0.2475	RED 0.2887	0.20	1.49	1.35
Recipe 2	DB 0.0756	BL1 0.2342	RED 0.2944	0.62	0.81	1.05
Standard 11	**L*=27.48**	**C*=10.34**	**h= 57.40** (ill. D65)	**D65**	A	**WWF**
Recipe 1	RED 0.6051	YEL 1.6653	BL2 0.5012	0.61	1.80	1.20
Recipe 2	RED 0.5741	YEL 1.6914	BL2 0.5084	1.09	1.38	0.59
Standard 12	**L*=35.83**	**C*= 5.75**	**h=308.15** (ill. D65)	**D65**	A	**WWF**
Recipe 1	RED 0.2208	YEL 0.3499	BL2 0.3572	0.38	1.51	1.37
Recipe 2	RED 0.2060	YEL 0.3412	BL2 0.3527	0.88	1.07	1.28

3. PREDICTED SENSITIVITY AND THE OBSERVED REPEATABILITY OF THE RECIPE COLOUR

The numerical experiments with the optical data of basic dyes applied to polyacrylic showed that the recipes for the lightest neutral target colours generally have the biggest predicted sensitivity to concentration errors.

In addition to a previous research [3], [4] the target-position dependence of the repeatability of the recipe colour was investigated in laboratory-scale dyeing of polyacrylic fabric with the basic dyes. For 16 different target colours chosen from the EUROCOLOR colour atlas, recipes were determined using the same combination of a yellow, a red and a blue colorant. According to each of these recipes 20 repeated laboratory dyeings were carried out with the use of standard graduated pipette. Scattering of colour in all particular groups (20 samples per recipe) was evaluated and mutually compared. The RMS colour difference ΔE CMC(2:1) against the group average was used as the measure for scattering of colour positions of samples in each 20-member group. Samples with colour positions exceeding the CMC(2:1)-distance of two standard deviations from the group average were treated as outliers and were excluded from further calculations. The biggest scattering of the recipe colour was observed in the cases where also the predicted sensitivity to concentration errors was the highest, that is in the cases of the light neutral target colours. Standard deviation of colour in groups of samples for light neutral targets was on average up to twice as large as the standard deviation of colour in groups of samples for medium-lightness neutral or intensively chromatic target colours. Also higher particular rates of this kind were observed. We noticed the biggest standard deviation 1,27 ΔE CMC(2:1) for target Grey 70 and the smallest standard deviation 0,21 ΔE CMC(2:1) for the violet-red target with L^*=50, C^*=30 and h=900.

Now we turn our attention to different recipes for a single given target colour. The above mentioned numerical experiments showed that for a particular target the sensitivity of the most sensitive recipes can be twice to five-times as large as the sensitivity of the least sensitive ones. Is this big difference in predicted sensitivity to concentration errors followed by a significant difference in repeatability of these (two) recipes? The answer depends on the relative contribution of colorant concentration error in total colour error. Thus we can state the main question of this paper. Are there situations, in which the predicted sensitivities to concentration error could assist in selection of the most reliable, the most repeatable recipes for a given target? In the previous research [3], [4] the biggest differences among repeatabilities of different recipes for a given target were observed just in the cases of light neutral targets.

Therefore, the search for a correlation between the predicted sensitivity of the recipe colour to dye concentration error and the repeatability of the recipe colour was continued with a set of light neutral and less saturated target colours. We chose the target Grey 70 and light, low saturated targets with lightness L^*=70 and chroma C^*=10 (orange EC 125.70.10, green EC 350.70.10 and blue EC 650.70.10). For each particular target eight recipes with different predicted sensitivities were treated, including two least sensitive ones available. The repeatability of these recipes was examined at three different levels of accuracy of laboratory experiments. For all four above targets, 20 repeated dyeings have been carried out with the use of standard graduated pipette, each time producing one sample according to each of the eight recipes per target. Additionally, using electronic pipette, 20 repeated dyeings per each of the eight recipes were produced for the blue and the green target. Finally, 20 almost "parallel" dyeings with the use of electronic pipette were produced per each of the eight recipes for the target Grey 70. All 20 samples for a particular recipe were produced in no more than two days using the same stock solutions and using all eight tubes in dyeing apparatus for this single recipe. The measure for scattering of colour in the obtained groups of samples was again standard deviation of colour in ΔE CMC(2:1) units against the group average. As before, the outliers were excluded from further calculations. A brief overview of the results concerning the repeatability of various recipes for a single light low-saturated target is as follows.

- In dyeing with the use of standard graduated pipette less sensitive recipes performed better in all four cases treated. They generally produced groups of samples with smaller scattering of colour (see Fig.1 and Fig.2)
- The use of electronic pipette in repeated dyeings of recipes for the green and the blue target diminished the scattering of colour in the corresponding groups of samples (with three exceptions out of sixteen). In the case of the blue target less sensitive recipes generally still performed better than the more sensitive ones, while in the case of the green target [5] no connection between sensitivity and repeatability was found (see Fig. 3).
- "Parallel" dyeing with the use of electronic pipette according to each of the eight recipes for the grey target essentially diminished the scattering of colour in comparison with scattering observed in case of repeated dyeing with the use of graduated pipette. Two exceptions in performance were detected: the least sensitive recipe produced the essentially smaller scattering of colour than the average, the most sensitive recipe produced a slightly bigger scattering of colour than the average. All other recipes performed approximately the same (see Fig. 4).

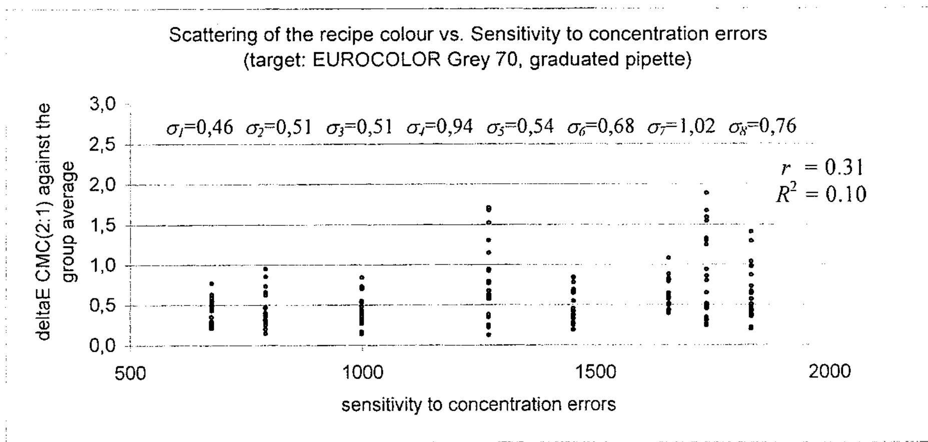

Figure 1: The scattering of colour in the groups of samples for target EUROCOLOR Grey 70. The standard graduated pipette was used in 20 repeated dyeings per each of the eight recipes. The inscribed numbers $\sigma_1,\ldots,\sigma_8$ are the standard deviations of colour in groups of samples.

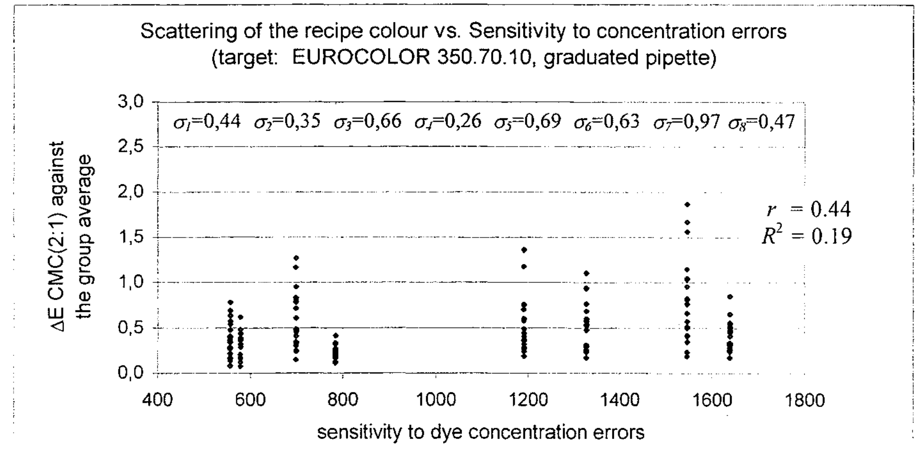

Figure 2: The scattering of colour in the groups of samples for the green target EC 350.70.10. The standard graduated pipette was used in 20 repeated dyeings per each of the eight recipes. The inscribed numbers $\sigma_1,\ldots,\sigma_8$ are the standard deviations of colour in groups of samples.

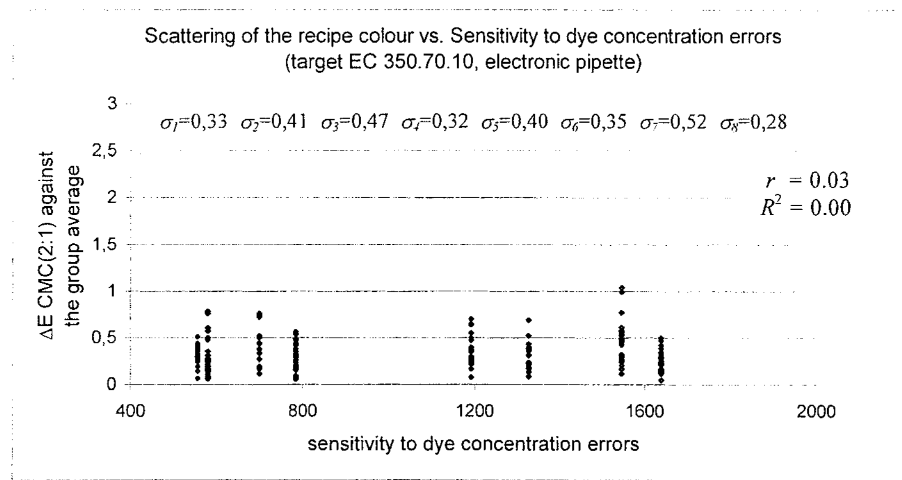

Figure 3: The scattering of colour in the groups of samples for the green target EC 350.70.10. The electronic pipette was used in 20 repeated dyeings per each of the eight recipes. The inscribed numbers $\sigma_1,\ldots,\sigma_8$ are the standard deviations of colour in groups of samples.

We can summarize: in the case of light neutral and less saturated target colours the recipes with the lower predicted sensitivity to colorant concentration errors generally exhibited a better repeatability of the recipe colour than the high-sensitivity recipes did. A weak, but still statistically significant correlation between the predicted sensitivity and the observed repeatability of the recipe colour was detected in six experiments

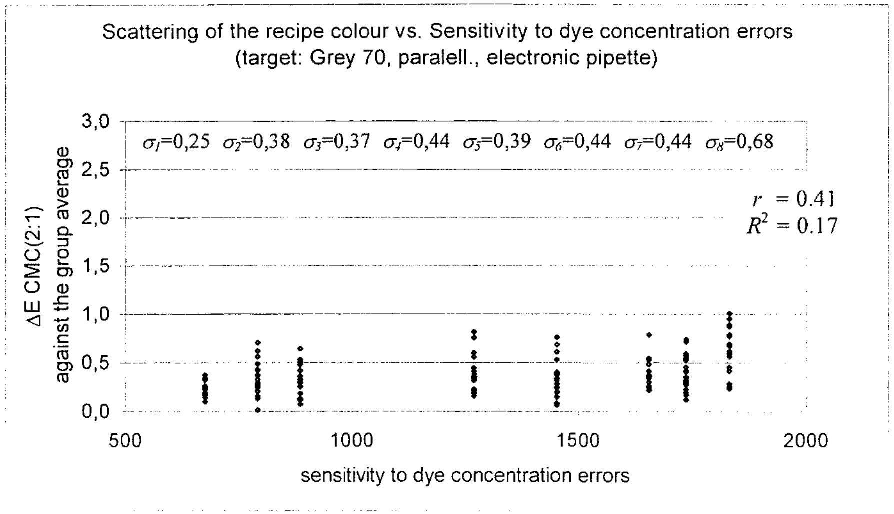

Figure 4: The scattering of colour in the groups of samples for target Grey 70. The electronic pipette was used in 20 "paralell" dyeings per each particular of the eight recipes. The inscribed numbers $\sigma_1,\ldots,\sigma_8$ are the standard deviations of colour in groups of samples.

out of seven performed. In these six cases the coefficients of correlation (r inscribed in Figures 1-4) were between 0.31 and 0.44. The coefficients of determination (R^2 inscribed in Figures 1-4) were between 0.10 and 0.20. Thus the sensitivities to dye concentration errors explained 10–20 % of total variation in measure for scattering of the recipe colour. Some cases were detected where the recipe with a middle-range or high sensitivity to concentration errors performed close to the most repeatable one(s). On the other hand, only one case was detected, where a low-sensitivity recipe performed worse than the majority of other recipes (see σ_3=0,66 in Fig. 2).

4. CONCLUSIONS

1. The multi-illuminant matching strategy successfully diminishes the metamerism of the recipe colour. It produces the recipes with more balanced predicted colour differences under several different illuminants than the usual single-illuminant strategy does.
2. The laboratory experiments involving dyeing polyacrylic with basic dyes show that in the case of light neutral and less saturated target colours there are situations where the lower predicted sensitivity to colorant concentration errors is generally followed by a better repeatability of the recipe colour. Some cases were detected where the recipe with a middle-range or high sensitivity to concentration errors performed close to the most repeatable one(s). On the other hand, only one case was detected, where a low-sensitive recipe performed worse than the majority of other recipes. Therefore, from the viewpoint of the repeatability of the recipe colour (in cases of light less saturated targets) the safest choice is a recipe with a very low sensitivity to colorant concentration errors.

5. ACKNOWLEDGMENT

This sesearch was supported by the Ministry of Education, Science and Sports of Republic Slovenia.

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Assist. Prof. Dr. Boris Sluban, University of Maribor, Faculty of Mechanical Engineering, Smetanova 17, SI-2000 Maribor, Slovenia. Phone: +386 2 220 7832, Fax: +386 2 220 7990, E-mail: boris.sluban@uni-mb.si
Olivera Šauperl, M.Sc., University of Maribor, Faculty of Mechanical Engineering, Department of Textiles, Smetanova 17, SI-2000 Maribor, Slovenia. Phone: +386 2 220 7889, Fax: +386 2 220 7990, E-mail: olivera.sauperl@uni-mb.si

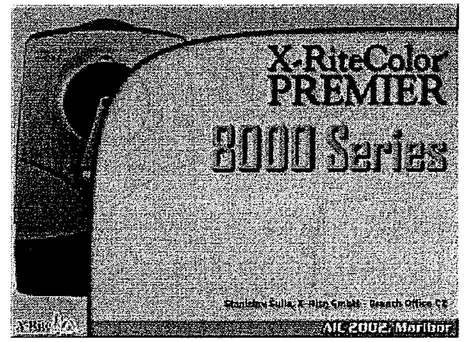
SETTING STANDARDS FOR PRECISION, ACCURACY AND FUNCTIONALITY

Stanislav Šulla
X-Rite GmbH – Czech Office, Vyškov, Czech Republic

Abstract
The Premier 8000 Series is the new benchmark in benchtop color measurement. It sets new industry standards for functionality, while meeting user demands for precision and accuracy. Featuring digital image capture technology, a dual-position body for front and top loading, unparalleled ease of use and seamless correlation with X-Rite portable sphere spectrophotometers, the Premier 8000 Series is a superior color measurement solution for the industrial lab. The Premier 8000 Series includes the high-performance 8400 unit and the mid-range 8200 unit (with optional add-ons). Both feature sphere interiors made of machined Spectralon®, X-Rite's proprietary reflectance material that ensures accurate spectral data and is durable enough to last the life of the instrument.
The Premier 8000 Series includes the following key features and benefits:

- *Built-in Image Capture: The 8000 Series is the first benchtop instrument to capture a digital image of a sample and let users view and verify it on a computer monitor before measuring.*
- *Horizontal and Vertical Positioning: In its standard, front-loading position, samples can be measured and sampled vertically. In its top-loading position, users can present samples horizontally on the aperture.*
- *Easy-Access Transmission Measurement Chamber: The 8000 Series has an extra-wide transmission chamber to accommodate larger samples, including various-sized sample holders and cuvettes.*
- *Inter-Instrument Agreement: The Premier 8400 model complements all X-Rite industrial color-measurement solutions, allowing data to be shared across the supply chain.*
- *Durable, Maintenance-Free Spectralon® Sphere: To avoid common, expensive recoating, the 8000 Series sphere is built of Spectralon®, a durable material that will not corrode, flake, peel, or yellow with age. Spectralon® offers the highest level of reflectance available in today's market.*
- *Internal and External Protection: An optically pure glass plate shields the lamp, detector and electronics from damage.*
- *USB Interface: The 8000 Series is the first benchtop instrument with a USB interface to the software. In addition to plug-and-play convenience, this means increased speed.*
- *User-Defined Instrument Configuration: The 8000 Series uses X-RiteColor® Master software, which manages both quality assurance and color formulation. The software allows users to save and store frequently used instrument configurations for quick selection.*

Keywords: *Benchtop spectrophotometer, reflection, transmission.*



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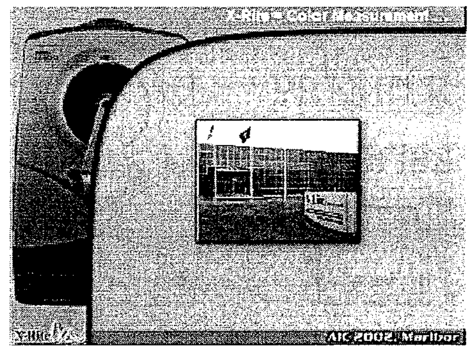

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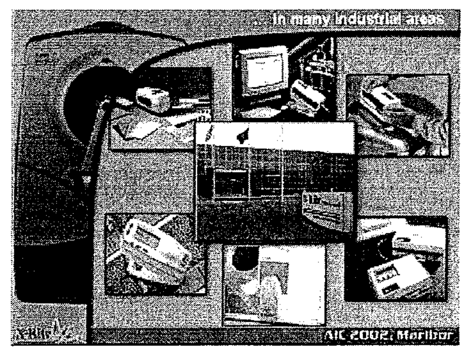

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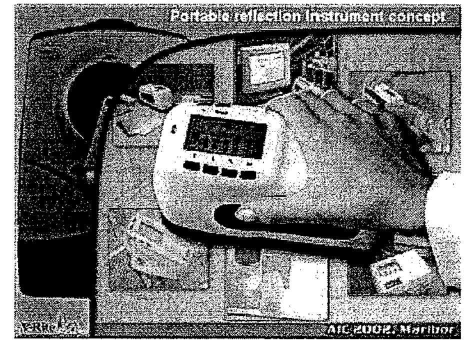

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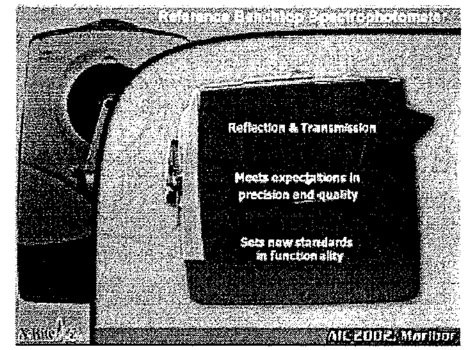

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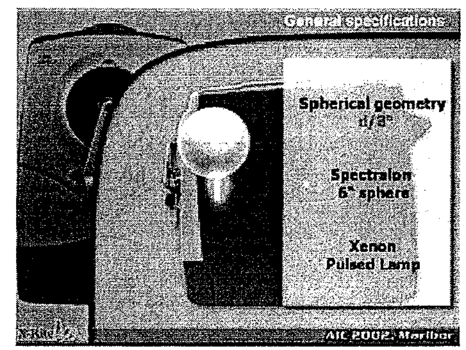

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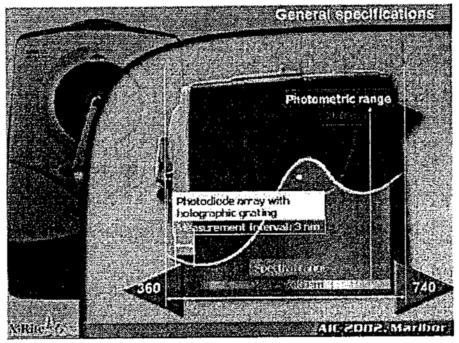

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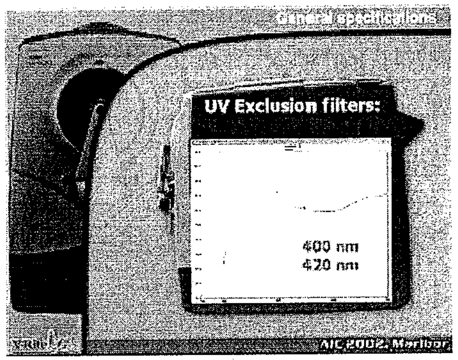

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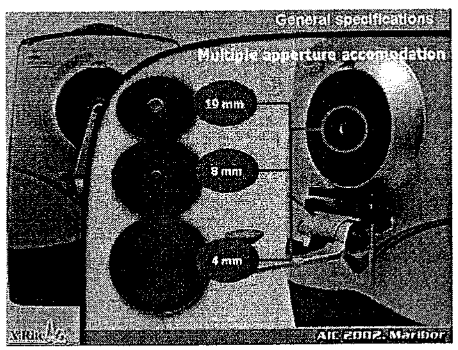

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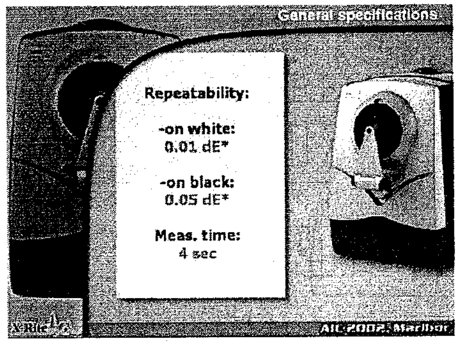

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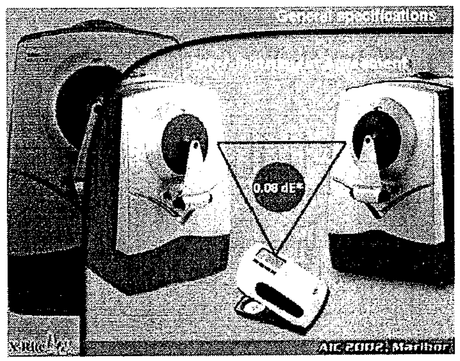

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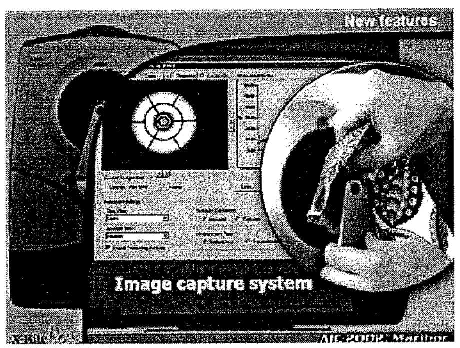

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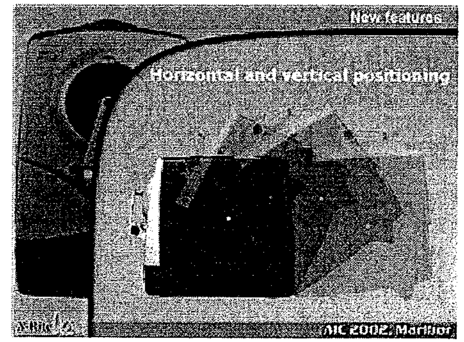

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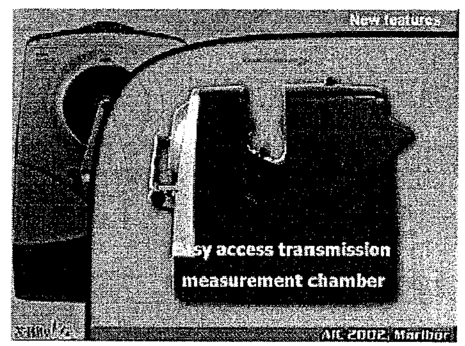

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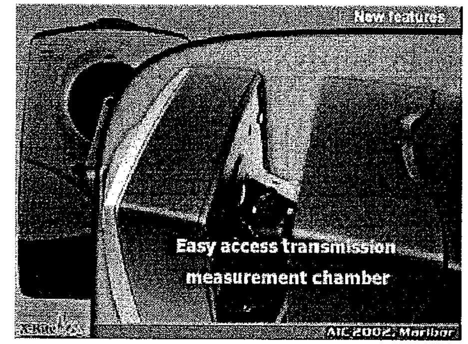

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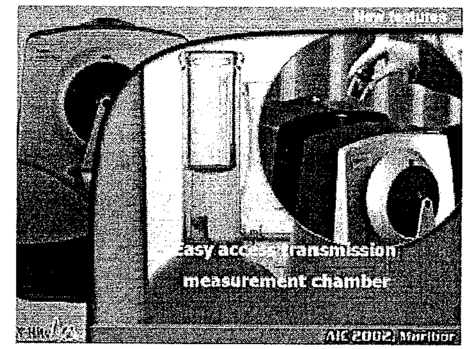

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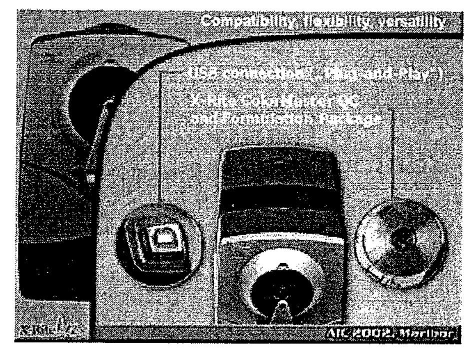

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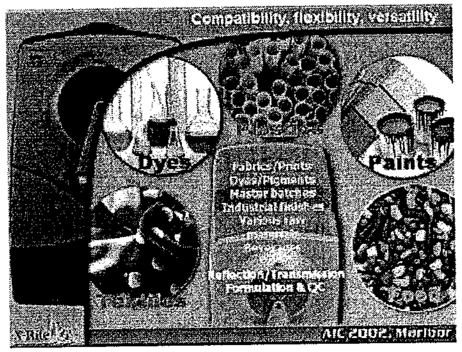

Figure 19

Figure 20

Stanislav Šulla, X-Rite GmbH – Czech Office, Jana Šoupala 2 , CZ-682 01 Vyškov, Czech Republic. Phone: +420 507 320 331, Fax: +420 507 320 335, E-mail: xritecz@infos.cz

A HISTORY OF THE INTERNATIONAL COLOR ASSOCIATION STUDY GROUP ON ENVIRONMENTAL COLOR DESIGN, FROM 1982 TO 2002

José Luis Caivano
National Council for Research, and Buenos Aires University, Argentina

Abstract
The AIC Study Group on Environmental Color Design was created during the Interim Meeting 1982 on Color Dynamics, in Hungary, and since that it has been active holding meetings at AIC congresses, making plans for research and achieving results in some aspects. Among the specific aims that have been proposed along the years there are: to collect a specialized bibliography, to arrange an annotated glossary on color and light in environmental design, to carry out surveys on preferences for color combinations, to make specific publications, to set up a web page and an e-mail list for communication. As a way of celebrating the twenty years from its creation, this paper makes a history of the activities of the study group and the persons involved in it, collecting and arranging information spread out in diverse media. In addition, because in the recent times there was an increasing number of new members that do not necessarily know the origins and history of the study group, this will be a means of providing them with background and contextual information about it.

Keywords: *environmental color design, study group, AIC, history*

1. INTRODUCTION

The Study Group on Environmental Color Design (ECD) of the International Color Association (AIC, Association Internationale de la Couleur) was created during the Interim Meeting on Color Dynamics, held in Budapest, Hungary, in 1982, and since that, it has been continuously active holding meetings at the AIC congresses, proposing aims for research and work to be done, and achieving results in some of these aspects.

Among the specific tasks that have been proposed along the twenty years of activity of the ECD Study Group there are: to collect a specialized bibliography, to arrange an annotated glossary on light and color in environmental design, to carry out surveys on preferences for color combinations, to make specific publications, to set up a web page and an e-mail list for discussion.

As a way of celebrating the twenty years from its creation, the aim of this paper is to make a history of the activities of the study group and the persons involved in it. Because in the recent times there was an increasing number of new members that do not necessarily know the origins and history of the group, this will be a means of providing them with background and contextual information about it.

2. ANTECEDENTS ON E.C.D. WITHIN THE A.I.C.

The AIC was founded in 1967,[1] and in 1969 had its first congress. Let us make a survey of the AIC activities previous to 1982, which provided the background and contributed to the creation of the ECD Study Group. Along the different AIC congresses, there was an increasing participation of architects, designers and other specialists interested on color in the environment.

Already in the 1st AIC Congress in Stockholm, Sweden, topics related to environmental color design appeared in various papers, for instance, the ones presented by Anders Hård, on qualitative attributes of color perception, Antal Nemcsics, on man's color preferences along history, Bohdan Lisowski, on color preferences in architecture, Csaba Klausz, on color associations, Oliver Izsak, on color in decorative illumination, Gerald Ewing, on color theory applied to the three dimensional environment, Bernard Lassus, on visual complexity in the artificial environment [1].

In the 2nd AIC Congress, held in York, England, in 1973, one of the survey lectures was delivered by Faber Birren on "The practical application of light and colour to human environment". In the Proceedings, under the heading of "Colour Applications", appear the sessions of "Colour in Design", with papers by Lothar Gericke, Janusz Nowicki, and Sachie Minato, and "Colour in Architecture", with papers by Margaret Campbell, Edgar Knoop, Witold Chróscicki, Antal Nemcsics, C. Klausz, J. Wozniakowski, and Péter Gáborjáni [2].

In 1976 there was an AIC Interim Meeting on Color Dynamics held in Budapest, which was the first AIC meeting specifically devoted to subjects such as color in architecture, design, and the environment. This congress constituted the most direct antecedent, because the ECD was created during the 2nd congress on Color Dynamics, in 1982, as we will see.

In the 3rd AIC Congress, held in Troy, New York, in 1977, one of the eight invited lectures was about "Color in industrial design", by Sachie Minato. In addition, a whole session was devoted to "Color in art, design, and architecture", with papers by Faber Birren, W. D. Cox, Shigenobu Kobayashi, M. Yamagishi & Y. Mori, S. Kobayashi & K. Sato, Werner Spillmann, Erdal Aksugür, T. Whitfield & T. Wiltshire, and Albert Garrett [3, 4].

Even at the AIC Midterm Meeting in Kyoto, 1979, which was on the specific subject of Color Appearance, already in the previous circular and tentative program [5] there appear papers by Antal Nemcsics, Anders Hård, and Lars Sivik, the three most important people that will be involved in the creation of the ECD Study Group a few years later.

During the 4th AIC Congress, held in Berlin, in 1981, there was a session on "Psychology and Design", with papers by T. Iijima & others, J. B. den Tandt, T. Whitfield & T. Wiltshire, Frans Gerritsen, B. Lisowski, H. Lang, F. Schmitt, and Michel Albert-Vanel. In addition, we can count various posters presented on topics related to environmental color design: T. Yanase & others, Paul Green-Armytage, J. Ruttenberg, A. Kodama & others, and Antal Nemcsics [6]. And here we come to the birth of the Study Group on Color Dynamics, whose name was later changed to Environmental Color Design. Let us review the details of its creation.

3. THE BIRTH OF THE E.C.D. STUDY GROUP

During the first half of 1981, previously to the 4th AIC Congress in Berlin, the president of the Hungarian National Color Committee (HNCC), Antal Nemcsics, had proposed the creation of a new AIC study group on the subject of color dynamics. This proposal was acknowledged in the quadrennial report of the AIC secretary/treasurer,[2] written by Andreas Brockes in June 1981 [7], and sent together with the invitation to attend to the meeting of delegates that was going to take place on September 24, during the 4th AIC Congress in Berlin.

In an undated letter in response to Brockes' invitation (received by Brockes on September 16, 1981), Nemcsics gives some details about the preparation of the next AIC Interim Meeting on Color Dynamics 1982, to be held in Budapest, and proposes that "in the course of the Conference the HNCC wants to convene an international committee to found the Working Committee for Colour Dynamics of the AIC and to elaborate its task and program" [8].

Already in the 4th AIC Congress, held in Berlin on September 21-25, 1981, the AIC Executive Committee inaugurated the activities of the study groups. In the meeting of the AIC delegates, on September 24, it was decided that "the preparation for a study group on colour dynamics as proposed by Nemcsics in his letter have been approved by the AIC" [9]. The president's address delivered in this congress by C. James Bartleson reports on the activities of two study groups (Color Order Systems, and Color Education), and indicates that "a new study group for 'Colour Dynamics' has just been established", being the purpose of any study group "to address color problems that are not considered within the frames of reference of other international organizations that deal with color and to disseminate information on these subjects to our members" [6, vol.1, p.4].

As it happens at every quadrennial congress of the AIC, that a new Executive Committee is elected for the next term, in Berlin 1981 Robert W. G. Hunt was elected as the president, Heinz Terstiege as the vice-president, and Johannes J. Vos as the secretary/treasurer for the 1982-1985 period (also, Anders Hård was elected as one of the four ordinary members).

The final configuration of the new study group was achieved during the AIC Interim Meeting on Color Dynamics (which was the second conference under this heading),[3] held in Budapest during June 8-10, 1982. In the *Colour Dynamics '82 Bulletin* Nr. 1, sent in advance to the congress, it is stated that "the Hungarian Commission for Colour has the intention to call together an 'ad hoc' International Study Group on Colour Dynamics during the Conference and to work out the task and the program of this board" [10]. The first proposed aims of the study group were also established in this *Bulletin*. The suggestion of the work to be done was:

- Forming a uniform terminology for the concepts taken over from different domains of sciences and used now in the new science of Colour Dynamics;
- Revelation of the connections between colour, man and environment;
- Description of the results revealed in order to make them applicable for planning;
- Survey and systematization of the research places and researchers, as well as results dealing with planning of definitely coloured environments; and
- Tracing the possibility for exchange of experience among designers.

In the Budapest congress, a group of around 20 persons gathered together to discuss the proposal further, and there was a general agreement that the main goal of the study group should be "to study the effects that color in environmental design has on people". The first proposed name for the new study group, "Color Dynamics", was a subject of some discussion and objections. For instance, the AIC president Robert Hunt considered that the expression "color dynamics" could be misunderstood as "colors in movement". Thus, the name was changed to "Environmental Color Design", because it was considered that it provides a more precise identification of the aims and scope of research.[4]

At this meeting, Anders Hård was elected to chair the study group, and the next step was to find people interested in becoming members from the different countries in which there were national color organizations or AIC observers, a task that was taken over by J. J. Vos, the AIC secretary/treasurer [11]. In the months following the Budapest meeting, there was "a poor response to Dr Vos' appeal to member organisations to supply … names of persons interested in taking part in this work". Hård and Sivik suggest that "the lack of a well-defined working program for the Study Group may have contributed to this lack of response" [12]. By the end of 1982 only three persons had been registered as ECD members. Thus, the beginning of the activities of the study group was delayed until the AIC Midterm Meeting that took place in Kungälv, Sweden, in August 1983, which was in fact the first meeting with the study group already constituted.

4. E.C.D. MEETINGS AND SESSIONS WITHIN A.I.C. CONGRESSES

The ECD Study Group held its first meeting under the chairmanship of Hård on August 29, 1983, at Kungälv, Sweden, immediately after the AIC Midterm Meeting. The meeting of the study group was attended by about 30 persons. Hård made an opening welcome, summarizing the immediate antecedents and original aims of the study group, and tracing the working program [13]:

- To study the terminology used by various people in describing environmental color.
- To collect information and relevant data about color in the environment; what is known; what is believed; what are doctrines.
- To consider for whom we are working and for which demands.
- To collect a bibliography (What should it cover of knowledge, opinions, experience, hypothesis? Should it consist of just titles or be annotated?).
- To formulate ideas and initiate research —preferably on an international level.
- To study the evaluative aspects of color in the environment and try to relate these to possible origins such as: genetic, biological, ecological…, socio-cultural, style, fashion, religion…, authoritarian dogmas, erratic statements derived from false analogies with other sciences (e.g. complementaries), uncontrolled "model-thinking".

After the introduction by the chairman, Lars Sivik was proposed and approved as the secretary of the study group. In the discussion that followed, the topic of color terminology and the question about having a common color language, by defining terms unambiguously, appeared among other questions. It was also stated that, besides color, the scope should include other aspects of appearance, such as gloss, texture, transparency, etc., and that another task of the group should be to collect color planning documents as examples of good or bad use of color in the environment.

By March 1984, Sivik and Hård sent a message to the AIC member organizations, containing an invitation to provide names and data of people interested in joining the ECD Study Group [12], and enclosing the minutes of the ECD meeting at Kungälv [13]. The *AIC Newsletter* **1**, issued on April 1984, contains a brief statement about this ECD meeting at Kungälv.

On June 1985, at the 5th AIC Congress in Monte Carlo [14], the study group held another meeting, attended by about 30 persons. In that opportunity, the study group had 21 official members. In the *AIC Newsletter* **3**, August 1986, there is a summary of what happened in this meeting [15]. Hård presented a report covering the period 1982-1985, where he says that one

of the originally proposed tasks, the compilation of a bibliography on environmental color design, had a weak response from the part of the members. The matter of the bibliography was discussed at some extent, and various participants made different proposals, including one by Werner Spillmann about contacting the Color Reference Library in London, which probably already had references arranged under the category of environmental design. In this way, the task of collecting a bibliography was excluded from the activities of the study group. Hård pointed out that some of the aims established for the study group in the previous meeting were not reached, and suggested to name a new chairman and secretary, but the members agreed on that him and Sivik continue for a new term.

The Interim and Midterm AIC Meetings following the 5th Congress were devoted to Color in Computer Generated Displays (Toronto 1986) and Color Vision Models (Florence, Italy, 1987, organized by Lucia Ronchi); being too specific, they seem not to have attracted many members of the ECD Study Group. However, John Hutchings and Werner Spillmann, both members of the AIC Executive Committee and also members of the ECD Study Group, participated in those congresses, and Leo Oberascher appears in the list of attendants to the Florence meeting, as well.

But in 1988, the AIC Interim Meeting in Winterthur, Switzerland, organized by Werner Spillmann, was entirely devoted to "Color in Environmental Design", and was attended by architects, interior and industrial designers, color consultants, perception psychologists and color researchers from 24 countries. With regard to the study groups, there were changes of chairpersons in the Study Groups on Color Order Systems and Color Education and, according to the minutes of the secretary/treasurer J. Walraven, "the Study Group on Environmental Design, led by Mr. Hård, is striving with a diversity of opinions on its course" [16].

By the 6th AIC Congress 1989, held in Buenos Aires, the chairmanship of the ECD Study Group had already passed from Hård to Leo Oberascher. In a report of this congress, written by Green-Armytage [17], he points out that "the study group on environmental colour design has ambitious plans for promoting world wide research in an area where little work has been done". It is quite interesting to note that in this congress, the first invited plenary lecture, which as a matter of fact had the characteristics of an opening lecture, was delivered by one of the most outstanding members of the ECD Study Group, Werner Spillmann, who talked about "Colour in architecture" [18]. It was the first time in an AIC quadrennial meeting that a topic on environmental color design occupied such a privileged position in the congress program [19, 20].

Under the chairmanship of Oberascher, a Newsletter of the ECD Study Group was produced at the end of 1989, and sent to more than 200 people. By 1990, the study group became an official member of the Coordination Group of Non Governmental Organizations in the field of Man-made Environment [21].

It is strange that at this same period, in September 1990, in a letter sent to the AIC president, Alan Robertson, and published in the *AIC Newsletter* **6**, Theano F. Tosca considers that "the Environmental Study group is sinking". However, I understand that she does not refer to a lack of activity of the study group; instead, the reason she sees for that situation is the lack of understanding between the two main groups of the "scientists" and the "artists-designers" within the AIC, which make interdisciplinary work only a mere wish.

At the AIC Midterm Meeting 1991 on Colour & Light, held in Sydney, there were three sessions devoted to color in the visual arts and architecture. This is a very good amount of time given to this topic if we consider that only 45 papers and 9 posters were presented at that conference in total.

In the Proceedings of the 7th AIC Congress, held in Budapest, June 13-18, 1993 [22, 23], Green-Armytage makes a synopsis of the round table discussion on environmental color design, including some ideas or contributions by Giovanni Brino, Christina Burton, José L. Caivano, Michel Cler, Shigenobu Kobayashi, Lars Sivik, and Magenta Yglesias [24].

In 1994, the AIC president Lucia Ronchi directed her attention to the activities of the different AIC study groups, detecting that the "speed" of their work was "inversely proportional to the extent of the matter they encompass" (as she says in the *AIC Newsletter* **9**), and suggested to narrow the aims to more specific matters by means of the creation of goal-directed sub-groups. Within the ECD Study Group, a sub-group working on Terminology in Urban Design prepared by 1994 an annotated glossary on "Light and color in environmental design" to be distributed for comments [25].

From 1993 to 1996, Oberascher tried to make contacts with the publication *Farbe+Design* in order to see the possibility of including articles and material from the ECD members in that publication, but the efforts were finally unsuccessful.

By 1995, the AIC president's report by Lucia Ronchi, published in the *AIC Newsletter* **10**, acknowledges a suggestion made by Green-Armytage about using the internet "to evaluate on a world-wide scale the definitions of specialist terms of interest that have been the outcomes of the activity of a subgroup of the Environmental Colour Design Study Group".

In 1996, at the AIC Interim Meeting on Color & Psychology, held in Gothenburg, Sweden, Oberascher chaired a session of the ECD Study Group, on June 16. The session continued on June 17, in this opportunity moderated by Green-Armytage. In his invited lecture, Oberascher [26] presented various projects on spatial simulation directed by himself, and a summary of contributions to the fields of color in architectural space and total color appearance by other authors [27, 28].

In 1997, during the 8th Congress of the AIC in Kyoto, Japan, there was a symposium on Color Design in the 21th Century, coordinated by Paul Green-Armytage and Miho Saito, and four oral sessions on Environmental Color Design, chaired by Don-Soh Park, Jin-Sook Lee, Silvia Rizzo, and John Hutchings. There were also two poster sessions on ECD [29, 30]. At the study group meeting, on May 27, it was decided that the ECD Study Group should be established on the internet, and José L. Caivano was appointed as chairman together with Oberascher [31]. A salient aspect of the Kyoto congress was also that Hård and Sivik, the two initial leaders of the study group, received the AIC Judd Award.

The AIC Midterm Meeting 1999 was held in Warsaw, Poland. The initially proposed subject of the congress, "Industrial Colorimetry", was changed to "Applications of Colorimetry in Industry and Design" in order to attract a broader interest. In spite that there was not a formally arranged ECD meeting, a call for ECD membership was presented and distributed among the participants. Various ECD members (including some who joined the group there) presented papers or posters and had the opportunity to have informal talks and exchanges: María M. Avila, José L. Caivano, Paul Green-Armytage, Youngin Kim, Maud Hårleman, Susan Habib, and Silvia Rizzo, among others [32, 33].

As it happened in 1988 with the Winterthur meeting, the AIC Interim Meeting 2000 was on a subject very central to the interests of the ECD members, "Color & Environment", and was held in Seoul, Korea, on November 6-7, 2000. The total number of papers included 36 oral presentations and 45 posters. Though there was not a formal meeting for ECD members, various of them presented papers or posters: Berit Bergström, Sidney Chung, Osvaldo Da Pos, Susan Habib, Youngin Kim, Harold Linton, Silvia Rizzo, and Lucia Ronchi [34].

In the *AIC Newsletter* **15**, there is a statement of the aims and a report about the situation and future steps of the study group [35]. During the 9th AIC Congress in Rochester, USA, June 24-29, 2001, there was a symposium on ECD, chaired by Caivano and Oberascher, and one related oral session on ECD/Architecture, chaired by Hutchings [36, 37]. Green-Armytage [38] makes a very good report of most of the papers presented on the subject of color in the built environment in Rochester; also, a specific report on the ECD symposium and session will appear in the *AIC Newsletter* **16**, 2002.

Since its creation until today, the membership of the ECD Study Group ranged approximately from 20 to 40 members, with variations along the years. Today, the group has 39 members representing 18 countries. There is an e-mail list for exchange of information, whose subscribers are ECD members and other interested people that could become future members. At present, this list has 182 subscribers from 28 countries. To stimulate the participation in AIC congresses, it has been established that new ECD members are incorporated only at AIC meetings, and that failure to attend or present a paper or poster to an AIC meeting in a period of more than four years (the term between two general congresses) makes a member to be excluded from the group. The names and addresses of ECD members can be found on the internet, www.fadu.uba.ar/sicyt/color/ecd.htm, along with a call to subscribe the e-mail list, links to other pages of interest, and future AIC meetings.

5. NOTES

1. A history of the early periods that gave rise to the creation of the AIC and its development until 1975 was published by G. Tonnquist [4, p.13-32]. A brief historical report of the AIC appears also in the *AIC Newsletter* **11**, 1996.

2. During the term 1978-1981, the AIC president was C. James Bartleson, the vice-president, János Schanda, and the secretary/treasurer, Andreas Brockes.

3. The first conference on Color Dynamics was in 1976. These conferences continued in Hungary after the AIC meetings of 1976 and 1982, but as international meetings not related to the AIC. The 3rd International Congress of Color Dynamics was held in November 1988.

4. However, it seems that the original identification remained in the minds of some people, to the extent that in 1989, seven years before the study group started under the name of "Environmental Color Design", in his presidential address, Heinz Terstiege said that "the existing study groups were active in the past quadrennium ... *Color Dynamics* under the chairmanship of Leo Oberascher" [15, vol.1, p.17].

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Prof. Arch. José Luis Caivano, SICyT-FADU-UBA, Ciudad Universitaria Pab. 3 piso 4, 1428 Buenos Aires, Argentina. Tel/fax: +54 11 4702 6009, E-mail: jcaivano@fadu.uba.ar

URBAN FABRIC: A COMPARATIVE STUDY OF COLOR AND PATTERN IN AERIAL VIEWS OF CITIES AND ORIENTAL CARPETS

Galen Minah, College of Architecture and Urban Planning, University of Washington, Seattle, Washington, U.S.A.

Abstract
The structure and design of Oriental carpets are similar to that of a city. Both begin with a conceptual design, which considers the total form as a synthesis of parts. This design is manifest in patterns derived from history, cultural tradition, local techniques, materials, and meaningful symbolism, all element which determine a sense of 'place'. Carpets are differentiated by design and color. When cities are seen in aerial views, as in the Marsilio Editori atlases of Rome, Venice, and Naples, design and color also provide identity. Cities and carpets share many design elements including similarities in design process, use of repetitive typologies, and similar edge patterns. In each, elements are organized as hierarchical compositions within and infrastructure of intersecting lines. Colors in roofscapes and ground planes of cities are similar to many Anatolian and Persian carpets in hue, range of hue variation, blackness, and chroma. Carpet spatial imagery, defined by line, color, figure-ground, and boundary are similar to the spatial density of these medieval core cities, defined by hue variation and shadow patterns. As the garden carpet demonstrates the influence of physical space in the design, the city, with its unique combination of color, pattern, and meaningful form, could be the inspiration for an expression of 'place' in carpet making.

Keywords: *Aerial, city, urban, oriental, carpet*

1. INTRODUCTION

An oracle was questioned about the mysterious bond between two objects so dissimilar as the carpet and the city. One of the two objects – the oracle replied – has the form the gods gave the starry sky and the orbits in which the worlds revolve; the other is an approximate reflection, like every human creation. Italo Calvino, 'Cities and the Sky', Invisible Cities.

Calvino touched upon the metaphysics of pattern and order. The idea that in both the carpet and the city, the accumulation of places of significance interwoven inextricably in an orderly system will, when seen as a totality, reveal a larger order. Some places become the field or background, others are the foreground. This relationship defines a hierarchy, which, in turn, reveals its meaning.

In this study, Oriental carpets are those produced prior to 1860 as antique carpets, and from 1860-1930 as semi-antique carpets. These are from Anatolia, Persia, The Caucasus, Turkestan, India, and China. Design and color determine the identity of a carpet, and, from an aerial view, the identity of the city. Design similarities between carpets and cities are numerous. Each begins with making patterns which can accommodate and articulate decorative motifs or physical space requirements. Each is constructed upon a rational infrastructure, and each is limited by the materials, technology, and economy of a particular place. Each must accommodate variety within its ordering systems. The parts may express individual character, but all parts are subordinate to the larger whole.

Carpets are seen, most commonly, from above. This view from above enforces the perception of plan imagery in the carpet, which is different from a pictorial or a window view one experiences with a framed painting on a wall. The color one experiences from the plan view can also enforce the perception of plan imagery by spatial effect in color contrast. The perception of the city from an aerial view is different from a plan drawing or a map in color. The textural quality given by shade and shadow, and the range of hues and color contrasts offer a unique perception of city form. There are available high quality aerial photographs of Italian cities in real color produced by Marsilio Editori of Venice. These are published in atlases at 1:1000 or as posters at 1:5000, and show these cities in extraordinary detail from views perpendicular to the plane of the city. This study uses these atlases and posters for the cities of Rome, Venice and Naples, and compares their design and color to Oriental carpets. These aerial views show a palette composed of colors from natural materials in ceramic roof tiles, pavers, stone, landscaped open space, streets, and water. The hues, chroma, and contrast variation of these materials is similar to the palettes of some Oriental carpets. The color from these aerial views, combined with shadow, give a perception of space within a city that can only be experienced from this view. Carpets have a spatial dimension, defined by line and color as figure or ground. Some carpets represent space as part of the design; others create the illusion of space through color contrast. This study will compare the design and color elements common to both cities and carpets, and discuss how each, at a conceptual level, share similarities as unique expressions of the sense of 'place'.

2. DESIGN ELEMENTS

The process of planning a city begins with a plan view of the physical site. The first considerations are the identification of zones, and significant places, connected by circulation infrastructure within the boundaries of the site. Kevin Lynch, The Image of the City, defined the contents of city imagery as paths, edges, districts, nodes and landmarks [3]. Nodes may be significant buildings (city hall, place of worship), or public open spaces for circulation or recreation. Similar activities are grouped in zones. All elements of the city have a specific place within the whole and each part is connected through the ordering geometry of streets. Color is used in the design process as a means to differentiate the individual parts. At the most basic level, black and white, figure-ground drawings become representations of solids and voids in the plan of the city. Giambattista Nolli's famous 18thc figure-ground map of Rome still inspires students and planners alike. These drawings of solids and voids depict public and private space within the city [11]. Color codes are used as conventions in plan drawings to differentiate the elements. The working drawing in city planning is the comprehensive plan, in which zoning and uses by color areas are based upon these conventional color symbols. Plans are sometimes rendered in shadow to show elevation and density. The carpet uses a cartoon as its comprehensive plan. This is also a color-coded working drawing. Maps of cities use other color conventions to differentiate the elements. Many of these maps show places of special interest in elevation, or perspective to make them more identifiable. These are similar to carpet imagery where abstract patterns are intermixed with figural objects shown in elevation, as in floral carpets, prayer rugs, hunting carpets, and garden carpets.

Most cities and some Oriental carpets rely on repetitive typologies in their organization. The city has building types arranged by blocks based upon patterns of use and structural system. These types repeat themselves throughout the city, and may change configuration to conform to specific site conditions without changing their basic structure. Some carpets, like those from western Turkestan, have motifs similar to blocks in cities. These designs use decorative tribal emblems, known as 'guls', which are octagonal medallions, in which the internal decorations vary depending upon tribal traditions where the carpet is made [8]. Cities used in this comparison have courtyard-building types, which conform to a variety of site conditions, and are similar, in conception, to gul motifs. The outside is a fixed geometry and the interior courtyard varies. Plans of many Baroque circular cities, such as Palmanova, Italy, and Willemstad, Netherlands, also resemble the geometry and design of the Turkestan gul motifs [4].

The use of streets in a grid forming blocks, has been used in Italy as a design stategy since Etruscan times. A great variety of scales can be accommodated in this system. Even the structural bays of buildings are related to the grid. When the grid is interrupted with lines, which do not conform to the system, a variety of edge conditions occur at the intersections. Rome has examples of multiple intersections of different patterns of streets [6]. Carpets are similar in the use of the warp and weft as a grid. Oblique and curved lines are accommodated by knotting techniques. These lines, in turn, must accommodate a variety of edge conditions. Edges and boundaries present design challenges common to both, where change must occur. Oriental carpet designs consist of at least one border, framing the rectangular area. This border often contains sub-borders. Guls and many decorative motifs have edges or borders, which require articulation in design. The carpet 'field' often consists of patterns and motifs that must stop or change at these edges. There are a number of strategies which address this problem. These include field motifs that terminate at the boundary by being in the same alignment as the border, such as the edge of the field in a garden carpet from Kurdistan (18thc), a Shirvan carpet from The Caucasus (19thc), or a Ushak 'bird' carpet from Anatolia (17thc). Another condition occurs when the field decoration slides under the border, dividing a design motif in half, such as an Ushak 'star' carpet (17thc). Sometimes edges of borders facing the field decoration transform to conform to the motifs. Examples of this condition are seen in the Ghirodes 'double-niche' carpet from Anatolia (18thc), and some Chinese, Gansu carpets (19thc). Often a motif will simply cross a border uninterrupted as seen in some Chinese medallion and floral carpets (19thc). Unlike Islamic borders, the Chinese border is not understood as a fundamental element to complete the field, but simply as an unimportant frame to be filled with floral or geometric motifs, often in harmonic contrast with the design in the field [8].

All of the Italian cities in this study have examples of building elements meeting edge conditions similar to those described above. Rome, in particular, demonstrates all of these conditions. Venice, with its curvilinear canals, has buildings which terminate directly at the water's edge without a transitional border. This requires the buildings to conform to many unusual conditions [5]. Italian walled cities dating from Etruscan times, planned 'ideal' cities of the Renaissance, and Baroque circular cities are examples of cities with fixed boundaries. Like carpets, these use planning strategies to articulate the space within.

A rectangular field defined by an edge creates a contained space or 'room', whether it is a two-dimensional plane or three-dimensional space. Figures placed in this space will determine the character of the field or room according to the arrangement. Symmetrical designs in either will create stasis, such as a central medallion figure in a carpet, or a fountain in the middle of a piazza. An asymmetrical design may create tension if the eye tries to find stasis in the arrangement. An example occurs when a figure is just off center. Arrangement can create movement as the eye follows the order of figures in the field. Rudolph Arnheim, Art and Visual Perception, demonstrates how different configurations in a design of a rectangular field will produce different perceptual experiences [1]. A hierarchical composition, where some motifs are dominant and others are subordinate, is a different perceptual experience from a uniform full field decoration, or an asymmetrical design. All of these examples are evident in city plans. Hierarchy is also part of city design. Significant places and buildings are often central, and on the axis of major streets. Some cities have singular elements that are central and treated in plan like a medallion design. Others, like Rome, have many significant places, each with their own hierarchical design.

Cities and carpets are products of the land. Each is made from the raw materials of a region which has a particular atmosphere and light. Color is derived from these elements. Each record the values and traditions of a particular culture, and reveal traces of their beginning and their history. These are the elements that define a sense of 'place'.

3. COLOR

The aerial photographs produced by Marsilio Editori are used in this study because of their exceptional quality of color rendition and detail. The publication of this work is at 1:1000 and 1:5000, which allows one to see the total form of a city and to study its detail. All three cities have medieval cores and are of relatively uniform height. Each is controlled by strict historic preservation ordinances. Modern additions must conform to these height regulations and renovation is strictly controlled. Significant figural structures such as cathedrals, campanile, and monuments are often taller than the housing and office blocks. Blocks appear like parterres in formal gardens. This gives the cities a uniform density (like a 'pile') which is revealed in the aerial photography by shade and shadow. The roofscapes in these examples consist of roof tile, ceramic pavers, marble, stone, and gravel, all natural materials. The hues are predominately in the YR range with chroma ranging from c=05 to c=30. Because of the number of subtle color variation within the enormous expanse of urban fabric, a very dense, highly textured, but relatively uniform color field results. Uniform shadows along streets define the elevation of the blocks and major structures, as well as the geometry of the circulation infrastructure. Surfaces at ground level include paved piazze, streets and sidewalks, which are often cobblestone (wider arterials are macadam), landscaped areas with natural vegetation, parks, and gardens with shrubbery and trees. In each of the three cities, water creates strong boundary conditions and strong color contrasts. The hue range of these ground elements contrast with the roofscape. Piazze are often lighter beige, streets are gray, shadows a darker gray, landscaped areas are green in multiple shades, and trees are dark green hues. Water is the darkest hue with large variation depending upon light reflection. Because of the relatively low building heights (these heights were established before elevators), the open courtyard, cortile, and light well are common throughout every block of these cities. By their shadow in this aerial view, they provide a continuous textural effect throughout the urban fabric. This texture is a characteristic of these Italian cities and would not be seen in Seattle, Washington. The roofscape hues, as a totality, give each of these cities a distinctive palette in a relatively homogeneous range with subtle hue and chroma variation, but greater contrast in blackness.

It is possible to find several examples of carpets with palettes very similar to the range of hue, chromaticness, and blackness of those described from aerial views. These would include many Persian, Kerman carpets (19thc), Kurdestan garden carpets (18thc), Kashan animal carpets (19thc), Herat carpets (17thc), and Ushak Lotto carpets from Anatolia (17thc). Many of these examples, particularly those dating before 1860 were made using natural dyes from materials such as saffron crocus, pomegranate skins, vine leaves, cherry juice, madder, nutshells, tobacco and tea [8]. These carpets fade subtly over time and present colors, which are within close proximity to the roofscape hues. The demand for carpets in the west influenced use of pastel colors in place of the higher chroma hues of earlier designs. Dyes from eastern Persia used madder root for the reds, browns, rust, orange, and rose brown [2]. These hues are very close to the hues of roofscapes in the Italian cities. Chemical dyes after 1860 are capable of even greater ranges of pastel hues. Persian, Kerman carpets are the most similar to the aerial roofscape hues and color contrasts of the Italian cities used in this study.

3.1 Color and Space

In 'Figural Color in the Seattle Cityscape' [9], it was shown that hues in an urban color field with c=50 or greater, advance as figural, due to both spatial effect and simultaneous contrast. In 'Color Constellations in the Seattle Cityscape' [10], it was shown that figural colors of similar hue and chroma in an urban color field could form clusters or constellations, and appear to advance spatially in a single plane normal to the viewing axis. Colors in an urban setting from an aerial view will behave in a similar fashion. The spatial effect created by chroma variation is minimal in the examples studied. Shade and shadow provide the primary imagery of spatial change. In the city examples discussed above, few, if any colors, at the scale 1:5000 will approach chroma levels above c=30. In the Naples photographs at 1:1000 there are examples of hues above these levels, but when seen at 1:5000 their chroma is reduced [5].

There is much spatial imagery in the decorative motifs and symbols of Oriental carpets. Garden carpets represent real physical space and imaginary space. Other more abstract references to clouds, sky, sun, moon, and gates imply a spatial awareness in the figure-ground design. In some floral carpet designs, the floral motifs appear to float in a plane above the field, intentionally created with light figures on a darker ground. In the more antique carpets, particularly those produced in nomadic cultures or small villages, the use of hues in higher chroma with strong color contrasts and bolder outlines, produce visually dynamic spatial illusions, such as a Luri carpet from Persia (late 19thc). The Khotan 'five-bud' carpet from eastern Turkestan (late 19thc), which is influenced by Persian design, uses dark linear motifs contrasted to a field of warm hues. These hues are similar to the roofscape and shadows seen in the 1:5000 aerial view of Rome. Kerman carpets (19th, 20thc) have subtle changes in spatial differences, and, like the Khotan carpets, are closer spatially to the relatively 'flat' space of the aerial city views.

Some carpets use geometric lines to order guls and other decorative motifs, such as the Tekke carpets from western Turkestan (18thc). Intersecting lines become the center of the gul and the form of its design. These lines are similar to straight circulation corridors, defined by shadow, particularly in the aerial views of Rome. Some Kerman carpets use lighter vine motifs and arabesques as linear ordering patterns throughout the entire field. These are similar to street patterns in the medieval parts of the cities. The garden carpet is the most directly influenced by spatial and architectural elements, and becomes the design most representative of urban fabric. The gardens, which portray a vision of paradise, were often inspired by the cities that contained these sublime spaces [2]. In some of these, such as a garden carpet from Kurdistan (18thc), raised planting beds surrounded by parterres, outlined by dark edges, and blue water is close to the imagery described in these aerial views.

4. CONCLUSION

The term 'urban fabric' is often used to define the density, block size, pattern of streets, and other visual characteristics related to plan views of the city. It also alludes to the horizontally and flatness of a two-dimensional plan of the city. Unlike a bolt of fabric, which is uniform and continuous in pattern and texture, urban fabric, like a carpet, is finite. Some cities are spaces defined by fixed boundaries, such as Venice, walled cities, or Baroque circular cities. Others, like Rome, are dynamic and continue to redefine their boundaries and edge conditions the way some field designs, in carpets, can expand continuously. Urban fabric, as visual imagery, carries expressive content, and can, as an object of both function and beauty, be appreciated as an artistic expression. Function and beauty are, therefore, characteristics of both cities and Oriental carpets; and, as art they share common themes.

The Oriental garden carpet is both an artistic expression of 'place', as well as a physical place to be occupied. These carpets are designed to represent the garden, which is both a reminder of a sublime place, and a conception of paradise [2]. A city is not a representation of paradise, although the Renaissance ideal city represented divine reasoning, and images of a 'holy city' do exist in some theologies. However, a city does represent the values, achievements, history, and mythology of a culture; and, as such, is an extension of ourselves. It is the definitive expression of physical place. Designers of cities do study geometric order and systems of hierarchy; and those who conceived the ideal cities may have seen examples of Islamic decoration. However, a conclusion from this comparison might reverse the order of influence. A carpet design (in the spirit of an Oriental carpet) could embody the geometry, scale, texture, color, and meaningful symbolism of a city abstractly through a design using hierarchical patterns and figural imagery. Like the garden carpet, the 'city' carpet could be used in the home functionally as useable art. As an expression of 'place' it would have a very special meaning to the home, and serve as a reminder of how important one's physical place in the world could be.

But if you pause and examine it carefully, you become convinced that each place in the carpet corresponds to a place in the city and all the things contained in the city are included in the design, arranged according to their true relationship, which escaped your eye distracted by the bustle, the throngs, the shoving. Italo Calvino, Invisible Cities.

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Associate Professor Galen Minah, College of Architecture and Urban Planning, University of Washington, 208 Gould Box 355720, Seattle, Washington 98195-5720, U.S.A. Phone: +206 543 4182, Fax: +206 616 4992, E-mail: gminah@u.washington.edu

STUDY OF THE COLOUR FIDELITY OF TEXTILE MATERIALS CAPTURED BY DIGITAL INPUT DEVICES

John H Xin, Institute of Textiles & Clothing, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

Abstract
Globalization of textile and clothing industry demands high speed and precise communication of product information. Digital colours have been gradually adopted by Textiles and Clothing companies as the use of digital colours for communication has significant advantages over the conventional physical colours. This is particularly true for textile and clothing industry in which the supply chain is relatively long. The main advantages of using digital colours are cost and time saving. For the digitising of the coloured textile materials, input devices such as digital camera and digital scanners are widely used. These devices can be characterized first so that the device independent colours defined by CIE colorimetry can be used. However, for different textile materials, the accuracy of the digitisation depends very much on the materials used in the characterization processes. If different materials are used, the accuracy of converting the digital counts to the CIE colour attributes will be affected. In this paper, the accuracy of the digitising of different textile fibre materials, such as synthetic and natural fibres by a digital camera and a digital scanner were studied and the results in terms of colour different were analysed in relation to the fibre materials used.

***Keywords**: digital colour communication, device characterization, digitising textile materials*

1. INTRODUCTION

The use of digital colour information can greatly shorten the communication lead-time in the globalized textile and clothing industry. The traditional way of digitising colour relies on the use of a spectrophotometer as an input device and a calibrated display device to visualise the colour. This method can achieve high colour fidelity since the technology of spectrophotometric measurement and display devices are quite mature.

However, as a spectrophotometer averages the reflected light with a certain aperture, it can not cope with the complex patterns and textures that a textile product may have. In addition, if a colour object is 3D, it is often difficult to be measured by a spectrophotometer. For some small companies, to invest a spectrophotometer may be too expensive. With the easily available and more economic digital input devices such as digital camera and flat-bed scanner, many textile and clothing companies started to use those to digitise their products to communicate to their customers and suppliers via Internet. Without any device characterisation, the colour fidelity is expected to be poor. Therefore, many times, wrong colour information is been communicated which could cause problems for the acceptance of the products.

In this paper, we discussed the characterisation of both digital cameras and scanners so that the device dependent digital information can be converted to CIE colour specifications. In particular, textiles materials with different fibre contents and structures were used in addition to standards used in graphic industry. The cross check with different characterisation materials and testing materials were also done, which could indicate the applicability of those input devices to different textile materials.

Input Device Characterisation

As the RGB results from an input device are device dependent, they needs to be converted to device independent values, CIE colorimetric values. This is done through the device characterisation. The regression method for input device characterisation has been applied by many researchers [1-4]. Other techniques such as the simple linear approximation, Neugebauer equation, lookup table etc, are also being used [5-7]. The schematic illustration of device characterisation is shown as the following:

Target → Device RGB → Transformation

↓ $XYZ_{measured}$ = $XYZ_{derived}$ ↓

Once a target was selected, the colorimetric values were measured using a spectrophotometer or a colorimeter. The target was then scanned in by the input device and The RGB results were obtained. The characterisation process is to establish the relationship between the digital counts and CIE colorimetric values (CIE tristumulus values, X,Y, and Z were used). In the above illustration, if a device can be accurately characterised, the $XYZ_{derived}$ should be very close to the $XYZ_{measured}$, the level of the difference can be calculated using colour difference equation. In this study, the 14 terms transformation from RGB to XYZ were used. An example of the equation for X is as the following:

$$X=a_1R+a_2G+a_3B+a_4R^2+a_5G^2a_6B^2+a_7RG+a\,GB+a_9RB+a_{10}RGB+a_{11}R^3+a_{12}G^3+a_{13}B^3+1 \quad \text{Eqn(1)}$$

For Y and Z, similar equations are applied. Since the RGB signals have no linear relationships with XYZ values, the linearization was performed and this step converted the RGB space to reflectance or XYZ space. Grey samples in Checker Chart were used for this purpose in scanner characterisation and in digital camera characterisation, Kodak Q13 grey scale was used. If the sample points are more than the number of the coefficients, the matrix can then be solved. In this study, the accuracy of the characterisation was tested by comparing the derived and measured colorimetric values using CMC(2:1) colour difference equation.

2. EXPERIMENTAL

The scanner used was Epson GT-10000+ Colour Image Scanner, Xenon fluorescent lamp. Photoelectric device of the scanner is color CCD line sensor with optical resolution of 600 x 2400 dpi. In order for the scanned samples to have the same size of the phsycial samples, the resolution of 50 dpi was selected for this work. The digital single-lens reflex camera used was a Canon new model EOS D30 with 3.25 million pixel (2160 × 1440) sensor with 45/0 illuminating/capturing geometry. The Macbeth ColorChecker Chart and Kodak Ektacolor IT8.7/2 colour target were used as reference to develop the characterization model. There are 24 samples in ColorChecker Chart and there are XXX colour sasmples in the IT8.7/2 chart. 228 colours in the chart were used in the experiment. In order to test the applicability of those input device to textile materials, seven sets of textile fabric samples were prepared. The samples are then scanned or captured by the scanner and digital camera. The sample numbers for those textile datasets are given in Table 1. In the digital camera experiment, each sample was placed in the centre of the view

field in order to reduce the uniformity of the light entering the camera lens.

3. RESULTS AND DISCUSSION

Device characterisation

The characterisation results using graphic colour charts for digital camera and scanner are shown in Table 2 and Table 3. The results from those two table indicate that the characterisation accuracy for those two devices are from 1.36 to 3.09 CMC(2:1) units on average. The worst samples were those black samples in the charts. The accuracy of the characterisation can be further improved if higher quality digital camera and scanners were used. However, the cost effectiveness should also be considered in a commercial organisation. The input devices used in this work were typical mid-range products. The results of the seven sets of the textile samples and the cross testing of different materials are given in Table 4. It can be seen from Table 4, that for the textile fabric materials, the accuracy of the characterisation is from 1.41 to 2.79 CMC(2:1) units. This accuracy is similar to those obtained from graphic colour standards. This indicates that relatively accurate results can be achieved on average. When further analysis of the colour of the samples, it was found that dark colours usually had worse results. When one type of colour samples for characterisation was used and the other type was used to perform the testing, the results varied quite a lot, depending very much on the similarity of the materials as well as the dataset used in characterisation. It is seen from Table 4 that the two graphic colour charts have quite different characteristics. If Checker Chart was used for the characterisation, and IT8 chart was used for testing, the results were quite poor, about 9.92 CMC(2:1) units and vice versa, although each had much better results when the characterisation and testing used the same set of material. The differences in the colorants used, and different surface characteristics (Checker Chart has quite matte surface while the other is glossy), may contribute to the difference. When using those two graphic charts as characterisation standards and textile materials for testing, the results were also very poor, and vice versa. The colour difference is in the range of 10 to above 15 CMC(2:1) units. The results were better if textile materials were used in characterisation and testing. The colour difference ranged from 2.73 to 8.03 CMC(2:1) units. If the similar materials are used in both characterisation and testing the accuracy was further improved. For example, if wool 1 is used in the characterisation, and wool 2 is used for testing, 2.73 CMC(2:1) units of colour different can be achieved. Similar result can be found for polyester micro-fibres. However, it is noticed that even similar materials were used in characterisation and testing, different sampling in characterisation data set can result in different accuracy, such as those indicated by both wool and polyester micro-fibres. Table 5 shows the cross testing results of the digital camera. Less data sets were tested. The characterisation results for cotton, nylon, and polyester data sets are 4.37, 3.28, and 3.49 CMC(2:1) units respectively, which is worse than using graphic standards and worse than those from the scanner. One of the possible causes may be the sampling. The distribution of the samples of textile data sets in the colour space is not so ideal. The cross testing results are also not good similar to those of the scanner. These results indicate that scanners and digital cameras are quite dependent on characterisation standards, their colorants, surface texture, etc. Therefore, in order to achieve better accuracy in using those devices, the materials used in the characterisation process should ideally be same as those used in the later digitisation process. Some degree of accuracy can be maintained if the materials, surface textures have some similarities. Otherwise the conversion from device dependent signals to device independent attributes will not be accurate.

4. CONCLUSION

Various materials including graphic colour charts, textile materials were used in the study of the accuracy of the conversion from device dependent signals to device independent CIE colorimetric attributes. The results show that the input device such as digital cameras and scanners are quite sensitive to different characterisation materials. To achieve good conversion accuracy, the same materials or very similar materials both in colorants and surface textures should be used. Otherwise, the conversion will not be accurate. It is suggested that further tests should be carried out to verify those initial findings and to determine the influence of the sampling for characterisation process.

Table 1: The number of samples in each colour data set.

Colour data sets	Number of samples in each set
Checker	24
Checker DC	240
It8	228
Cotton	40
Nylon	40
Polyester	25
Polyester Micro	30
Polyester Micro 1	24
Wool 1	72
Wool 2	126

Table 2: The characterisation results from the digital camera.

ΔECMC(2:1)	Macbeth ColorChecker®	IT8 colour target	Macbeth ColorChecker® DC
Mean	1.67	3.09	3.02
Minimum	0.32	0.24	0.20
Maximum	3.60	16.60	16.55

Table 3: The characterisation results from the scanner.

DECMC (2:1)	Macbeth ColorChecker®	IT8 colour target
Mean	2.74	1.36
Minimum	0.27	0.13
Maximum	12.47	10.65

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Table 4: The accuracy of the scanner characterisation models tested using different textile materials.

		Test data set (mean ΔECMC(2:1))								
		Checker	It8	Cotton	Nylon	Poly-ester	Polyester Micro	Polyester Micro 1	Wool 1	Wool 2
Characterisation sample set	Checker	2.74	9.92	11.73	13.86	14.94	13.96	11.23	11.36	10.19
	It8	9.25	1.36	13.18	12.43	13.49	14.38	12.37	13.09	13.57
	Cotton	>15	>15	2.38	7.67	4.84	4.75	4.39	4.52	3.88
	Nylon	13.91	>15	5.37	2.79	5.85	6.78	6.11	6.52	5.01
	Polyester	>15	>15	3.59	7.02	2.28	3.86	4.17	5.04	4.24
	Polyester Micro	>15	>15	5.69	7.55	7.01	2.33	2.75	6.07	5.06
	Polyester Micro 1	>15	>15	7.73	8.03	7.64	5.61	1.41	6.83	5.89
	Wool 1	>15	>15	4.82	6.99	6.73	4.96	5.57	2.57	2.73
	Wool 2	>15	>15	4.81	8.00	5.65	5.27	4.96	3.56	1.94

Table 5: The accuracy of the digital camera characterisation tested using different textile materials.

		Test data set (mean ΔECMC(2:1))				
		Checker	Checker DC	Cotton	Nylon	Polyester
	Checker	1.67	7.00	7.43	7.91	10.69
	Checker DC	4.57	3.02	4.05	6.88	4.62
	Cotton	>15	>15	4.37	>15	10.12
	Nylon	7.21	8.96	7.31	3.28	9.50
	Polyester	>15	8.63	5.28	>15	3.49

Assoc. Prof. Dr John H Xin, The Hong Kong Polytechnic University, Institute of Textiles & Clothing. Hung Hom, Kowloon, Hong Kong, CHINA. E-mail: tcxinjh@inet.polyu.edu.hk, tel: +(852) 2766 6474, fax: +(852) 2773 1432

COLOR MEASUREMENT EMULATOR WITH A SCANNER AND ITS APPLICATION TO CMS

A. Hansuebsai, K. Kitisarakulchai and P. Pungrassamee
Department of Imaging and Printing Technology
Chulalongkorn University, Bangkok, Thailand

Abstract
Using a desktop flatbed scanner to capture an image of a known color test chart, the profile for color transformation can be created to be an emulator of a color measurement tool. The 264-color patch of an IT8 color chart was tested and found that the total average color differences were around 6. Gray and high saturated colors can affect the increase of the color difference (ΔE). Among these colors, reddish tone give better result than others.

***Keywords**: Color measurement, Color management*

1. INTRODUCTION

A color measurement tool is an essential device for recent Imaging technology that is important for many related technology and business such as textile, graphic art, etc. Even it is a necessary device but the cost still is not affordable for an ordinary use or even for a small business firm. The use of the device is another point of difficulty. When measuring colors, the measuring head is placed on the color targets spot by spot manually. In the progressive way, using an optional tool such as XY arms that will move the measuring head automatically has solved measuring spot by spot method. Unfortunately, XY arms cost nearly the same as the color measuring tool itself. Note that to measure the color of reflective sample needs different tool from transmission sample. It means more cost too. The desktop flatbed scanner thus may be another choice for emulating the measurement tool. It can scan the color in one pass, both reflection and transmission. This paper proposes scanning technique to capture color values of standard test chart, whereby the color profile is obtained through color measurement. These algorithm is possible a linear function to be an emulator of a color measurement tool.

2. METHODS

The main methodology using in this experiment is the color transformation of scanned color RGB to the colorimetric coordinate, CIEXYZ. The color transformation is a tool to calculate the value of color values in colorimetric coordinate, CIEXYZ from the destination color coordinate, RGB. There are many algorithms to do the transformation such as linear and non-linear function, 3D LUT and linear interpolation, etc. This includes the combination of these algorithms. We propose the technique of linear functions in this experiment as they give possibly satisfactory results.

Utilizing the following equations performs the linear function technique;

$$X = a_1R+a_2G+a_3B$$
$$Y = a_4R+a_5G+a_6B$$
$$Z = a_7R+a_8G+a_9B$$

The profile expresses with 3x3 matrix which contains nine coefficients; a_1, a_2, …, a_9. This is the reason why the "matrix transformation" is named. Using statistics knowledge, these coefficients can be calculated from the set of data. There also is much calculating software that can aid establishing these coefficients such as MS-Excel or SPSS.

The profile can rewrite into the form of Polynomial function as following;

$$P(x,y,z) = a_1x+a_2y+a_3z$$

The profile can be 3 x 3 matrix as above which have only 3 terms of the polynomial. It can have more terms also. Table 1 shows some linear functions used for color transformation.

The linear function is based on the assumption that the correlation between X, Y, Z and R, G, B are approximated by a set of simultaneous equations. The schematic diagram of the method is depicted in the Figure 1.

Table 1: Examples of the Polynomials for Transformation

1. $P(x,y,z) = a_1x+a_2y+a_3z$
2. $P(x,y,z) = a_0+a_1x+a_2y+a_3z$
3. $P(x,y,z) = a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx$
4. $P(x,y,z) = a_0+a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx+a_7xyz$
5. $P(x,y,z) = a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx+a_7x^2+a_8y^2+a_9z^2$
6. $P(x,y,z) = a_0+a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx+a_7x^2+a_8y^2+a_9z^2+a_{10}xyz$
7. $P(x,y,z) = a_0+a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx+a_7x^2+a_8y^2+a_9z^2+a_{10}xyz+a_{11}x^3+a_{12}y^3+a_{13}z^3$
8. $P(x,y,z) = a_0+a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx+a_7x^2+a_8y^2+a_9z^2+a_{10}xyz+a_{11}x^3+a_{12}y^3+a_{13}z^3+a_{14}xy^2+a_{15}x^2y+a_{16}yz^2+a_{17}y^2z+a_{18}z^2x+a_{19}zx^2$

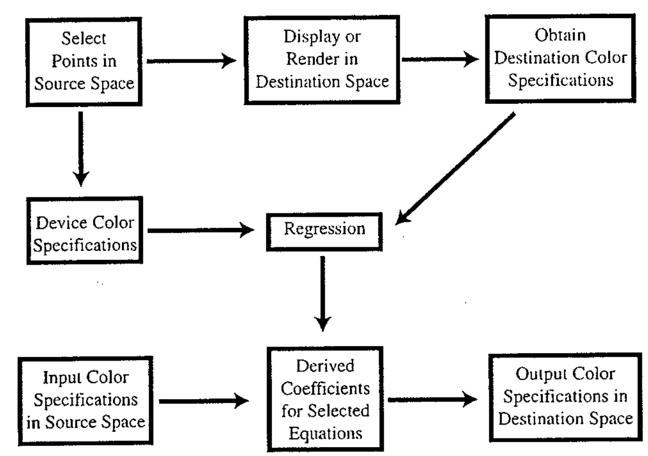

Figure 1 : The schematic diagram of the Linear Function method

Regression is performed to select relevant points with known data in both X, Y, Z and R, G, B, for deriving the coefficients of the polynomial. The requirement is that the number of points should be higher than the number of polynomial terms; otherwise, there will be no unique solutions to the simultaneous equations because there are more unknown variables than equations.

In most case, linear function can be improved by modifying the value of R, G, B. It is called "RGB correction". The RGB correction is the process that simply takes n power to the normal RGB value before doing regression. The recommended n that used in this paper should be 2.5.

To emulate scanner as a color measurement tool, a known color test chart, IT8, was placed on the scanner and scanned into RGB 24 bits file format. The image was read into RGB values of each color patch. There are many ways to handle these color values. Using Visual Basic (VB) program with GDI library did one method. This method has advantages as the color can be read in many different points in each patch and averaged easily by only one line of VB command. The known value of XYZ can be put into VB program to derive the profiles. Note that this experiment, mathematics software is used to calculate them. SPSS is superior software over MS-Excel in this function. It is because MS-Excel can perform up to 16 terms of the polynomial, which is not enough for some transformation such as equation 8 in Table 1.

3. RESULTS AND DISCUSSION

To evaluate the result of the functions, color difference (ΔE) is used to judge. Using scanner as the color measurement tool, we used the obtain profiles (3 x 3, 3 x 4, 3 x 9 and 3 x 11) to transform color values RGB to XYZ values. The results are compared with those color values measured directly by a spectro-photometric method.

The color differences are computed. The result shows that the average total color difference (ΔE) is not over than 6. It is also found that the profile without constant term, such as 3 x 3 and 3 x 9 give maximum ΔE (Table 2).

Table 2: Average total color differences (ΔE)

(ΔE)	3×3	3×4	3×9	3×11
Min	0.68	0.34	1.69	0.25
Max	32.91	24.81	32.21	21.67
Average	5.33	5.59	5.10	5.07

Further study is to observe what color shade generates high ΔE, a VB program is created to plot a chart that show the amount of ΔE among each color patch. The 3D-color chart is best suit to this job. It is because that it shows explicitly how each color patch performs.

The charts in Figure 2 show that gray and high saturated colors, estimated one-sixth of the total color patches seem to influence the increased ΔE. Among these colors, reddish tone gives better result than others.

In addition, the applications of color management system (CMS) were considered. The purpose is to produce a printed image by scanning original image and printing via an inkjet color printer. The original image and the print are compared. The result shows the improvement of corrected color especially on the reddish region, corresponding well with the above result.

4. CONCLUSIONS

Comparing a flatbed scanner to an available colorimeter or spectrophotometer, the cost is still extremely different. In case of using colorimeter to measure color target with many color patches on it, the difficulty is

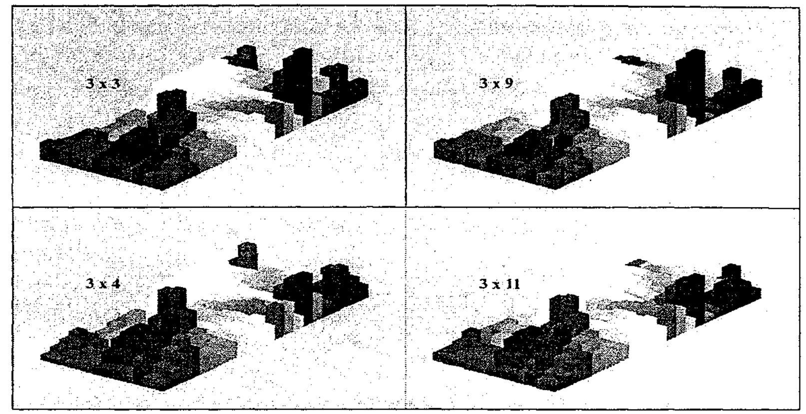

Figure 2: 3D Images showing the amount of ΔE of each color patch IT8.7

time-consumed and not easy. We need special option such as XY arm facility. Even using such kind of aid device, the time consumption for measuring still long. With the result of average ΔE of 6, this method of emulator may be fair enough to be used in some kind of job such as textile printing. In addition, this method of color measurement improves CMS much easier, as the color reference target can be measure by one scan rather than measuring step by step as in the standard colorimeter. For characterizing the devices, both scanner and printer can be done by one measurement too. It is because the printer test target is measured by scanning via the scanner that is used for both measuring and scanning images. Interestingly, this technique can be applied on a transmission scanner, including a digital camera, to evaluate colors that can not be measured by an ordinary colorimeter or spectrophotometer.

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Associate Prof. Dr. Aran Hansuebsai, Chulalongkorn University, Faculty of Science, Department of Imaging Technology, Pha-yathai Road, Pratumwan, Bangkok, Thailand. Phone: +662 218 5588, Fax: +662 208 9439, E-mail: aran@sc.chula.ac.th
Associate Prof. Porntawee Pungeassamee, Chulalongkorn University, Faculty of Science, Department of Imaging Technology, Pha-yathai Road, Pratumwan, Bangkok, Thailand. Phone: +662 218 5567, Fax: +662 208 9439, E-mail: porntawee@mail.sc.chula.ac.th
Mr. Krisada Kitisaragulchai, Imaging Technology, Pha-yathai Road, Pratumwan, Bangkok, Thailand. Phone: +662 921 7711, E-mail: g3942500@hotmail.com

ACCURATE RECORDING OF COLOR INFORMATION OF MUSEUM MATERIALS BY DIGITAL STILL CAMERAS --- IN CASE OF "UKIYO-E" AND "KIMONO" ---

Takuzi Suzuki[1], Mituo Kobayasi[2]
[1]National Museum of Japanese History, Chiba, Japan
[2]The University of Electro-Communications, Tokyo, Japan

Abstract
With the rapid development of information technology, "digital archiving" has become an essential issue in museums and galleries. Accurate recording of color information of museum materials is an important factor in digital archiving.
Nowadays, digital still cameras (DSCs) on the market have a potential of accurate color image recording. We devised color transfer functions of two DSCs (Olympus C3040ZOOM and Minolta Dimage7). These functions are estimated by the relation between machine-dependent RGB values and CIEXYZ values of 240 color chips of Macbeth ColorCheckerDC. The average error of estimation was 2.5 ΔE_{ab} *for each DSC, which shows that they have high potential of accurate color recording.*
As an application to real museum materials, we took images of ten UKIYO-E pictures (woodblock prints of 17c-19c in Japan) in the National Museum of Japanese History by a DSC (Minolta Dimage7). We compared the estimated color values with the measured values by a colorimeter (Minolta CM-2600d) for several sampling points of each image. The average error was 4.8 ΔE_{ab}. *The result shows that DSCs are useful for accurate color recording of color information of museum materials.*

Keywords: *Digital still camera, Accurate recording, Museum materials, Color transfer function*

1. INTRODUCTION

With the rapid development of information technology, "digital archiving" has become an essential issue in museums and galleries. Accurate recording of color information of museum materials is an important factor in digital archiving.

Nowadays, digital still cameras (DSCs) on the market have potential of high resolution image capturing that is equal to potential of 135-size films. Photo detectors of DSC (CCD, etc.) have stable performance, and DSCs have an advantage for accurate color image recording. Some papers reported that custom made DSCs (MARC camera, etc.) have high performance for image recording of paintings in art museums [1, 2].

Almost all of DSCs capture a color as a machine-dependent RGB value. It is not adequate for preservation of long time. Unfortunately a color transfer function from RGB to colorimetric value (e.g. CIEXYZ) of a DSC is hardly provided by the manufacturer.

This paper first describes an efficient method to estimate a color transfer function of a given merchandised DSC. We investigated two DSCs (Olympus C3040ZOOM and Minolta Dimage7). The result tells that they have high potential of accurate color recording.

This paper also describes that DSCs are useful for accurate color recording of color information of museum materials.

We took images of ten UKIYO-E pictures (woodblock prints of 17c-19c in Japan) in the National Museum of Japanese History by a DSC (Minolta Dimage7), from which estimated color values were computed. We compared the estimated color values with the measured values by a colorimeter (Minolta CM-2600d) for several sampling points of each image (95 points in total). The result shows the estimation of useful level succeeded to real museum materials.

2. ESTIMATION OF COLOR FROM THE OUTPUTS OF DSC

2.1 Color transfer function of a DSC

The CIEXYZ tristimulus value of a give light is expressed by

$$(X,Y,Z) = \langle \bar{x}, p \rangle,$$

where $\langle \bar{x}, p \rangle$ denotes a linear process to calculate a tristimulus value from color matching functions $\bar{x} = (\bar{x}, \bar{y}, \bar{z})$ and the spectral distribution p of the light.

When the same light is captured by a DSC, the output RGB value of the DSC is expressed by

$$(R,G,B) = \varphi[p],$$

where $\varphi[p]$ denotes a process to generate RGB output of the DSC from the spectral distribution p. Here several parameters of the DSC, for example, exposure value, white balance parameter, etc., are fixed.

If a CIEXYZ tristimulus value is uniquely determined by a RGB output value of the DSC, the relationship are expressed with a one-to-one function by

$$\langle \bar{x}, p \rangle = f(\varphi[p]).$$

f is called "color transfer function."

The EXIF standard [3] tells that the output values of DSC are given by sRGB [4]. If the sRGB value represents the actual CIEXYZ value of the light, we have no problem to use DSCs. But most of the merchandised DSCs modify color information of images to give more preferred color impression to the customers. The process φ is nonlinear which includes light sensing phase and signal processing phase for preferred color reproduction. Unfortunately both φ and f of almost all DSCs are not known. To utilize DSCs for accurate color recording, we must estimate f using some way.

2.2 Ideas to get better training samples

To estimate the color transfer function f, a collection of spectral distributions is necessary. For each spectral distribution p, pair of $\langle \bar{x}, p \rangle$ and $\varphi[p]$ is made as a training data. The easiest way to make various sorts of p is to use of a set of color chips and an illuminant. But there are some problems to make high quality data. Training data must cover whole area of the gamut of the DSC. All color chips must be uniformly illuminated. The following tells two ideas to solve these problems.

(a) Light intensity control of the illuminate by exposure value setting

RGB outputs that is given by a combination of a set of color chips and an illuminant are distributed in a narrow area of the gamut of the DSC. Taking images of the same target by several different exposures is effective in case of brighter or darker data are required.

It is equal to make the amount of exposure e time and to make the strength of an input light e time. We can easily control intensity of input lights imaginarily.

(b) Cancellation of the effect of nonuniform lighting

It is very difficult to illuminate all of color chips uniformly. To know the CIEXYZ tristimulus value of a color chip accurately, the nonuniformity of illuminance must be detected and cancelled.

When an image of a gray sheet of constant reflectance is taken, the difference of illuminance between a certain point and the reference point on a screen is expressed by

$$f(R,G,B)=k\cdot f(R_0,G_0,B_0),$$

where (R,G,B) and (R_0,G_0,B_0) are the RGB value at the certain point and at the reference point respectively. We can express the nonuniformity of illuminance by k. k is determined only depend on location of a point.

Even if f is unknown, we can calculate k. In our experiment, Y value of gray color chips is only estimated from G value. It is not difficult to illuminate narrow area (about 5~6cm×1~2cm by fluorescent lamps) uniformly. Then we can estimate a function $g: G \mapsto Y$ which is used for the compensation of f, and k is calculated by

$$k = g(G)/g(G_0).$$

2.3 Idea for good estimation of the color transfer function

$\hat{f}$ denotes an estimated function of f. When $\hat{f}$ is given by a quadratic or cubic polynomial, the difference between $f(R,G,B)$ and $\hat{f}(R,G,B)$ is very large (about 5~10 ΔE_{ab} in an average) [5]. A strategy that $\hat{f}$ is constructed by some of polynomials is effective.

Let $A=[0,1]^3$ $(0\le R,G,B\le 1)$ be the domain of f. A is divided into n parts $A_1, A_2, \cdots, A_n$. The boundary between A_i and A_{i+1} is on the plane $R+G+B=S_i$, where $0=S_0<S_1<\cdots<S_{n-1}<S_n=3$.

Then, polynomials $\hat{f}_1,\hat{f}_2,\cdots,\hat{f}_n$ are assigned to $A_1, A_2, \cdots, A_n$ respectively and $\hat{f}(R,G,B)$ in A_i is given by

$$\hat{f}(R,G,B)=\hat{f}_i(R,G,B).$$

But $\hat{f}_i(R,G,B)$ and $\hat{f}_{i+1}(R,G,B)$ may have different values at the boundary between A_i and A_{i+1} in this way.

With a parameter $0<a<1/2$, a neighborhood area of boundary of A_i and A_{i+1} is given by

$$B_i=\{(R,G,B)\mid S_i-ar_i\le S\le S_i+ar_{i+1}\},$$

where $S=R+G+B$, $r_0=r_{n+1}=0$ and $r_i=S_i-S_{i-1}$.

Then $\hat{f}(R,G,B)$ in B_i is given by a linear interpolation:

$$\hat{f}(R,G,B)=(1-p)\hat{f}_i(R,G,B)+p\hat{f}_{i+1}(R,G,B),$$

where $p=\dfrac{S-(S_i-ar_i)}{a(r_i+r_{i+1})}$. (See Figure 1.)

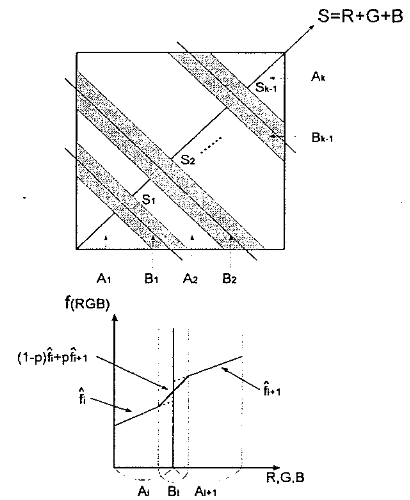

Figure 1: Partition of A and a linear interpolation at B_i

2.4 Algorithm of an estimation of color transfer function

The following shows an algorithm of an estimation of color transfer function.

1. Make g by the method of section 2.2(b).
2. Calculate k at every point on a screen by the method of section 2.2(b).
3. Take pictures of color chips by the DSC with several exposures, and extract the RGB value (R,G,B) of every color chip.
4. Calculate the CIEXYZ tristimulus value of every color chip. The value is calculated from already-measured value, and is corrected by the exposure and k. (See section 2.2.)
5. Estimate $\hat{f}$ by the method of section 2.3.

2.5 Procedure of an color estimation of a DSC image

A procedure of an estimation of the CIEXYZ tristimulus value from taken RGB value is shown in the following.

1. Calculate k of every point on a screen. (Same as process 2 of section 2.4.)
2. Take a picture by the DSC, and extract the RGB value (R,G,B) of every point of the taken image.
3. Calculate the CIEXYZ tristimulus value with k by

$$(X,Y,Z)=\hat{f}(R,G,B)/k.$$

3. EXPERIMENTS

3.1 Estimation of color transfer function of two DSCs and their performance

Color transfer functions of two real DSCs (Olympus C3040ZOOM and Minolta Dimage7) were estimated. Specifications of each camera are:

Camera A (Olympus C3040ZOOM):
maximum pixel size is 2040×1536, CCD with CMY color filter (subtractive type), 35-105mm (in terms of 35mm film camera) zoom lens, open F number is 1.8~2.6, shutter speed is from 4 secs to 1/800 secs, white balance mode is auto, preset (4 variation) or customize, 8 bit representation of RGB value.

Camera B (Minolta Dimage7):
maximum pixel size is 2560×1920, CCD with RGB color filter (additive type), 28-200mm (in terms of 35mm film camera) zoom lens, open F number is 2.8-3.5, shutter speed is from 4 secs to 1/2000 secs, white balance mode is auto, preset (4 variation) or customize, 12 bit representation of RGB value.

We used Macbeth ColorCheckerDC as a sheet of color chips. It has 12×20 chips and spectral reflectance of every color chip is given by the manufacturer. And we used a fluorescent lamp Toshiba FL20S·N-EDL as an illuminant. (Measured color temperature was 4864K.) This lamp is made for exhibition in museums. Infrared light and ultraviolet rays are not included in this lamp. (Photo detector of many DSCs has sensitivity for infrared light. To avoid occurring of unexpected effect by infrared factor, use of infrared cutting filter or infrared cutting light is recommended.)

Figure 2 shows an installing of devices for taking images. A DSC is installed at top of a copy stand. The stage of the copy stand is illuminated by four fluorescent lamps. A sheet of color chips to get training data is on the stage of the copy stand. An object that takes an image is also put on the stage. Monitoring display is convenient for framing and focusing but not all DSCs can monitor a preview image.

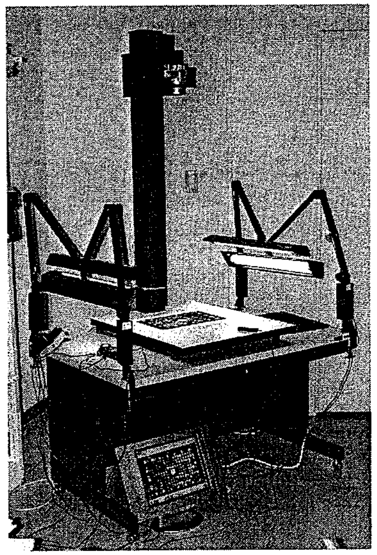

Figure 2: Installing of devices for taking images

In camera A, 2764 training data were extracted from 13 images which is taken by different exposure each other. In camera B, 3960 data were extracted from 16 images. Unreliable data, especially glossy color chips is rejected from training data.

In estimating $\hat{f}$, n was made 10.

Table 1 shows color difference between exact color value and estimated value of every color chip. The result is very good.

Table 1: Error of estimation of training data

Camera	Average	Std.Dev.	Max.
A	2.56	1.69	21.79
B	2.49	1.37	17.28

Table 2 shows number of data whose color value is estimated better than $5\,\Delta E_{ab}$. 90 percents of data or more satisfy this criterion. This result is a match for potential of MARC camera [6].

Table 2: Number of data whose color value is estimated better than $5\,\Delta E_{ab}$

Camera	#data	%
A	2584	93.5
B	3788	95.7

3.2 Experimental taking of "Ukiyo-E" picture and color estimation

"UKIYO-E" picture is woodblock prints of 17c-19c in Japan. We took images of ten UKIYO-E pictures in the National Museum of Japanese History by Minolta Dimage7 (camera B). Table 3 shows the title of pictures and figure 3 shows these pictures.

Table 3: Titles of ten UKIYO-E pictures

Id	Title	#point
(a)	Iwai Hansirô (a KABUKI actor with a costume in a play)	7
(b)	Sakigake mitate zyûgan, Nakamura Sikan (a KABUKI actor with a costume in a play)	12
(c)	Inuzuka Sino Inutaka, Hikiroku-ga musume Hamazi (1) (a scene in a KABUKI play)	8
(d)	Inuzuka Sino Inutaka, Hikiroku-ga musume Hamazi (2)	11
(e)	Tôsê 32-sô, Kaze-ga hosiso (a beautiful woman)	5
(f)	Hanazoroe bizin-kurabe (1) (beautiful women and morning glories)	8
(g)	Hanazoroe bizin-kurabe (2)	15
(h)	Hanazoroe bizin-kurabe (3)	15
(i)	Tôkyô meisyo-nouti Asakusa Kinryû-san (a landscape of Tokyo)	7
(j)	Tôkaidô meisyo-nouti Yodo-gawa (a landscape of Osaka)	7
	Total	95

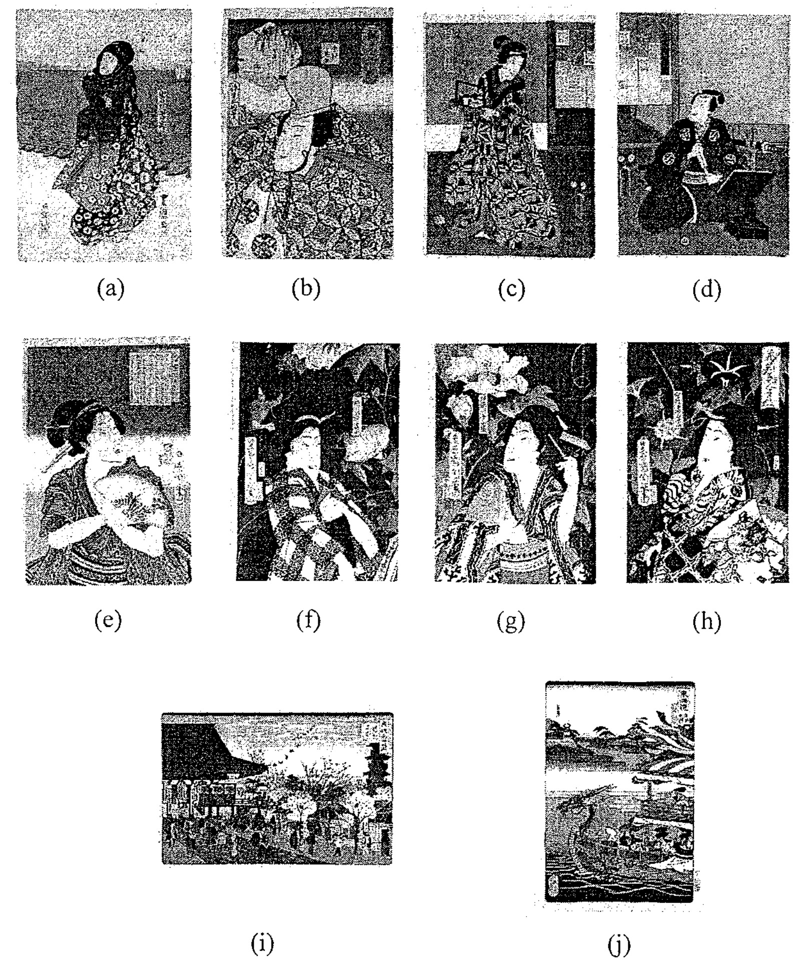

Figure 3: Sample UKIYO-E pictures

For all images, several points on an image were selected and exact color values of each point were measured by a colorimeter Minolta CM-2600d. Table 4 shows color difference between exact color value and estimated color value from DSC captured image of each image.

The result is worse than the result of section 3.1, but it is acceptable and useful. Color sensitivity of CCD is different from of human beings, and behavior of metamerism is also different. Papers [1, 2] say that the estimation error of general data is about twice of training data.

The result shows that merchandised DSCs have a potential quality of accurate color image recording.

Table 4: Error of estimation at sample points of each image

Id.	Min.	Max	Average	Std.Dev.
(a)	1.29	8.71	4.44	2.37
(b)	1.77	8.15	4.57	2.12
(c)	2.41	8.60	5.43	2.20

(d)	0.90	7.36	4.30	1.81
(e)	2.78	10.40	5.63	2.67
(f)	2.02	7.10	4.78	1.76
(g)	1.93	9.51	5.72	2.27
(h)	1.49	8.74	4.07	1.93
(i)	1.17	8.14	4.88	2.42
(j)	2.37	7.13	3.96	1.44
Total	0.90	10.4	4.76	2.18

4. CONCLUSION

Some ideas for estimation of color transfer function from DSC-RGB to CIEXYZ are proposed. The method is general and can be applied to many kinds of DSCs.

Experimental image capturing of real museum materials are executed. Accurate digital color image capturing by DSC is useful method and should be presented by museums.

We, the National Museum of Japanese History have many KIMONO materials. The result of color estimation of KIMONO will be reported at a different opportunity.

Multiband digital still cameras that can capture 5 or 6 bands spectral image give us more detailed and rich information [7]. But color image capturing by normal DSC is still valuable for digital archiving. We believe that digital archiving in museums contributes to raise our cultural standard.

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Mr. Suzuki Takuzi, Research Associate, Museum Science Department, National Museum of Japanese History, 117 Jonai-cho, Sakura-shi, Chiba, 285-8502 Japan. Phone: +81-43-486-0123, ext. 409, Fax: +81-43-486-4299, E-mail: suzuki@namazu.rekihaku.ac.jp.

Dr. Kobayasi Mituo, Professor, Department of Information and Communication Engineering, Faculty of Electro-Communications, The University of Electro-Communications, 1-5-1 Chofugaoka, Chofu-shi, Tokyo, 182-8585 Japan. Phone: +81-424-43-5324, Fax: +81-424-43-5334, E-mail: kobayasi@ice.uec.ac.jp. The author is a visiting professor of the National Museum of Japanese History since Apr., 2000.

INTERPOLATION REFLECTANCE VALUES AND EFFECT IN CALCULUS CIELAB COORDINATES

Natividad Alcón, Marcela Picó, Francisco Redondo, Ángel Tolosa, Elena Sanjuán.
AIDO, Paterna, Spain

Abstract

The CIE Standard on Colorimetric Observers (CIE 1986b) recommends that the CIE Tristimulus values of a colour stimulus be obtained by multiplying at each wavelength the value of the colour stimulus function Φ_λ (λ) by that of each of the CIE colour–matching functions and integrating each set of product over the wavelength range corresponding to the entire visible spectrum, 360 to 830 nm. The integration may be carried out by numerical summation at wavelength intervals, Δλ, equal to 1 nm.

Nowadays, the industrial requirement has been that the manufactures offer measurement equipments smaller, portables and cheaper. This evolution requires more simplicity of its components, what implicates bigger wide of slit in the diffraction gratings.

In relation with this subject a problem is detected in some industrial environments. They attempt to improve results making measurements with bigger wide of slit width and offering CIELAB results after interpolation reflectance values to 1 nm intervals.

The objective of this study is to value the error introduced by this practice in the calculus of chromatics coordinates values L, a*, b*, it means, the error that is introduced to carry out 5 nm bandpass scan for reflectance measurement and its later interpolation to values of 1nm bandpass in order to CIELAB calculus.*

Keywords: *wide of slit, reflectance, colour difference*

1. INTRODUCTION

CIE Standard on Colorimetric Observers (CIE 1986b) recommends that the CIE Tristimulus values of a colour stimulus be obtained by multiplying at each wavelength the value of the colour stimulus function $\Phi_\lambda(\lambda)$ by that of each of the CIE colour–matching functions and integrating each set of product over the wavelength range corresponding to the entire visible spectrum, 360 to 830 nm.

The integration may be carried out by numerical summation at wavelength intervals, Δλ, equal to 1 nm.

$$X = K\sum_\lambda \phi(\lambda)\bar{x}(\lambda)\Delta\lambda \quad (1)$$

$$Y = K\sum_\lambda \phi(\lambda)\bar{y}(\lambda)\Delta\lambda \quad (2)$$

$$Z = K\sum_\lambda \phi(\lambda)\bar{z}(\lambda)\Delta\lambda \quad (3)$$

$$K = \frac{100}{\sum_\lambda S(\lambda)\bar{y}(\lambda)\Delta\lambda} \quad (4)$$

Where X, Y, Z are tristimulus values, $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$, are colour matching functions of a standard colorimetric observer, and K is a normalizing constant. Nowadays, the industrial requirement has been that the manufactures offer measurement equipments smaller, portables and cheaper. This evolution requires more simplicity of its components, what

implicates bigger slit width in the diffraction gratings.
In relation with this subject a problem is detected in some industrial environments. They attempt to improve results making measurements with bigger wide of slit width and offering CIELAB results after interpolation reflectance values to 1 nm intervals.
The objective of this study is to value the error introduced by this practice in the calculus of chromatics coordinates values L*, a*, b*.

2. EXPERIMENTAL PHASE

For the realization of this study we dispose of four coloured ceramics samples (10x10 cm) red, green, yellow and cyan. The samples are no fluorescent and homogeneous in its surface. These samples were characterized by the chromatics coordinates corresponding to CIE 1976 (L* a* b*) colour space (10° observer and D65 illuminant).

$$L^*=116(Y/Y_n)^{1/3}-16 \quad (5)$$

$$a^*=500[(X/X_n)^{1/3}-(Y/Y_n)^{1/3}] \quad (6)$$

$$b^*=200[(Y/Y_n)^{1/3}-(Z/Z_n)^{1/3}] \quad (7)$$

with: $X/X_n>0.008856$

$Y/Y_n>0.008856$

$Z/Z_n>0.008856$

Where X, Y, Z describe the colour stimulus considered and X_n, Y_n, Z_n, describe a specified white object colour stimulus.
The equipment used was a double beam spectrophotometer with diffuse reflectance accessory, illuminating/viewing geometry 8/t (specular component included) and measurement area 2 cm ϕ.
In the reflectance measurement we take the value 100 for a PTS white standard reference. The measurement 0 has been made with a light trapdoor in the place of the sample.
The chromatic characterization of the samples was carried out, in a first phase, establishing 1 nm wide of slit width for reflectance measurement.
In a second phase, the reflectance was obtained establishing 5 nm slit width. After, and with these values, we interpolate the reflectance values to 1 nm intervals. So that we have three measurement groups:

Reference group: 1 nm slit width.
Group A: 5 nm slit width
Group B: 5 nm slit width and interpolated to 1 nm intervals.

3. RESULTS

Measurements were realized in three different days, using always the same process, obtaining three reflectance values for each group and sample; the means of this reflectance values are represented in Figures 1, 2 and 3. The Table 1 shows the means calculated for the coordinates L*, a*, b* for each group and samples:

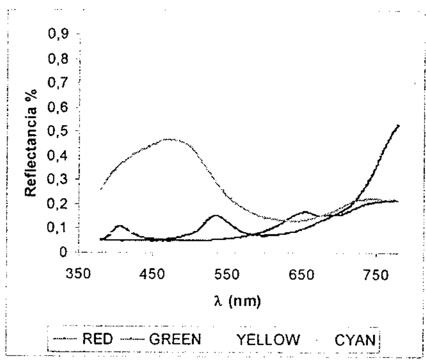

Figure 1: Mean reflectance for the reference group.

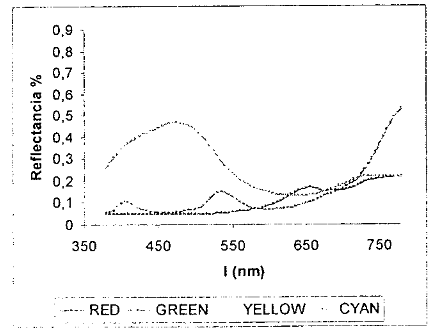

Figure 2: Mean reflectance for the group A.

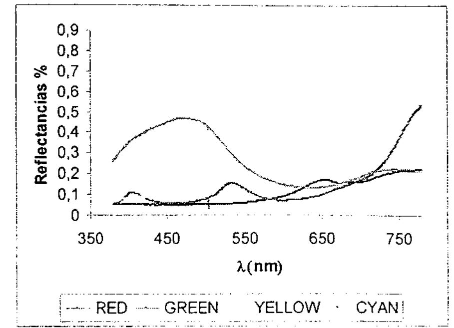

Figure 3: Mean reflectance for the group B.

Table 1: Means for the CIELAB coordinates

Sample		L*	a*	b*
Red	Reference group	30.8546	13.3066	8.5346
	Group A	31.0992	13.3085	8.6340
	Group B	31.0812	13.4586	8.5836
Green	Reference group	37.2156	-11.5866	12.2810
	Group A	37.2781	-11.5299	12.3498
	Group B	37.2499	-11.3793	12.3144
Yellow	Reference group	84.0136	-0.3196	70.3294
	Group A	84.0146	-0.5175	69.8304
	Group B	84.0124	-0.4762	69.8373
Cyan	Reference group	58.2770	-16.7134	-23.5897
	Group A	58.1428	-16.5476	-23.7693
	Group B	58.1334	-16.3019	-23.7737

With the coordinates values showed in Table 1, we calculated colour differences, using the reference group values as reference in order to calculate those differences for both groups, A and B; Table 2, and figure 4 shows the results obtained:

Table 2: Colour difference

Sample		ΔE
Red	Group A	0.2640
	Group B	0.2773
Green	Group A	0.1471
	Group B	0.0603
Yellow	Group A	0.5368
	Group B	0.5164
Cyan	Group A	0.2789
	Group B	0.4731

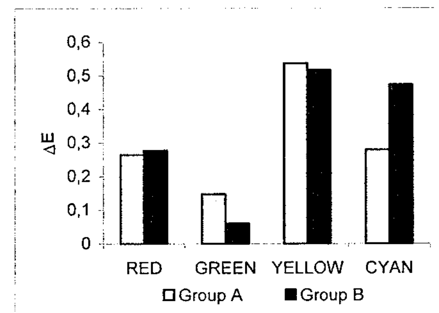

Figure 4: Colour difference

As we can see in the Table 2, the colour differences are included between 0.06 and 0.54.

The green sample shows smaller differences in both groups and the yellow bigger, too for both groups. The colour difference values are similar for the two groups, in function of the hue samples, but for the cyan sample, the difference between the group A and the group B is much bigger than the difference between these groups for the rest of the samples.
If we fix on the group A, this, shows bigger colour difference for the samples green and yellow than the group B, but for the samples red and cyan, the difference is smaller.

4. CONCLUSION

The colour difference values for both groups are within of the industrials margins of tolerance for the colour.
Viewing the colour differences obtained, is difficult to establish the error introduced by the interpolation.
The study induces to think that the hue of the samples is a factor to be considered to use a method or other. This brings to conclude that the study should be made for a bigger number of samples that includes an extensive range of coloured samples.

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Dra. Natividad Alcón; Dña. Marcela Picó; D. Francisco Redondo; D. Angel Tolosa; Dña. Elena Sanjuán, Asociación Industrial de Óptica, Color e Imagen (AIDO), Laboratorio de Colorimetría, Valencia Parque Tecnológico, C/Nicolás Copérnico 7, 46980 Paterna (Valencia) España. Phone: 34 96 131 80 51, Fax: 34 96 131 80 07, E-mail: nalcon@aido.es.

COLORIMETRICAL EVALUATION OF DYEBATH ACIDITYS' EFFECT ON WOOL COLOR

Sonja Čelan Benkovič, Darinka Fakin, Vera Golob
Faculty of Mechanical Engineering, Textile Department, Maribor, Slovenija.

Abstract

The effect of a dyebath's acidity on the exhaustion of three dyestuffs was investigated, differing in chemical constitution and color (yellow acid dye, blue and bordeaux 1:2 metal-complex dyes). The dyeing of wool tops was performed by the prescribed procedure at dyebath pH values 4, 5 and 6. The sorption of each dyestuff and their mixtures from the dyebath into the fibers was followed on-line during the dyeing process and dyed wool samples were colorimetrically evaluated.

The study of individual dye sorption from dyebaths containing mixtures of dyes in a real dyeing process is important for color reproducibility in industrial practice. The obtained results indicate great differences in the sorption of the used dyes at various pH values, which lead to color differences in wool production.

Keywords: *wool dyeing, acid dye, metal-complex dye, dyebath pH value, dye sorption, colorimetry*

1. INTRODUCTION

Wool is a natural protein fiber, composed of polymer chains containing different amino acids as monomer units. Acidic carboxyl (-COOH) and basic amino ($-NH_2$) side-groups of amino acids are responsible for the amphoteric character of wool, i.e. its ability to contain different electrical charges under varying pH conditions [1]:

H_3N^+-R-COOH ↔	H_3N^+-R-COO^- ↔	H_2N-R-COO^-
Acidic condition	isoelectric state	basic condition

In isoelectric state at pH value 4,9 both types of group are fully ionized and the net electrical charge of fiber is zero. In acidic solutions hydrogen ions react with the carboxylate anions to form carboxylic acid groups and the basic amino groups remain protonated. Hydrogen ions are abstracted from the positively charged amino groups under alkaline condition and the carboxyl ions confer a negative charge of the wool.
The dyeing of wool takes place in an acidic dyebath, where protonated basic amino groups ($-NH_3^+$) predominate and are able to bind dye anions in the dye-fibre system due to electrostatic forces. Various anionic dye classes are used for wool dyeing, amongst which the most important are:

- Acid dyes – mainly monoazo, bisazo and anthraquinone dyes that contain solubilising groups with a general formula D - $(SO_3^-)_n \cdot nNa^+$; these dyes yield brilliant ranges of colors.
- Metal complex dyes 1:2 – premetallized acid dyes during manufacture in which a metal ion (Cr, Co, Ni) is complexed with 2 molecules of monoazo dyes that contain groups (-OH, -COOH, $-NH_2$) capable of coordinating with the metals; they yield duller shades on dyed wool than acid dyes.

The dye exhaustion from the dyebath and dye diffusion and sorption into the fiber during the dyeing process depends mostly on the chemical constitution of the dyes and pH values of the dyebaths. The pH variation of the dyebath markedly influences the net positive charge of wool which affects the dye sorption and, consequently, the color of the wool [2].

The effect of dyebath acidity on the exhaustion i.e sorption of three dyestuffs was investigated. Selected dyes differing in chemical constitution and color; yellow dye is acid dye whilst blue and bordeaux are1:2 metal-complex dyes, but all three are sold in the same group as metal complex 1:2 and are usually combined in industrial practice. The obtained results indicate great differences in the sorption of the used dyes at various pH values, which lead to color differences in wool production.

2. EXPERIMENTAL

2.1 Substrate

In the dyeing experiments, Australian wool tops marked as KP-5, were used with the following properties: fineness 22.5 μm, width 70 mm, fat 0.4%, pH of water extract 6.8.

2.2 Dyes

The dyeing experiments were carried out using three dyestuffs, differing in chemical constitution and color:

- C.I. Acid Yellow 158 – acid dye (saled in the group of 1:2 metal-complex dyes);
- C.I. Acid Red 213 – 1:2 metal complex dye;
- C.I. Acid Blue 335 - 1:2 metal complex dye;

2.3 Dyeing process

The dyeing of the wool tops was performed by the prescribed procedure (Figure 1) in liquor ratio 1:20 using the Turby laboratory dyeing apparatus (producer W. Mathis).

The dyeing process started at 50°C with the addition of chemicals and auxiliaries (A). After 10 minutes the dyes were added (B) and the temperature was raised at a gradient of 1°C/min, until it reached 98°C. This temperature was maintained for 45 minutes and then reduced to 60°C. The wool samples were rinsed with warm and cold water after dyeing.

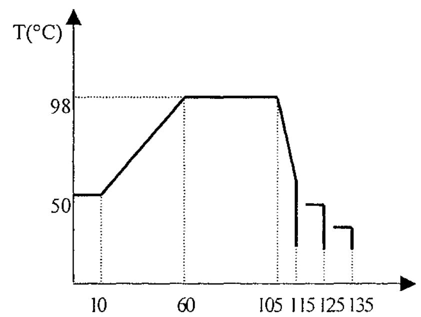

Figure 1: Dyeing procedure

Recipe:

A: wetting of wool with a bath made up of:
4% ammonium sulphate (VI)
0.4% levelling agent
acetic acid (pH 4, 5 and 6)

B: 1 % dyes

The pH values 4, 5 and 6 of the dyebath were regulated with acetic acid (CH_3COOH) and maintained at an appropriate value during the entire dyeing process using MA235 pH/Ion Analyzer (Mettler-Toledo) with a special electrode for high temperature measuring.

2.4 Analytical methods

VIS spectroscopy

The sorption of each dyestuff and their mixtures from the dyebath into the fibers was followed on-line during the dyeing process using a CARY 50 spectrophotometer (Varian) with special measuring sound (optical length l=0.2 cm).

The concentration of dye in the dyebath was determined according to the Lambert-Beer law [3]:

$$T = 10^{-k \cdot l \cdot C}; \quad A = -\log T = k \cdot l \cdot C$$

where is:

T - transmittance
A - absorbance
k - absorptivity (l/g-cm)
l - optical length (cm)
c - concentration (g/l)

The absorptivity coefficient k of each dye was determined by measuring the absorbance of five concentrations (0.01-0.05 g/L) at a wavelength of maximum absorption.

The use of a two-simultaneous equation system was applied for the analyses of two component dye mixtures:

$$A_m(\lambda_{max1}) = k_1(\lambda_{max1})C_1 + k_2(\lambda_{max1})C_2$$
$$A_m(\lambda_{max2}) = k_1(\lambda_{max2})C_1 + k_2(\lambda_{max2})C_2$$

where is:

A_m - absorbance of dye mixture
1,2 - dye 1 and 2 respectively.

Colorimetry

The reflectance values of the dyed samples were measured using a SF 600+ Spectrophotometer (Datacolor). CIELAB colour values were calculated according to next equations [4,5]:

$$L^* = 116\,(Y/Yn)^{1/3} - 16$$
$$a^* = 500\,[(X/Xn)^{1/3} - (Y/Yn)^{1/3}]$$
$$b^* = 200\,[(Y/Yn)^{1/3} - (Z/Zn)^{1/3}]$$
$$C^* = (a^{*2} + b^{*2})^{1/2}$$
$$h = \arctan(b^*/a^*):$$

where:

X,Y,Z – tristimulus values
X_n,Y_n,Z_n – tristimulus values of the pefect diffuser
L* - lightness
a* - red(+a*)/green(-a*) axis
b* - yellow (+b*)/blue (-b*) axis
C* - chroma
h – hue (+a*=0°;+b*=90°;-a*=180°; -b*=270°)

CIELAB 1976 colour differences were determined according to the equation:

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

where is:

$\Delta L^* = L^*_{sample} - L^*_{standard}$;
$\Delta a^* = a^*_{sample} - a^*_{standard}$;
$\Delta b^* = b^*_{sample} - b^*_{standard}$;
$\Delta C^* = C^*_{sample} - C^*_{standard}$;
$\Delta H^* = [(\Delta E^*)^2 - (\Delta L^*)^2 - (\Delta C^*)^2]^{1/2}$

3. RESULTS AND DISCUSSION

Sorption curves define the time-dependant distribution of the dyes between the dyebath and wool fibers during the dyeing process. The effect of dyebath pH values on the sorption of selected dyes and their mixtures at real dyeing conditions is presented in Figures 2-6.

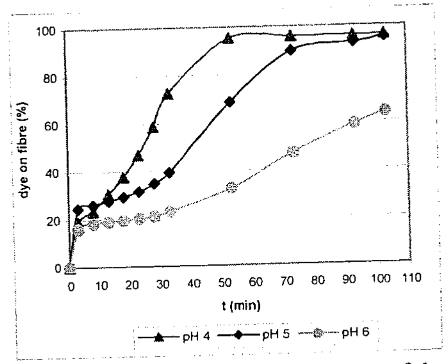

Figure 2: Effect of pH on sorption of dye C.I. Acid Yellow 158.

Figure 2 shows the effect of various dyebath pH values on sorption of acid dye C.I. Acid Yellow 158. It is obvious from the shape of sorption curves that at pH 4 more than 95% of dye is already exhausted during the heating time of dyebath from 50°C to 98°C. At dyeing temperature 98°C (45min) the dye concentration on fiber remains almost constant, only a slight migration or desorption of the dye is observed.

The rate of dye sorption is markedly reduced with increasing pH value of the dyebath. At pH 5 rapid sorption of the dye is avoided during the heating phase of the dyeing but the same final dyebath exhaustion is achieved as at pH 4. This dyeing condition is favorable for better level-dyeing performance. The dyeing at pH 6 is inappropriate for this acid dye, because only 65% of dye is uptaked by the wool fibers. The low level of dyebath exhaustion is economically and ecologically unacceptable since the dye that remains in the dyebath represents wastewater pollution.

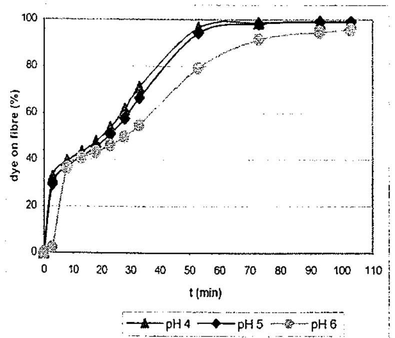

Figure 3: Effect of pH on sorption of dye C.I. Acid Blue 335.

It is evident from Fig. 3 that metal complex dye 1:2 C.I. Acid Blue 335 shows very similar exhaustion results at all given dyeing conditions. The dye is completely exhausted at pH 4 and 5 already during the heating time of the dyebath to boiling and after that no migration or desorption process occurs which can lead to unlevel results. Up to 6 the rate of sorption is reduced with the increasing of pH dyebath but the final level of dye-uptake is high.

Sorption curves of metal complex dye 1:2 C.I: Acid Red 213, illustrated in Figure 4, indicate their behavior at dyebath pH variation. The desorption of the dye is observed at pH 6 after an initial high dye exhaustion level (approx. 30% in 3 min). Total dye exhaustion is achieved at pH 4, 92% at pH 5 and 88% at pH 6 respectively during the heating of the dyebaths to 98°C and a final dye sorption of 95% is reached by both higher pH values.

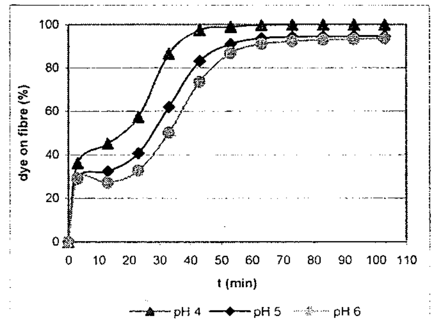

Figure 4: Effect of pH on sorption of dye C.I. Acid Red 213.

Interactions of dyes in the dyebath during the dyeing process and their effect on dye sorptions were studied by simultaneous dyeing with a mixture of two dyes in equal ratio (0.5% of each dye).

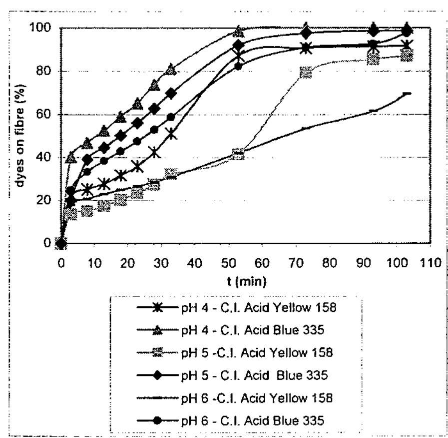

Figure 5: Effect of pH on the sorption of a singular dye when dyeing with a mixture of dyes C.I. Acid Yellow 158 and C.I. Acid Blue 335.

The sorption curves for singular dye when dyeing with a mixture of dyes C.I. Acid Yellow 158 and C.I. Acid Blue 335 are displayed in Figure 5. The sorption behavior of metal complex dye C.I. Acid Blue 335 does not change in the presence of dye C.I. Acid Yellow 158 under the used experimental conditions, since the shape of the curves remain similar to when dyed with singular dye. The sorption rate of the acid dye C.I. Acid Yellow 158 is influenced by the presence of the dye C.I. Acid Blue 335, since the sorption curves are time shifted, especially at pH 4 and 5 and the final exhaustion level is also reduced (at pH 4 by 5% and at pH 5 by 10%). At pH 6 the sorption curve of yellow dye in the mixture is identical to that when dyeing with a single dye and the rest of the dye in the dyebath is 35%.

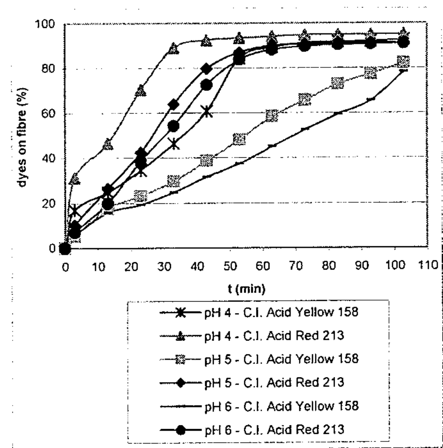

Figure 6: Effect of pH on the sorption of a singular dye when dyeing with a mixture of C.I. Acid Yellow 158 and C.I. Acid Red 213.

Similar results are obtained as for the former mixture in regard to the dye mixture of C.I. Acid Yellow 158 and C.I. Acid Red 213 (Figure 6).

The shapes of sorption curves for C.I. Acid Red 213 remain equal at defined pH values in both cases, with and without the presence of acid yellow dye, but the final exhaustion level is reduced by approx. 5% when dyeing with dye mixture. The sorption characteristics of dye C.I. Acid Yellow 158 are also similar as for the former mixture, only the final dye uptake at pH 6 is higher (80%).

Dyed samples were colorimetrically evaluated and their CIELAB color values are graphically represented in Figures 7-11.

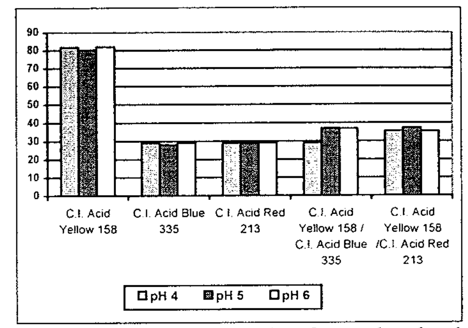

Figure 7: Lightness (L*) of samples dyed at various pH dyebath values

In figure 7 the effect of dyeing conditions on the lightness L* of the dyed samples is presented. It is obvious from the diagram that the lightness of the yellow color is much higher than the bordeaux and blue. When dyed with the mixtures of two dyes in equal ratio, the influence of the yellow dye on the lightness is insignificant compared to the other two dyes. Various pH conditions during the dyeing process only slightly affect the lightness of the wool samples.

Chromaticity values a* (red-green axis) for the dyed wool samples are presented in Fig. 8. Yellow color has negative a* value which indicates a yellow/green shade for this acid dye. The a* value for bordeaux dye is high (over 30), slightly positive a* value for blue dye indicates a reddish shade of C.I. Acid Blue 335 dye. In the yellow-bordeaux mixture the a* values are slightly reduced, while the yellow-blue mixtures turn to negative. The change in dyebath pH values doesn't significantly influence the a* values of the dyed samples, the only notable change is the mixture of C.I. Acid Yellow 158 and C.I. Acid Blue 335 at pH 6, since the sample is less green than at pH 4 in 5 due to low exhaustion of the yellow dye.

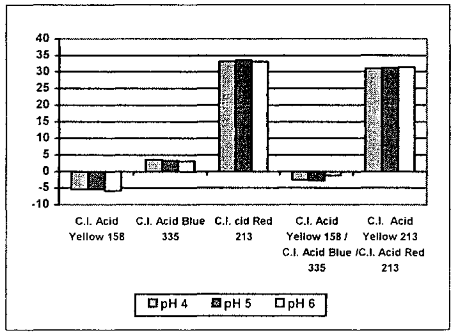

Figure 8: Chromaticity value a* of samples dyed at various pH values.

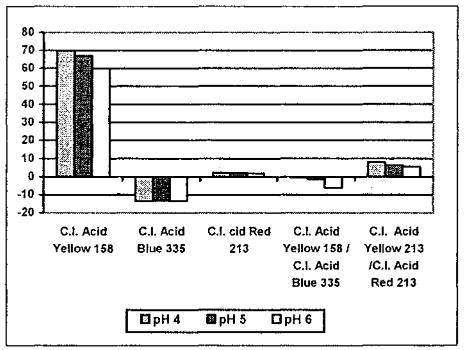

Figure 9: Chromaticity value b* of samples dyed at various pH values.

Chromaticity value b* (yellow-blue axis) of C.I. Acid Yellow 158 dye is very high, but is significantly decreased with increasing dyebath pH value (Fig. 9). The b* value for bordeaux is slightly positive and for blue, negative and both remain constant with pH variation. Both dye mixtures have the lowest b* value at pH 6.

All three used dyes have different chroma values when dyed in 1% concentration (Fig. 10). C.I. Acid Yellow 158 exhibits the highest C* which changes similar to b* value at various pH. The chromas of C.I. Acid Blue 335, C.I. Acid Red 213 as well as the mixture of C.I. Acid Yellow 158 and C.I. Acid Red don't significantly change with pH variations. Only a slight increase of chroma is obvious for the mixtures of C.I. Acid Yellow 158 and C.I. Acid Blue 335.

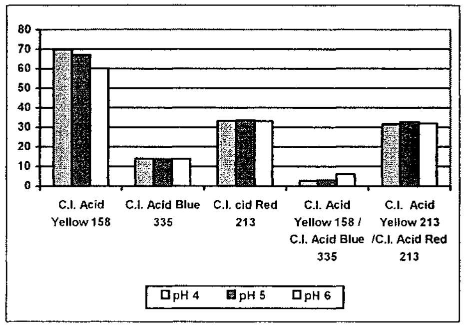

Figure 10: Chroma(C*) of samples dyed at various pH values.

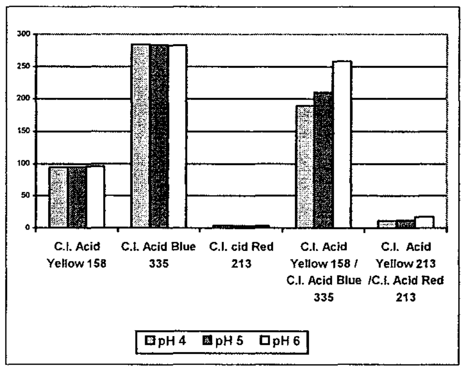

Figure 11: Hue h of samples dyed at various pH values

Hue of the samples dyed with single dyes (Figure 11) remains unchanged at various dyebath pH values. For both mixtures the dyes C.I Acid Blue 335 and C.I. Acid Red 3 have a dominant effect on hue values that increase with increasing pH.

Table 1: CIELAB colour differences of samples dyed at various pH values (d/8; D65/10; standards-samples, dyed at pH 4)

Sample	*pH*	*ΔE**	*ΔL**	*Δa**	*Δb**	*ΔC**	*ΔH**
C.I. Acid Yellow 158	5	3.13	-1.39	-0.03	-2.80	-2.79	0.25
	6	9.84	0.34	-0.52	-9.82	-9.74	1.37
C.I. Acid Blue 335	5	0.55	0.10	-0.54	0.05	-0.17	-0.51
	6	1.05	-0.99	-0.30	0.19	-0.26	-0.25
C.I. Acid Red 213	5	0.33	0.19	0.02	-0.27	0.01	0.27
	6	0.63	-0.44	0.39	-0.22	0.38	-0.25
C.I. Acid Yellow 158 and C.I. Acid Blue 335	5	1.16	-0.21	-0.12	1.14	0.51	1.02
	6	5.87	0.03	1.36	-5.71	3.62	4.62
C.I. Acid Yellow 158 and C.I. Acid Red 213	5	1.17	0.23	0.40	-1.08	0.16	-1.14
	6	1.78	0.72	-0.46	1.56	-0.06	1.62

For determination of color differences (Table 1) all samples dyed at pH 4 were used as standards. The greatest color difference occurs for the yellow dye at pH variation. As a result the different dyeing properties of this acid dye at various pH values lead to color differences for both mixtures. Dye mixtures of C.I. Acid Yellow 158 and C.I. Acid Red 213 exhibit the highest Δb* and ΔH*. Color differences for C.I. Acid Red 213 and C.I. Acid Blue 335 are acceptable.

4. CONCLUSION

The study of individual dye sorption from dyebaths containing mixtures of dyes in a real dyeing process is an important parameter, which makes possible quality preparation and realization of dyeing processes and assures color reproduction in industrial practice. The obtained results indicate that:

- Varying of pH dyebath values effects the dye sorption.
- The best dye exhaustion from the dyebaths is obtained at pH 4.
- The most sensitive to pH variation is acid dye C.I. Acid Yellow 158; at pH 6 aprox. 35% remains in the dyebath.
- 1:2 metal-complex dyes C.I. Acid Red 213 and C.I. Acid Blue 335 have similar dyeing properties at applied pH values.
- Colorimetrical evaluation and determined color differences prove the exhaustion results.
- The greatest color differences occur when dyeing wool at pH 6 using dye C.I. Acid Yellow 158 and its mixture with dyes C.I. Acid Blue 335 and C.I. Acid Red 213, because this acid dye exhibits the worst exhaustion level compared to the other two dyes.
- Better exhaustion of the dyes from the dyebaths during the dyeing process reduces dye concentration in wastewater and enhances environmental protection.

5. REFERENCES

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Sonja Čelan Benkovič; M.Sc. Darinka Fakin; Assoc. Prof. Dr. Vera Golob, University of Maribor, Faculty of Mechanical Engineering, Department of Textile, Smetanova 17, SI-2000 Maribor, Slovenia. Phone: +386 2 220 7901, Fax: +386 2 220 7990, E-mail: sonja.celan@uni-mb.si

COLOR MEASUREMENT OF FLUORESCENT TEXTILES

Helen H. Epps
The University of Georgia, Athens, Georgia, USA

Abstract
Increasing use of fluorescent dyed textiles has drawn attention to the problem of accurately measuring the color of fluorescent materials. In the typical non-fluorescent sample, visible light that leaves the sample surface (the reflectance of the sample) at a particular wavelength depends totally on the amount of light incident on the surface at that particular wavelength. However, the situation is different in a fluorescent sample. In a fluorescent sample, the visible light that leaves the surface at a particular wavelength is dependent upon both the incident light at that particular wavelength, and light which is incident at other wavelengths, which may be absorbed at the incident wavelength and emitted at another wavelength. Standard color spectrophotometers measure light that leaves the sample surface at particular wavelengths. Such measurements are accurate for non-fluorescent materials, but may be of questionable accuracy for fluorescent materials. Four textile samples of different colors, which exhibited different levels of apparent fluorescence, were evaluated. Measurements were taken using a more traditional type color spectrophotometer and also using a bispectral reflectance colorimeter, which separates regular reflectance spectra from spectra of light that is emitted as fluorescence. Spectra from each type of instrument are compared for the four fabrics.

Keywords: *reflectance, fluorescence, color spectrophotometer, bispectral colorimeter*

1. INTRODUCTION

Because they are highly conspicuous, fluorescent colored textiles are often used in safety applications and in recreational apparel. Many fluorescent-dyed fabrics have poor colorfastness to light, while most of the safety applications for which they are used require that they be subjected to sunlight continuously. Typically, as fluorescent colored fabrics fade, they lose their fluorescent quality, and therefore, are no long conspicuous in safety warning applications. For these reasons, an accurate measure of the color of fluorescent materials is crucial in determining the usefulness of such products.

The amount of visible light that leaves the surface of a non-fluorescent material at a particular wavelength depends solely on the amount of light incident on the material at that particular wavelength. However, the visible light that leaves the surface of a fluorescent material is dependent on both the incident light at that particular wavelength, and the incident light at other wavelengths. This characteristic of absorbing light at one wavelength and emitting it at a different wavelength complicates the color measurement of fluorescent materials. Methods used and possible problems associated with color measurement of fluorescent textiles and other materials have been addressed by previous researchers [1-7].

Standard spectrophotometers of the visible-range type are designed primarily to measure color of non-fluorescent materials, although some such instruments provide partial characterization of fluorescent

materials. For example, reflectance spectra measured using a 31-point color spectrophotometer will indicate a reflectance of greater than 100 percent in the region of fluorescence. This may indicate that incident ultraviolet light is emitted or "reflected" in the visible region of the electromagnetic spectrum. Not only is this indication of greater than 100 percent reflectance misleading to some users, measured tristimulus values and other standard measurements such as CIELAB values determined using such an instrument may be inconsistent and inaccurate.

A bispectral reflectance colorimeter is intended to provide more accurate color measurement of fluorescent materials. The bispectral colorimeter utilizes two monochromators, namely an excitation monochromator which separates light before it reaches the specimen, and an emission monochromator which enables measurement of the light at different wavelengths as it is emitted from the specimen.

The objective of this research was to compare reflectance measurements taken by the two different types of instruments on fabrics of various colors exhibiting different amounts of apparent fluorescence.

2. MATERIALS AND METHODS

Samples of four different commercially available textile fabrics were used. The fabrics were selected for the study based on their apparent fluorescence or non-fluorescence as assessed visually under ultraviolet light in a standard light box. Two samples, red, and blue, did not exhibit fluorescence when viewed under ultraviolet light, while the other two samples, pink, and green, were obviously fluorescent when viewed under ultraviolet light. To more specifically characterize the different fabrics, their CIELAB values are indicated in Table 1. The CIELAB measurements were taken using a standard 31-point color spectrophotometer, illuminant D-65, and 10-degree observer functions.

Table 1: CIELAB Values of Fabrics

Sample	L*	a*	b*
1. Blue	42.36	4.25	-46.53
2. Pink	67.93	59.33	-14.26
3. Green	81.85	-44.78	53.12
4. Red	36.57	53.88	22.55

Spectral measurements were taken of the samples using using two instruments: a Macbeth Color Eye, 31-point visible range spectrophotometer, and a Labsphere BFC-450 bispectral fluorescence colorimeter. Using the BFC 450 instrument, spectral radiance factors were analyzed every 10 nm of the visible region from 380 to 780 nm, based on incident light that spanned the range of 300 to 780 nm. Measurements were compared with reflectance spectra using the traditional visible range spectrophotometer.

3. RESULTS AND DISCUSSION

Results will be presented separately for each of the four fabrics, including both reflectance spectra taken with the standard color spectrophotometer, and bi-spectra measured with the bispectral fluorescence colorimeter.

Blue Fabric
Measurements of Fabric 1, which was relatively dark blue in color and had been previously determined to be non-fluorescent when viewed under ultraviolet light, are shown in Figures 1 and 2.

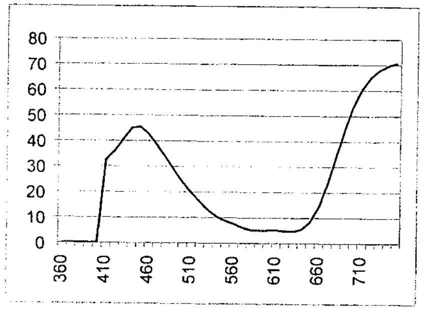

Figure 1: Standard Reflectance Spectra of Blue Sample

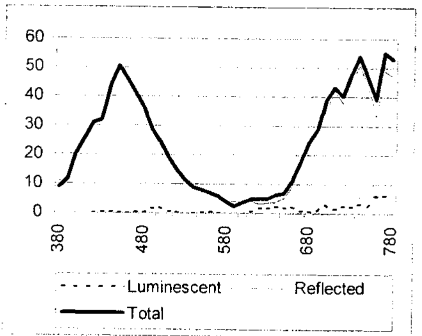

Figure 2: Bispectral Colorimeter Spectra of Blue Sample

Figure 1 shows the characteristic blue peak near 460 nm, and also a peak near 700 nm, corresponding with the purple-blue color, and with the CIELAB values shown in Table 1. Figure 1 also shows that the maximum reflectance of the specimen is less than 100%, which would be typical of the spectra of such a fabric as measured by the standard color spectrophotometer. Figure 2 shows the measurement taken by the bispectral colorimeter. These spectra show a small but negligible amount of luminescence (fluorescence). When combined with the measured reflectance, the total, indicated by the bolder line, shows a maximum percentage of approximately 55.

Pink Fabric

The representative spectra for fabric 2, pink, are presented in Figures 3 and 4. This fabric did appear to be fluorescent when viewed in the light box under ultraviolet light, although its fluorescence was not as obvious visually as that of the green fabric.

Figure 3: Standard Reflectance Spectra of Pink Sample

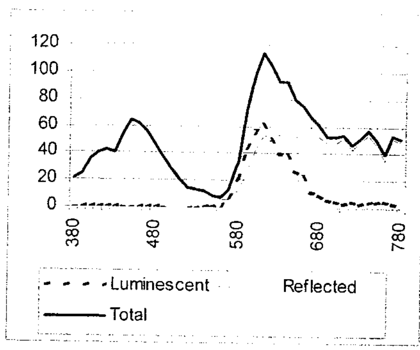

Figure 4: Bispectral Colorimeter Spectra of Pink Sample

The light bluish-pink color corresponds with the high L* value and positive a* and negative b* values, and with the peak at approximately 610 nm in its standard reflectance spectrum, and a smaller peak, corresponding with the sample's blueness, between 410 and 460 nm. (Figure 3). Figure 3 also indicates a reflectance measurement of greater than 100%, near 610 nm.

Measurements taken with the bispectral colorimeter, shown in Figure 4, provide additional information about this specimen. While the solid bold line, representing the total of luminescence and reflection, is near 120% at approximately 610 nm, the actual reflectance spectrum, indicated by the finer solid line, shows a maximum true reflectance of slightly less than 60%, and a fluorescent (luminescent) component of up to 60%. Thus, it is the combination of the actual reflectance and the fluorescent component shown in Figure 4, which results in the indication of greater than 100% reflectance in Figure 3.

Green Fabric

The green fabric, which visually appeared to be highly fluorescent when viewed under ultraviolet light, was the lightest of the four fabrics. Representative spectra for this fabric are presented in Figures 5 and 6.

Figure 5: Standard Reflectance Spectra of Green Sample

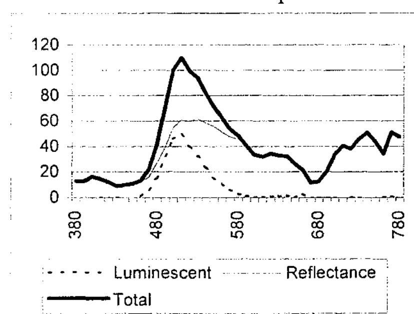

Figure 6: Bispectral Colorimeter Spectra of Green Sample

Figure 5 shows a characteristic "green" peak near 520 nm, but interestingly, the total reflectance shown in Figure 5 is less than 100 %, which would not cause the user of this data to suspect that the fabric might exhibit fluorescence.

The bispectral Figure 6 more accurately characterizes the specimen. The figure shows an actual reflectance of approximately 60% at the green peak, and a very significant fluorescence peak of about 50% in the same region of the spectrum. When combined, the total spectrum peaks at 100%.

Red Fabric

The red specimen was the darkest of the four fabrics. It did not appear to be fluorescent when viewed under ultraviolet light, nor was fluorescence indicated in its reflectance spectrum as measured by the color spectrophotometer. The representative spectra for this fabric are presented in Figures 7 and 8. The apparent reflectance shown in Figure 7 is higher than that shown in Figure 8, and the raw data do indicate possible activity of a fluorescent component at a very low level, which might account for a portion of the difference between the two spectra.

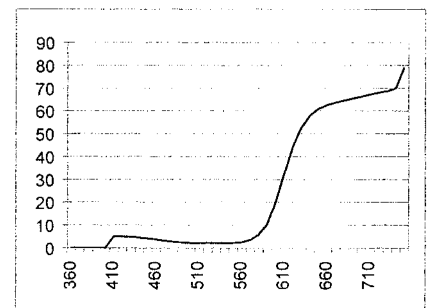

Figure 7: Standard Reflectance Spectra of Red Sample

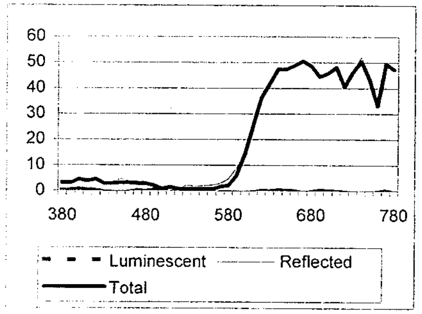

Figure 8: Bispectral Colorimeter Spectra of Red Sample

4. SUMMARY AND CONCLUSIONS

The findings of this study indicate that compared to the traditional type of color spectrophotometric measurements, the bispectral fluorescence colorimeter more accurately characterizes the color and fluorescence of both fabrics that are visibly fluorescent and those that do not exhibit fluorescence when viewed under ultraviolet light. Also, color measurements were found to be more reproducible using the BFC-450, and were more accurate measures of the true color of the materials. Darker colored textile specimens, which showed less fluorescent color as measured by the bispectral colorimeter, were more consistent with traditional spectrophotometric readings. However, it is possible that in darker specimens such as the blue and red fabrics, a small amount of fluorescence may have been masked by the dark color. This is more likely to have occurred in the blue fabric, whose bispectral raw data indicated slightly more fluorescent activity than in the red fabric.

Although measurements require more time, and the instrument is more expensive, for applications in which accurate color measurement of fluorescent materials is necessary, a bispectral instrument is recommended because of its accuracy and reproducibility.

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Dr. Helen H. Epps, Professor, Department of Textiles, Merchandising and Interiors, Dawson Hall University of Georgia, Athens, Georgia, USA 30602. Phone: 706-542-4913, Fax: 706-542-4890, E-mail: Hepps@fcs.uga.edu

COLORIMETRICAL DETERMINATION OF DISPERSE DYES' COLOR GAMUT

Darinka Fakin[1], Darko Golob[1], Veronika Vrhunc[2]

[1]University of Maribor, Faculty of Mechanical Engineering, Textile Department, Maribor, Slovenia.

[2]IBI Kranj, Slovenia

Abstract

Designers have to consider color gamut when creating a new pattern collection that depends on the selections of substrate, available dyes and the dyeing process. Most of the colors required can be obtained by mixing three dyes for ternary combination in different proportions. Samples were prepared for the color gamut determination of PES yarns dyed with selected disperse dyes using various concentrations of a single dye and mixtures of two adjacent dyes after a high– temperature exhaustion dyeing procedure. The dyed samples were colorimetrically evaluated using CIELAB color values L, a*, b*, C* and h, and graphically presented in CIELAB color space.*

Keywords: *PES, dyeing, disperse dye, colorimetrical determination, color gamut*

1. INTRODUCTION

Contemporary manufacturing trends demand a prompt response to the Market. This primarily means reliable scheduling of textile production starting from the development and design of the product, continuing with optimization of the technological processes and, finally, quality control. The assurance of these elements demands a lot of knowledge and collaboration work for designers and technologists supported by advanced information technology and equipment. In the production of colored textiles a computer-aided system for color evaluation and match predictions is particularly important.

Definition of color space enables quick determination of any possibility to achieve a desired color using selected dyestuffs and a foreseen technological process. It is also a useful aid in communication among designers, technologists and sellers. It also enables optimal recipe preparation, reduces the number of dyes needed for the dyeing of selected substrates, shortens production time and reduces recipe preparation costs, as well as dyeing costs.

2. DYEING OF POLYESTER

2.1 Polyester

The production of polyester fibers is based on the condensation of ethylene glycol and dimethylterephtalate (or terephthalic acid), followed by polymerization (Figure 1)[1]:

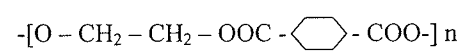

Figure 1: Chemical constitution of PES

The chemical and supramolecular structure has a marked effect on the dyeing properties of PES fibers. The absence of ionic groups and high degree of crystallinity inhibits the uptake of water and, consequently, dyes below glass transition temperature (T_g>80 °C). T_g can be influenced by variations in chemical structure and by the degree of crystallinity. Heat - setting before dyeing influences the dyeing properties such as rate of dye diffusion, uptake of dyes and fastness.

Polyester is the most important of all synthetic fibers and is renowned for its high tensile strength (39 – 49 cN/tex), excellent durability of wear and resistance to chemicals. The deficiency of polyester is its hydrophobic character, tendency to pill and to electrostatic charge. PES fibers are used in staple and filament form and are suitable for blending with cotton and wool.

Only disperse dyes can be applied for the dyeing of polyester due to its high crystallinity, hydrophobic character and close packing of the polymer chains in the direction of the fiber axis.

2.2 Disperse dyes

Disperse dyes are hydrophobic, nonionic aromatic compounds, derived largely from azo and anthraquinonoid chromophores [2]. They are crystalline substances with low molecular mass and high melting-point (150°C) and their structures also include groups such as $-NO_2$, $-OH$, $-NH_2$ or $-NHR$.

Disperse dyes are sold as fine powders or dye pastes with the particles size in the range of 0.5 – 2 μm and form stabile dispersions with additional dispersing agents. Disperse dyes are scarcely soluble in water (approximately 0.1mg/l).

Disperse dyes are classified into different groups according to their dyeing properties and fastness. The dyeing characteristics of disperse dyes vary considerably and are largely influenced by molecular structure. The chemical structure of an azo disperse dye is shown in Figure 2.

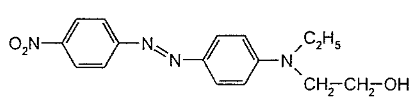

Figure 2: Structure of an azo disperse dye

Dyes of low molecular size (relative molecular mass about 250 – 300) have good diffusing and leveling properties, but poor fastness to heat treatments. Dyes of higher molecular size have improved fastness, but the migrations properties and rate of sorption are affected.

2.3 Exhaustion dyeing process of PES

In the exhaustion dyeing process, disperse dyes are applied from stable aqueous dispersion, therefore, the inclusion of anionic surface–active dispersing agents in the dyebath is a crucial factor in the application of disperse dyes. Above the critical concentration in the aqueous dyebath dispersing agents form, due to their dual character, spherical micelles, in which the hydrophobic chains are oriented toward the center and hydrophilic anionic groups toward the surface. The hydrophobic part of the micelles encapsulates the disperse dye particles and solubilises dye molecules. Negatively charged micelle surfaces repel each other and consequently enable an equilibrious distribution of solid dye particles of various sizes, thus preventing agglomeration and the crystallization of disperse dyes. In the presence of dispersing agents and at higher application temperature disperse dyes dissolve to the molecular state sequentially during the dyeing process [1,3].

PES macromolecules become more flexible and mobile at higher dyeing temperatures, above 100°C, which leads to the formation of free volume in the amorphous phase of fibers. Only dyes in the molecular state are first adsorbed onto the fiber's surface and then transferred into the free volume of polyester fibers. Dyeing, therefore, takes place from a saturated dye solution where undissolved particles of dye act as a reservoir, i.e., as dissolved dye is taken up by the fiber, the dyebath is continuously replenished by progressive dissolution of dye particles in dispersion.

The thermal agitation of both polymer and dye molecules is increased at high temperature dyeing (120-130 °C) and the rate of dye diffusion into the fiber is

enhanced. The conventional dyeing process of PES is performed under acid conditions, about pH 5.

The dye-fiber system originates in hydrogen bonding, dipol-dipol interactions and dispersion forces. The fiber reverts back to its close packing state after cooling below glass transition temperature which traps the dye molecules within the polymer structure.

The undesired occurrence of oligomers during dyeing requires reduction clearing as an after-treatment.

3. EXPERIMENTAL

3.1 Dyeing of PES yarn using selected disperse dyes

The PES yarns were dyed for color gamut determination of the selected disperse dyes using three dyes for ternary combination:

- Foron yellow RD – 4GRL
- Foron red RD – GL 200%
- Foron blue RD – 3GN 300%

The dyeing of the PES yarn was performed using an exhaustion dyeing process according to the dye-producer's procedure (see dyeing method - fig. 3) at liquid ratio 10:1, using a LABOMAT BFA laboratory machine (producer - W. MATHIS AG).

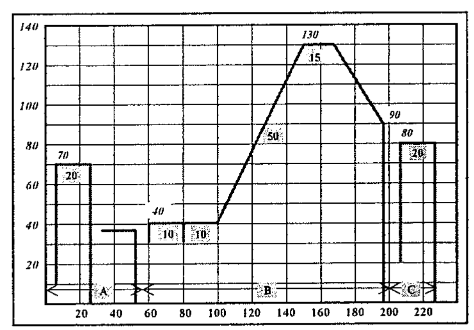

Figure 3: Dyeing procedure

Recipe and dyeing conditions:

A - pretreatment

0.3 g/l Nofome BLF A 82
2.0 g/l Kyolox FOL
1.0 g/l Na_2CO_3

B - dyeing

0.3 g/l Nofome BLF A 82
1.0 g/l Sandacid DSB
1.0 g/l Lubit PRT
1.0 g/l Tanadey M conc.
2.5 g/l DS – 14
0.6 g/l Tanapal LD – 3
x % FORON dyestuff

C - reduction clearing

1.0 g/l Tanavel DC
1.0 g/l NaOH
1.0 g/l $Na_2S_2O_4$

Samples were dyed using all three single dyes and combinations of two dyes (Yellow-Blue, Yellow-Red, Red-Blue), each in ratio 1:3, 1:1 and 3:1. Four different concentrations were chosen (0.01%, 0.2%, 1%, 4%) to provide dyed samples varying in lightness, chroma and hue.

3.2 Colorimetric definition of color gamut

The spectral reflectances of dyed PES sampes were measured using a Datacolor SF600+ Spectrophotometer and evaluated using CIELAB color space [4,5].

The 1976 CIELAB color space is widely used in the textile industry. It is a combination of the Cartesian and cylindrical coordinate systems as shown in Figure 4.

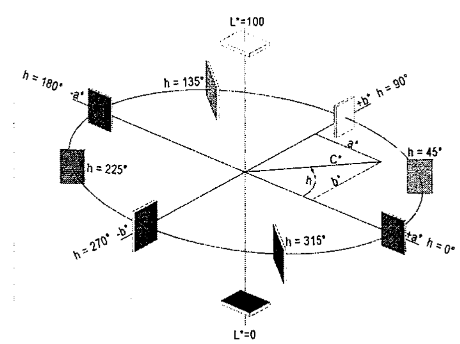

Figure 4: CIELAB color space.

Cartesian CIELAB coordinates are calculated from the tristimulus values according to the following equations:

$$L^* = 116\,(Y/Yn)^{1/3} - 16$$
$$a^* = 500\,[(X/Xn)^{1/3} - (Y/Yn)^{1/3}]$$
$$b^* = 200\,[(Y/Yn)^{1/3} - (Z/Zn)^{1/3}]$$

where:

X,Y,Z – tristimulus values

X_n, Y_n, Z_n – tristimulus values of the perfect diffuser

L* - lightness

a* - red(+a*)/green(-a*) axis

b* - yellow (+b*)/blue (-b*) axis

Recognizing the usefulness of the cylindrical coordinate concept, the chroma and hue were defined, derived from the rectangular coordinates a* and b*:

$$C^* = (a^{*2} + b^{*2})^{1/2}$$
$$h = \arctan(b^*/a^*)$$

where:

C* - chroma

h - hue (+a*=0°;+b*=90°;-a*=180°; -b*=270°)

4. RESULTS AND DISCUSSION

Figure 4 shows the reflectance curves of the samples dyed using 0.5 % of a single dye or mixtures of two dyes in equal ratio.

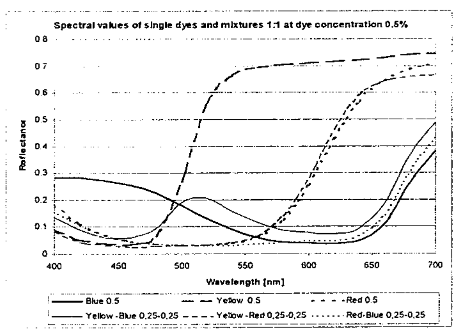

Figure 4: Reflectance curves for single dyes and their mixtures of two (concentration 0.5 %)

CIELAB color coordinates a*and b*of the PES samples dyed with different dye concentrations of a single dye and two-dye mixtures, are graphically presented in the a*-b* diagram (Figure 5). The color of the samples and, thus, the position on the diagram depends on the amounts of each dye in the recipe, which leads to different CIELAB color values. In spite of the constantly changing steps in the dyes' concentrations in the two-dye combinations (1:3, 1:1 and 3:1), the color samples are rather unequally dispersed in a color space.

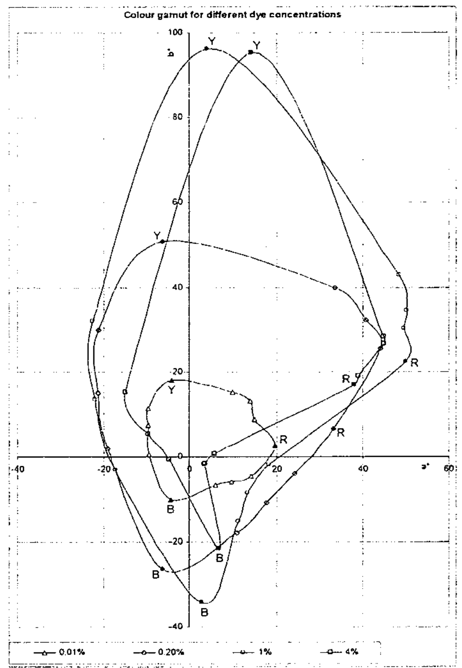

Figure 5: Color gamut of samples dyed with different dye concentration

From the graphical representation of the dyed samples' positions using dye concentrations of 0.01%, 0.2%, 1%, and 4%, it can be seen that selected disperse dyes and their combination in different concentrations define different dimensions of the color gamut. The position of samples, dyed with lower concentrations (0.01%), shows a narrower color space, while the

samples, dyed in a concentration of 1%, are arranged on the outer edge of a color space because of clearer, more chromatic colors. The increased dye concentration causes a narrowing of the color space, namely, brighter and darker colors are less chromatic. The yellow region (+b* axis) is the only exception to the rule. Higher concentration of yellow dye causes increased chroma, which also stays high at 4% coloration. The decrease in the a* value of the samples, dyed with a combination of red and blue in higher concentrations is especially interesting.

The relationship between the lightness L* and hue h of the samples is shown in the L*-h diagram, Figure 6. Hue value increases in the circle from red (+a*, h=0), over orange to yellow (+b*, h=90), over green (-a*, h=180), blue (-b*, h=270) violet and concludes with magenta color shades. It can be seen from these results that yellow dye (h=90) has the highest lightness L*, which decreases only slightly with any increase of dye concentration. In combination with red or blue dye, its lightness decreases. The lowest lightness was observed when combining blue and red dyes, i.e., in violet color shades.

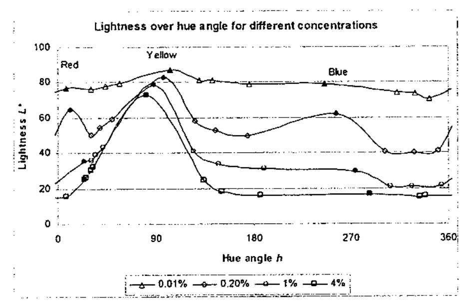

Figure 6: Relationship between lightness L* and hue h of the samples

5. CONCLUSION

Modern work procedures and the definition of a color space, as determined by CIELAB values L*, a*, b*, C*, and h of dyed samples and their graphical representation in CIELAB color space, enable us to produce the desired, resp. requested color shades using selected dyes and substrates. The majority of requested color shapes can be achieved by combining three dyes, i.e., using a ternary combination by mixing the dyes in different proportions.

The a*-b* diagram shows the color gamut achievable using three selected disperse dyes at different concentrations. It is evident that the green part is very narrow indicating a shortage of disperse dyes. The purple area at higher concentration also offers low chroma. The yellow colors are lighter and more saturated than the others.

Color gamut definition quickly determines whether it is possible to achieve the desired color using selected dyes and a planned technological process and is useful in helping communication among designers, technologists and sellers.

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M.Sc.Darinka Fakin[1], M.Sc.Darko Golob[1], Veronika Vrhunc[2], [1]University of Maribor, Faculty of Mechanical Engineering, Textile Department, Maribor; [2]IBI Kranj, Slovenia. Phone: +386 2 220 7637, Fax: +386 2 220 7990, E-mail: darinka.fakin@uni-mb.si

BIOPREPATION OF COTTON - INFLUENCE ON DYEING PROPERTIES

Ana Marija Grancarić, Đurđica Parac-Osterman, Ivo Soljačić
University of Zagreb, Faculty of Textile Technology, Zagreb, Croatia

Abstract
Scouring of cotton removes impurities from the primary wall of cotton fibres in order to reach much more water absorptivity of cotton which is main condition for dyeing, printing and finishing. These impurities contain waxes, pectins, proteins, noncelullosic polysaccharides, inorganic compounds, lignin, coloring materials etc. that makes cotton hydrophobic.
Traditional scouring with sodium hydroxide solution effectively removes impurities but has several disadvantages. Such scouring process leads to high weight loss of cotton fibers, having high-energy requirement and yield waste products.
Recently biopreparation (or "bioscouring") of cotton was developed as an alternative scouring process using newly isolated powerful pectinase that removes impurities under slightly alkaline conditions. These pectinase are able to hydrolyze the glucosidic linkages of polygalacturonic acid into galacturonic acid monomers. With removal of polygalactironic acid the rest of pectic material and other substances from primary wall are mainly removed. Such scouring can be targeted to only the impurities with intacted cellulose structure.
The objective of our paper is to investigate the influence of bioprepared and conventionally scoured cotton knit fabric on differences of reactive dyestuff yield. For such purpose dyeing processes were performed using bifunctional reactive dyestuff Bezaktiv Red S-3B by an exhaustion method.
The percentages of dyebath exhaustion and fixation values were determined specrophotometrically. Color yields of cotton knit samples, in the form of K/S and CIELAB values were measured using Datacolor system.

Keywords: *Cotton knit fabrics, cotton pretreatment, pectinase scouring, reactive dyeing of cotton*

1. INTRODUCTION

Cotton preparation is important part of events that converted greige cotton to a dyeable material using different wet processes. The goal of scouring and bleaching of cotton is to remove the impurities and render the fabric suitable for dyeing. These processes require the use of harsh chemicals like high concenrtration of NaOH and H_2O_2 respectively. The effects of scouring is a fabric that has good wetting characteristics and high level of whiteness necessary for white goods and for dyeing to light shades. For such environmentally "unfriendly" systems over the past few years alkaline pectinase was involved as a novel process in cotton preparation referred to as "Biopreparation " or "Bioscouring". The improvements of such processes are increased.
Experiments were carried out to determine the kinetics of uptake od two reactive dyes on both a pectinase and caustic cotton knitted fabric.

The purpose of this work is to compare dyeability of traditionaly scoured and enzymatic scoured cotton knit fabrics.

2. MATERIALS AND METHODS

The fabric used was raw 100% carded cotton circular weft knitted fabric (163 g/m^2), 56 cm (22 inch) width in tubular form, having 15 wale/cm and 20 courses/cm.
A commercial pectate lyase product BioPrep3000L (3000 APU alkaline pectinase units) from Novozymes A/S of Bagsvaerd was used for bioscouring of cotton-.
Saples of cotton fabric were cut to the desired size for achieving weigth of 20g. One set of samples was traditionally scoured with NaOH, prebleached and bleached in peroxide baths. One set of samples was enzymatic treated with alkaline pectinase BioPrep 3000L supplied by Novozymes in the following standard strengh 3000 APSU/g was applied. Enzymatic treatments was performed in the bath containing 0.1% (owf) BioPrep 3000 L, nonionic surfactant Kemonetzer NI (Kemo) 0.5 g/L and buffer (Na_2HPO_4), pH 9.2 and 65°C, at liquor ratio 1:10 in the Linitest (Original, Hanau). Sodium salt of EDTA (0.4g/L) was added at the end of the treatment followed by rising the temperature to 90°C and continues to treat for next 15 minutes. The enzymatic treated samples were washed in hot water followed by warm and cold water and then air dried.
The pretreated cotton knit samples were dyed with vinylsulfon C.I. Reactive Blue 19 in two depth of shade (1% and 3% owf). The dying was performed in Linitest's stainless steel dyepots of 300 cm^3, using liquor ration 10:1, at 60°C, 45-90 min. At the end of dyeing, the cotton sample was removed, rinsed thoroughly in hot water (80°C) following by rinsing in cold water and drying in the open air.
Absorbancy of cotton samples were measured according to standard vertical wicking test, SNV 9858, and wicking test according Chibowski. In the vertical wicking test the lower edge of a sample with dimensions of 20.0 by 3.0 cm was placed 1cm vertically in the vessel with water. The time allowed for the water front to move was set to 5 minutes. In the wicking test according Chibowski a procedure was like a vertical test but a cotton strip was placed under the small angle (10°) in the closed chamber used for planar chromatography.
CIE whiteness degree and K/S value for dye uptake were measured using Datacolor SF 600 PLUS CT.
The uptake of dyes on cotton was calculated by measuring the absorbance of the dye liquor before and after dyeing, for Bazaktive Red S3-B at nm and for Bezaktive Brillant Blau V-R at nm. The percentage covalent fixation of dye on fibre was measured by extracting any unfixed dye from the cotton sample using 0.02 mol/L NaOH and 0.06 mol/L NaH_2PO_4 solution. Sample was refluxed in this solution at boiling point until the solvent remained colourless.
After drying K/S values of samples were measured Whiteness degree and Kubelka-Munk index (K/S) were evaluated on Datacolor SF 600 Plus:CT. The percentage of covalent fixation of the C. I. Reactive Blue 19 on the cotton fabric was determined by measuring the absorbance values degree of dye fixation. Dye yield is defined as the amount of dye required to obtain and desired color shade.
Scouring process today is process of environmental problems due to high COD, BOD and salt contents in the effluents. Enzymatic scouring of cotton has been established by using small dosages of alkaline pectinase to treat cotton and obtain adequate water absorbancy, the key objective in the preparation of cotton. These advanteges that make enzymatic scouring commercially attractive include more readily treatable wastewater, energy saving

and non attaching the cotton cellulose what is of same importance as well.

3. RESULTS

In Tab. 1 weight loss, absorbancy data and degree of whiteness are summarized. Compared with traditionally scoured cotton of 4.1% weight loss obtained with pectinase is little lower, 3.14 %. Water absorbancy of pectinase and alkaline scoured samples clearly showed highest values of alkaline scoured cotton in wicking test according Chibowski and only a little lower values in the vertical test. In alkaline scouring and bleaching the cotton cellulose is demaged and than expected considerable higher weight loss. From data in Tab.1 it can be seen that whiteness of alkaline scoured and pectinase scoured cotton is of minor difference. There is no doubt for highest whiteness of bleached samples.

In Fig. 1. and 2. uptake of 1% and 3 % of C-.I: Reactive Blue 19 on conventionally scoured, enzymatic scoured, prebleached and bleached cotton knit fabric are shown. Fig.3 and 4 show the percentage of extracted C.I. Reactive Blue 19 from dyed above cottons. In Fig.5. it can be seen the colour strength (K/S) of uptaked and fixed C.I. Reactive Blue 19 on the cotton samples.

Table 1: Relative Weight loss (%), Wicking length (*l*/cm); Vertical by method according Chibowski, CIE Whiteness (CIE W) for Raw (R) and Pretreated (S -Scoured, E-Enzymatic scoured, P-Prebleached and B - Bleached) Cotton Knit Samples

Cotton Knit Sample	Weight loss %	Wicking length **(vertical)** *l*/cm	Wicking length **(Chibowski)** *l*/cm	CIE - W
R-raw	-	0.0	0.0	8.8
S-scoured with NaOH	4.41	7.3	14.0	13.3
E-enzymatic scoured	3,14	1.5	2.8	11.7
P- prebleached	5.46	7.1	13.5	58.6
B-bleached	6.21	5.4	11.2	78.6

The results indicate that enzymatic scouring provides better wetting properties that conventional scouring.

The wettability of pectinase treated raw cotton fabric improved but remained less then the conventionally scoured fabric. Comparing the pretreatment of cottons with dyebility it is clear that for applied C.I. Reactive Blue 19 dye the uptake dye is of the highest value for enzymatic scoured cottons, for 1% and 3% dye as well.

Figure 1: Uptake of C.I.Reactive Blue 19 on conventionally scoured (S), enzymatic scoured (E), preableached (P) and bleached (B) cotton knit fabric

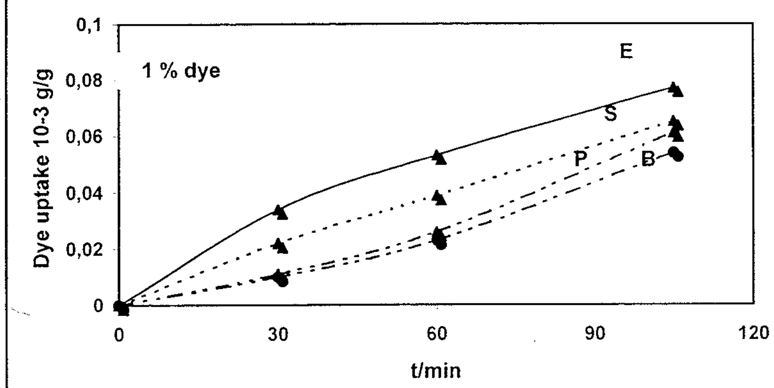


Figure 2: Uptake of C.I.Reactive Blue 19 on conventionally scoured (S), enzymatic scoured (E), preableached (P) and bleached (B) cotton knit fabric

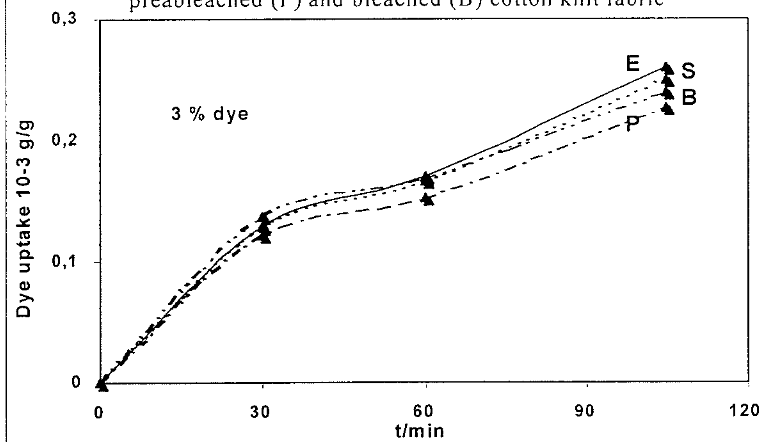


Figure 3: Extracted C.I.Reactive Blue 19 from dyed cotton knit fabric-conventionally scoured (S), enzymatic scoured (E), prebleached (P) and bleached (B)

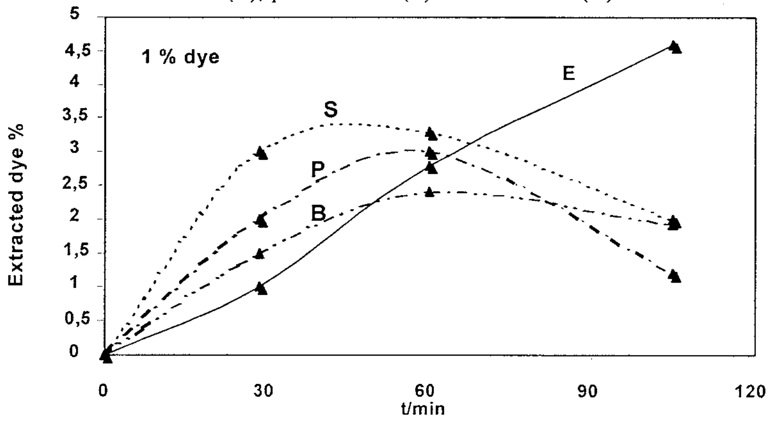


Figure 4: Extracted C.I.Reactive Blue 19 from dyed cotton knit fabric-conventionally scoured (S), enzymatic scoured (E), prebleached (P) and bleached (B)

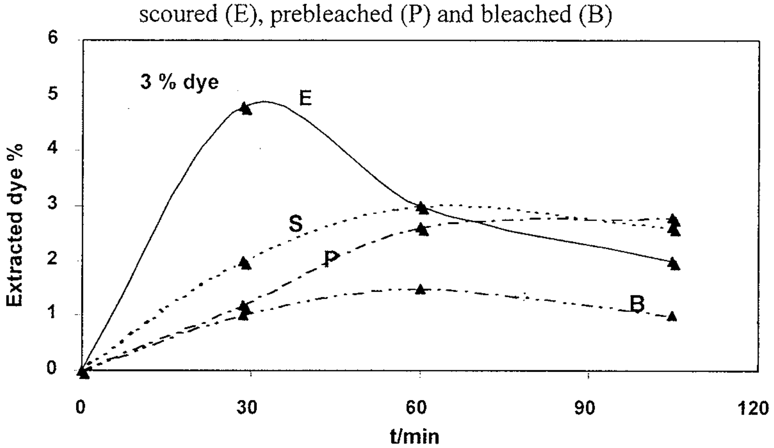
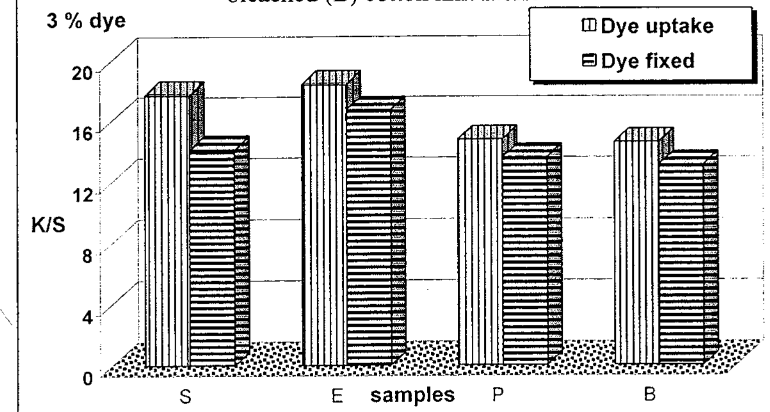


Figure 5: Colour strength (K/S) value for uptaked and fixed C.I.Reactive Blue 19 on conventionally scoured (S), enzymatic scoured (E), prebleached (P) and bleached (B) cotton knit fabric



4. CONCLUSION

Water absorptivity of knit cotton fabric obtained with caustic scouring and bleaching show significantly higher values than pectinase scoured fabric.

As wet these processes it is important for knitted fabrics to consider the shrinkage appeared in those structures as the consequence of swollen fibres and yarns.

The results of C.I. Reactive Blue 19 V-R uptake and color strength of knit cotton fabrics demonstrate the highest values for enzymatic scoured than for other samples.

The influence of cotton pretreatment on exhaustion of C.I. Reactive Blue 19 is important especially during the first 30 minutes of dyeing process. Dyeing at lower dye concentration in this period show better dyeability of enzymatic than other pretreated cotton knit fabrics.

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Prof. Dr. Ana Marija Grancarić, Faculty of Textile Technology, University of Zabreb, Pierottijeva 6, 10000 Zagreb, Croatia. Phone: ++ 385/14877360, Fax: ++ 385/14836058, E-mail: amgranca@ttf.hr.

Prof. Dr. Đurđica Parac-Osterman, Faculty of Textile Technology, University of Zabreb, Pierottijeva 6, 10000 Zagreb, Croatia. Phone: + 385 1 487 7359, E-mail: djparac@ttf.hr

THE CHARACTERISTICS AND CHANGE OF COLORS ON FASHION COLLECTIONS IN 1990s

Youngin Kim[1], Honey Kim[2], Sooyoun Kim[3]

[1]Department of Human Environment & Design, Yonsei University, Seoul, Korea

[2]Department of Clothing & Textiles, Yonsei University, Seoul, Korea

[3]Department of Clothing & Textiles, Yonsei University, Seoul, Korea

Abstract

*The purpose of this study is to examine color characteristics and color changes of the fashion collections through 1990s, and provide efficient color information for color planning appropriate to fashion themes. For this research, a total of 30084 colors were collected from Paris, Milan, London, New York Collections during 1990s. Those colors were first measured using the Pantone Textile Color Specifier and COS Color System and then spectrophotometer(Color Eye 1500). These measured color values L*a*b* of CIE colormetric system were converted into H V/C of Munsell System, and 12 tones of PCCS as well as 5 achrometic colors. The general characteristics of collected colors were analyzed and more specifically by seasons, cities, years. Following the result of this study, the hues of neutral, purple blue, yellow red, red, yellow and the tones of grayish, pale, white, dark grayish, black, dull and light grayish are most widely distributed in 1990s fashion collections. Also fashion themes such as 'seductive', 'shiny' and 'active' were mainly used in fashion collections during 1990s.*

Keywords: *fashion collection, fashion color, fashion theme*

1. INTRODUCTION

Today, colors, as well as textiles, are considered an important factor in fashion design. The 'International Commission for fashion textile colours' predicts color trend 2 years before the people wear the colors. The color trend suggested is then applied to fabric and textile trend exhibitions 12 months before and then fashion collections 6 months before. Finally, people in the world wear these trends in colors. So, fashion collections like prêt-à-porter are the reflections of the color trend the 'International Commission for fashion textile colours' suggested and the source of color trend to the fashion makers in the world.[1] [2]

The prêt-à-porters in Paris, Milan, New York, London are regarded as the most famous and influential collections. Paris collections have made world fashion trends as Paris historically, is the center of fashion. Milan collections were developed in the 1960s. The characteristics of Milan fashion are comfortable, casual and colourful with knits and leather. New York collections are successful in marketing with useful fashion design that is clean, modern or sporty. London collections pursue two contrary styles, one traditional, the other avant-garde. [1] [3]

So the construction of the database through analysis of the color characteristics of the fashion collections in Paris, Milan, New York and London is needed for the development of efficient color trend.

2. AIMS

The purpose of this study is to examine color characteristics and color changes of the fashion collections through 1990's, and to provide sufficient color information for color planning appropriate to fashion themes.

3. METHODS

For this research, a total of 30084 colors and 1362 themes were collected from Paris, Milan, New York and London collections in fashion collection magazine 'Collezioni donna prêt-à-porter' from 1990 S/S to 1999 A/W as [Table 1].

Table 1: Figures of Collected Colors

city	Paris	Milan	New York	London
S/S	4398	4331	2101	3258
A/W	5736	5114	2337	2784
total	10134	9445	4438	6042

The colors discoloured by light effects of the fashion show or those difficult to measure with eyes were excluded. The colors on transparent fabrics were measured in accordance with the designer's purpose to express layered color effects. In melange fabrics, the overall color derived from the mixed colors were used. All accessories were excluded in this research.
These collected colors were first measured using both the 'PANTONE Textile Color Specifier' made by Pantone and the 'COS Color System' made by the Korea Fashion Color Association. They were then measured to the color values L*a*b* of CIE colormetric system using the spectrophotometer (Color Eye 1500) and then the value L*a*b* were converted into HV/C of Munsell System. The color characteristics were analysed by both 10 hues and 40 hues of Munsell color system and 17 tones of PCCS color notation including 5 achromatic colors as follows.
10 hues : R (Red), YR (Yellow Red), Y (Yellow) , GY (Green Yellow), G (Green), BG (Blue Green), B (Blue), PB (Purple Blue), P (Purple), RP (Red Purple)
40 hues : 2.5R, 5R, 7.5R, 10R ~ 7.5 RP, 10 RP
17 tones : p (pale), lt (light), b (bright), v (vivid), s (strong), sf (soft), d (dull), dp (deep), dk (dark), ltg (light grayish), g (grayish), dkg (dark grayish), W (White), ltGy (light Gray), mGy (medium Gray), dkGy (dark Gray), Bk (Black)
The general characteristics of collected colors were analyzed and more specifically by seasons, cities, years and themes.

4. RESULTS & DISCUSSION

4.1. The Characteristics of Colors on Fashion Collections in 1990's

4.1.1. General characteristics of colors on Fashion Collections in 1990's

The hues of purple blue, yellow red, red and yellow are most widely distributed in the result of the general analysis. Yellow is disproportionately in 2.5Y, which means yellow or reddish yellow was used more than greenish yellow. And neutral colors

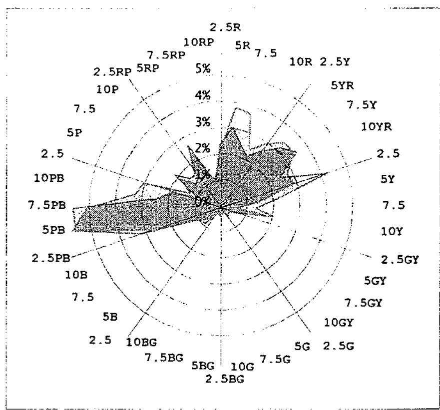

Figure 1: Hues on Collections in 1990s

and low chromatic colors like the tones of grayish, pale, white, black, dark grayish, dull and light grayish are most widely distributed.
The hues of yellow and green yellow showed up more frequently in S/S while the hue of purple, purple blue and red were Frequent in A/W as shown in [Figure 1]. The tones of white, pale and light showed more frequently in S/S while the tones of dark grayish, grayish and black in A/W as shown in [Figure 2]. The seasonal difference were more prominent in the tones than the hues.

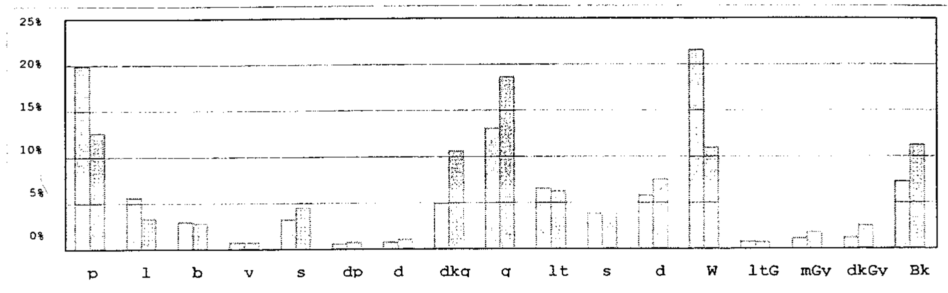

Figure 2: Tones on Collections in 1990s

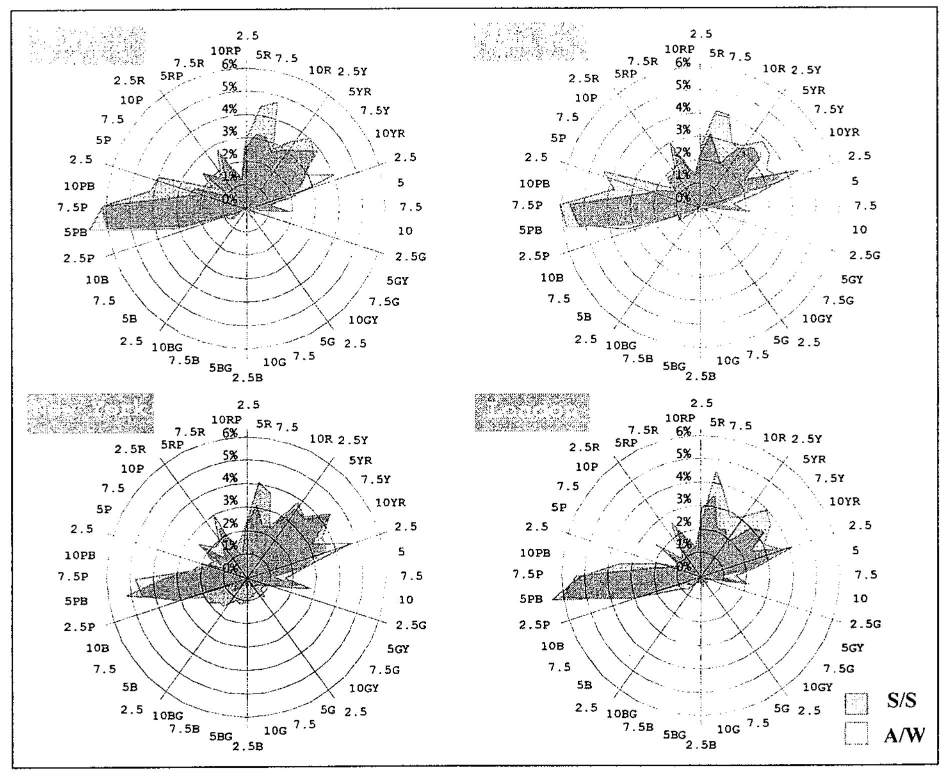

Figure 3: Hues on Paris, Milan, New York and London Collections in 1990s

4.1.2. Characteristics of colors on fashion collections in Paris, Milan, New York and London in 1990s

The color characteristics by cities are similar to the general color characteristics in the 1990's on the whole but there are some differences in color characteristics between 4 cities as shown in [Figure 3]. In Paris, the hues of red and purple blue and the low tones such as grayish, dark grayish and dull are more prominent than in the other cities. The prominent colors in Milan are the hues of purple and red purple and the moderate tones such as light grayish and soft. The prominent colors in New York are yellow red, yellow, green yellow, but purple blue appear less than the other cities. Also, the tones of pale and light showed more frequently in S/S while neutral colors, such as light gray, medium gray and black in A/W in New York. In London, the hue of purple and red purple are less common, and the colors are generally concentrated in purple blue, red and yellow red. The loud tones such as bright, vivid and strong showed more frequently in S/S in London.

4.1.3. Change of colors on Fashion Collections in 1990s

Red, yellow, green yellow showed prominent changes in the analysis of hues and bright, grayish, black in the analysis of tones.

Red was most widely distributed in early the 1990s and in '97. Green yellow generally showed low frequency, but was a little more distributed in '96 S/S, similarly to green and blue green. Purple was most widely distributed in 92-93 A/W and in '97 S/S-'98 S/S similarly to red purple as [Figure 4] shows.

Bright was widely distributed in the early 1990s and then showed low frequency similar to the light tone. Grayish was most widely distributed in '97 but declined rapidly in '98-'99 A/W. Black was most widely distributed in '98-'99 A/W similarly to light gray and medium gray as seen in [Figure 5].

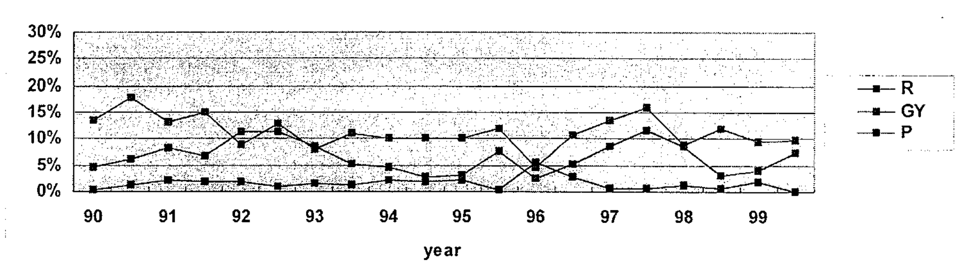

Figure 4: Change of Hues on Collections in 1990s

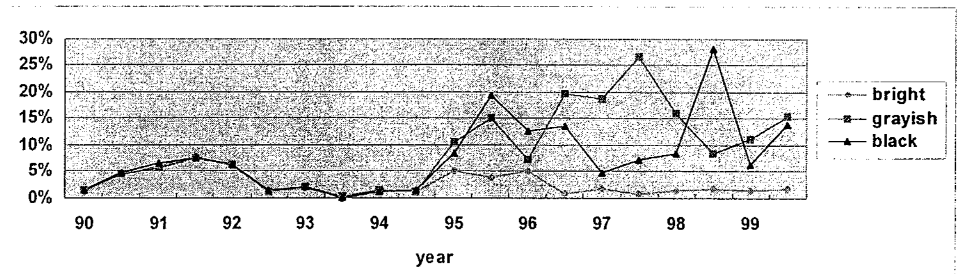

Figure 5: Change of Tones on Collections in 1990s

4.1.4. Representative color palettes in 1990's

Red, yellow red, yellow were widely distributed in early 1990s and green yellow, green, blue green in '95-'97, purple blue and purple in '97-'98 and neutral colors in '99.

The representative color palettes in 1990s are shown in [Figure 6].

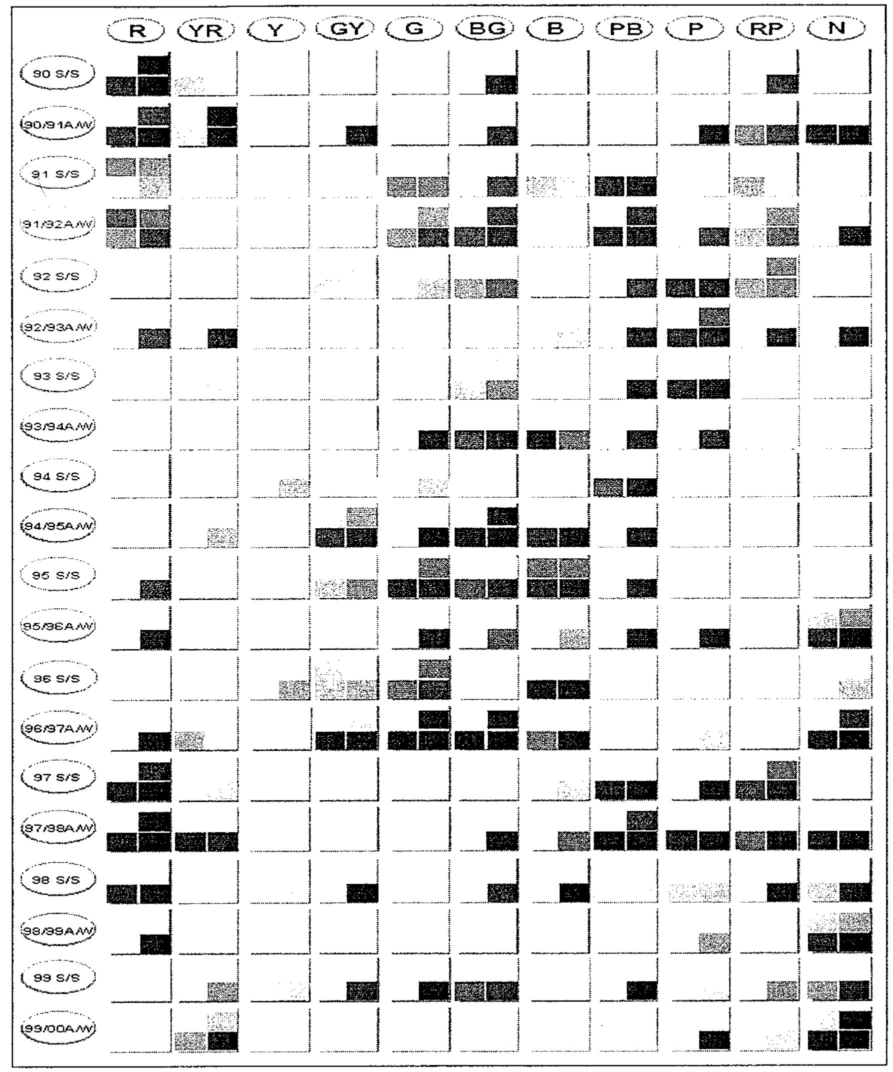

Figure 6: Representative Colors on Collections in 1990s

4.2 The Characteristics of Colors by Themes on Fashion Collections in 1990's

1283 themes collected from the fashion collections in 1990s were classified into 54 theme groups and the themes of 'seductive', 'shiny', 'luxurious', 'active', 'little' and 'reminiscent' were most widely distributed. And the themes of the prominent color characteristics were 'luxurious', 'military', 'rebellious', 'traditional', 'modern' and 'pure' as [Table 2].

Pale tones of yellow red and yellow such as gold with strong tone of red showed prominently with strong tone of red in the theme of 'luxurious'. Grayish tones of yellow red, yellow, green yellow and purple blue were main colors in the theme of 'military'. Dark and low chromatic colors such as dark grayish, grayish tones of purple blue, dark gray and black were main colors in the theme of 'rebellious' and they were sometimes coordinated with pale tones of yellow red and yellow. Pale, grayish, light grayish tones of red, yellow red, yellow such as beige and browns with navy were most widely distributed in the theme of 'traditional'. In the theme of 'modern', the range of neutral colors was distributed in about 50%. White was the main color in the theme of 'pure' and pale or light grayish tones of yellow red, yellow, purple blue showed somewhat.

Table 2: Reperesentative Colors of Themes in 1990s

themes	Colors (Pantone or COS number / hue and tone)							
luxurious	11-4202 N/W	13-4105 7.5PB/p	Y1-90010 2.5Y/p	14-1118 2.5R/p	15-1142 10YR/p	YR4-50060 10YR/d	19-1664 5R/s	19-6110 N/Bk
military	11-4202 N/W	13-1106 7.5YR/p	17-1118 2.5Y/g	19-0809 7.5YR/g	19-0414 2.5GY/g	PB3-30030 7.5PB/g	17-5102 N/mGy	
rebellious	12-0807 7.5YR/p	19-1664 5R/s	17-1501 N/mGy	PB3-20030 7.5PB/dkg	PB2-30020 5PB/g	19-4205 N/Bk		
traditional	11-0601 N/W	13-1108 7.5YR/p	19-1118 5YR/g	18-1661 5R/s	19-1338 5R/g	11-0105 2.5Y/p	PB2-60040 PB/ltg	18-0000 N/mGy
modern	11-4202 N/W	14-4203 2.5PB/p	NP-35010 7.5P/g	18-0000 N/mGy	PB3-20020 7.5PB/dkg	19-4205 N/Bk		
pure	11-4202 N/W	11-0105 2.5Y/p	14-1210 7.5YR/p	Y2-80010 5Y/ltg	14-4203 2.5PB/p	17-3817 10P/sf		

5. CONCULUSIONS

In this research, the color characteristics and changes of the fashion collections in the 1990s were analyzed and the relation between fashion colors and themes were examined closely as above. A total of 30084 colors and 1283 themes were collected from Paris, Milan, London, New York collections during 1990s. The results of the study are as follows. First, the hues of purple blue, yellow red, red, yellow and the tones of grayish, pale, white, dark grayish, black, dull, light grayish are most widely distributed. Second, neutral, yellow, green yellow showed more frequently in S/S while purple, purple blue, red, yellow red in A/W. White, pale, light, light grayish, light gray showed more frequently in S/S while black, dark grayish, grayish, dark gray, dark in A/W. Third, color characteristics by 4 cities were similar to the general color characteristics in 1990s. Forth, red, yellow red, yellow were widely distributed in the early 1990s and green yellow, green, blue green in '95-'97, purple blue, purple, red purple in '97-'98, neutral colors in '99. High range of chroma was widely distributed in '90-'92 and '95-'96 to some extent. Grayish, gray, black were widely distributed in '97-'99. Finally, fashion themes such as 'luxurious', 'military', 'rebellious', 'traditional', 'modern', 'pure' showed the particular(distinct) color distributions.

The academic significations of this research are to organize the color characteristics of the fashion collections by standard color systems and to examine the color trend using a scientific method. Also, the practical signification is to present the color pallets and the color characteristics related to the themes which can be applied to databases useful for fashion color planning in business.

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Prof. Youngin Kim, Yonsei University, Department of Human Environment & Design, 134 Sinchon-dong Seodaemun-gu, Seoul, Korea. Phone: +82 02 2123 3105, E-mail: youngin@yonsei.ac.kr
Honey Kim, Yonsei University, Department of Clothing & Textiles, 134 Sinchon-dong Seodaemun-gu, Seoul, Korea. Phone: +82 02 2123 3100, E-mail: honey76@hotmail.com
Sooyoun Kim, Yonsei University, Department of Clothing & Textiles, 134 Sinchon-dong Seodaemun-gu, Seoul, Korea. Phone: +82 02 2123 3100, E-mail: reginasoo@hotmail.com

COLOUR APPEARANCE OF FLASH IMAGE DISPLAYED ON COMPUTER MONITOR

Saori Kitaguchi, Kazuomi Gokuta, Tetsuya Sato, Yoshio Ohtani, Yukitoshi Takahashi*
Kyoto Institute of Technology, *Shizuoka Medical Institute of Neurological Disorders

Abstract

The development of the multimedia instruments such as TV and a computer has caused a problem that some people fall down during watching a TV program or playing a computer game. Most of the fallen people were children. In December 1997, around five hundred children had been fallen by a red / blue flash image used in a TV animation in Japan. The main cause of the problems is thought a photosensitive seizure. And it is estimated that the triggers induced the seizure are wavelengths and light-quantity, colour, visual pattern of the images. Therefore, we thought that the factors induced the seizure would be in the relationships between the optical characteristics and human sensation.

To find a way for protecting the people from the problem, we investigated about the relationship between the optical characteristics and human sensation, with the viewpoints of colour physics and sensory engineering. We paid attention to visual sensation such as uncomfortableness and flickering speed of flash images displayed on a computer monitor. We also tried to investigate the influence of colours.

Consequently, human sensations of uncomfortableness and flickering speed of flash images were not constant, even though the frequencies of flash images were the same. And, the relationship between human sensations and the luminance differences of colours of a flash image was proportionate.

***Keywords**: flash image, colour, photosensitive seizure, epilepsy, human sensation*

1. INTRODUCTION

As TV and a computer have become a universal source of information and entertainment, the stimulation of flash images displayed on a television or a computer monitor has caused an incident that some people fall down during watching a TV program, or playing a computer game. Most of the people were children. In December 1997, around five hundred children had fallen down by red / blue flash images used in a TV animation, Pokemon, in Japan. The main cause of the incident is a photosensitive seizure.

In another situation, photosensitive epileptic patients recurrently have photosensitive seizures. And around the age of puberty, when more time is spent watching television and playing computer games, the incidence of photosensitive epilepsy is high. It is estimated that the triggers induced the photosensitive seizure are wavelengths, high-quantity of light, visual patterns of flash images and colour.

To find a way for protecting children from the incidents, we have been trying to look for the cause of the incidents with a few viewpoints of medicine, colour physics and sensory engineering [1-4].

Firstly, we thought that we might take a hint to solve the incidents from the relationships between psychological feelings induced by flash images and optical properties of flash images. We paid attention to two kinds of visual sensation, *midurasa* and *hayasa* in Japanese. *Midurasa* means a sensation of 'uncomfortableness', and *hayasa* means a sensation of 'flickering speed'. We also tried to investigate the influence of colours to the two visibilities.

In a previous study [5], we studied about the relationships between the visibilities and flash images, and analysed about the influence of hue and chroma. In this paper, we discussed the influences of whiteness/ blackness and high contrast.

2. EXPERIMENT

2.1 Colour

We arranged two groups of flash images. One (ColourI) is a low contrast combination group. Another (ColourII) is a high contrast combination group. Those are as follows.

ColourI**:** To investigate the influence of the whiteness/blackness on the visibilities, 30 colours for flash images as shown in Figure 1 were arranged. The standard colours used for the flash images were Red (r), Blue (b), Green (g), Yellow (y), White (w) and Black (k). And three middle colours between two standard colours were arranged.

ColourII**:** To investigate of the influence of higher contrast as shown in Figure 2 we arranged 7 colours.

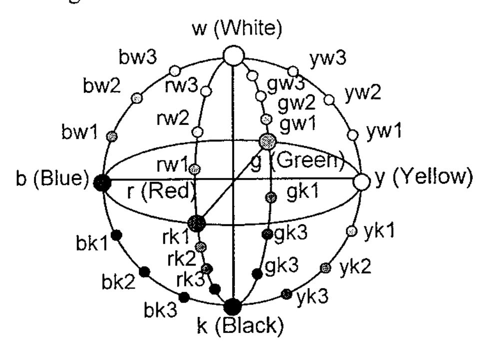


Figure 1: Colours used for flash images of Colour I group

Big circle: standard colour
Small circle: middle colour

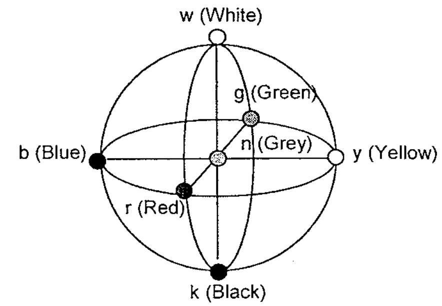


Figure 2: Colours used for flash images of Colour II group

2.2 Flash image image

We made computer software to display flash images flickering two colours on a computer monitor as shown in Figure 3.

A flash image displayed on a computer monitor changes two colours quickly and continuously. The frequency of the flickering was 15Hz, 15 flames per a second.

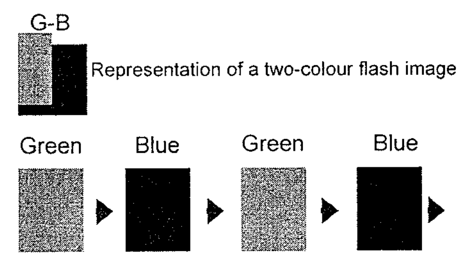


Figure 3: An example of flash image used in this study

In the case of ColourI (Figure 1), a flash image flickers two colours: One is a standard colour as a fixed colour. Another is an arranged colour adjoined from standard colours or middle colours among the two standard colours.

In the case of ColourII (Figure 2), two standard colours were paired.

2.3 Assessment

Visual assessments were carried out through Paired Comparison. Two flash images were used for an assessment as shown in Figure 4. Observers were requested to answer which flash image is *midurai* (which flash image is more uncomfortable) and which flash image is *hayai* (which flash image is quicker) as show in Figure 5. The assessments were independently carried out as ColourI and ColourII.

ColourI: The total number of assessments was 2880; 30 observers and 96 Paired Comparison patterns.

ColourII: The total number of assessments was 4200; 20 observers and 210 Paired Comparison patterns.

The assessments were carried out as shown in Photo 1. The colorimetric properties of flash images were measured by a spectroradiometer Minolta CS-1000 as shown in Photo 2.

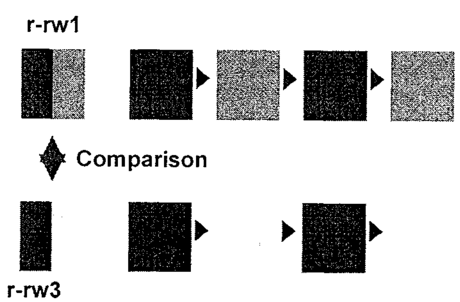
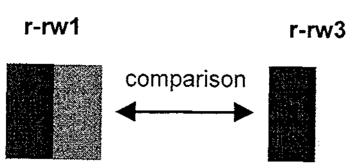


Figure 4: Paired Comparison used in the visual assessments

Midurasa / Which flash image is more uncomfortable?



Hayasa / Which flash image is quicker?

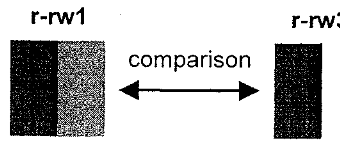
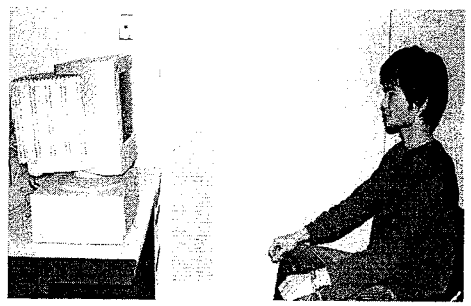
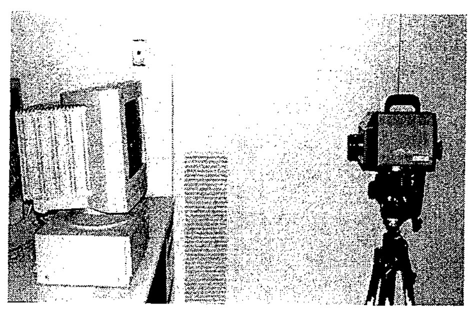


Figure 5: *Midurasa* and *hayasa* assessments through Paired Comparison



Observers:	30 students (Colour I)
	20 students (Colour II)
Age:	From 19 to 25
Distance:	70cm – 100cm
Frequency:	15Hz
Time:	2 seconds for a flash image
Size:	21×28cm
Order:	Randomised
Ambient lighting:	
	Normal room lighting

Photo 1: Visual assessment and viewing condition



Spectroradiometer:	Minolta CS-1000
Standard Colorimetric Observer:	
	2 degree
Distance:	75cm
Measurement:	5 repetitions

Maximum and minimum colorimetric values were discarded, and the average was computed.

Photo 2: Instrumental assessment and measuring condition

3. RESULT

3.1 Data analysis

For scoring of the visual assessments and analysing, we used Schffe's method. With the results, we obtained 95% confidence intervals and hedonic scales. The hedonic scales were used as a sensational parameter corresponding to *midurasa* (uncomfortableness) and *hayasa* (flickering speed). With the confidence intervals, we investigated about the difference between the responses of *midurasa* and *hayasa*. We also investigated about the relationship between the hedonic scales expressing the responses and colorimetric properties.

3.2 Confidence interval

Figures 6, 7, 8, and 9 show some results of the analysis through the 95% confidence interval. The flash image symbols in the figures show the colours of flash images. The flash images were plotted at the relative points of their hedonic scales. The length of arrows in the figures shows the 95% confidence interval, $Y_{0.05}$ (yardstick).

When the length between two flash images is longer than that of the arrow, there is a significant difference between their two flash images. Reversely, when the length between two images is shorter than that of the arrow, there is not clear the difference between their two flash images.

With the analysis through the confidence interval, in the case of ColourI, we found that 92 % of flash images have a significant difference in *midurasa* (uncomfortableness) response and 37% of flash images have a significant difference in *hayasa* (flickering speed) response. In the case of ColourII, we

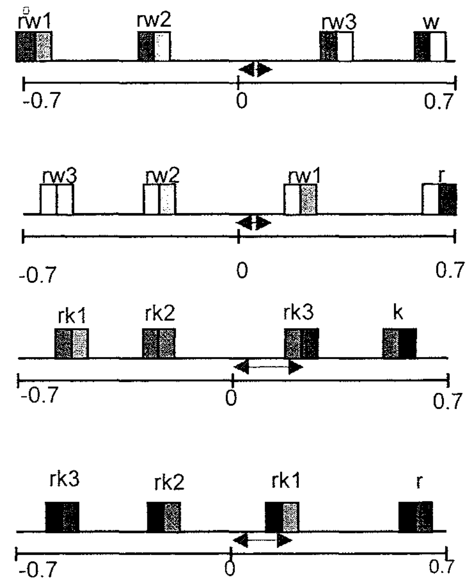
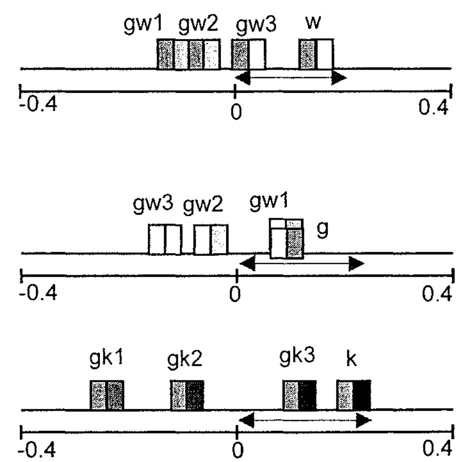


Figure 6: Confidence interval on *midurasa* of Colour I group



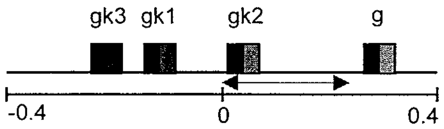


Figure 7: Confidence interval on *hayasa* of Colour I group

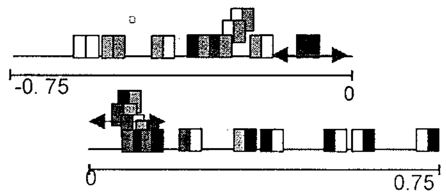


Figure 8: Confidence interval on *midurasa* of Colour II group

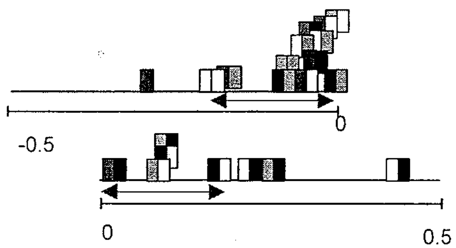


Figure 9: Confidence interval on *hayasa* of Colour II group

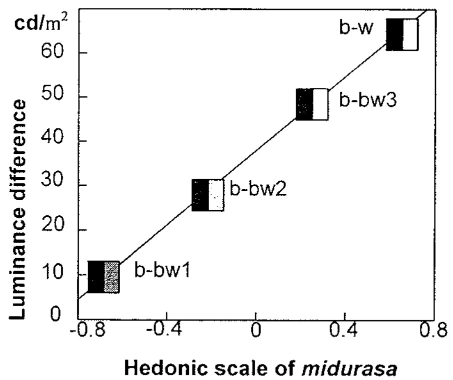
found that 80 % of flash images have a significant difference in *midurasa* response and 39% of flash images have a significant difference in *hayasa* response.

Comparing the results of the *midurasa* response with those of the *hayasa* response, we found that the difference of colour combination of a flash image influences to *midurasa* response, but not so much to *hayasa* response.

3.3 Relationship between hedonic scales and luminance differences

Figures 10, 11, 12 and 13 show the relationship between hedonic scales and luminance differences in two colours of a flash image. The relationship means that large luminance difference flash images were more uncomfortable. Similarly, *hayasa* response (flickering speed) was relevant to the luminance difference, but some flash images were not influenced so much by the luminance difference.

In the case of ColourII as shown in Figures 12 and 13, the large luminance difference flash images were more uncomfortable and quicker as well. But it was not clear. When we paid attention to relative uncomfortable combinations which were plotted at the right side of Figure 12,



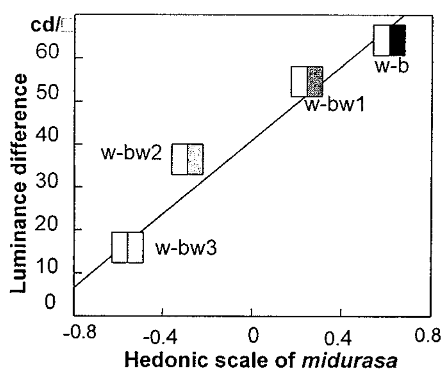
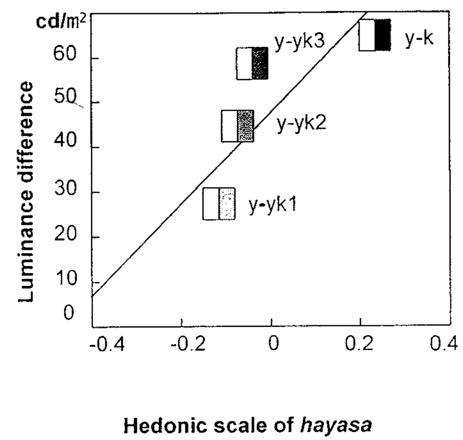


Figure 10: Relationship between *midurasa* and luminance differences in Colour I group: Blue-White

we found that the flash images including black intensified the uncomfortableness.

Although the luminance difference between red / blue was not large, red / blue flash image that was the cause of many children falling down in Japan was uncomfortable. On the other hand, when we paid attention to relative not uncomfortable combinations which were plotted at the left side of Figure 12, the flash images including Grey reduced the uncomfortableness.



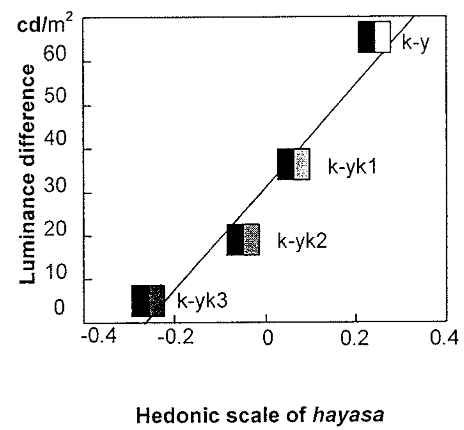


Figure 11: Relationship between *hayasa* and luminance differences in Colour I group: Yellow-Black

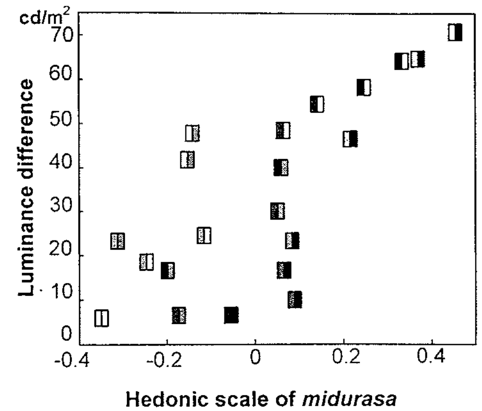


Figure 12:Relationship between *midurasa* and luminance differences in Colour II group

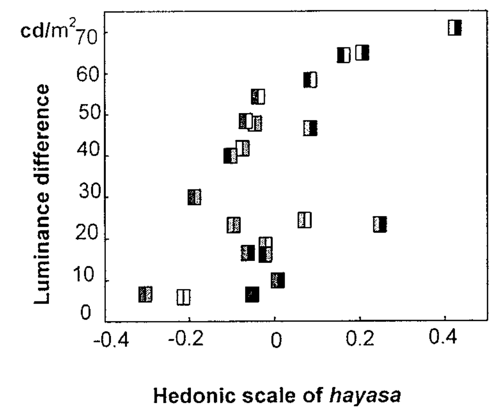


Figure 13: Relationship between *hayasa* and luminance differences in Colour II group

4. SUMMARY

To investigate two kinds of visibilities such as *midurasa* (uncomfortableness) and *hayasa* (flickering speed) induced by a flash image, we tried to analyse the relationship between the visibilities of the flash images and colorimetric properties of the flash colours, with the viewpoints of colour physics and sensory engineering. Comparing the luminance difference of flash colours with visual assessments of *midurasa* and *hayasa*, we found out the followings;

1. *Midurasa* and *hayasa* responses were not constant, even though the frequencies of flash images were the same. This means that the magnitude of human sensation is different from physical magnitude.
2. The luminance difference in the colour combination of a flash image influenced *midurasa* response, but not influenced *hayasa* response so much.
3. *Midurasa* and *hayasa* responses were in relevant to the luminance difference in colours of a flash image. In the case of a low contrast combination group (ColourI), the relationship between the magnitude of the responses and the luminance difference was proportionate.
4. In a high contrast combination group (ColourII), the colour combination of a flash image influenced *midurasa* response.

The conclusions 1, 2 and 3 were the same to the results and the conclusion in the previous study [5]. Therefore, we confirmed again that the low contrast combination with whiteness/blackness, hue or chroma influences human sensation as well.

In the conclusion 4, we found *midurasa* and *hayasa* responses are influenced by the colour combination of a flash image, but we have not found why the colour influences human sensation. As further study, we need to find the reason.

5. ACKNOWLEDGEMENT

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Master course student: Ms.Saori Kitaguchi and Mr.Kazuomi Gokuta
Associate Professor Dr.Tetsuya Sato, Professor Dr.Yoshio Ohtani, Kyoto Institute of Technology
Goshokaido-cho, Matsugasaki, Sakyo-ku, Kyoto 606-8585, Japan. Phone/Fax: +81 75 724 7578, E-mail: tsato@ipc.kit.ac.jp
M.D., Dr.Yukitoshi Takahashi, Shizuoka Medical Institute of Neurological Disorders, 866 Urushiyama, Shizuoka-shi, 420-8622, Japan

MEASUREMENT OF THE EFFECT OF CAMOUFLAGE ON THE VISIBILITY OF THE CLOTHING

Masashi Kobayashi[*1], Wonjong Lee[*1] and Ikuko Okamoto[*2]
[*1] Osaka-Shoin University, Osaka, Japan
[*2] Osaka Kyoiku University, Osaka, Japan

Abstract
For evaluate the effect of camouflage patterns on visibility, a computer program was developed and the experiment was performed by using a personal computer system. The stimulus, displayed on the CRT successively, ware consisted of nine small squares arrayed in a large square. The central small square was used for indicate a number character selected at random from one to eight. The others ware the selection part which ware consisted of the circle models and the natural scene background. The circles are the simplified clothing models and they colored by a plain color or patterned by a camouflage pattern.
The experimental subject selects, as quickly as possible, the small square that contains circles of the same number as the central number by the mouse operation. The times from the indications of central numbers to the correct selections by the subject ware measured and used for the evaluation.
In the comparison between the plain color models and the camouflage one, the latter needed longer time for search, and was more effective. In addition, comparison between camouflage patterns, there was a difference of the effect owing to their colors or the pattern of their self.

Keywords: *camouflage, visibility, measurement, personal computer, searching time*

1. INTRODUCTION

Camouflage patterns had been originally designed for military use, but they are also used for leisure nowadays. In some countries such as Japan, it was interpreted also as a fashion, and rouse interest of ordinary young people.
A camouflage pattern on clothing will disguise and conceal itself by lowering its visibility. The effect may be changed by color, the form of the pattern, the background and so on.
For evaluate the effect of camouflage patterns on visibility, a computer program was developed and the experiment was performed by using a personal computer system.

2. METHODS

2.1 Clothing Models and Stimulus

Figure 1 shows the circle model used. The circles are the simplified clothing models and they colored by a plain color (gray; Gy, green; G) or patterned by a camouflage pattern (the U. S. Marine Corps pattern; CF1, the U. S. Army pattern; CF2, the Japanese Self-Defense Force pattern II, CF3). The pattern data of the camouflages had been obtained from a web page [1], and the RGB values of the color used for the camouflages are given in Tables 1 - 4. The colors G and CF3-2 are the same, and Gr have the sâme lightness as G.
Figure 2 and 3 show the examples of the stimulus portrait. The part for selection, as

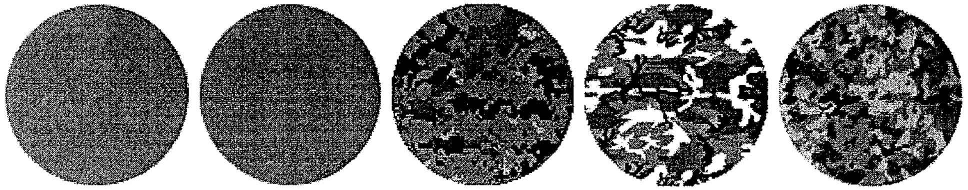

Figure 1: The circle model of clothing used.

Table 1: RGB value of Gr and G.

	Gr	G
R	120	82
G	120	132
B	120	54

Table 2: Color used for CF1 (RGB value).

	light	← lightness →		dark
	CF1-1	CF1-2	CF1-3	CF1-4
R	186	119	50	50
G	178	115	98	48
B	142	68	73	41

Table 3: Color used for CF2 (RGB value).

	light	← lightness →		dark
	CF2-1	CF2-2	CF2-3	CF2-4
R	255	95	113	0
G	249	133	86	0
B	184	65	21	0

Table 4: Color used for CF3 (RGB value).

	light	← lightness →		dark
	CF3-1	CF3-2	CF3-3	CF3-4
R	167	82	107	28
G	172	132	75	32
B	122	54	28	34

Figure 2: Magnified example of an select part of the stimulus. [CF2, No. 5]

shown in Figure 2, was consisted of the circle clothing models and the natural scene picture as the background. The number of the circles ranged from one to eight. The stimulus, shown in Figure 3, consisted of nine small squares arrayed in a large square. The central small square was used for indicate a black Arabic number character selected at random from one to eight on gray (same as Gr) background, and the others are the parts for selection which have different number of circle models. It was displayed on the CRT screen (17 inch, Trinitron type).

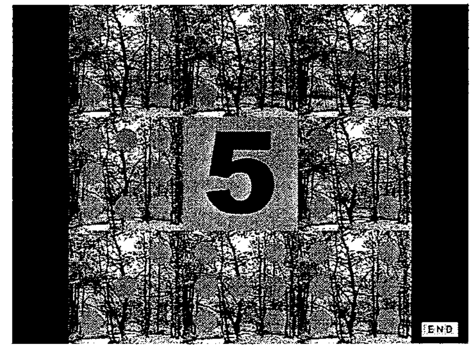

Figure 3: Example of the stimulus. [grey circle (Gr), No. 5]

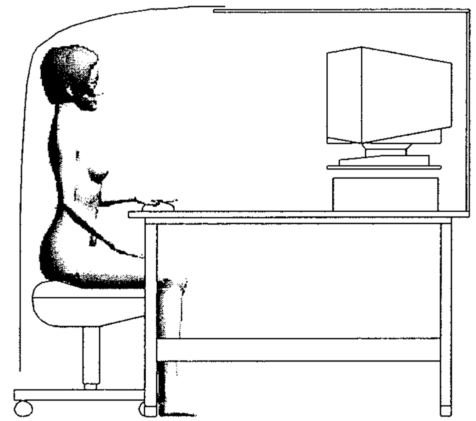

Figure 4: Illustration of the experimental booth.

2.2 Experiment
Two types of stimulus sets were used for the experimental computer program. One of them (Exp. I) used Gr, G and CF3 stimulus, and the other (Exp. II) used CF1, CF2, and CF3. Each of them was consisted of twenty-four kind of stimulus, in which the color/pattern of the model, the number character, and the positions of the selection parts were differ from each other.
The experimental subjects were twenty Japanese female, university students, aged twenty to twenty-two. The experiments had carried out by using a DOS/V type personal computer system in an air-conditioned dark booth as shown in Figure 4.
As quickly as possible, the subject selects the small square (select part) that contains the same number of circles as the central number by the mouse operation (move the mouse cursor on the select part and press the left button of the mouse). The times from the indications of central numbers to the correct selections by the subject ware measured and used for the evaluation. The precision of the time recorded was ms (millisecond) order. If the subject missed the selection, the number of mistake was registered, and the measurement was continued.

2.3 Calculation
The search times obtained by the experiment were totaled up for each clothing model, and the arithmetic average times calculated for one correct selection. On the other hand, the times obtained ware t-tested.
The probabilities of mistake were calculated by dividing the total mistake times by the number of the experimental stimulus. It indicates the average number of mistake occur until a correct selection.

3. RESULTS AND DISCUSSION

3.1 Time for Search
Figure 5 shows the time for search obtained by Exp. I, and Table 5 shows the results of the t-test. In comparison between the plain colored stimulus such as Gr or G and camouflaged CF3, the most effective pattern was CF3. The camouflage pattern was, therefore, more effective on reduction of visibility than the plain color. On the other hand, there was slight difference between Gr and G. The effect of color itself was not clearly detected, therefore, by the experimental method in this study.
Figure 6 and Table 6 show the results obtained by Exp. II. In comparison between

camouflage patterns, the most effective pattern was also CF3. This suggests that the effect of camouflages ware different owing to its color and pattern. There is some possibility that the result depends on the kind of the background. Though the CF3 pattern matched the background used in this experiment, it is not able to mention about other background.

3.2 Probability of Mistake

Figure 7 and 8 show the probability of mistake obtained by Exp. I and II respectively. Their tendencies were similar to those of the selection times shown in

Table 5: Resurts of t-test (Exp. I).

	Gy	G	CF 3
Gy	–	0.15995	6.88737
G	×	–	6.78800
CF3	*	*	–

*; significance level > 5 %

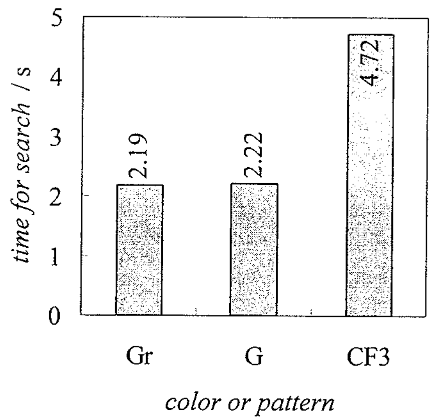

Figure 5: Search time obtained by Exp I.

Figure 5 and 6. The effect of camouflage patterns not only makes it difficult to find out itself, but also cause the mistakes of the observer.

4. CONCLUSIONS

A camouflage pattern on clothing will disguise and conceal itself by lowering its visibility. For evaluate the effect of camouflage patterns by the time for search model clothing, a computer program was developed. The camouflage pattern was more effective than the plain color on visibility of itself. The effect of color itself was not detected by this experimental method. The effect depends on the kind of the camouflage pattern and background.
The effect of camouflage patterns not only makes it difficult to find out itself, but also cause the mistakes.

Table 6: Resurts of t-test (Exp. II).

	CF 1	CF 2	CF 3
CF1	–	1.14477	6.66429
CF2	×	–	5.75727
CF3	*	*	–

*; significance level > 5 %

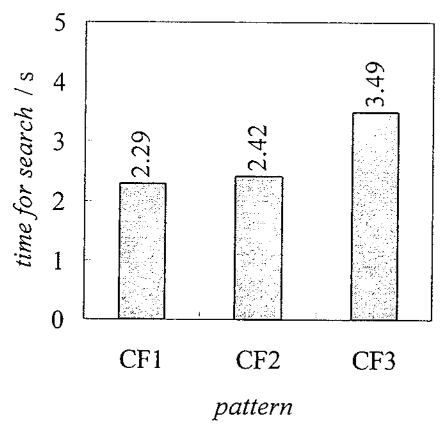

Figure 6: Search time obtained by Exp II.

5. ACKNOWLEDGEMENT

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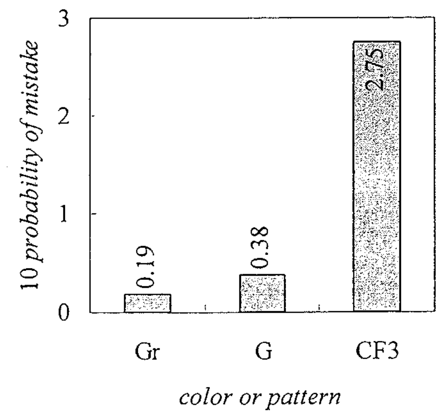

Figure 7: Probability of mistake obtained by Exp. I.

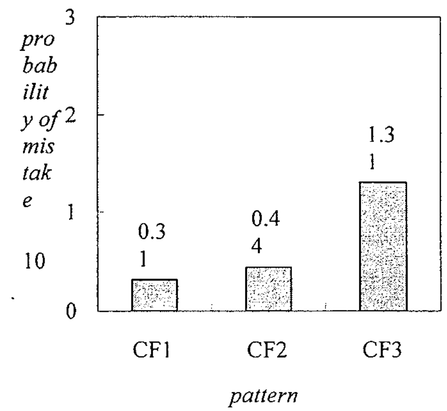

Figure 8: Probability of mistake obtained by Exp. II.

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Associate Prof. Dr. Masashi Kobayashi, Osaka-Shoin University, Faculty of Arts and Science, Department of Clothing, 2-26 Hishiya Nishi 4-chome, Higashi-Osaka, Osaka 577-8550 Japan. Phone: +81-6-6723-8227, Fax: +81-6-6723-8227, E-mail: kobayashi.masashi@osaka-shoin.ac.jp
Dr. Wonjong Lee (Research worker), Osaka-Shoin University, Faculty of Arts and Science, Department of Clothing, 2-26 Hishiya Nishi 4-chome, Higashi-Osaka, Osaka 577-8550 Japan. Phone: +81-6-6723-8227, E-mail: wlee@livedoor.com
Prof. Dr. Ikuko Okamoto, Osaka Kyoiku University, Faculty of Education, Department of Arts and Science, 4-691-1 Asahigaoka, Kashiwara, Osaka 582-8582, Japan. Phone: +81-729-78-3602, E-mail: okamoto@cc.osaka-kyoiku.ac.jp

INTERACTIONS BETWEEN PRINTING PASTE COMPONENTS STUDIED BY COLORIMETRY

Vanja Kokol[a], Reinhold Schneider[b], Sonja Šostar-Turk[a]
[a]University of Maribor, Faculty of Mechanical Engineering, Textile Department, Slovenia
[b]Institute of Textile Chemistry, Denkendorf, Germany

Abstract
The possibility of using a guar gum thickener at cellulose printing together with a bireactive dye, when an appropriate nonionic surfactant is added into the printing paste, was studied. The efficiency of surfactants (a) with respect to their chemical structure and concentration, and (b) in combination with different types (nonsubstituted and carboxymethylated) and concentrations (solid content) of thickeners used was investigated by assessing fabric stiffness, color depth, color values and dye penetration parameters. It is ascertained that some surfactants diminish the stiffness of prints to an acceptable degree causing practically no changes in color, while the dye penetration is exclusively surfactant-dependent (it diminishes in regard to surfactant/guar gum interactions causing a highly pseudoplastic and elastic system). The colorimetry investigations confirmed the reduction of reactive dye/guar gum interactions due to the occurrence of surfactant/guar gum and surfactant/reactive dye interactions. The best quality of prints are obtained with a printing paste containing a 5% $C_{18}EO_{10}$ nonionic surfactant and a highly carboxymethylated (DS=1.1) guar gum thickener.

Keywords: *viscose printing, guar gum, bireactive dye, nonionic surfactants, interactions, fabric stiffness, color*

1. INTRODUCTION

Sodium alginate is still placed among the most widely used natural thickeners in the reactive printing of cellulose fibers, due to its resistance to chemical reactions with reactive dyes as well as its good washing properties. The application of less expensive and qualitatively more stable alternative polysaccharide guar gum thickeners in cellulose/bireactive dye printing is still impossible because the chemical covalent binding of guar gum macromolecules via bireactive dye, as well as directly into the cellulose substrate [1, 2], resulting in an extreme increase of fabric stiffness and color changes of the printed substrate. The occurred chemical cross-linking of the thickener on the fiber surface is most strongly expressed for non-substituted guar gums with a high solid content [3]. Although, the undesired polysaccharide/reactive dye interactions decrease when the modification/carboxy-methylation of guar gum thickener increases; the results are in spite of this unsatisfactory. The solid content of the thickener is more important than the degree of substitution. The other alternative, i.e. reactive printing with mixtures of highly carboxymethylated guar gum and sodium alginate thickeners, also yielded no applicable results [4]. Additionally, in the case of sodium alginate, the chemical cross-linking via the bireactive dye could take place depending on the chemical structure of the dye, its reactivity and concentration [3].

An alternative way to reduce or prevent these undesired interactions during the

fixation of printed cellulose fabric can be performed by adding an appropriate additive into the printing paste. Printing trials with some natural thickeners have shown that different additives, especially some anionic and nonionic surfactants, reduce the stiffness of such a printed substrate to a certain extent [5].

In this contribution the interactions occurring among the individual printing paste components (i.e. guar gum thickener, bifunctional bireactive dye and nonionic surfactants) is studied by color evaluation, and fabric stiffness and dye penetration of differently printed viscose fabric determination. Additionally, the efficiency of the nonionic surfactant with respect to (a) the chemical structure (the hydrophilic and the hydrophobic chain length) and concentration of the surfactant, and (b) the type (regarding to the degree of carboxy-methylation and the amount of the solid content) of guar gum thickener used is presented.

2. EXPERIMENTAL

2.1 Materials used

Nonsubstituted (NSG) and carboxy-methylated (CMG) guar gums (Fig. 1) with different concentrations of solid content were used as polysaccharide thickeners. The abbreviation, the degree of substitution (DS) and the quantity of solid content of applied thickeners are given in Table 1. Commercially available (Remazol Black B 133%, DyStar GmbH) bifunctional bivinylsulphone C.I. Reactive Black 5 dye was used (Fig. 2). The selection of nonionic surfactants used was done on the basis of commercially available products, obtained in a non-purified form (Table 2). All printing experiments were made on 100% CV regenerated viscose fabric (Art Novalis) with a weight of 119.5 g/m^2, a thickness of 0.296 mm and a density of 32 threads/cm in the warp and 26 threads/cm in the weft positions. The viscose fabric was pretreated according to the usual procedure for printing: singed, desized (starch), lixiviated (4% NaOH), washed, acidified and dried.

Table 1: The used guar gum thickeners

Guar gum	Abbr.	DS	Solid content
Nonsubstituted – high viscose	NSGHV	0	2.0 %
Nonsubstituted – medium viscose	NSGMV	0	5.75 %
Nonsubstituted – low viscose	NSGLV	0	9.0 %
Carboxymethylated	CMG	0.13	5.6 %
Carboxymethylated	CMG	0.26	6.6 %
Carboxymethylated	CMG	0.4	8.0 %
Carboxymethylated	CMG	1.1	8.0 %

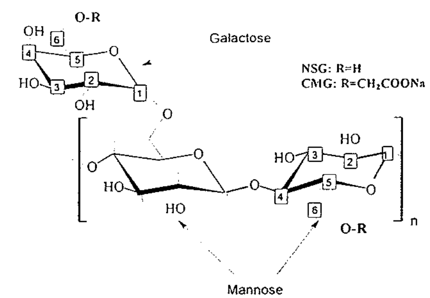

Figure 1: Nonsubstituted (NSG) and carboxymethylated (CMG) guar gums

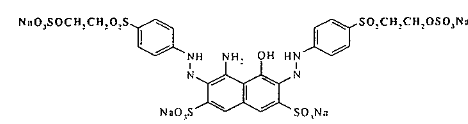

Figure 2: Bifunctional bireactive dye

2.2 Preparation of printing pastes and the printing process

The stock pastes were prepared in accordance with the thickener used: the defined quantity of solid content (Table 1) and the demineralized water were stirred in a mixer and left in a refrigerator overnight to attain full swelling. To prepare the printing pastes 600 g/kg of the stock paste of each thickener, 25 g/kg $NaHCO_3$ (pH=8-

9), 10 (50) g/kg of the reactive dye and the required amount of demineralized water were stirred for another 15 minutes; all printing pastes were adjusted to a constant viscosity of η=7000±500mPa s at $\dot{\gamma} = 10s^{-1}$ and T=25°C. The required amount (0, 10, 30 or 50 g/kg) of each individual nonionic surfactant was added to each paste and stirred again to obtain a homogeneous paste. The printing samples (prints) were prepared by the flat screen-printing technique using the Laboratory printing machine Type VP-RSF (J. Zimmer GmbH), flat printing screen (77 thread/cm, 80 μm thread distance) and squeegee of 10 mm diameter. The prints were made with speed of 5 m/min and pressure grade of 3. The printed samples were dried in drying machine (W. Mathis AG) (T=40°C, t=5min), fixed in laboratory steamer Type DHE 15973 (W. Mathis AG) (saturated steam, T=102°C, t=10min) and washed 4 times at T=95°C using demineralized water.

2.3 Methods

In order to determine fabric handle, the stiffness of the washed and conditioned (T=20°C, RH=65%, t=24hours) printed samples was measured according to DIN 53212 by determining the bending rigidity value (S) with a Type 58963 fabric stiffness measuring apparatus (Frank GmbH). The depth of color $(K/S)_f$, extent of dye penetration (Penetration=$(K/S)_r/(K/S)_f$x100 [%], where the $(K/S)_r$ and the $(K/S)_f$ are the color depth values on the reverse and the front side of the printed substrate; the higher the percentage, the greater the extent of dye penetration [6]), the CIE color values (L*a*b*C*h) and total color differences (ΔE*) of the printed samples were determined using a reflectance measuring Spectraflash SF 600 spectrophotometer (Datacolor GmbH) at standard measuring condition (D65/8°).

3. RESULTS AND DISCUSSION

Previous studies [2, 3] have shown that the bending rigidity of the viscose printed with a bireactive dye and polysaccharide guar gum thickener decreases primarily with the decreasing solid content and, secondly, with the increasing DS of the thickener used. The color depth changes proportionally to the bending rigidity values.

Accordingly, the influences of different types (hydrophilic/ hydrophobic chains length) and concentrations of nonionic surfactants on the bending rigidity, color depth and dye penetration of viscose printed with printing pastes containing surfactant and reactive dye of various concentrations and the highest solid content thickener (NSGLV/0) were investigated.

Table 2: The quality of viscose printed with printing paste containing different type and concentration of nonionic surfactants, bifunctional bireactive dye and NSGLV/0 thickener ($S_{row\ viscose}$=0.31 mN cm²)

Nonionic surfactant	Surf. conc.	Dye conc.	S [mN cm²]	$(K/S)_f$	Penetr. [%]
/	0%	1%	6.55	8.83	11.36
	0%	5%	17.71	20.22	8.80
$C_{18}EO_4$	1%	5%	17.58	21.08	17.36
	5%	5%	10.17	19.71	6.27
$C_{18}EO_{10}$	1%	1%	4.61	8.67	11.22
		5%	11.91	20.76	8.18
	3%	5%	7.87	18.80	4.94
	5%	1%	2.80	8.77	6.26
		5%	4.48	18.57	5.52
$C_{18}EO_{20}$	1%	5%	17.63	24.02	20.63
	5%	5%	p. s.*	p. sep.*	p. sep.*
$C_{16}EO_{10}$	1%	5%	10.20	21.61	10.39
	3%	5%	6.97	21.39	5.82
	5%	5%	3.37	20.46	11.77
	20%	5%	0.70	16.66	20.53
$C_{12/14}EO_5$	1%	5%	10.51	23.06	17.12
	3%	5%	8.11	22.00	7.26
	5%	5%	6.37	21.82	8.86

* strong hydrophilic surfactant/guar gum interactions resulting to a phase separation [6,7]

It is evident from the Table 2, that the bending rigidity values of prints made with pastes containing a surfactant decreases, depending on the type and concentration of

the surfactant used, in comparison to the values of prints made without a surfactant. Contrary, the $(K/S)_f$ values are practically unchanged with respect to the surfactant application. The smallest bending rigidity or the softest fabric handle of the printed substrate is obtained when $C_{18}EO_{10}$, $C_{16}EO_{10}$ or $C_{12/14}EO_5$ surfactants are used. They are already effective at 1% addition and their efficiency additionally increases with their concentration increasing.

3.1 The influence of interactions on bending rigidity

In order to assess the influence of the concentration and the DS of the thickener on the quality of printing when a nonionic surfactant is used, the viscose was printed using different guar gum thickeners in combination with the individual surfactant.

The Figure 3 present the bending rigidity values of viscose printed with printing pastes containing the most effective surfactants ($C_{16}EO_{10}$ or $C_{18}EO_{10}$) and different guar gum thickeners. It is evident that the addition of a surfactant into the printing paste results in intensive bending rigidity decrease in the cases of all guar gum thickeners used, and that it additionally decreases with the increasing DS of the thickener. Among all non-substituted guar gums the NSGHV/0 one with the lowest solid content (12 g/kg) causes a certain bending rigidity which, in the case of other guar gums (NSGMV/0, NSGLV/0), increases considerably because of the much higher solid content (34.5 g/kg, 56.7 g/kg) contributing a higher number of reaction capable -OH groups. The bending rigidity again decreases with the increasing DS of the thickener. The effect is expressed more for prints made with guar gums of similar solid content (NSGLV/0, CMG/0.4, CMG/1.1) (56.7 g/kg, 44.0 g/kg, 52.0 g/kg) owing to the negative charge of dissociated carboxyl groups ($-COO^-$) in the cases of CMG thickeners that diminish the probability of reactive dye/guar gum interactions. In view of fabric handle softness the printing paste containing 5% $C_{18}EO_{10}$ surfactant and CMG/1.1 thickener is the most effective one.

Since the high bending rigidity of the sample is a consequence of chemical cross-linking of the guar gum on the cellulose surface via the bireactive dye and it decreases when the surfactant is present, we can assume that the nonionic surfactant prevents the undesired reactive dye/guar gum chemical reactions.

It is obvious that for a soft fabric handle the following interactions are important: (1) between the reactive dye and guar gum macromolecules, (2) between the surfactant and guar gum macromolecules, (3) between the surfactant and reactive dye molecules, and (4) the interactions of individual components with the cellulose fiber. It can also be observed that the efficiency of the surfactant varies depending on the concentration and that each surfactant may have its own optimum depending on the concentration of dye and on the type of guar gum thickener used.

3.2 The influence of interactions on color depth

It is evident from Table 2 and Fig. 4 that the $(K/S)_f$ values of individual samples do not differ significantly in the presence or the absence of the surfactant, except at NSGHV/O thickener with a low solid content (Fig. 4) where the $(K/S)_f$ value obviously increases after a surfactant addition to this printing paste. Such a result is the consequence of a higher amount of printing paste add-on and could be a consequence of interactions between surfactant and guar gum [6] that prevent the reactive dye interacting with the guar gum leading to a higher amount of dye applied to the viscose fiber. In contrast, for thickeners with higher solids, small drops of $(K/S)_f$ values are observed in some cases,

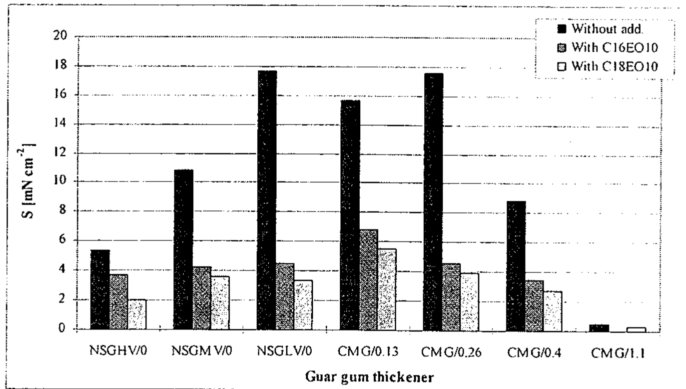

Figure 3: The influence of different guar gum thickeners on the bending rigidity of viscose printed with a nonionic surfactant (5%) and bifunctional bireactive dye (5%)

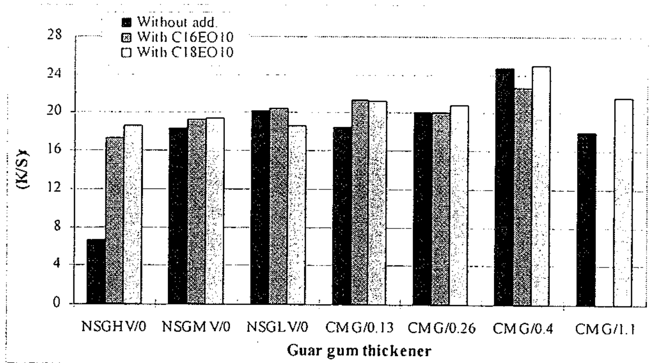

Figure 4: The influence of different guar gum thickeners on the $(K/S)_f$ of viscose printed with a nonionic surfactant (5%) and bifunctional bireactive dye (5%)

when the surfactant is used which can be explained by the interactions between surfactant and reactive dye; it is known that those types of reaction products have a lesser affinity for the substrate than individual dye molecules [6]; the occurrence of these interactions is confirmed by the bending rigidity and $(K/S)_f$ values (Table 2) of prints printed with the $C_{16}EO_{10}$ surfactants of various concentrations (0%, 1%, 3%, 5%, 20%). It can also be assumed that the surfactant reduces (1) the amount of the thickener cross-linked on the fiber via the bireactive dye as well as (2) the amount of chemically -bounded reactive dye on the fiber. Since the bending rigidity decreases rapidly and the $(K/S)_f$ relatively slowly with the increasing surfactant concentration, it can be concluded that the surfactant molecules react with the guar gum macromolecules to a greater extent than with the reactive dyes.

3.4 The influence of interactions on dye penetration

The dye penetration depends [6] primarily on the viscosity/viscoelastic properties of the printing paste (the higher the degree of elasticity, the more expressive is the surface printing or the poorer is the penetration), and secondly on the physical properties of the participating components (the swelling capability of the thickener, porosity and wetting of the cellulose fiber) and on the affinity of the reactive dye for the substrate, to the guar gum thickener or the surfactant.

From the comparison of results present in Table 2 and Fig. 5 it can be resume that the type and the concentration of a surfactant have a much greater effect on the extent of dye penetration than the guar gum thickener used. The effect of the chemical structure of the surfactant is much more strongly expressed at a 1% surfactant concentration, since the dye penetration of prints made with the NSGLV/0 thickener is markedly higher in the case of $C_{18}EO_4$, $C_{18}EO_{20}$ and $C_{12/14}EO_5$ surfactants. At a higher surfactant conc. (5%) the penetration decreases and it is comparable with the print made without a surfactant. The dye penetration is at both concentr. the lowest in the case of $C_{18}EO_{10}$, which is ascribed to the explicit hydrophilic interactions between the surfactant and guar gum yielding a highly pseudoplastic and more elastic printing paste [7].

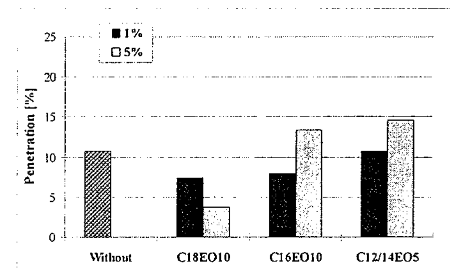

Figure 5: The dye penetration of viscose printed with the paste containing CMG/0.4 thickener, 5% reactive dye and different surfactants

The extent of dye penetration of prints made with a paste containing the CMG/0.4 thickener and the $C_{18}EO_{10}$ surfactant (Fig. 5) decreases with the increasing surfactant concentration, whereas it increases when $C_{16}EO_{10}$ and $C_{12/14}EO_5$ surfactants are used.

3.3 The influence of interactions on color values and color differences

It is evident from the CIEL*a*b* color values of individual prints, collected in Table 3, that the samples made with 1% surfactant and the NSGLV/0 thickener show only a light deviation in the lightness of color with respect to the print made without a surfactant. The darkest prints are the samples made with printing pastes containing the $C_{18}EO_{20}$ or $C_{12/14}EO_5$ surfactants, while the brightest sample is that one printed with a printing paste containing the $C_{18}EO_{10}$ surfactant. Higher surfactant concentrations (5%) have a greater effect on the color changing. The greatest deviation is observed with samples printed with $C_{18}EO_4$ or $C_{16}EO_{10}$ surfactants: the sample printed with the $C_{18}EO_4$ tends to move into the red, whereas the sample printed with the $C_{16}EO_{10}$, which also has the greatest extent of saturation, tends to move into the blue region. The change in color is a consequence of printing paste intermolecular interactions in the presence of the cellulose fiber: the more red, the lighter and the less saturated the print, the greater the amount of guar gum macro-molecules bounded via the bireactive dye on the substrate, or the smaller the capacity of the surfactant to prevent the interactions between the reactive dye and the guar gum thickener. In the case of the samples made with the CMG/0.4 thickener, the most blue and the most saturated print is obtained with the $C_{16}EO_{10}$ surfactant.

The ΔE^* of samples (Fig. 5) additionally confirm the influence of the surfactant in the printing paste; the samples are compared with the standard (the sample printed with the paste without a surfactant). ΔE^* is the highest with the sample printed with the $C_{16}EO_{10}$ surfactant because the greatest effect in the case of this surfactant.

Investigating the influence of different guar gum thickeners with higher solid content (Table 3) on CIEL*a*b* color values of viscose printed with 5% $C_{18}EO_{10}$ surfactant and 5% reactive dye, we can see that the samples printed with nonsubstituted NSGLV/0 thickener are more red and less blue, whereas prints made with carboxymethylated guar gums (CMG/0.4 and CMG/1.1) vary intensively only in the strength of the blue color since the DS hinders the reaction of reactive dye with the guar gum. The higher the DS of a thickener, the less red is the print. The sample printed with the CMG/0.4 thickener is the most important one: it is the darkest with a high purity and expressive blue color. Prints made with other guar gums are lighter and less saturated.

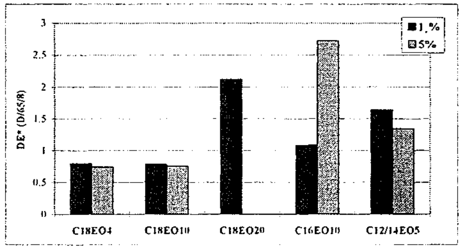

Figure 5: The influence of different surfactants on the total color differences of viscose printed with the paste containing NSGLV/0 thickener and 5% reactive dye

Table 3: The CIE color values of viscose printed with different thickener and surfactants

Thickener	Surfactant		Dye conc.	L*	a*	b*	C*	h
NSGLV/0	Without		5%	17.73	1.66	-1.06	1.97	327.31
	$C_{18}EO_4$	1%	5%	17.22	1.09	-1.48	1.84	306.40
		5%	5%	17.99	2.04	-0.72	2.17	340.50
	$C_{18}EO_{10}$	1%	1%	31.02	1.20	-12.80	12.86	275.37
			5%	17.39	1.10	-1.40	1.78	308.25
		3%	5%	18.56	1.27	-1.89	2.28	303.81
		5%	1%	32.84	-1.11	-14.75	14.79	265.69
			5%	18.18	1.63	-1.97	2.33	314.22
	$C_{18}EO_{20}$	1%	5%	15.82	0.71	-1.49	1.65	295.47
		5%	5%	phase sep.	/	/	/	/
	$C_{16}EO_{10}$	1%	5%	16.95	1.00	-1.54	1.84	303.02
		3%	5%	17.12	1.18	-1.62	2.01	306.03
		5%	5%	18.00	1.23	-3.76	3.96	288.18
		20%	5%	22.14	4.65	-12.72	13.55	290.09
	$C_{12/14}EO_5$	1%	5%	16.25	0.94	-1.35	1.65	304.84
		3%	5%	16.84	1.43	-1.52	2.09	313.23
		5%	5%	17.00	1.29	-2.14	2.50	301.08
CMG/0.4	Without	/	5%	15.54	0.51	-1.56	1.64	287.90
	$C_{18}EO_{10}$	1%	5%	14.72	0.62	-1.75	1.86	289.43
		3%	5%	15.28	0.73	-1.84	1.98	291.60
		5%	5%	15.64	0.74	-2.66	2.76	285.57
	$C_{16}EO_{10}$	1%	5%	14.20	0.63	-1.99	2.08	287.66
		3%	5%	15.73	0.50	-2.18	2.23	282.84
		5%	5%	17.18	0.56	-4.61	4.64	276.89
	$C_{12/14}EO_5$	1%	5%	14.40	0.60	-1.90	2.00	287.62
		3%	5%	14.73	0.65	-1.79	1.90	290.10
		5%	5%	15.85	0.59	-1.86	1.95	287.54
CMG/1.1	Without	/	5%	19.13	0.42	-2.13	2.17	281.26
	$C_{18}EO_{10}$	5%	5%	17.03	0.40	-1.78	1.82	282.70

4. CONCLUSIONS

The investigation of the influence of a nonionic surfactant on the quality of viscose printed with printing pastes containing a guar gum thickener and a bifunctional bireactive dye has shown that the addition of an nonionic surfactant to the printing paste results in: (1) a considerably softener fabric handle due to the reduced undesired covalent interactions between the reactive dye and guar gum, (2) a lower extent of dye penetration due to the occurrence of the interactions between surfactant and guar gum leading to a more pseudoplastic/elastic printing paste and consequently to surface printing, and (3) a slightly poorer depth of color due to the occurrence of the interactions between the surfactant and reactive dye that weaken the affinity of the reactive dye for the viscose substrate, in comparison to the prints made with a printing paste containing no surfactant.

The surfactant efficiency increases with the increasing surfactant concentration, the increasing DS of the guar gum and with the decreasing reactive dye concentration. The undesired interactions can not be totally avoided, but it is possible to reduce them to a minimum. The interactions between the surfactant and guar gum are quantitatively greater than the interactions between the surfactant and the reactive dye. Among all nonionic surfactants used, the $C_{18}EO_{10}$ in combination with highly carboxymethylated (DS=1.1) guar gum thickener is the most interesting paste mixture, since the quality of prints is the best.

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Dr. Vanja Kokol, Assist. Prof. Dr. Sonja Šostar-Turk, University of Maribor, Faculty of Mechanical Engineering, Textile Department, Institute for Textile Chemistry, Ecology and Colorimetry, Smetanova ul. 17, SL-2000 Maribor, Slovenia. Phone: +386 2 220 7896, Fax: +386 2 220 7990, E-mail: vanja.kokol@uni-mb.si. Phone: +386 2 220 7894, Fax: +386 2 220 7990, E-mail: sonja.sostar@uni-mb.si
Dr. Reinhold Schneider, Institute of Textile Chemistry of the German Institutes for Textile and Fiber Research Stuttgart, Körschtalstr. 26, D-73770 Denkendorf, Germany. Phone: +49 711 9340 103, Fax: +49 711 9340 185, E-mail: reinhold.schneider@itc.itvd.uni-stuttgart.de

THE INFLUENCE OF ENZYMES ON VISCOSE DYEABILITY

Vanja Kokol, Nataša Štandeker, Vera Golob
University of Maribor, Faculty of Mechanical Engineering, Textile Department, Slovenia

Abstract
The present paper studies the influence of different enzymatic cellulase treatments on the dyeability (color depth and CIELAB color values) and mechanical properties (weight and strength change) of viscose fabric using different mono-/bi-functional bi-reactive dyes (MCT/VS, VS/VS, MCT/MCT).
It is ascertained that the enzymatic pretreatment of the viscose results in considerably better color depth in the cases of all bireactive dyes used at no particular weight decrease or fabric strength reduction. The samples are also darker, more saturated and with the highest color purity. The dyeability effect depends on the conditions of the enzymatic pretreatment, i.e. the treatment time and the concentration of the enzyme applied, as well as the type and concentration of the bireactive dye used when dyeing. In the case of mono-functional dye, the enzyme pretreatment time and the enzyme concentration are inversely proportional and dependent on dye concentration (the higher the enzyme concentration the shorter the time needed to obtain the same dyeability effect). However in the case, of both bi-functional dyes and at both dye concentrations, the dyeability effect increases with increasing enzyme concentration and the lengthening of enzyme pretreatment, reaching a maximum value and again decreasing. The mono-bireactive dye results in lower dyeability effect when increasing ($\Delta K/S$=9.84%-13.33%) than the bi-bireactive one ($\Delta K/S$=12.19%-21.47%). Optimization of the enzymatical fabric pretreatment is necessary according to the dyestuff used.

Keywords: *viscose, dyeing, cellulase enzyme, bireactive dyes, color, mechanical properties*

1. INTRODUCTION

Growing consciousness regarding environmental issues continues to promote the development of alternative processes in the textile industry. The use of bio-technology, above all enzymatic systems, offers innovative solutions and interesting perspectives for optimizing these processes and reducing waste emission, especially in textile finishing. The intention of enzymatic treatment is the achievement of physical, instead of chemical, fabrics finishing, and consolidating the efficacy of the treatment (improvement of the product in its usage and efficacy) with economical (optimizing the procedures and processes) and ecological (reducing waste substances and/or prevention of their formation) demands.

The enzymatic/cellulasic treatment of cellulose textile materials as a nontoxic bio-finishing process has gained increasing practical importance for various kinds of textile goods, primarily to enhance the softness and surface appearance of the substrate and, secondly, to reduce it's pilling [1-4]. However, the problem is still unsolved in regard to practical application, since the rate of cellulase catalytic reaction is affected appreciably not only by pH and temperature, but also by coexisting chemicals such as dyes or other chemicals in the treatment solution or on/in the substrate. Numerous studies dealing with the enzymatic pre- or after- treatments of cellulose have focused on the investigation of efficacy and the action mechanisms of different processes [5-7]). It is acknowledged, that only the charged organic compounds (such as dyes and textile auxiliaries), present in the treatment solution and/or adsorbed/bounded on the cellulose substrate, inhibit the velocity and efficacy of celluloses catalytic hydrolysis with the cellulase enzyme. Contrary, the addition of inorganic salts (such as NaCl, Na_2SO_4) into the treatment solution produces insignificant effects. Enzymatic hydrolysis reduces all on the substrate binded reactive dyes, above all, bireactive ones [8].

Generally, the cellulase complex consists of endo-1,4-β-D-glucanase, exo-1,4-β-D-glucanase and β-glucosidase, which in a complexity of steps of various mechanism types, synergistically attack the amorphous and/or crystalline regions of the cellulose, effecting the hydrolysis of its molecules at β-glycoside linkages and so modifying the cellulose or, under extreme conditions, yielding glucose as the final product [4, 10]. Cellulases are large-sized sphere-shaped proteins (M_w= 5000 - 100 000, d = 5 - 50 nm) of several different depolymerases, most of them unable to fully access the amorphous areas of the cellulose substrate due to geometric constraints, but, therefore, under appropriate conditions capable of modifying the cellulose surface area to a certain degree [9]; the major features being crystallinity, accessible surface area, and pore dimension [11]. In contrast, reactive dyes can also enter the less ordered areas of the cellulosic fiber through water-filled pores, forming covalent bonds with their –OH groups and thus changeing its structure to some extent [12].

Since the pore volume and surface areas of cotton are predominant parameters for the accessibility of dyes and finishes during wet processing, the cellulase enzyme hydrolysis results in their changes (above all to the increasing amount of amorphous areas [9]) and, consequently, to higher absorption of dye molecules and better dyeability [5,9]. In the cases of other natural fabrics, i.e. linen, ramie and viscose rayon, these effects are relatively unknown.

Being aware of the different physical-chemical properties of reactive dyes (chemical reactivity, affinity, adsorption, diffusion capability) different types (the number and steric position of reactive systems and reactive groups, the type of chromogen and other present substituents in the molecule) of reactive dyes can interact differently with viscose, and therefore different dyeing results are to be expected [12,13].

Thus, in this paper the influence of different chemical structure, reactive systems and reactive groups of bireactive dyes on the dyeability (K/S and CIELAB color values), of differently enzymatically-pretreated viscose fabric is studied. The criterion is the highest color depth, the lowest color modification, and the lowest weight and strength losses of the substrate.

2. EXPERIMENTAL

2.1 Material used

All experiments were done on 100% CV - regenerated and cloth-bonded viscose fabric with 110/40 dtex viscose rayon in the warp and 26/1 Nm 1300 S + Z viscose yarn in the weft directions. The fabric weight was 185.0 g/m^2 with a density of 47 threads/cm in the warp and 23 threads/cm in the weft positions. The viscose was pretreated according to the usual procedure for dyeing: wetted, washed and dried.

Three commercially available bireactive dyes of different types were used in this study: monofunctional monochlorotriazine/vinylsulphonyl (MCT/VS) Bezaktiv Red S-3B (Bezema), bifunctional bi-monochlorotiazine (MCT/MCT) Procion Red H-E3B (ICI) and bifunctional bi-vinylsulphonyl

(VS/VS) Remazol Black B 133% (Dystar GmbH). The chemical structures of the dyes are shown in **Figures 1 - 3.**
The Bactosol® CA liquid concentrated cellulase enzyme by optimum application pH and temperature region between pH = 4.5 - 5.5 and T = 55°C - 60°C [14] was provided by Clariant International Ltd.

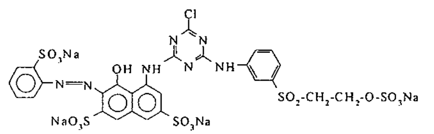


Figure 1: Bezaktiv Red S-3B (MCT/VS)

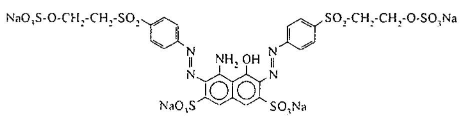


Figure 2: Remazol Black B (VS/VS)

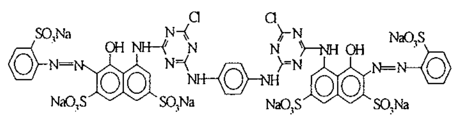


Figure 3: Procion Red H-E3B (MCT/MCT)

2.2 Enzyme treatment and dyeing procedures

The enzymatic treatments were performed at T = 55°C and pH = 5 for t = 10 (20, 30, 40, 50, 60) mins using c_E = 1(3) % enzyme concentration. The optimum pH medium was established with a buffer solution made from 20.26 g citric acid (1-hydrate $C_6H_8O_7xH_2O$) and 196.4 ml 1 M NaOH. After treatment, the fabrics were immersed in boiling water for t = 10 min to deactivate the enzymes (i.e. to terminate the enzyme catalytic reaction). The samples were then washed in cold water and air-dried.
The dyeings of previously enzymatically treated material were carried out in the new bath under standard exhaustion dyeing procedure, using the time-temperature conditions of dyeing as well as salt ($Na_2SO_4x10H_2O$, NaCl) and alkali (Na_2CO_3, NaOH; pH = 10.5) dosages in accordance with the dye concentration (c_D = 0.5(1.0, 3.0) %), and the recommendations of the dyes manufacturers. All dyed samples were neutralized with 1 g/l acetic acid (CH_3COOH) at T = 35°C for t = 10 min and washed-off with 1 g/l nonionic washing agent Tanaterge INF (Tanatex) at T = 95°C for t = 10 min and the same liquor ratio, to remove the unfixed dye.
Both the enzymatic treatment and all dyeing procedures were carried out in a Turby T (W. Mathis GmbH, Switzerland) dyeing apparatus at maximum dyeing/treating bath migration.

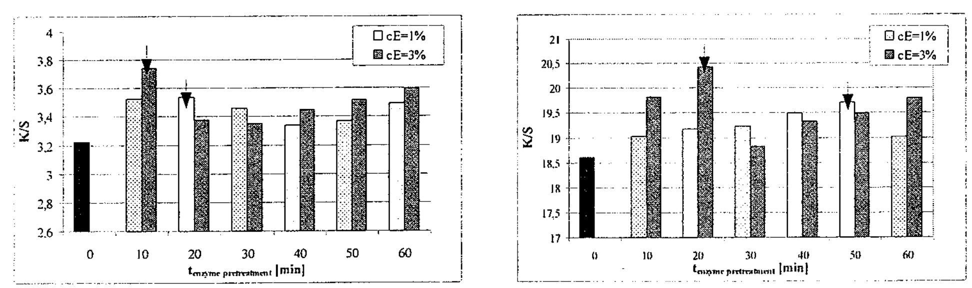
2.3 Methods

The dyeability of the samples was determined colorimetrically by reflectance measure-ments. The reflectance values were measured by a Spectraflash SF 600 spectrophotometer (Datacolor GmbH, Switzerland) using a computer system PC – AT (486) and the OSIRIS (COCOS, IRIS) program. The measuring was done under measuring condition D65/10°. The results of the measurements are expressed by depth of color (K/S) and CIELAB color values (L*a*b*C*h). The K/S values were calculated according to the Kubelka-Munk equation at the wavelength of maximum absorption [15]. The efficiency of the cellulase catalytic reaction was evaluated by determining the weight change and measuring the breaking strength (F) of the samples. Prior to these measurements, the samples were conditioned at T = 20°C and 65% relative humidity for t = 24 hours. The weight change was determined gravi-metrically: from the differences in the mass of the samples determined before and after the treatment/dyeing procedures. The breaking strength of the fabric in the warp direction was determined according to the ISO 5081 (ISO 13934-1) with a Stategraph M dynamometer measuring apparatus (Textechno AG, Germany) [16].

3. RESULTS AND DISCUSSION

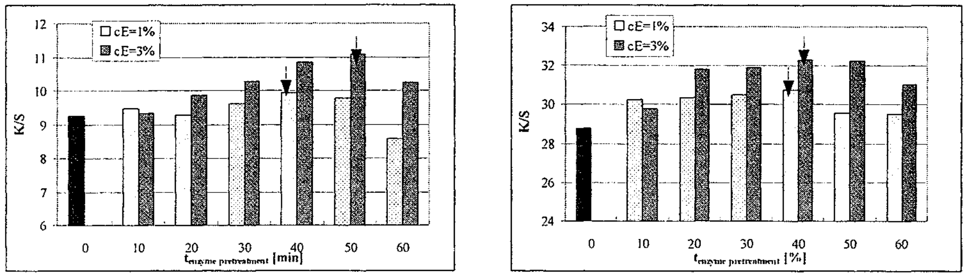
Color depth

It was ascertained that, in the case of reactive dyes, covalent substitution with hydroxyl groups of cellulose could prevent access of the enzyme and thus impede cellulose surface modification [7,8]. In order to avoid these undesirable reactive dye - enzyme interactions, differently enzymatic pretreated viscose fabric was dyed in two bath processes as described in Chapter 2.2.
Figures 4 - 6 represent the influence of differently enzymatic pretreated (T = 55°C, t = 10 - 60 min and pH = 5) viscose on its dyeability when using different bireactive dyes. It is apparent from the results of the K/S values that viscose dyeability depends on (a) the time and concentration of the enzyme pretreatment, as well as (b) the type/functionality and the concentration of the reactive dye used.
It was observed that, in the case of the lowest reactive mono-monochlorotriazine/ vinylsulphone (MCT/VS) dye and at higher enzyme concentration (c_E = 3%) less enzyme pretreatment time (t = 10 min at c_D = 0.5% and t = 20 min at c_D = 3 %) is required to assess the same K/S value as with treatment using lower enzyme concentration (c_E = 1 %: t = 20 min at c_D = 0.5% and t = 50 min at c_D = 3 %). The enzyme pretreatment time and the enzyme concentration are inversely proportional and dependent on dye concentration, i.e. the higher the enzyme concentration the shorter the time needed to obtain the same dyeability effect. Ina addition, no special weight decrease (Figure 8) or strength reduction (Figure 9) of the substrate was observed. In contrast, in the cases of both bi-functional dyes (MCT/MCT and especially VS/VS) and both enzyme concentrations, the K/S values increased with the lengthening enzyme pretreatment time, reaching a maximum value and again decreasing.
It is obvious that the dependence of the enzymatic treatment on fixed dye content varied according to the chemical structure, i.e. the position and the homogeneity of reactive groups, and the reactivity of the reactive dye applied. Since mono-functional dye molecules can only be fixed to the accessible sites of cellulose, they have much less chance of fixation at the surface of the highly ordered regions than in the amorphous regions. The bi-functional dyes, especially at higher fixed dye contents, may form cross-links within the highly accessible regions as well as between chain molecules of differently ordered domains [12,13].



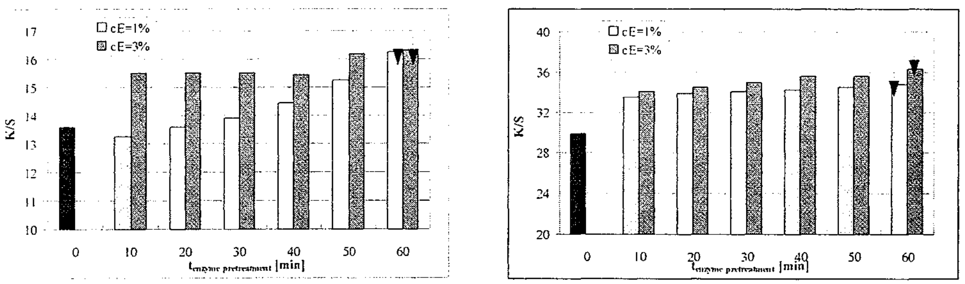
c_D = 0.5% c_D = 3.0%

Figure 4: The influence of the enzyme pretreatment on the dyeability of viscose dyed with Bezaktiv Red S-3B (MCT/VS) reactive dye



c_D = 1.0% c_D = 3.0%

Figure 5: The influence of the enzyme pretreatment on the dyeability of viscose dyed with Remazol Black B (VS/VS) reactive dye



c_D = 1.0% c_D = 3.0%

Figure 6: The influence of the enzyme pretreatment on the dyeability of viscose dyed with Procion Red H-E3B (MCT/MCT) reactive dye

Table 1: The K/S, weight and strength changes, and CIELAB color differences of the most effectively dyed viscose samples (standard: the sample dyed without enzyme pretreatment)

Type of reactive dye	Enzyme pretreat. c_D [%]	c_E [%]	t [min]	Changes [%] of ΔK/S	Δweight	ΔE	CIELAB color differences ΔL*	Δa*	Δb*	ΔC*	Δh	ΔE*
MCT/VS	0.5	3.0	10	13.33	2.52	-4.98	-1.349	2.125	1.315	1.812	1.720	2.640
VS/VS	1.0	3.0	50	20.00	1.28	-1.64	-2.562	0.356	0.387	0.496	0.175	2.715
MCT/MCT	1.0	3.0	60	20.34	2.44	-4.07	-0.023	2.066	1.589	2.213	1.377	2.716
MCT/VS	3.0	3.0	20	9.84	3.51	-5.59	-0.412	-0.240	0.645	0.226	0.650	0.802
VS/VS	3.0	3.0	40	12.19	2.57	-3.94	-1.496	0.546	0.269	0.394	0.463	1.615
MCT/MCT	3.0	3.0	60	21.47	3.22	-5.31	-0.668	0.777	1.373	1.175	1.052	1.713

It is obvious from the K/S and CIELAB color value changes (Table 1) of the viscose dyed according to the most effective enzymatic pretreating/dyeing procedures and with respect to the reactive dye used, that the highest dyeability effect (ΔK/S) at both dye concentrations is obtained when highly reactive bi-monochlorotriazine (MCT/MCT) (ΔK/S = 20.34 % at c_D = 0.5 % and ΔK/S = 21.47 % at c_D = 3 %) dye is used and that it decreases from the medium reactive bi-vinylsulphone (VS/VS) (ΔK/S =

20.00 % at c_D = 0.5 % and ΔK/S = 12.19 % at c_D = 3 %) to lower reactive mono-monochlorotriazine/vinylsulphone (MCT/VS) (ΔK/S = 13.33 % at c_D = 0.5 % and ΔK/S = 9.84 % at c_D = 3 %) dye. If the dye concentrations increase, the ΔK/S samples dyed with the mono-functional MCT/VS dye, at which two reactive groups are bonded at the same reactive system (Figure 1), increases less than it does in case of samples dyed with the other bi-functional dyes (VS/VS and MCT/MCT) at which each reactive group is bonded at each individual reactive system (Figures 2 and 3). Furthermore, the dyeability change of the fabric dyed with the MCT/MCT dye shows practically no change in respect to the MCT/VS and VS/VS when the dye concentration increases. As described, the reason could be in the better accessibility of individual reactive groups of dye molecule to free –OH groups on the cellulose molecule, where, beside the reactive dye reactivity, the size and sterical structure of the dye molecule also has an important role [12,13]. Namely, the intermolecular interactions make it more difficult for a large and branched dye molecule to penetrate to the fiber to free nucleophilic cellulose groups.

However, since the diffusion of the dye is limited by the molecular weight of the dye and by the interactions that depend on the length and branching of the molecule and since a higher dyeability effect in the cases of all enzymatically pretreated and dyed viscose samples is obtained, it could be established that the enzyme treatment changes the substrate surface structure, i.e. the volume and surface area of the pores.

In addition, this effect is practically obtained for all samples under the same enzyme treatment conditions: c_E = 3 % and t = 10(20) min at the MCT/VS dye, c_E = 3 % and t = 50(40) min at the VS/VS dye, c_E = 3 % and t = 60(60) min at the MCT/MCT dye.

Weight change and breaking strength

It is evident from the results in Figure 7 that the changes in viscose weight after different enzymatic treatments results in insignificant weight losses after 30 minutes of treatment, which additionally increases with the increasing time and enzyme concentrations. However, the weight decrease depends primarily on the time of treatment and, secondly, on the enzyme concentration applied.

As can be observed from Figures 8 and 9, and the results in Table 1, enzymatic pretreatment also has no particular effect on weight or strength deterioration in the case of dyed fabrics, but does significantly improve their dyeability (Figures 4 - 6).

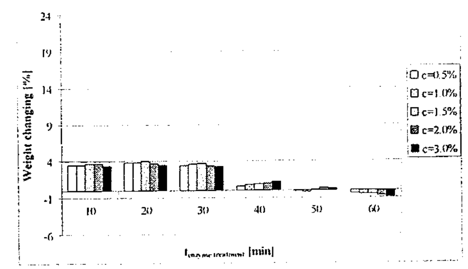
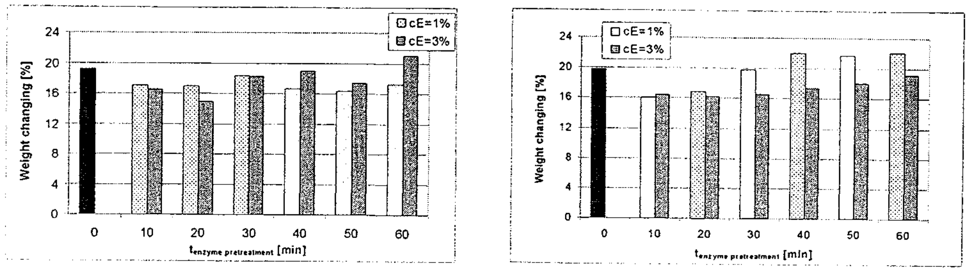


Figure 7: The influence of enzyme treatment on the weight change of viscose

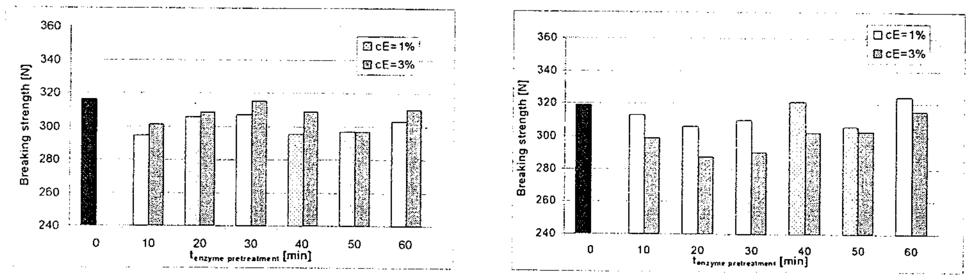
CIELAB color values and color differences

CIE-L*a*b*C*h color values and color differences (differently enzymatically pretreated samples were dyed for each type and concentration of reactive dye and when compared to the samples dyed under standard conditions) as presented in Tables 1 - 4, additionally confirm the previous (color depth) results: the viscose treated with enzymatic agent before dyeing is characterized not only by a higher intensity (ΔL* = -0.023 – -2.562, Δh = 0.175 - 1.720), but also an increased brightness and purity (ΔC* = 0.226 – 1.812) of color in relation to the enzymatically un-pretreated one.



$c_D = 0.5\%$ $c_D = 3.0\%$

Figure 8: The influence of the enzyme pretreatment on the weight change of viscose dyed with Bezaktiv Red S-3B (MCT/VS) reactive dye



$c_D = 0.5\%$ $c_D = 3.0\%$

Figure 9: The influence of the enzyme pretreatment on the breaking strength of viscose dyed with Bezaktiv Red S-3B (MCT/VS) reactive dye

Table 2: CIE-L*a*b*C*h and K/S values of viscose dyed with Bezaktiv Red S-3B (MCT/VS) after different enzymatic pretreatment

c_D [%]	c_E [%]	$t_{enz. pret.}$ [min]	L^*	a^*	b^*	C^*	h	K/S
0.5	0	0	58.20	52.37	-10.43	53.40	348.74	3.30
	1	10	56.99	52.71	-10.46	53.73	348.77	3.52
		20	56.70	53.55	-9.79	54.44	349.64	3.54
		30	57.35	52.83	-9.95	53.76	349.33	3.46
		40	57.68	52.27	-10.28	53.27	348.88	3.34
		50	56.85	50.07	-10.15	51.08	348.54	3.36
		60	57.76	53.74	-10.57	54.76	348.87	3.49
	3	10	57.05	54.39	-10.35	55.36	349.22	3.74
		20	58.10	53.39	-10.75	54.47	348.62	3.37
		30	57.68	52.07	-10.96	53.21	348.11	3.35
		40	57.73	53.25	-10.66	54.31	348.68	3.45
		50	57.15	53.61	-10.26	54.59	349.16	3.52
		60	58.18	52.87	-10.30	53.09	348.71	3.20
3	0	0	42.52	63.81	0.71	63.81	0.63	18.60
	1	10	41.21	62.13	0.51	62.14	0.47	19.03
		20	41.66	62.31	0.40	62.31	0.37	19.17
		30	41.54	62.82	0.65	62.83	0.59	19.24
		40	41.06	62.13	0.56	62.14	0.52	19.48
		50	40.80	62.66	1.54	62.68	1.41	19.70
		60	41.53	62.51	0.45	62.51	0.41	19.00
	3	10	41.19	62.61	1.25	62.62	1.14	19.82
		20	41.09	62.85	1.61	62.87	1.47	20.43
		30	41.81	62.80	0.80	62.81	0.73	18.82
		40	41.17	61.81	0.42	61.81	0.39	19.33
		50	41.26	62.07	0.58	62.07	0.53	19.48
		60	41.29	62.74	1.08	62.75	0.98	19.80

Table 3: CIE-L*a*b*C*h and K/S values of viscose dyed with Remazol Black B (VS/VS) after different enzymatic pretreatment

c_D [%]	c_E [%]	$t_{enz. pret}$ [min]	L^*	a^*	b^*	C^*	h	K/S
1	0	0	37.06	-8.23	-18.98	20.69	246.57	9.25
	1	10	36.36	-8.06	-18.66	20.32	246.64	9.49
		20	36.68	-7.96	-18.59	20.22	246.82	9.28
		30	35.05	-7.85	-18.72	20.30	247.23	9.60
		40	36.54	-7.66	-17.46	19.06	246.32	9.95
		50	36.05	-7.94	-18.70	20.32	246.99	9.79
		60	37.82	-8.15	-18.71	20.41	246.47	8.57
	3	10	37.41	-8.14	-18.91	20.58	246.72	9.33
		20	35.15	-7.95	-18.65	20.28	246.91	9.86
		30	36.31	-8.07	-18.71	20.37	246.67	10.26
		40	34.94	-8.03	-18.79	20.43	246.86	10.84
		50	34.50	-7.87	-18.60	20.19	247.06	11.10
		60	32.95	-7.96	-23.62	24.84	251.97	10.24
3	0	0	20.58	-4.02	-15.00	15.53	255.01	28.78
	1	10	19.54	-3.61	-14.92	15.35	256.41	30.24
		20	19.69	-3.54	-14.86	15.27	256.61	30.37
		30	21.06	-4.13	-15.88	16.41	255.43	30.50
		40	19.60	-3.61	-14.85	15.28	256.35	30.73
		50	20.40	-4.03	-15.32	15.84	255.27	29.58
		60	20.59	-4.06	-15.62	16.14	255.42	29.53
	3	10	19.88	-3.66	-14.75	15.20	256.08	29.79
		20	19.31	-3.68	-14.70	15.15	255.95	31.80
		30	19.43	-3.53	-14.59	15.02	256.40	31.91
		40	19.09	-3.47	-14.73	15.14	256.74	32.29
		50	18.73	-3.32	-14.09	14.48	256.74	32.25
		60	20.17	-4.10	-15.49	16.02	255.16	31.03

Table 4: CIE-L*a*b*C*h and K/S values of viscose dyed with Procion Red H-E3B (MCT/MCT) after different enzymatic pretreatment

c_D [%]	c_E [%]	$t_{enz. pret.}$ [min]	L^*	a^*	b^*	C^*	h	K/S
1	0	0	46.81	63.37	5.61	63.62	5.06	13.57
	1	10	47.94	63.91	5.35	64.13	4.79	13.24
		20	48.36	64.83	5.68	65.07	5.00	13.58
		30	47.50	64.01	5.85	64.28	5.22	13.90
		40	47.26	64.20	6.25	64.50	5.56	14.44
		50	47.29	64.99	6.76	65.34	5.94	15.25
		60	46.77	65.14	7.43	65.56	6.51	16.26
	3	10	47.02	65.07	7.28	65.48	6.38	15.50
		20	47.13	64.93	7.06	65.31	6.21	15.51
		30	47.44	65.29	7.06	65.67	6.17	15.51
		40	47.81	64.79	5.91	65.06	5.22	15.46
		50	47.05	65.39	7.40	65.81	6.46	16.19
		60	47.04	65.44	7.20	65.83	6.28	16.33
3	0	0	38.89	63.32	20.82	66.65	18.20	29.94
	1	10	38.79	64.09	21.27	67.53	18.36	33.58
		20	38.55	63.92	21.14	67.32	18.30	33.89
		30	38.83	64.34	21.36	67.80	18.37	34.06
		40	38.64	64.19	21.87	67.81	18.82	34.31
		50	38.93	64.41	21.18	67.80	18.20	34.57
		60	38.62	63.91	21.17	67.32	18.32	34.77
	3	10	38.35	63.61	21.03	67.00	18.29	34.07
		20	38.30	63.78	21.84	67.42	18.90	34.56
		30	38.25	63.80	21.67	67.38	18.76	35.03
		40	38.20	63.82	21.66	67.40	18.75	35.64
		50	38.17	63.90	21.75	67.50	18.80	35.63
		60	38.22	64.10	22.19	67.83	19.09	36.37

3. RESULTS

We have studied the effect of cellulase enzyme activity on the dyeability and mechanical properties of viscose fabric enzymatically pretreated with differently treated solutions and processes, and subsequently dyed with different types of bireactive dyes, mono- and bi- functional.

The enzymatic pretreatment of the viscose significantly improves the absorption of dye molecules and, consequently, in the cases of all reactive dyes used, results in higher depth of color in regard to enzymatically non-pretreated ones, without any special weight decrease or strength reduction of the substrate. The samples are also darker, more saturated and with the highest purity of the color. The quality of dyeing depends on the time and the enzyme concentration at pretreatment, as well as on the type and concentration of bireactive dye used when dyeing. In the case of mono-functional dye (MCT/VS), the higher the enzyme concentration the shorter the time needed to obtain the same dyeability effect, whereas in the cases of both bi-functional dyes (VS/VS, MCT/MCT) and both enzyme concen-trations it increases with the lengthening time of enzyme pretreatment, reaching no maximum value and again decreasing. The mono-functional dye results in lower dyeability effect increase than the bi-functional dyes. The highest dyeability effect is obtained when highly reactive bi-monochlorotriazine (MCT/MCT) dye is used and it decreases from the medium reactive bi-vinylsulphone (VS/VS) to lower reactive mono-monochloro-triazine/vinyl-sulphone (MCT/VS) dye.

We can conclude that additional research work is required in order to optimize the dyeing processes from the ecological point of view, above all to shorten the treatment time and/or reduce the quantity of enzyme and/or other components in the treating/dyeing solutions.

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Dr. Vanja Kokol, Nataša Štandeker, B.Sc., Ass. Prof. Dr. Vera Golob. University of Maribor, Faculty of Mechanical Engineering, Textile Department, Institute for Textile Chemistry, Ecology and Colorimetry, Smetanova ul. 17, SL-2000 Maribor, Slovenia. Phone: +386 2 220 7896, Fax: +386 2 220 7990, E-mail: vanja.kokol@uni-mb.si. Phone: +386 2 220 7891, Fax: +386 2 220 7990, E-mail: vera.golob@uni-mb.si.

DYE SORPTION OF DIFFERENT REGENERATED CELLULOSE FIBRES DETERMINED USING COLORIMETRIC EVALUATION OF COLOR

Tatjana Kreze, Slava Jeler, Karin Stana-Kleinschek
Institute for Textile Chemistry, Ekology and Colorimetry, University of Maribor, Slovenia

Abstract
This work correlates fine structure with the adsorption behavior of the new (lyocell) and conventional (viscose, modal) regenerated cellulose fibers. In the research an overall analysis of the structural characteristic of lyocell fibers was performed and a comparison with the conventional viscose and modal fibers was made. We studied the molecular structure, the fine structure and, most important of all, the amorphous regions and void system. Their effect on the adsorption properties of the fibers was investigated. The differences in adsorption properties of all three fibers types were obtained on the basis of various methods for determining the water, dye and the iodine adsorption. The structural analysis shows that higher molecular weight, a higher degree of crystallinity and a higher molecular orientation are observed with lyocell fibers [1]. Our results, obtained by different independent methods, demonstrate clearly, that the adsorption properties of cellulose fibers depend, with the exception of the portion and orientation of amorphous regions, predominantly on the void system (diameter, volume and inner surface of voids) [2].

Keywords: *Regenerated cellulose fibers, Structure, Water adsorption, Dye adsorption*

1. INTRODUCTION

The structure of conventional and new regenerated cellulose fibers is already well known [3-9]. The viscose production processes (viscose, modal fibers) are based on the derivatisation of cellulose using carbon bisulphide [10-13]. Lyocell fibers belong to the new generation of regenerated cellulose fibers produced by on environmentally clean process [14-18]. Their supramolecular structure is different from the conventional regenerated cellulose fibers, what explains their different sorption properties. There are many publications on the determination of lyocell fiber structure and morphology. Much less is known about the correlation between the structure of fiber and their behavior during the finishing processes. The properties of fibers in the swollen state are of major interest. Accessibility in the water-swollen state is of even greater importance than accessibility in the dry state for many industrially performed processes on cellulose fibers. Under these circumstances the less ordered regions determine the fiber properties and, therefore, the accessible amorphous regions and void fraction are supposed to be responsible for the reactivity and adsorption processes. The accessibility of cellulose to water and consequently to dyes dissolved in water, varies with the size and distribution of the crystalline regions, amorphous regions and the connecting regions of low order. The measurement of accessibility involves either measuring the equilibrium adsorption of some species (water, dye) or measuring the rate at which cellulose is attacked by the chosen reagent.

Cellulose materials are most commonly dyed with direct, reactive, vat and aziotic dyes. Direct dyes are anionic and have disazo or trisazo structure. Most direct dyes have high molecular masses and the direct dye anions are essentially planar and rather large [19,20]. The anion transfer and diffusion processes take place from aqueous solution in a bath-containing electrolyte, and both depend on there being some level of attraction (substantivity) between the color bearing dye-bath anions and the nonionic cellulose fibers [20]. The different intermolecular interactions are responsible for sorption in a dyeing system. Hydrogen bonding has been suggested as the source of the attraction, but there is evidence that cellulose is so strongly hydrogen bonded to water that preferential hydrogen bonding to the amino, hydroxyl or other groups present within direct dyes seems quite improbable. The most likely cause of substantivity appears to be the combination of relatively weak forces, including the same short range van der Waals forces which contribute to the association of dye-ions with one another in the form of aggregates, either in solution or after the single dye-ions have passed across the potential barrier and have reached the fiber–water surface boundary [20,21].

The dyeing process of water-soluble dyes in aqueous dye solution in fibers is always a distribution process between two phases (dye solution and substrate). Two experimental methods play a dominant role: dyeing kinetics, i.e. the rate of transfer of dye in solution from the dye bath into the substrate, and dyeing equilibria (sorption and desorption process in the state of equilibrium). In theoretical treatments of diffusion, it is usual to characterize the migration of dyes in terms of the diffusion coefficient. The diffusion coefficient is most usually evaluated by the application of Fick's laws [22,23]. Complete solutions to Fick's equations present considerable computational problems because of the number of variables involved. Under quite specific, limiting assumptions, sorption of molecular probes by cylindrical fibers can be described by use of the conventional diffusion equation solutions of Hill, Newman, Wilson, Crank. For finite bath conditions the dye uptake can be estimated by the diffusion equation solution of Wilson [24-27]. The dye concentration in dye solution can be evaluated in dyeing process scpectrophotometrically based on the transmission measurement (absorbency measurements of dye solution). The color of dyed samples can be evaluated using the colorimetric evaluation of color based on measurement of reflectance values.

This research work correlates the fine structure of cellulose fibers [1] with its adsorption ability. In addition the structural parameters, which significantly influence the sorption properties of the fibers dye adsorption was determined.

2. EXPERIMENTAL

2.1 Materials

Three different types of regenerated cellulose fibers (viscose CV, modal CMD and lyocell fibers CLY) produced by Lenzing AG Austria were used. Their structural characteristics and water sorption ability are presented in Table 1.

2.2 Methods

2.2.1. Dye sorption was determined using colorimetric evaluation of color of dyed fiber samples. The C.I. Direct Blue 71 was used. The dyeing method used was the Isotherm Method recommended by Bezema. Final dyeing of fibers was carried out in the Turbomat Ahiba laboratory dyeing apparatus at a liquor ratio of 1:30 by an addition of 1%, 2%, 3% of dye and 20 g/l of electrolyte. The dyeing started at 50°C, after 20 min the dye was added then the temperature was raised to 100°C.

Table 1: The specifications and structural characteristics of investigated cellulose fibers [1]

Fiber type	Viscose CV	Modal CMD	Lyocell CLY
Linear density [dtex]	1.88 ±0.15	1.78 ±0.23	1.82 ±0.30
Molecular mass M	38 005 ±881	82 097 ±538	104 021 ±730
Degree of polymerization DP	235 ±5.13	507 ±3.61	642 ±4.58
Crystalinity index CrI	0.25	0.37	0.44
Orientation factor $f_{\Delta n}$	0.58 ±0.07	069 ±0.08	0.71 ±0.04
Void volume V_p [cm^3/g]	0.68	0.49	0.62
Void diameter d [nm]	3.1	2.4	3.0
Specific inner surface S_p [m^2/g]	439	409	432
Water retention value [%]	84.9 ±1.1	57.8 ±0.7	72.8 ±2.7
Swelling in aqueous medium [%]	36.3 ± 1.5	17.4 ± 0.9	22.0 ±1.1

After addition of electrolyte the dyeing continued for a further 60 min. The reflectance values of the dyed samples were measured using Datacolor Texflash spectrophotometer. Dye sorption or dye concentration on the fiber was determined using reflectance measurements of dyed fiber samples with Kubelka-Munk values K/S at the wavelength of maximal absorption - minimal reflectance. Measured reflectance R-values served for calculation of K/S value, which is directly proportional to the concentration of colorant in the substrate. The appropriate form of the equation for textile surfaces is [21] :

$$K/S = (1-R)^2/2R \quad \text{(Eq.1)}$$

where R is the reflectance of an infinitely thick layer of material illuminated with light of a known wavelength, K is the absorption coefficient and S is scattering coefficient. The color of dyed samples has been evaluated also with the help of CIELAB colorimetric system using a DC 3881 Datacolor spectrophotometer and appropriate software for determination of CIELAB color coordinates and color differences. The color has been evaluated with the following color coordinates: L* lightness, C* chroma, h hue, a* position on red/green axis, b* on yellow/blue axis.

2.2.2. Dye sorption evaluated by determination of diffusion coefficient D. D was determined spectroscopically on the basis of absorbency measurements of dye solution at the maximum absorbency (determination of dye concentration in dye solution – Beer's law). The dyeing of the samples was carried out in the Turbomat Ahiba laboratory dyeing apparatus; the absorbency of dyeing solutions was measured using a UV/VIS Lambda 2 spectrophotometer (λ_{max} = 588 nm). The C.I. Direct Blue 71 with the molar mass 1029 g/mol was used for this experiment:

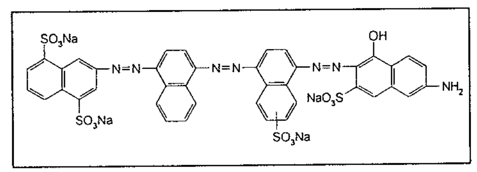

Figure 1: C.I. Direct Blue 71

The dyeing process was carried out under constant dyeing conditions: at low temperature (30°C), at a high liquor ratio (1:3000), by an addition of 3% of dye and 20 g/l of electrolyte, up to equilibrium. The dye concentration on the fiber at equilibrium $[c_f]_\infty$ and dye solution exhaustion E was calculated. D was calculated by a simplified solution of Fick's diffusion equation [28]:

$$\frac{M_t}{M_\infty} \cong 4 \cdot \left[\frac{D \cdot t}{\pi \cdot r^2}\right]^{1/2} \quad \text{(Eq.2)}$$

where M_t and M_∞ are the dye uptakes after time t and at equilibrium and r is fiber radius. This equation is used for calculating D by obtaining the time of half dyeing from a plot of dye exhaustion versus time [28]. When dyeing time is relatively short and liquor ratio is high, the quotient $F = (A_0 - A_t / A_0 - A_\infty)$ is proportional to square root of time. In the following equation for calculating the diffusion coefficient, the value b represents the inclination of straight line dependence of $F = f(t^{1/2})$:

$$D = \frac{b^2 \cdot \pi \cdot r^2}{16} \quad \text{(Eq.3)}$$

3. RESULTS AND DISCUSSION

From previous research work [1] it is clear that the crystal structure of the new environmentally friendly fibers differs from conventional (viscose or modal) fibers. The structure analyses of investigated regenerated cellulose fibers show that the most important structure characteristics (molecular mass, degree of polymerization, density, orientation factor, crystallinity index) are decreasing from lyocell to modal fibers, and the most significant decrease of these parameters is evident in the case of viscose fibers. The trend is different for the void structure of fibers. The analyses of voids using the size exclusion chromatography show that amount of void fraction (voids diameter d, volume V_p and specific inner surface of voids S_p) is the largest among the viscose fibers. Lyocell fibers follow, they are very similar to viscose fibers regarding the structure of the voids. The amount of void fraction is the smallest in most stretched modal fibers. All three types of regenerated cellulose fibers differ in terms of their crystalline area structure, amorphous area and also in void structure. The amorphous regions of lyocell fibers are smaller in comparison with viscose and modal fibers. The void fraction, above all the amount of the voids, is similar to that of viscose fibers. Differences in molecular and fine structure of fibers cause different sorption properties. A significant influence on the adsorption properties of fibers having accessible regions in fiber structure (the portion of less ordered amorphous regions and void fraction), where the adsorption processes takes place.

The dyeability of investigated fibers has been determined on the basis of measurement of reflectance values of fiber samples, dyed with C.I. Direct Blue 71 using appropriate technological procedure. K/S values and color coordinates of CIELAB color space have been determined using the colorimetric evaluation of the color of dyed fiber samples. In the Table 2 the Kubelka-Munk values K/S of the fiber samples, dyed by different concentrations of C.I. Direct Blue 71 (1%, 2% and 3%) are presented. From Table 2 and Figure 2 it can be seen that highest K/S values, resulted from all applied concentrations of dye, have been obtained for viscose fibers, lyocell fibers follow. The lowest K/S values have been obtained for modal fibers. At maximal dye concentration (3%) viscose fiber's K/S value is 25.22. K/S value of lyocell fibers is 14% lower while this value is 20% lower for modal fibers regarding the viscose fibers.

Figure 3 shows the color coordinates of CIELAB color system, namely lightness L*, measured on samples of regenerated cellulose fibers, dyed with C.I. Direct Blue 71. The lightness L* of dyed samples decreases along with increasing dye concentration. The lowest L* values have been found for viscose fiber samples; these samples are the darkest ones. Modal fiber samples have the highest L* value irrespective of dye concentration.

Table 2: K/S values and CIELAB color coordinates of fibers, dyed with C.I. Direct Blue 71

Sample	dye conc.	K/S	L*	C*	h	a*	b*
Viscose	1%	15.5441	25.8099	23.4168	277.4404	3.0320	-23.2200
Modal	1%	11.7552	28.4166	18.7643	272.2930	0.7510	-18.7490
Lyocell	1%	13.0785	26.5750	17.7260	274.2165	1.3030	-17.6780
Viscose	2%	23.4482	19.2760	17.9670	280.5671	3.2954	-17.6625
Modal	2%	17.1036	23.0710	14.5410	270.6802	0.1732	-14.5406
Lyocell	2%	18.1775	21.1540	12.3070	275.9384	1.2731	-12.2412
Viscose	3%	25.2150	17.2616	13.8082	283.9669	3.3330	-13.4000
Modal	3%	20.2884	20.6922	12.9571	270.4524	0.1020	-12.9570
Lyocell	3%	21.7176	18.5883	9.6354	278.4363	1.4140	-9.5310

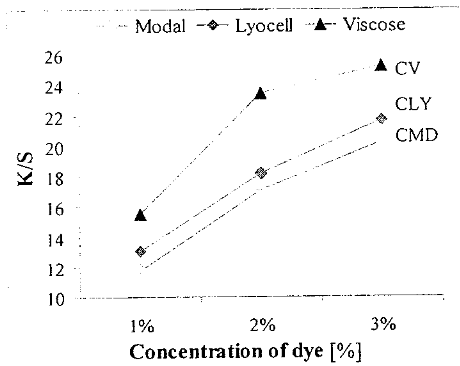

Figure 2: K/S values of dyed regenerated cellulose fibers

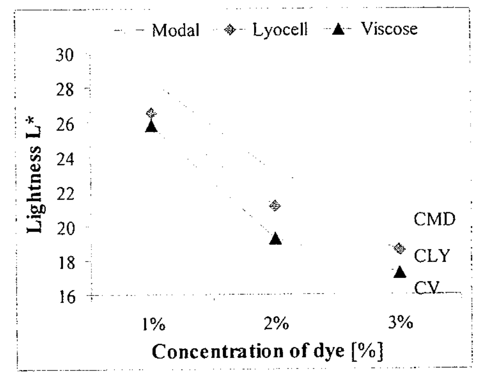

Figure 3: Lightness L* of dyed regenerated cellulose fibers

The differences in lightness between modal, viscose and lyocell fibers increase along with increasing dye concentration in the dye solution. Color coordinate lightness L* correlates well with K/S values (dye concentration on the fiber). Figure 4 shows the influence of crystallinity index CrI and voids volume V_p on amount of the dye absorbed on fiber (K/S, L*), dyed at maximal dye concentration (3%). Values K/S (dye concentration on the fiber) correlates with the amount of void fraction (V_p, S_p, d) of viscose and modal, as well as new lyocell fibers. Viscose fibers with the highest void volume have large inner surface; hence the dye adsorption ability is the greatest.

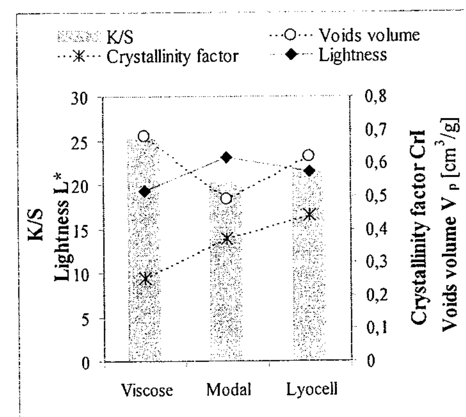

Figure 4: Effect of structure characteristics on K/S value and lightness L*

Table 3: Dye adsorption of regenerated cellulose fibers

Sample	A_0	A_∞	E	$[c_f]_\infty$ [mol/kg]	r [cm]	b [$s^{-1/2}$]	D [cm^2/s]
Viscose	0.5877	0.4890	0.17	$5.81\ 10^{-3}$	$7.17\ 10^{-4}$	0.0111	$1.24\ 10^{-11}$
Modal	0.5927	0.5405	0.09	$2.32\ 10^{-3}$	$7.10\ 10^{-4}$	0.0098	$0.95\ 10^{-11}$
Lyocell	0.5926	0.4618	0.22	$4.39\ 10^{-3}$	$6.40\ 10^{-4}$	0.0115	$1.06\ 10^{-11}$

Lyocell fibers follow, they are very similar to viscose fibers regarding the structure of the voids; however, they have significantly higher crystallinity index in comparison to viscose fibers. Modal fibers showed the lowest dye concentration on the fiber because of their essentially smaller void volume despite of greater portion of amorphous regions when compared with lyocell fibers.

In Table 3 the results of dye sorption measurements of investigated regenerated cellulose fibers are presented: initial absorbency A_0, absorbency at equilibrium A_∞, dye solution exhaustion E, radius of fibers r, inclination of straight line dependence of $F=f(t^{1/2})$ b, dye concentration on fiber at equilibrium $[c_f]_\infty$ and diffusion coefficient D of C.I. Direct Blue 71. Aqueous solutions of dye can only penetrate into the less ordered amorphous regions and voids of the fiber. The molecules of dyestuff are essentially greater in comparison with water molecules; therefore their penetration is heavier inside the fiber. As can be seen from the Figure 5, the diffusion coefficient of C.I. Direct Blue 71 is the lowest in modal fibers D = 0.95 10^{-11} cm^2/s, in lyocell fibers D = 1.06 10^{-11} cm^2/s and the highest in the case of viscose fibers D = 1.24 10^{-11} cm^2/s. In addition, the dye concentration on the fiber at equilibrium $[c_f]_\infty$ increases from modal (2.32 10^{-3} mol/kg) over lyocell (4.39 10^{-3} mol/kg) and up to viscose fibers (5.81 10^{-3} mol/kg). The viscose fibers with the lowest degree of crystallinity, greatest portion of amorphous regions, volume and inner surface of voids, adsorb the most dyestuff.

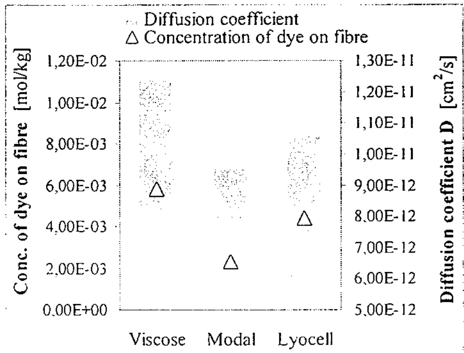

Figure 5: Diffusion coefficient of C.I. Direct Blue 71 and the dye concentration on fiber at equilibrium

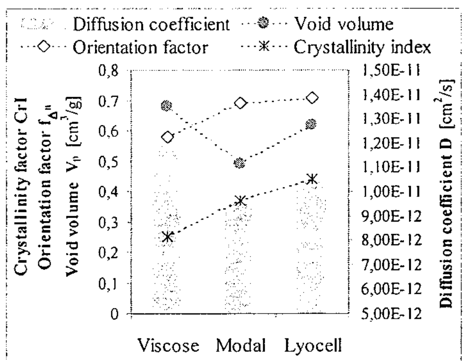

Figure 6: Effect of structure characteristics on dye adsorption

In regard to lyocell fibers, the relatively greater specific inner surface and void volume (similar to those of viscose fibers), the highest diffusion coefficient and dye concentration on the fiber were expected. We can see the influence of the higher degree of crystallinity (smaller amorphous regions, few accessible –OH groups) of lyocell fibers in comparison to viscose fibers. The diffusion coefficient shows the same correlation as in the case of colorimetric evaluation of color of dyed regenerated cellulose fibers (Figure 6). Above all the results depend on the void fraction. The voids of lyocell fibers are similar to those of viscose fibers, and so are the swelling and dyeing properties in aqueous medium.

Correlation between structural parameters (crystallinity index CrI, orientation factor, structure of voids etc.) and sorption ability (water retention value, swelling in the aqueous medium, dye adsorption: diffusion coefficient, K/S values) of fibers with the same chemical composition proves that the void system is responsible for the interaction of the fiber forming polymers.

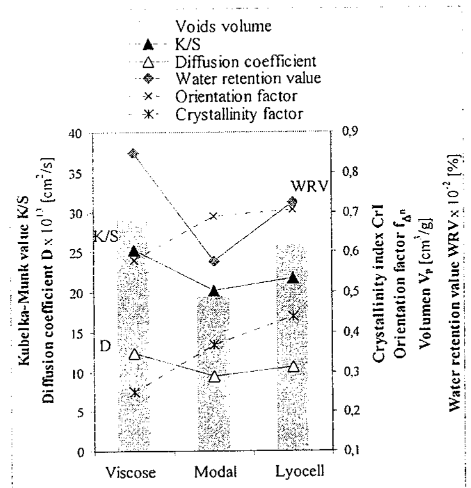

Figure 7: Correlation between structure characteristic and adsorption ability of regenerated cellulose fibres

Figure 7 shows that viscose fibers with higher void volume and the largest amorphous regions have consequently superior sorption properties. They absorb the largest amount of water, as well as dyestuff. Lyocell fibers follow - despite the smallest amorphous regions. With relatively high diameter, volume and inner surface of voids, similar to viscose fibers, lyocell fibers come close to sorption properties of viscose fibers. Modal fibers with smaller diameters and volume of voids, despite relatively large inner surfaces, show the worst sorption properties; they retain the smallest quantity of water after soaking and centrifuging, they swell the least in aqueous medium and adsorb the smallest amount of dyestuff (Table 4).

Table 4: Correlation between structural characteristics (crystallinity index CrI, void volume V_p), water (water retention value WRV, swelling in the aqueous medium SW) and dye adsorption (D, K/S, L*)

	Viscose	Modal	Lyocell
CrI	⇒ 0.25	0.37	0.44
	Viscose	Lyocell	Modal
V_p [cm^3/g]	⇐ 0.68	0.62	0.49
WRV [%]	← 84.9	72.8	57.8
SW [%]	← 36.3	22.0	17.4
D [cm^2/s]	← 1.24 10^{-11}	1.06 10^{-11}	0.95 10^{-11}
K/S	← 15.54	13.08	11.76
L*	← 25.81	26.58	28.42

4. CONCLUSION

In general, the new generation of regenerated cellulose fibers, lyocell fibers, behave in a similar manner to other cellulose fibers. As with other fibers, the dye adsorption and the dyeability depend on a great extent on the structure of fibers. The sorption properties of regenerated cellulose fibers are (besides the size and orientation of amorphous regions in the fiber), influenced above all by the voids fraction; the void diameter, volume and specific inner surface. The influence of the crystalline regions, their size and orientation on the adsorption character is less important. The voids of lyocell fibers are similar to those of viscose fibers, and so are the swelling and dyeing properties in aqueous medium. In spite of the highest degree of crystallinity and orientation, lyocell fibers have excellent sorption properties, similar to those of viscose fibers.

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Assistant Prof. Dr. Tatjana Kreze, Prof. Dr. Slava Jeler, Associate Prof. Dr. Karin Stana-Kleinschek, University of Maribor, Faculty of Mechanical Engineering, Department of Textiles, Smetanova 17, SI-2000 Maribor, Slovenia. Phone: +386 2 220 7890, Fax: +386 2 220 7990, E-mail: tanja.kreze@uni-mb.si; Phone: +386 2 220 7540, Phone: +386 2 220 7890, E-mail: karin.stana@uni-mb.si

THE SIGNS AND SYMBOLS OF RED COLOR IN EAST ASIAN COUNTRIES

Young Gull Kwon
Faculty of Design
Seoul National University
Seoul, Korea

Abstract

Color is just a physical property of every object in nature. At the same time, it acts as an environmental indication on human being and also exists as a sign and a symbol in a cultural area. Human being can perceive the character and existence of an object through the color. The perceptual process on the object has three steps; objectification, concretization and developing to symbolization. Those three phases are collectively shared in a cultural community, a country moreover an ethnic group. The social perception and symbolization of colors are dominant parts of culture in each country or ethnic group. This research is on the color preference in East Asian countries cultural context, and how red has been shared as signs and inherited as symbols in East Asian countries.

Keywords: *East Asia, red, sign, symbol, culture*

1. INTRODUCTION

Though color is perceived through the sense of sight, it combines with social system, custom and ideology to bear meanings and becomes a culture through repetitive and customary uses in a certain region and then forms system of sign. It builds up a philosophy on color beyond a mere perception and the society can be systemized on the basis of that philosophy. This formation of meaning is originated from cultural environments such as ethic history, ideology, language, custom in a certain social group and also from natural environments such as geology, climate, geographical features not from personal thoughts or preferences of color. It is based on. After all, it settles down in everyone's mind as a common consciousness of color. Therefore the consciousness and meanings of color that act as 'conceptualized generality' on the people in a same cultural area can be the most significant clue to find out sociocultural characteristics and contents of that area.

2. GENERAL MEANINGS OF RED

2.1 Ideological Background

East Asian countries including Korea, China, Japan were under the same dominant influences of Confucianism, Buddhism and Taoism. These philosophies established the fundamental of their spiritual culture and social infrastructure, which had a great influence on application of colors. For instance, **'*Yin-Yang* and Five-element School'** built the harmony of **'*Yin-Yang* (negative-positive)'** and the concept of circulation on the thinking system. On the basis of these thoughts, people in East Asian countries made religious and ideological system needed for daily life. Through these thought system, the distinctive color system, '***Obang-Saek*(Five-element-color)'** was created and has been applied to every field of society.

Table 1: *Obang-Saek*(Five-element-color)

5 Elements	5 Directions	5 Colors
Wood	East	**Blue**
Fire	South	**Red**
Earth	Center	**Yellow**
Metal	West	**White**
Water	North	**Black**

2.2 Examples of Application

In Korea, there was the color application principle, which came from the transformation of color consciousness. Chromatic colors were used for expressing the strict regulation and hierarchy of ruling classes and achromatic colors were used for ordinary people. For example, in *Chosun*

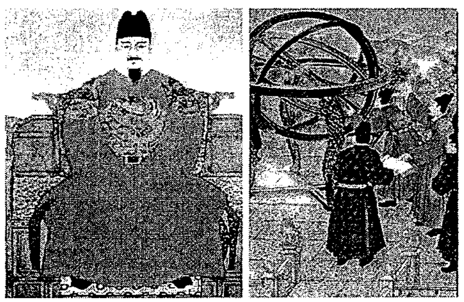

Figure 1: Examples of the color application. Robes of king and officers in Korea; *Sejong the Great, Chosun* dynasty.

dynasty (1392-1910), red and yellow were used for royal robes, and light red and purple were limitedly used for color of government officers' uniforms. For ordinary people, the use of red color was allowed only for wedding and ritual ceremony to prevent the evil, moreover its use should be followed the direction of *'Obang-Saek* (Five-element-color)'. Chinese people believe that red color brings them wealth and happiness, thus at China towns placed all over the world, red color is dominant on urban environment, architectures, clothes and products. At the era of Shogun in Japan,

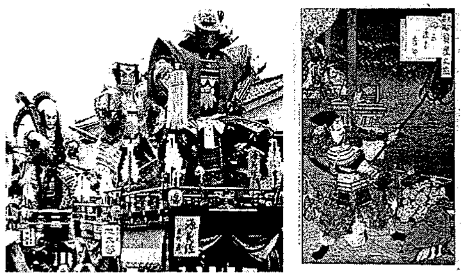

Figure 2: Red in Japanese traditional culture; Mikuni festival and an art work from 18th century

red color was regarded sanctified because red stood for blood of sacrifice. So red was used only for the Imperial Family. It was very similar to the case of Korea and China.

3. RED AS SOCIAL INDICATION

Red used to be called crimson, scarlet, vermilion and so on. The pure red is called 'Genuine red' and also 'Cardinal red', 'Fresh red', 'Sacred red' by the meaning of dark and unmixed feature. In Korean folklore, red points out the direction of south, which means that the place is warm, full of energy and covered with all things. Also, red is the exact color for south, and stands for fire based on *'Yin-Yang and Five-element School'*. At the emotional aspect, delight means the fire, and is represented by red in accordance with the science of divination. It comes from the fact that face of human is getting red and shiny when he is pleased and laughing.

3.1 Red in Korean History

Red was the symbolic color of power and represented nobility and social status. For example, red robes of office were only for the senior grade of the first, second and third lank as a symbolic color according to the court ranks of *Chosun* dynasty. Red was regarded as a noble color in *Chosun* dynasty, accordingly light red and purple were allowed only for men of dignitaries and noble families in the reign of *Sejong the Great* (the forth king of *Chosun* dynasty, crowned 1418~1450). Also in the reign of *Jungjong* (the eleventh king of *Chosun* dynasty, crowned 1508~1554), the use of crimson was considered as impertinence as being similar to dress of king and then prohibited. Those strict prohibitions were released in the reign of *Gojong* (the twenty sixth king of *Chosun* dynasty, crowned 1863~1907) as the color of royal robes changed from red to yellow so that red clothes started to be allowed for the ordinary people. It brought a fashion genre called 'Green jacket and red skirt' which means colorful and beautiful women's dresses and rose pink was popular among women, so was scarlet among children.

3.2 Red in Chinese History

Since red color has a character to be aggressive and masculine, it frequently represents battle and reminds fighting and burning world. In East Asian countries, red symbolizes the bellicosity, thus was used for encouraging soldiers. When solders occupy the enemy's position, they hoisted up a red flag as a meaning of victory and to indicate the marshalling area. According to *Yieji*, a Chinese old text, the flag painted red bird should be at the head of military procession. Especially, in China, the red flag symbolized the mood of revolution and meant the southern area where the revolution had begun. Therefore, it

Figure 3: Posters from 1967, China

spontaneously became the representative color of communism.

The beginning of 1967 in Heilongjiang Sheng, China, there was a mass rally on a large scale to celebrate the organization of Revolutionary Committee formed upon an appeal of ***Mao Tse-tung***. Their catchphrase was "Vie for power and seize the power". *Mao* insisted that they have to take power back from the party leaders who became a new group of power after a revolution and his insistence received strong public support from the crowd with big portraits of *Mao* at the head of the procession. The crowd raised up analects of *Mao* bound in red cover while red flags made a sea of red. Ironically, the red color was mobilized as meaning of defiance and struggle for power although the red color is the sign and symbol of power in most cases.

4. RED AS INCANTATORY PURGATION

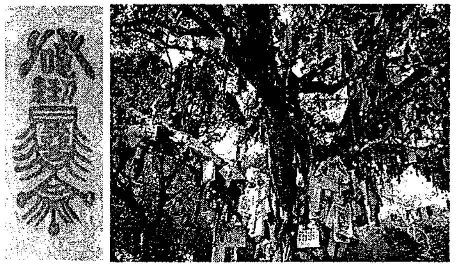

Figure 4: A wishing tree with amultets China

Chinese people believe that the amulet has a power to confront against the evil spirit. The amulet is produced with drawings by red cinnabar on yellow paper. They put the red paper with a couplet on the doors to bring a good luck at the beginning of the New Year. To protect the home from minor demons, they put a pair of hanging scrolls of red paper. These are the symbolized texts against evil spirits. The red walls of *Zhijincheng*, The Forbidden Palace in Beijing means the sun and good fortune, the yellow roofs are symbol of the great earth.

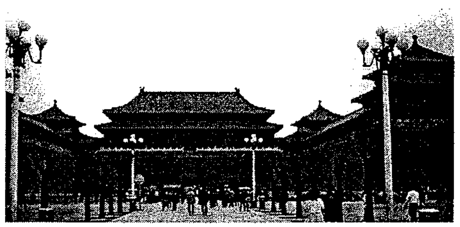

Figure 5: The red walls of *Zhijincheng*, The Forbidden Palace.

The former follows the principle of *Yang* (positive), the latter follows the principle of *Yin* (negative). At Chinese government building or *Shiheyan,* the traditional residence enclosed with four buildings that is people's common house in Beijing, there is a *Yingbi*, the spiritual wall that has a picture of big sun. It facilitates officers in the government building to deal with government affair fairly with the meaning to prevent evil spirits. They believe that red color has the power to protect themselves from evil will.

According to Korean custom and folk belief, red has an incantatory meaning to purge away evil spirits. At wedding ceremony, a bride puts *Younji-Gonji*, red lipstick and rouge spots on a bride's forehead and chicks. People believed that it expels the dissolute ghost envying a bride, and protects a bridegroom from evil power. Therefore, the coat and wrap clothes for wedding ceremony were red. And when making them, people used red thread to purge away ghosts and wish healthy and longevity.

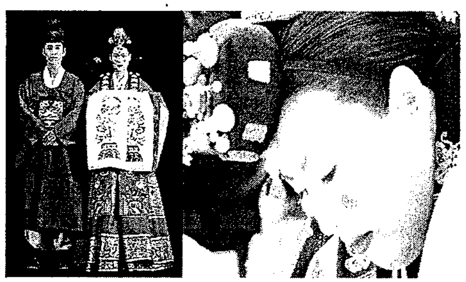

Figure 6: Dress and make-up for Korean traditional wedding

In China, bride wears red dress embroidered dragon. She rides a red palanquin with red- embroidered lanterns hanging on it. She puts up a red parasol and people set off red firecrackers for her. On the ceremony, the bride and bridegroom drink liquor and honey with two cups corded with red string as pledge of love. Besides, cinnabar red represented the glory of dignitary in Ancient China. The Chinese Emperor held a ceremony to pray for the repose of the sky in pale blue robes as an intimation of the sky, ceremony for the earth in yellow robes and for the sun in red.

5. CONCLUDING REMARK

Abstracted concepts are always expressed with colors as symbols in history and social structures formulated with colors get more practical power. As color is examined as universal function given by ideals and as a kind of sign system to represent meanings, the color of red has been used for meaning of authority, power, wealth, good luck, ideology and purging away evil as described above. At the bottom of these meanings, there exist religious and philosophic background and interpretation shared within East Asian countries. It has been the sense code of East Asian people and still has a dominant effect on their lives.

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Prof. Dr.Young Gull Kwon, Seoul National University, Faculty of Design, San 56-1, Shinlim-dong, Kwanak-ku, Seoul 151-742 Korea.Univ. Tel: +82 2 880 7516, Fax: +82 2 888 2513. Home Tel: +82 2 3216 5566, Fax: +82 2 3216 6677. Mobile: 82-11-281-2220, E-mail: kwonyg@snu.ac.kr

BLOCKING PROPERTY AGAINST UV-RAYS: EFFECT OF FABRIC AND DYE MATERIALS

Tomoko Mima [1)], Masako Sato [2)]
[1)]Seian University of Art and Design, Ohtsu [2)]Osaka City University, Osaka, Japan

Abstract
This study describes the relation between absorption of electric magnetic wave from the region of 700 to 280nm by fabrics and dyes and its blocking properties against UV-rays. Cotton shirting fabrics dyed with fourteen kinds of direct dyes and polyester taffeta fabrics dyed with eight kinds of disperses dyes were examined. The dyed fabrics were categorized into three names of color as red, yellow and blue.
Molar absorption coefficients of dye were respectively examined at the regions of 700-400nm in wavelength (visible light region: VIS), 400-320nm (UVA) and 320-280nm (UVB). Dye exhaustion (%) on fabrics, and blocking efficiency (%) against UV-rays by dyed fabrics were investigated.
Results were as follows. Non-dyed polyester fabrics were examined much higher UV-rays blocking than non-dyed cotton fabrics and more than 90% efficiency especially in the region of UVB. Blocking property of polyester fabrics dyed with disperse dyes were resulted in improving in the region of UVA, but polyester fabrics dyed with disperse dyes were not so effective as cotton fabrics dyed with direct dyes. Disperse red and blue dyes were inferior to direct dyes of each color. Yellow colored fabrics dyed with disperse, or direct dyes were examined higher than red colored fabrics.

Keywords: *UV-rays blocking property, polyester fabric, disperse dye, cotton fabric, direct dye*

1. INTRODUCTION

In the near future blocking against harmful UV-rays might be more important problem for human health. Blocking property against UV-rays by fabric would greatly depend on the functions of fiber kinds and the construction parameters of textile, and dye or dyed fabric. Another hand, clothes are exposed to sunshine under the daily use and the clothes fade by degrees. Color fading greatly depends on color fastness of dyes used. The authors have reported on the dyes in expectation of UV-rays blocking materials [1-2]

Even the light colored fabrics were examined superior blocking property compared to non-dyed fabric and increased the properties with decreasing of the lightness of fabric by dye up-taken on the fabrics. The yellow colored fabrics were examined high luminance even at the high up-taken of dye and showed effective UV-blocking even at the light colored level. Dyed fabrics were tested on the fading by irradiation of xenon arc–lamp for twenty hours. The absorption of electric magnetic energy by dye caused the color fading of dyed fabric. Even after the irradiation the deep colored fabrics were examined high UV-blocking property, the other the light colored fabrics were decreased on the property. The purpose of this article is to investigate the mechanism of blocking property against UV-rays by fabric substrate and dyed fabric.

2. MATERIALS AND METHODS

2.1 Fabric and Dye Materials

Plain cotton fabric with 40^s yarns in thickness and polyester taffeta with 75d yarns in thickness were used for the substrate of dyeing. Table1 shows eight kinds disperse dyes (Red, Blue and Yellow colors) used. The sample dyes are regent grade of Aldrich Chemical Company. The molar concentration of dye solution were prepared by reducing purity with the dye content (%) indicated by Aldrich Chemical Company.

2.2 Examination of Molar Absorption Coefficient of Dyes

The spectral distribution curves of absorption with dye solutions adjusted molar concentration were measured using UV-VIS Spectrophotometer (UV-3000, SHIMADZU). The molar absorption coefficients were examined by established method using the maximum absorbance of the spectral distribution curve of absorption respectively in the regions of UVA, UVB and VIS and then the coefficient ratio UVA/VIS and UVB/VIS were calculated.

2.3 Dyeing Condition and Quantitative Measurement of Dye Up-taken on the Fabric

Four pieces of the polyester fabric, $10\times7cm^2$, were dyed in the 60ml dyeing liquor respectively controlled with four different levels of molar concentration of dye from 0.2 to 4.0×10^{-4}mol /l. The dyes up-taken, mol/g fabric, were quantitatively determined by absorption method using before and after dyeing bath liquors. The coloring of dyed fabrics resulted in the colors from light to deep shade in this dyeing condition.

2.4 Measurement of the Surface Color and the Spectral Transmittance of Dyed Fabrics

The surface colors of dyed fabric, namely spectral reflectance in the region of visible wavelength, were measured as parameters of CIE 1931 Yx,y and CIE L*a*b* using Color Measuring SystemΣ80 (NIHON DENSHOKU). Spectral transmittance and reflectance of dyed fabrics were measured on the wave length from 200 to 800nm using UV-VIS-NIR Spectrophotometer UV-3150 (SHIMADZU). UV-rays blocking efficiency (%) of dyed and non-dyed fabrics were calculated by transmittance curves respectively in the region UVA, UVB and its total UVT.

3. RESULTS AND DISCUSSION

3.1 Molar Absorption Coefficient of Dyes

Table1 shows molar absorption coefficients of disperse dyes used. Disperse yellow 3,7 and 9 show higher coefficients of UVA than UVB. Other red and blue disperse dyes show higher molar absorption coefficients of
UVB than UVA.

Table 1: Characteristic and molar absorption coefficent of dyes

Disperse Dye (C.I.No)	M. W	Molar absorption coefficient	UV / VIS
Red 1 (C.I. 11110)	314	UVA : 4850 UVB : 10810 VIS (505 nm) : 39650	0.122 0.273
Red 13 (C.I. 11115)	349	UVA : 3020 UVB : 11320 VIS (518 nm) : 29150	0.104 0.388
Yellow 3 (C.I. 11855)	269	UVA : 47100 UVB : 23650 VIS (400 nm) : 42500	1.108 0.556
Yellow 7 (C.I. 26090)	316	UVA : 28230 UVB : 9370 VIS (400 nm) : 39560	0.714 0.237
Yellow 9 (C.I. 10375)	274	UVA : 6290 UVB : 3190 VIS (400 nm) : 6590	0.954 0.484
Blue 1 (C.I. 64500)	264	UVA : 5950 UVB : 16420 VIS (630 nm) : 21660	0.275 0.758
Blue 3 (C.I. 61505)	296	UVA : 11470 UVB : 30240 VIS (637 nm) : 39030	0.379 0.775
Blue 14 (C.I. 61500)	266	UVA : 1630 UVB : 3340 VIS (639 nm) : 9620	0.169 0.347

Table 2: Dyeing property of dyes and coloriometry

Dyed fabrics (disperse dye)	Y	L*	a*	b*	Dyed fabrics (direct dye)	Y	L*	a*	b*
Red 1 (1)	50.95	76.64	21.9	15.81					
Red 1 (2)	31.93	63.28	39.11	28.55					
Red 1 (3)	20	51.83	47.84	33.79					
Red 1 (4)	**16.9**	**48.13**	**48.88**	**32.84**	**Red 23 (6)**	**18.48**	**42.98**	**52.51**	**16.16**
Yellow 3 (1)	68.63	86.32	-8.91	38.22					
Yellow 3 (2)	68.18	86.09	-9.47	48.76					
Yellow 3 (3)	61.24	82.5	-6.34	66.37					
Yellow 3 (4)	**55.51**	**79.33**	**-3.3**	**71.31**	**Yellow 50 (7)**	**63.23**	**83.56**	**0.77**	**70.65**
Blue 3 (1)	32.32	63.6	-1.05	-20.97					
Blue 3 (2)	23.24	55.31	2.45	-29.68					
Blue 3 (3)	11.57	40.52	8.26	-34.68					
Blue 3 (4)	**8.22**	**34.43**	**11.02**	**-34.48**	**Blue 71 (7)**	**8.28**	**34.74**	**7.82**	**-28.88**

The number in brackets indicate the concentration of dye at dyeing (1), (2), (3) and (4) indicate the concentration of disperse dye at dyeing (6) and (7) indicate the concentration of direct dye at dyeing:
Disperse dye (1) 0.2×10^{-4} mol/l, (2) 0.5×10^{-4} mol/l, (3) 2.0×10^{-4} mol/l, (4) 4.0×10^{-4} mol/l
Direct dye (6) 0.5×10^{-4} mol/l, (7) 1.0×10^{-4} mol/l

3.2 Surface Color and Spectral Transmittance Curve of Dyed Fabric

Table 2 shows the surface colors of dyed fabric as functions of kinds of dye and dye concentration of bath liquor at dying. This table lists only six kinds of dye having nearly equal luminance reflectance Y (%) of dyed fabrics between each color of disperse and direct dye. The dyed fabric dyed by disperse Red1 at the condition of concentration of 4.0×10^{-4} mol/l (level 4) at dying shows relatively similar Y(%) to dyed fabric dyed by direct Red 23 at the condition of concentration of 0.5×10^{-4} mol/l (level 6) at dying. The same as them, disperse Yellow3 (level 4 of disperse) and direct Yellow50 (level 7 of direct), and disperse Blue3 (level 4 of disperse) and direct Blue71 (level 7 of direct) show similar Y(%) respectively. The detail results of direct dyes are described in the previous paper [1].

Fig.1 shows the spectral transmittance curves of polyester fabrics, non-dyed and Red1, Blue3 and Yellow3. Non-dyed polyester fabric shows considerably low transmittance at UVB.

3.3 UV-rays Blocking Property of Dyed Fabrics

Fig.2 shows the blocking efficiency (%) of polyester fabric dyed with disperse Red 1 in the regions of UVA, UVB and UVT respectively as a function of molar concentration of dye on the gram weight of fabric and Fig.3 shows on the cotton fabric dyed with direct Red 23.

It is said that the threshold of effective blocking would be efficiency of 90% (1.95 in log%). Then polyester fabric can accomplish the threshold level of blocking efficiency against UVB rays even at the low level of dye concentration on the fabric. But compared with cotton fabric, polyester fabric was examined as nearly equal as cotton fabric on the blocking efficiency against UVA rays at the same dye concentration on the fabric.

Blocking efficiency as a function of luminance reflectance of polyester fabric dyed with disperse Red 1, Yellow 3 and Blue 3 are showed in Fig.4, 5 and 6 respectively. Yellow colored polyester fabrics would have superior blocking property to the other red and blue colored fabrics. Same as them, Fig.6, Fig.7 and Fig. 8 show the relations between luminance reflectance and blocking efficiency (%) on the cotton fabrics dyed with direct Red23, Yellow50 and Blue71.

Blocking efficiency of cotton fabric and polyester fabric increase with decreasing of luminous reflectance respectively.

The direct dyes had much effect on blocking efficiency in the regions of UVA and UVB respectively, but the disperse dyes were not more effective than cotton fabric on blocking efficiency in the region of UVA. Only yellow colored polyester fabric would have superior blocking property to the other red and blue colored polyester fabrics. property against UV rays of polyester

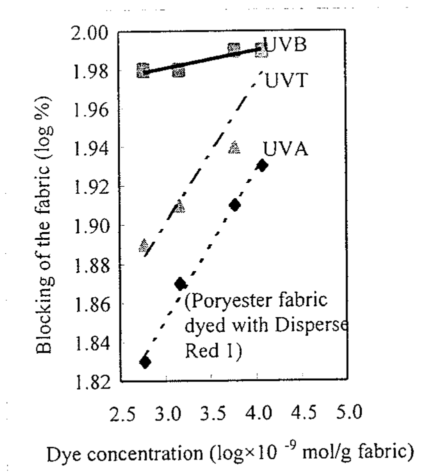

Figure 2: Relation between the concentration on the fabric and UV-blocking of the fabric

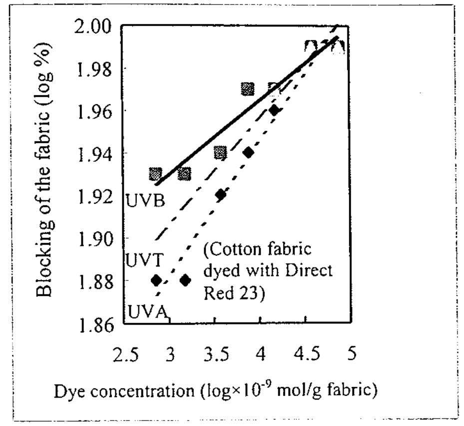

Figure 3: Relation between the concentration on the fabric and UV-blocking of the fabric

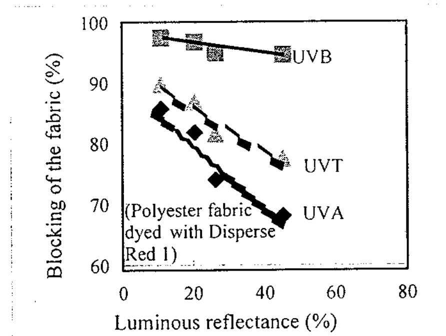

Figure 4: Relation between luminous reflectance and UV-blocking of the fabric

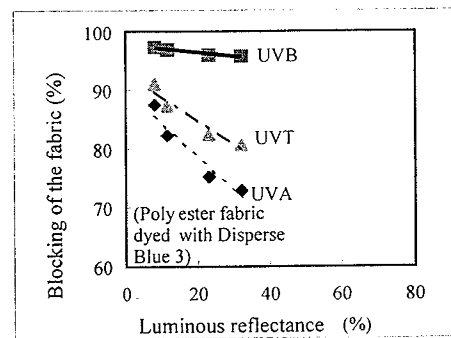

Figure 5: Relation between luminous reflectance and UV-blocking of the fabric

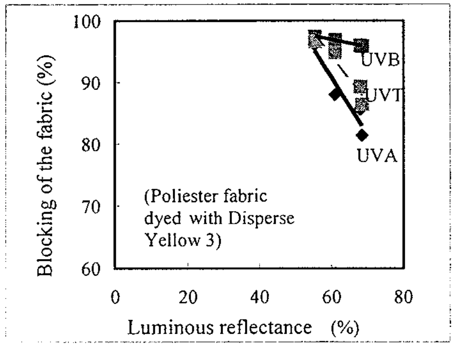

Figure 6: Relation between luminous reflectance and UV-blocking of the fabric

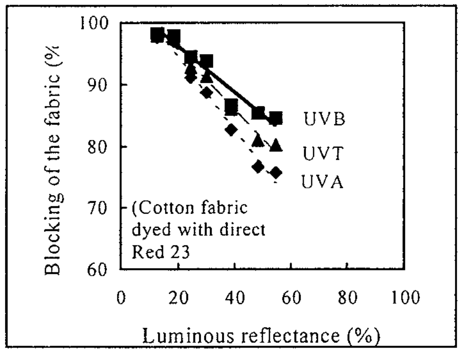

Figure 7: Relation between luminous reflectance and UV-blocking of the fabric

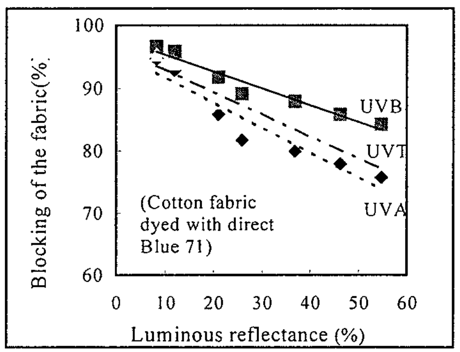

Figure 8: Relation between luminous reflectance and UV-blocking of the fabric

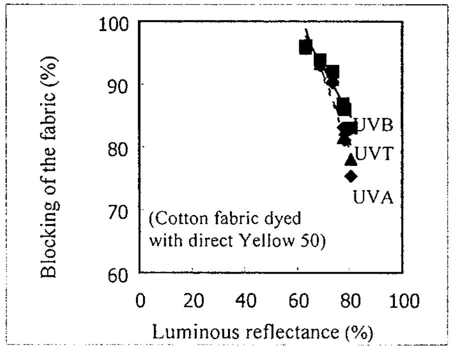

Figure 9: Relation between luminous reflectance and UV-blocking of the fabric

4. CONCLUSION

1) Non dyed polyester fabric has more than 90% and higher blocking property than cotton fabric in the region of UVB.
2) Blocking property of polyester fabrics dyed with disperse dyes were resulted in improving in the region of UVA, but polyester fabrics dyed with disperse dyes was not so effective as cotton fabrics dyed with direct dyes.
3) Yellow colored fabrics dyed with disperse or direct dyes were examined higher than red and blue colored fabrics.

5. ACKNOWLEDGMENT

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6. REFERENCES

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Prof. Tomoko Mima, Seian University of Art and Design, 4-3-1, Ohginosato-higashi, Ohtsu City, Japan. Phone: +81-77-574-2111, Fax: +81-77-574-2120
Prof. Dr. Masako Sato, Osaka City University, Graduate School of Human Science, 3-3-138, Sugimoto, Sumiyoshi-ku, Osaka, Japan. Phone: +81-6-6605-2825, Fax: +81-6-6605-2824, E-mail: sato@life.osaka-cu.ac.jp

COLOR EVALUATION OF TEXTILES USING A FLATBED SCANNER

Igor Nahtigal, Vera Golob, Bojan Dolšak,
University of Maribor, Faculty of Mechanical Engineering, Textile Department

Abstract
Conventional reflectance measurement using spectrophotometers is limited by insufficiently colored surfaces on the textile samples and, therefore, inappropriate for many multicolor fabrics with small color patterns, such as colored wovens, mélanges, jacquard, and printed fabrics. The possibility of using a flatbed scanner was studied as a measuring device for the color evaluation of such textile samples.

Keywords: *color measurement, a flatbed scanner, color profile, color target, CIEL*a*b* color space, RGB color space*

1. INTRODUCTION

Conventional industrial color evaluation of textile samples is based on reflectance measurements using spectrophotometers connected to computers with powerful software programs. Sufficient sample size is required for spectrophotometrical measurement; therefore, this method is inappropriate for many multicolor fabrics with small color patterns, such as colored wovens, mélanges, jacquard, and printed fabrics.

2. REFLECTANCE SPECTROPHOTOMETERS

Reflectance spectrophotometers measure the amount of light reflected by a surface, as a function of wavelength, to produce a reflectance spectrum. The reflectance spectrum of a sample can be used, in conjunction with the CIE standard observer function and the relative spectral energy distribution of an illuminant, to calculate the CIE *XYZ* tristimus values for that sample under that illuminant.
The operation of a spectrophotometer is based on illumination of the sample using D65 light and to calculate the amount of light that is reflected by the sample at each wavelength interval. Typically data are measured at 31 wavelength intervals centered at 400nm, 410nm, 420nm, ..., 700nm. This is done by passing the reflected light through a monochromatic device that splits the light up into separate wavelength intervals [1].

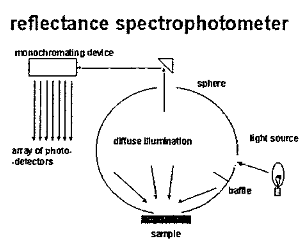

Figure 1: Schematic representation of a reflectance spectrophotometer

3. FLATBED SCANNERS

A flatbed scanner, also called a desktop scanner, is a computer input device, much like a keyboard or mouse, except that it takes its input in graphical form. Most scanners today use the single pass method. The lens splits the image into three smaller versions of the original. Each smaller version passes through a color filter (either red, green or blue) onto a discrete section of the CCD (CCD-Charge Coupled Device) array. The scanner combines the data from the three parts of the CCD array into a single full-color image. The CCD converts the light to proportional voltage. This voltage is converted to digital form (binary bit pattern) by an A/D Converter (analogue to digital converter). These digital values are assigned to RAM where they make up the graphical image. The graphic can be saved on disk in standard graphic file format.

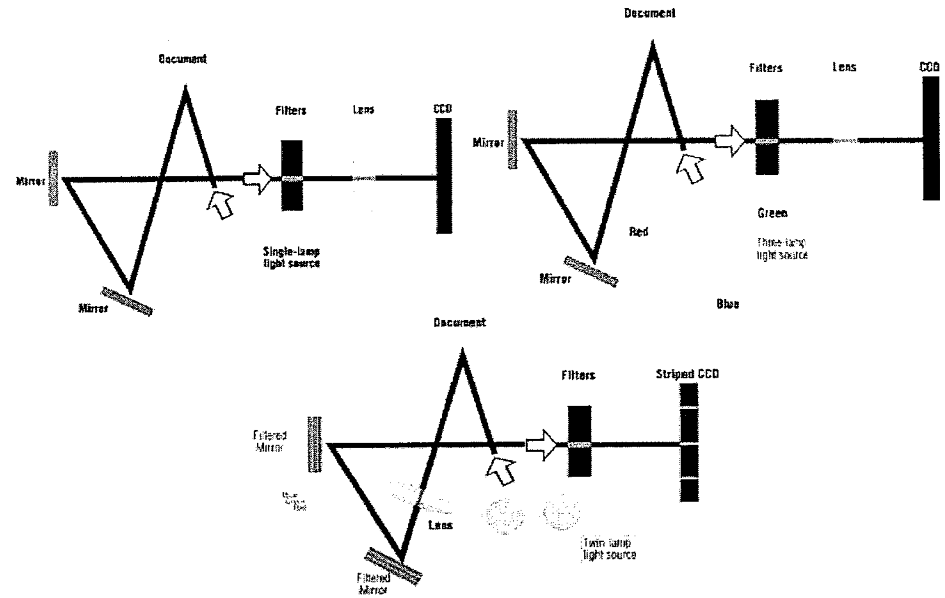

Figure 2: Three schematic representations of flatbed scanners

Important parts of a flatbed scanner are:

- Charge-coupled device (CCD) array
- Mirrors
- Scan head
- Glass plate
- Lamp
- Lens
- Filters
- Stepper motor
- Interface port(s)

Color scanners also have some limitations and disadvantages:

- not producing standard illuminant D65 by used lamps,
- no data on the underlying spectral data,
- limited information for a particular illuminant/observer combination,
- can't detect metamerism,
- repeatable transformation of light in proportional voltage on CCD,
- transmission of color filters.

3.1 The use of flatbed scanner in color evaluation

To use the scanner as a measuring device, we have to define the relationship between the device 'color space' (RGB) and the CIE system of color measurement (L*a*b*). In other words we have to characterize (profile) the scanner. Scanner profiles translate raw digital RGB values into a standard color space like CIELAB. The profile is generated by scanning an 'IT8' color target. Profiling software combines the digital scanner value with the data measured from the target using the spectrophotometer to form a 'source' profile, which translates RGB values into CIELAB.
To convert a flatbed color scanner into a measuring device we have make a color target (similar to IT8.7/2 for photography) and a reference values file to create our own input profile for the textile materials.
Multicolor fabrics were scanned and individual colors were colorimetrical evaluated.
Measurement of the color target was carried out using DATACOLOR's Microflash 200d spectrophotometer with standard illuminant D65 and 10° observer.

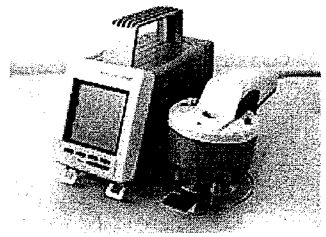

Figure 3: Microflash 200d

CIELCH values from measured textile tiles (D65/10°) were transformed into D50/2° values and stored a reference file for use by the scanner profiling software.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
A	34,0 71,0 34,3	37,1 72,0 33,7	39,3 72,6 35,1	40,0 72,2 41,5	28,2 53,1 59,1	29,5 51,6 54,2	32,2 54,9 60,3	38,3 58,3 68,8	30,3 41,6 65,5	30,2 39,0 62,2	34,3 44,7 71,5	40,3 49,8 78,3	31,6 37,1 67,3	30,5 35,1 62,1	34,9 40,3 73,4	40,0 46,4 80,7	93,6 77,1 84,0	346,7 19,4 18,4	149,2 21,0 9,1				A
B	59,2 74,9 38,3	71,2 69,3 18,6	66,2 48,3 21,2	67,3 77,4 42,3	48,9 60,7 64,8	62,9 44,7 20,9	62,4 37,0 19,1	57,2 62,5 68,7	46,1 47,6 73,5	55,9 25,3 18,0	57,9 27,4 18,6	53,1 55,4 81,8	42,9 40,6 73,2	53,0 20,5 14,1	52,1 19,2 13,5	49,6 51,5 84,8	85,6 76,6 97,6	334,9 36,2 35,8	92,0 31,0 18,1				B
C	68,4 69,4 44,5	70,7 75,5 39,7	70,5 76,4 46,4	74,2 78,8 42,9	64,7 61,5 49,5	61,5 61,3 60,6	61,8 67,0 70,7	63,4 65,6 69,6	62,3 54,5 52,4	56,2 52,6 70,3	57,8 59,5 85,6	58,4 60,0 85,1	59,1 45,7 52,6	51,7 47,9 72,6	54,3 55,6 88,5	54,7 56,5 89,5	94,3 65,4 67,8	311,8 24,5 28,3	69,0 32,3 9,6				C
D	96,6 85,0 44,0	98,1 85,4 42,5	99,4 84,8 43,5	101,9 85,3 53,4	91,1 80,7 70,5	95,3 82,4 73,0	97,4 84,3 75,5	99,3 84,9 81,5	86,5 78,5 87,5	92,7 82,1 92,3	94,8 82,5 89,5	96,1 83,7 91,8	83,4 76,1 93,8	90,3 80,4 99,6	93,2 82,4 97,4	94,3 80,2 93,3	57,6 58,3 91,0	282,7 22,8 23,6	91,4 22,7 10,8				D
E	153,7 56,7 38,9	153,5 56,5 38,0	192,9 23,0 13,3	141,3 34,7 25,8	155,4 48,6 40,5	155,5 47,5 40,8	187,4 33,5 14,9	142,0 44,2 26,9	156,2 39,6 40,7	156,0 40,3 40,5	178,2 27,5 16,4	127,2 32,6 9,3	155,6 30,9 37,1	155,0 30,6 37,2	177,1 37,5 18,1	124,7 44,5 10,4	48,4 49,6 83,5	290,2 19,0 11,2	73,9 54,5 28,9				E
F	183,1 50,2 26,2	88,0 34,8 20,5	186,8 49,1 23,8	101,2 30,1 11,4	186,8 41,1 27,7	91,8 45,7 19,5	190,0 40,5 24,6	100,9 36,4 12,5	189,4 31,9 27,1	87,7 31,3 10,8	191,8 30,1 23,7	87,0 31,4 13,3	189,2 25,0 22,7	88,5 51,4 13,1	191,3 23,2 19,7	89,8 41,6 14,9	36,2 39,6 74,8	296,1 18,4 9,9	57,0 46,4 25,4				F
G	104,2 67,2 8,8	212,9 67,8 16,7	206,6 66,4 7,8	238,0 65,0 14,3	126,0 40,0 4,2	255,1 45,8 36,7	245,1 43,3 18,8	262,1 41,7 28,2	137,2 24,5 2,2	272,0 35,7 45,8	258,6 28,8 21,5	277,1 27,1 32,1	79,6 14,0 2,6	286,1 26,9 51,4	278,2 17,3 14,8	286,7 20,0 30,5	32,9 37,9 72,4	225,6 34,5 29,6	48,0 30,3 34,9				G
H	232,9 67,2 9,0	240,6 64,5 14,0	219,3 66,2 5,2	91,6 65,1 9,6	261,2 41,7 23,8	266,9 40,6 29,5	259,7 40,1 17,5	122,6 41,8 5,2	275,5 26,1 26,8	281,3 26,9 34,5	267,3 27,3 18,9	127,5 23,8 3,1	286,1 19,3 26,0	291,2 20,1 34,7	280,4 17,1 12,8	86,8 14,3 2,9	13,0 38,2 62,9	259,1 26,7 25,2	59,5 35,1 34,5				H
I	208,0 68,9 3,3	243,6 65,8 10,5	225,7 67,6 3,2	253,7 67,2 5,0	261,8 42,8 14,5	272,5 40,4 32,2	260,3 41,1 15,9	269,7 40,6 19,0	274,1 25,8 18,7	285,5 26,6 36,6	270,5 26,2 17,8	278,1 27,2 22,6	288,9 16,7 12,7	293,8 20,6 37,4	284,7 17,0 11,3	288,6 16,7 16,1	20,0 31,5 56,2	164,1 61,4 42,9	63,7 23,8 13,5	67,5 71,1 25,0	67,3 71,7 49,0	72,5 80,1 40,3	I
J	304,7 66,5 12,8	333,6 65,9 18,6	17,6 69,8 33,6	12,5 66,3 47,5	301,3 40,0 37,4	322,3 42,1 39,9	13,2 50,3 54,6	13,3 52,1 66,2	304,6 26,4 46,5	323,3 27,5 45,9	17,0 39,2 60,4	17,1 43,6 71,4	306,9 19,8 45,3	325,1 20,2 43,3	21,4 33,7 60,9	21,5 39,1 71,9	1,4 27,2 45,7	134,1 46,7 61,7	44,5 17,1 10,1	60,6 47,5 31,2	63,7 65,1 55,5	60,4 65,9 66,4	J
K	22,7 69,9 31,4	19,4 68,3 38,1	17,7 68,8 47,5	20,8 69,0 41,5	16,7 50,4 51,6	16,9 48,2 60,5	18,7 52,2 69,3	18,6 52,9 62,5	18,6 37,9 56,4	21,9 37,9 66,3	23,0 42,7 70,3	22,9 43,4 70,5	21,2 32,5 56,1	24,8 33,5 63,8	25,4 36,1 64,1	25,3 38,7 69,0	359,5 26,3 32,8	147,2 40,8 54,6	36,2 34,6 3,2	56,1 32,7 30,2	60,7 58,1 59,8	54,7 55,4 78,0	K
L	28,2 70,3 37,3	34,3 72,0 35,4	40,7 72,2 37,1	47,6 73,3 36,9	25,2 53,1 59,5	28,4 55,0 61,1	35,4 56,5 61,9	39,3 57,0 60,9	28,3 42,7 67,3	30,4 44,4 69,7	36,3 47,2 72,7	38,3 44,9 68,3	30,5 37,1 68,3	31,7 38,7 70,9	36,5 40,7 73,4	36,8 39,7 71,0	16,4 20,8 28,6	141,6 33,2 25,3	112,5 14,2 1,6	49,6 25,0 24,8	58,0 50,8 61,4	50,2 49,2 77,6	L
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
H L C	80,3 86,5 7,1	91,4 85,8 12,9	47,1 78,3 3,5	84,8 71,2 4,2	89,0 71,8 7,0	92,5 63,5 4,4	94,1 63,7 6,9	101,0 42,6 5,9	100,7 40,4 7,6	101,9 32,3 5,4	100,1 29,9 6,1	107,1 26,7 4,0	100,3 25,7 6,0	101,3 23,0 3,7	96,9 22,1 5,2	97,8 21,7 5,1	96,6 20,5 3,3	92,4 19,6 4,5	92,2 19,8 4,5	90,5 18,4 4,4	89,7 18,3 4,1	76,6 17,0 4,4	78,3 16,6 4,2

Figure 4: Close look on reference (CIELCH) values for color target

3.2 Creating scanner's color profile

Device profiles provide color management systems with the information necessary to convert color data between native device color spaces and device-independent color spaces. The specification divides color devices into three broad classifications: input devices, display devices and output devices. For each device class, a series of base algorithmic models are described which perform the transformation between color spaces. These models provide a range of color quality and performance results, which provide different trade-offs in memory footprint, performance and image quality [2].
The device profiles obtain their openness by using a well-defined reference color space and the capability of being interpreted by any ICC operating system or application that is compliant with the specification. In combination with profiles for other devices, color transformations may be determined that enable colors captured on one device to be reproduced satisfactorily on many others. The information required in the profile is adequate enough to ensure the level of color fidelity selected by the user and for the design of a default color management module (CMM) to transform color information between native device color spaces. Such CMMs are found in many operating systems and applications [2].
The International Color Consortium Profile Format supports a variety of device-dependent and device-independent color spaces divided into three basic families: 1) CIEXYZ based, 2) RGB based, and 3) CMY based (including CMYK). A subset of the CIEXYZ based spaces is also defined as connection spaces [2].

Scans were made using a Linocolor 1400 flatbed scanner at 100dpi resolution and Newcolor 5000 color management software by HEIDELBERG AG was used to produce color profile.

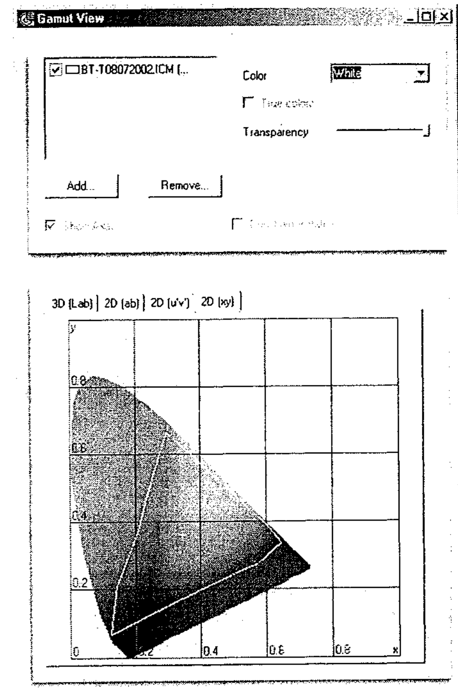

Figure 5: Created scanner profile viewed by Gretag Macbeth ProfileMaker Pro 4 DEMO.

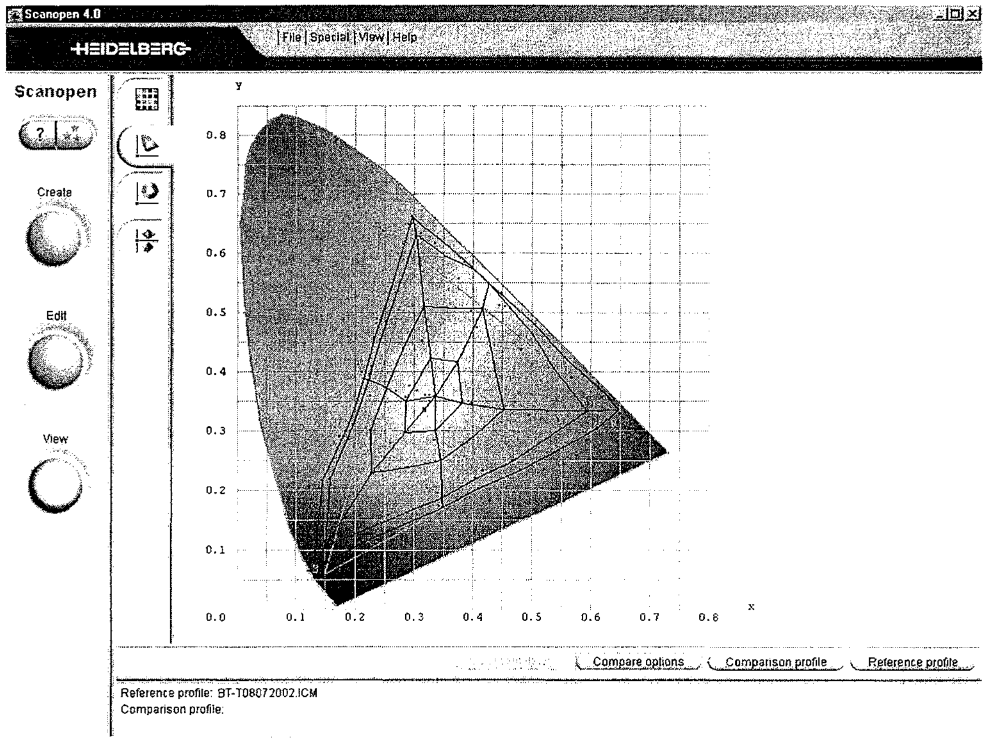

Figure 6: Created scanner profile viewed by HEIDELBERG Scanopen 4.0.5. DEMO

4. CONCLUSION

This paper discusses how a scanner's input color profile can be made by the use of an ISO similar scanner calibration target.
This is just the beginning. Many more measurements and various profiles have to be made to get a good color evaluation of textile samples using a flatbed scanner.

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Igor Nahtigal, B.Sc; Assoc. Prof. Vera Golob, Ph. D.; Assist. Prof. Bojan Dolšak, Ph.D; University of Maribor, Faculty of Mechanical Engineering, Textile Department, Smetanova 17, 2000 Maribor, Slovenija. Phone: +386 2 220 7515, Fax: +386 2 220 7994, E-mail: igor.nahtigal@uni-mb.si, vera.golob@uni-mb.si, dolsak@uni-mb.si

EFFECTS OF TIME VARYING COLOUR ADAPTING SEQUENCES ON THE APPEARANCE OF SURFACES

J.L. Nieves, E. Valero, J. Romero
Departamento de Óptica, Facultad de Ciencias, Universidad de Granada, 18071-Granada (Spain)

Abstract
This work reports an experiment where subjects judged colour appearance in the context of time-varying colour sequences. We analyse temporal context effects for asymmetric matching arrangements rather than spatial context adaptation. For each contextual area observers established pairs of stimuli that appeared identical when viewed in the context of that area. We selected for the comparison and the test areas adapting colour distributions along red-green and yellow-blue axes (selective conditions). For both the selective and mixed (non-selective) conditions tested, observers' matches show approximate colour constant appearance. Although light adaptation does not fully compensate the colour changes, we obtained average colour-constancy index values of 0.65, which coincides with previous findings employing artificial rather natural environments to test colour appearance. Results from the two opponent conditions show similar context effects. No significant differences between each condition for the L- and S-cone mechanisms and the three test illuminants were found. On the contrary, some degree of interaction between the comparison-field cone excitations and the colour axis is found when colour mechanisms are analysed separately. This seems to be more pronounced for S-cone mechanism and suggests that colour selectivity of the adapting sequences could affect match chromaticity.

Keywords: *Colour vision, Colour appearance, Colour constancy, Adaptation*

1. INTRODUCTION

The colour appearance of surfaces depends on both the adaptations to previous lights or surfaces in view and on the lights or surfaces surrounding the stimulus of interest. Chromatic adaptation mediates this process and adjusts visual sensitivity depending on the light (with a given luminance and chromaticity) entering the eye. There have been many studies which analyse the influence of context on colour appearance, but only a few works have examined possible interactions between chromatic mechanisms at post-receptoral levels and its effect on colour appearance [1]-[4], and on colour constancy [5]-[9].

Perceived colour under different illuminant conditions may be influenced by contrast adaptation. Using surface reflectances derived from a Munsell set of colours, Webster and Mollon [7] found that adapting stimuli with temporal contrast biased colour appearance relative to the axes of the adapting colour distributions. These authors also obtained similar results when examined visual adaptation processes in response to natural images [2]. Their results showed partial chromatic selectivity if the adapting stimuli vary the bias in colour appearance along different chromatic axes. Adaptation to high contrast yellow-blue variation of the colour distributions result in a relative loss in perceived colour contrast that is selective for the yellow-blue axis. Because of these results, contrast adaptation, at least for stimuli with temporal rather than spatial contrast, does not seem to discount the illuminant completely (i.e. to acquire perfect colour constancy). The effects of steady-state adaptation on colour appearance suggest partial chromatic selectivity with red-green and yellow-blue adaptation resulting in asymmetric matches that differ mainly in the L-2M or S-cone coordinates, respectively [1].

The effect of spatial colour context in the colour appearance have also been studied by Delahunt and Brainard [4], which develop failures of independence (context effects ocurring independently within each cone classes). Their results show that S-cone context effects are influenced by the L- and M-cone contextual planes, and indicates that signals from separate cone interact. In addition, other results suggest that illuminant changes induce additive changes along the red-green dimension and multiplicative changes along the yellow-blue dimension [10]. These changes are adequately described by an affine transformation between test and standard illuminant conditions, although some discrepancies were found along the yellow-blue dimension [11].

Two main questions arise from the above considerations. The first one is how subjects judge colour appearance in the context of selective temporal adapting sequences; the second one is how chromatic selectivity alters the additive and multiplicative effects that an illuminant change has on colour appearance. To this end, we report experiments where a series of asymmetric matches are made with a similar experimental paradigm employed by Webster and Mollon [2]. The work analyses temporal context effects rather than spatial context adaptation, and studies the influence of selective and non-selective adapting conditions in the chromatic mechanisms.

2. METHODS

2.1 Apparatus

The experiment was run on a Pentium II computer with an 8-bit per gun Number Nine graphic card. Object colours were reproduced and presented on a high-resolution 17'' Multisync E700 NEC colour monitor. A Photo Research Spectrascan PR-704 was used to calibrate the monitor. The apparatus provided a relative error in the measuring of luminance of 2% and ±0.003 for the chromaticity coordinates (applied to the CIE A standard illuminant). A more detailed description of the calibration procedure can be found in references [12], [13]. The calibration was periodically repeated, and we verified that both luminance and chromaticity coordinates of the selected stimuli were precisely reproduced.

2.2 Stimuli

There were two basic sets of surfaces: the *comparison surfaces*, which reproduce the surfaces to be matched under a given illuminant, and the *adapting surfaces*, which comprise each of the surfaces used in the time-varying adapting sequence of colours.

All the surfaces used in this experiment were selected from the set of natural and manmade objects that were measured by [14]. The gamut of colour signals for each illuminant change was then calculated from the product of these surface spectral reflectances S(λ) and the spectral power distributions *E*(λ) of each of the illuminants. From these colour signals it was straightforward to determine their L, M, and S-cone excitations, by using the cone fundamentals of [15], and the subsequent two opponent-colour mechanisms —the red-green channel and the yellow-blue channel— and one non-opponent mechanism —the luminance channel. The two colour-opponent signals are represented by the axes of the MacLeod-Boynton chromaticity diagram [16]. Table 1 shows the chromaticity coordinates in the MacLeod-Boynton chromaticity space of the comparison surfaces under each of the three illuminants used in the experiment. Their luminance was fixed at 20 cd/m^2.

For the present experiment, three illuminants were used: a 2000 K-illuminant, representing the radiation of the black body at 2000 K, a 10000K-illuminant, which represents the radiation of the black body at 10000 K, and a 6500K-illuminant, representing a daylight phase with a correlated colour temperature of 6500 K. The 6500K-illuminant was also used as the comparison —reference— illuminant. The illuminants, which were typical for natural daylights, were drawn from the daylight locus and were reproduced using a three-dimensional linear model [17].

Table 1: Chromaticity coordinates of the 9 surfaces which were used as comparison surfaces (under a 6500K daylight-type illuminant) and each of the test illuminants.

Surface		D65-Illuminant			2000K-Illuminant			10000K-Illuminant		
		l	s	lum	l	s	lum	l	s	lum
r-g axis	3	0,621	0,035	20,0	0,651	0,010	18,1	0,610	0,045	20,6
	8	0,638	0,035	20,0	0,676	0,009	19,1	0,626	0,047	20,3
	1	0,655	0,035	20,0	0,698	0,008	20,0	0,642	0,048	20,0
	9	0,671	0,036	20,0	0,718	0,007	20,9	0,658	0,048	19,8
	2	0,688	0,036	20,0	0,735	0,006	21,7	0,674	0,050	19,5
y-b axis	5	0,655	0,019	20,0	0,690	0,005	20,0	0,644	0,026	19,8
	7	0,655	0,027	20,0	0,695	0,006	20,0	0,643	0,037	19,9
	1	0,655	0,035	20,0	0,698	0,008	20,0	0,642	0,048	20,0
	6	0,654	0,045	20,0	0,702	0,009	20,0	0,641	0,059	20,2
	4	0,655	0,054	20,0	0,707	0,011	20,0	0,640	0,072	20,3

2.3 Spatial configuration

The surfaces were presented at a viewing distance of 100 cm (maximum visual field of 7.5 horizontal x 10.6 vertical deg). The matches were always made binocularly and a forehead rest was used to maintain stable head position. All the experimental sessions were run with the monitor embedded in a black chamber to avoid distractions by any other objects in view.

The comparison surfaces were presented in a uniform background (upper field in the monitor) with a visual angle of 7.5 x 5.3 deg; this area maintained the chromaticity of the comparison 6500K-illuminant with a luminance of 19.5 cd/m^2. The comparison stimuli occupied a 2-deg field centred 0.6 deg above a red cross-shaped fixation point. The test surfaces were presented also in a uniform background (lower field in the monitor) with a visual angle of 7.5 x 5.3 deg; in this case, this area maintained the chromaticity of the test illuminant with an average luminance of 19.5 cd/m^2. The test stimuli occupied a 2-deg field now centred 0.6 deg below fixation. The time-varying adapting colour sequence is presented, as explained below, on both the upper and the lower fields.

2.4 Procedure

Each of the observers set matches to nine different comparison surfaces. The sessions began with 3 min of dark adaptation. This was followed by 10 sec of adaptation to both the comparison (upper field) and the test (lower field) achromatic backgrounds. A beep indicated the end of this period and the beginning of a further 5 min of adaptation to a random sequence of surfaces every 1 sec. These adapting colour distributions appeared simultaneously in the upper comparison field and in the lower test field under a 6500K or a test illuminant, respectively. Once the adapting period was completed, the comparison and the test fields were held at

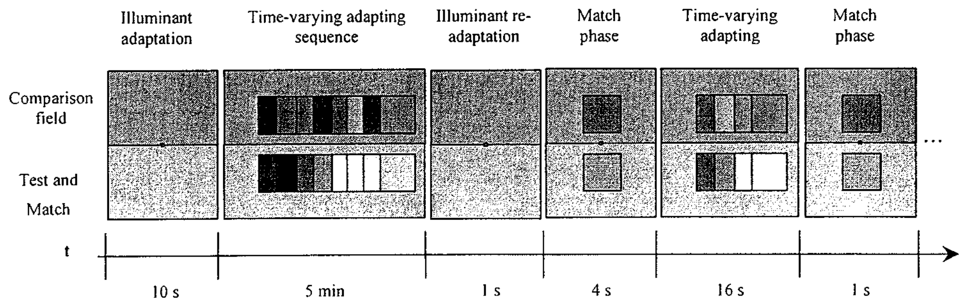

Figure 1: Time sequence of the experiment.

the chromaticity of the 6500K and test illuminant for 1 sec. Then, the observer viewed in turn a comparison surface in the upper field for 4 sec, followed by the achromatic background and a 16 sec interval of re-adaptation to the time-varying colour sequence (figure 1). While the comparison surface was present in the upper field, the observer set a colour match between this surface and the test field placed below fixation; the match surface was then followed by a 16 sec interval of re-adaptation to the test colour sequence. The observer had six buttons available in the keyboard to increase or diminish by one unit the DAC values of the red, green, and blue guns of the monitor, each separately. Two additional buttons were used for brightness control.

Based on the colour distributions —adapting sequences— selected, there were three kinds of experimental conditions: the *'Rg-Yb condition'*, in which the comparison field was presented with a red-green colour-adapting sequence and the test field was presented with a yellow-blue colour-adapting sequence; the *'Yb-Rg condition'*, in which the comparison field was presented with a yellow-blue colour-adapting sequence and the test field was presented with a red-green colour-adapting sequence; and the *'Non-selective condition'*, in which the comparison and the test fields were presented without any privileged selection in the time-varying colour adapting sequence. The observers were not informed about the kind of the experimental session in course. In each session, the observers set matches to five different comparison surfaces and only one test illuminant condition was presented. The matches reported were based on the average of four colour matches made for each comparison surface and adapting-sequence combination.

2.5 Observers

One of the authors and two naïve observers participated in the experiment. All were corrected to normal acuity and had normal colour vision according to standard tests (Ishihara and Farnsworth D-15).

3. RESULTS AND DISCUSSION

Selective chromatic adaptation was measured for the *'Non-selective condition'*, which was used as a standard to investigate the effect of the opponent colour-adapting sequences, and the two opponent conditions —the *'Rg-Yb condition'* and the *'Yb-Rg condition'*.

Previous to all of these experiments, a series of control matches were made to test the influence of time-varying adapting sequences when no illuminant change was induced. These were symmetric matches and were only influenced by the time-varying adapting sequences. The mean distance bet ween the comparison objects and the matches was 4 ΔE^*_{uv} units, which agrees with the errors found in similar

experiments [5], [18]. This result reject the possibility that the subsequent experiments could be biased by chromatic induction effects due to the spatial configuration of the comparison and test areas.

3.1 Non-selective adapting experiment

Here the comparison area is viewed under the reference 6500K-illuminant, and the test area is viewed under one of the test illuminants (either the 2000K- or 10000K-illuminant). The results for observer E are shown in figure 2. The top panels plot results for the L-cone class while the bottom panels plot results for the S-cone class. The temporal context effects are revealed in the figures if the match and test coordinates differ for one cone class. The dashed lines in the figures provide a description of the time-varying context effects. These lines conects the origin and a point (the crossed square symbols) which specifies the average colour of the adapting sequence under comparison and test conditions.

The results suggest no contextual effect for both test illuminants since the observers' matches lie close to the positive (solid line) diagonal. We have evaluated the colour constant appearance trend —colour constancy— via a standard colour-constancy index [19], which is usually defined as:

$$CI = 1 - \frac{a}{b} \qquad (1)$$

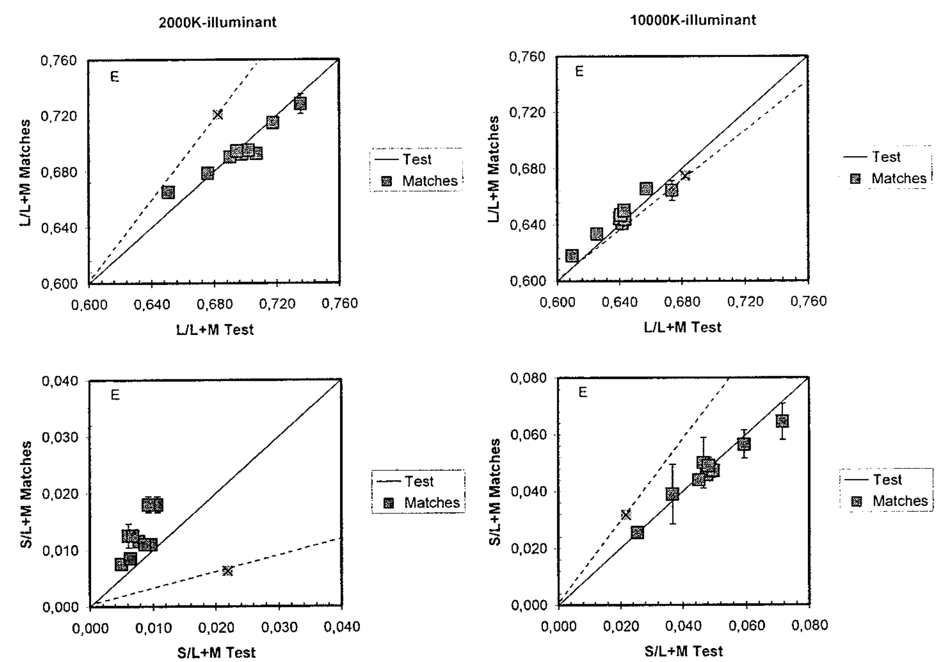

Figure 2: Results derived from one of the observer's matches for the non-selective condition. The upper panels coresponds to the L-cone mechanism and the lower panels to the S-cone mechanism.

where a is the distance between the observers' matches and the comparison objects (reproduced under the 6500K-illuminant), and b is the distance between the test objects (reproduced either under the 2000K- or 10000K-illuminants) and the comparison objects. The indices were calculated for CIELUV colour space; the comparison 6500K-illuminant and the luminance of 20 cd/m^2 were taken as the nominally white for the calculations. Although light adaptation does not fully compensate the colour changes, we obtained average colour-constancy values of 0.6.

3.2 Selective adapting experiment

Next, we test if the time-varying colour selectivity of the adapting sequences influences the cone coordinates of the matches. The matches were made under the 2000K and the 10000K illuminants. We used the two opponent adapting conditions —the Rg-Yb and the Yb-Rg conditions— which correspond to different comparison and test colour distributions along critical axes.

The figure 3 shows the context effects for the two opponent adapting sequences and the observer E (similar results were obatined from the other observers). The effect is clear for the 2000K-illuminant where the S-cone values derived from the observer's matches fall off the positive diagonal. In adition, the figures suggest an almost perfect coincidence between triangle and square symbols, which

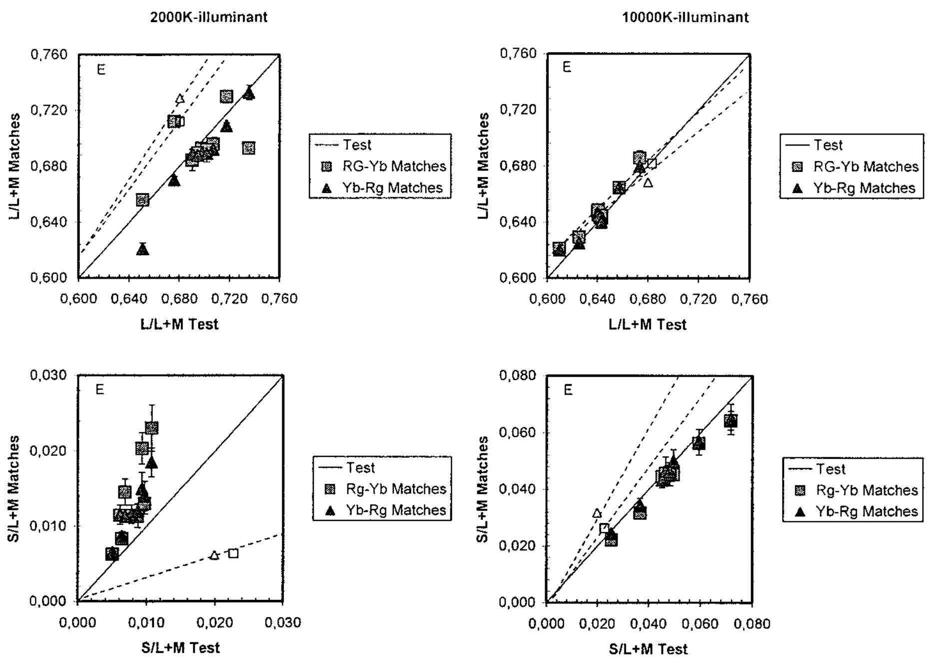

Figure 3: Results derived from one of the observer's matches for the selective conditions. The upper panels coresponds to the L-cone mechanism and the lower panels to the S-cone mechanism. The open symbols represent the average chromaticity of the tiem-varying adapting sequences.

indicates no differences between each of the selective adapting sequences. Only for the S-cone mechanism and the 2000K-illuminant some differences appear. A 3x3 MANOVA analysis was made separatly for each surface and cone mechanism to test possible interactions beteween illuminant (10000K, 2000K, 6500K) and condition (two selectives and one non-selective). As expected, we found significant differences for the illuminant factor for all the objects and mechanisms. The analysis of the interaction illuminant*condition leads to the following results: for S-cone, the interaction is closely to the significant level only for surface 2 ($F=6.287$; $p=0.076$), surface 8 ($F=5.409$; $p=0.084$), and surface 5 ($F=3.569$; $p=0.140$); contrary to this behaviour, for L-cone and L+M mechanism the interaction does not appear significant. Also, no significant differences were found between each condition (selectives and non-selective) for the L-cone, S-cone and L+M mechanism and each of the test illuminants.

4. CONCLUSIONS

The results suggest a *time-varying* context effect associated to selective adapting colour sequences. The effect depends on the illuminant and is independent of the colour mechanism consider. Also, some differences appear between each of the selective conditions, and are more evident for surfaces far from the white under the test illuminant. In each case, the constant colour appearance —colour constancy— is similar for each time-varying colour sequences tested.

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Associate Prof. Dr. Juan L. Nieves, University of Granada, Faculty of Sciences, Department of Optics, Campus Fuentenueva, 18071 Granada, Spain. Phone: +34 958 246367, Fax: +34 958 248533, E-mail: jnieves@ugr.es

COLORIMETRIC PROPERTY OF COLOUR DEPTH

Gen Nishimura, Tetsuya Sato, Taeko Nakamura* and Ronnier M.Luo**
Kyoto Institute of Technology, Kyoto, Japan
* Nara Saho College, Nara, Japan
** University of Derby, Derby, U.K.

Abstract
In the textile industry, the concept of colour depth is very important for assessing colour properties of dyed fabrics. However, it is difficult to quantify the colour depth, because it is depend on human sensation. Therefore, we have been investigating the colorimetric properties of the colour depth, and also trying to express it numerically [1-6].
In this study, we tried to know the colorimetric property of the colour depth through visual assessment with using step-dyed fabrics as samples. The fabrics had 8 hue, 2 dyer's brightness (vivid, dull) and achromatic colour. The number of the hue/brightness sample sets was 17. And every sample set had 46 steps. On the other hand, 5 fabrics were chosen from achromatic colour fabrics as standards, and the standard fabrics were compared with the sample fabrics through colour depth assessments. Then the colorimetric values of the same colour depth to the standard fabrics were numerically estimated. With the results, we discussed the colorimetric properties of the colour depth.

Keywords: *colour depth, dyeing, textile, visual assessment, CIELAB colour space*

1. INTRODUCTION

When colourists assess colours, the assessment is influenced by various factors such as environments and their mental situation. Generally, there are some differences among their assessments, even when they assess the same colour.

As for object colours, any colours are described by the correlation of three kinds of parameters. For example, Munsell colour system classifies a colour by three basic attributes as hue, value and chroma. In the dyeing industry, in order to have to assess object colours of dyed fabrics, the concept of 'depth' is needed. Godlove and Judd had suggested to use dyer's colour system based on hue, depth and dyer's brightness for dyeing industry [7,8].

In this paper, we tried to investigate the colorimetric property of colour depth.

2. EXPERIMENT

2.1 Sample colour

Sample colours were arranged into 17 directions, vivid and/or dull series of 8 hues (red, yellow red, yellow, green yellow, green, blue green, blue, and red blue) and achromatic colour, as shown in Figures 1 and 2. Every sample set of a same hue/brightness group had 46 steps, and the total number of the produced samples was 782.

2.2 Dyeing

Sample fabrics were dyed with reactive dyestuffs in using Mini-Colour dyeing machine of Texam Research Institute. In order to dye the planed colours, the dyestuffs were used by mixture. The materials and dyeing conditions were as follows.

Fabric: Mercerized cotton broad, No.40
Chemical: Na_2CO_3 and Na_2SO_4
Dyestuff:
Remazol Yellow GR HI-GRAN 150
Remazol Black DEN HI-GRAN
Remazol B. Blue R-KN HI-GRAN 150
Remazol B. Red BB HI-GRAN 150
Remazol B. Orange 3RN HI-GRAN 133
Remazol Turq. Blue G HI-GRAN 150

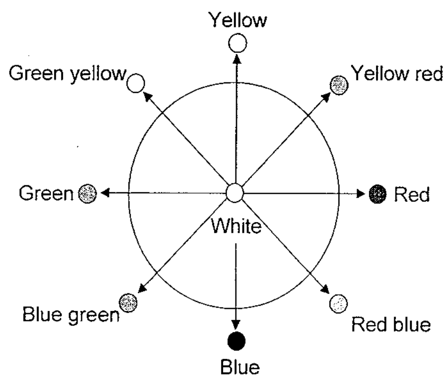

Figure 1: The arrangement of the sample colours: 8 hue directions

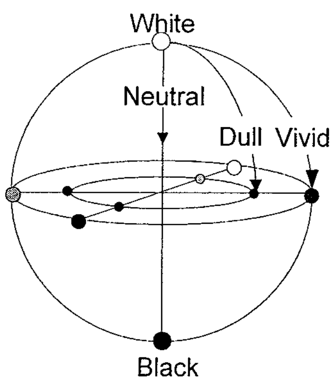

Figure 2: The arrangement of the sample colours: 2 dyer's brightness directions and achromatic directions

Bath ratio: 1:25
Dyeing temperature: 60 C degree
Dyeing time: 40 minutes
Dyeing temperature: 60 C degree
Soaping time: 30 minutes

The colours of the fabrics dyed by the above method were measured by a spectrophotometer CM-2002 (Minolta Camera Co., Ltd) under D65 light source and 10 degree condition.
The colour samples were stuck on a Kent paper (12cmx70cm) with the order of CIE Y value. The 46 steps of each sample group were stuck on four sheets, which are also stuck two same colour samples to samples on other sheet in the top and last of the sheet.

2.3 Colorimetric value of sample

Figure 3 shows the colorimetric properties of dyed samples of vivid series on the CIELAB a* b* plane. Figure 4 shows the colorimetric properties of the dyed samples of a vivid red, dull red and achromatic colour on the CIELAB L* C* plane. With the figures, we confirmed that sample colours mostly took the planned locations in the CIELAB colour space.

3. VISUAL ASSESSMENT

3.1 Method

Four colour samples were chosen as standards of colour depth from the achromatic colour sample group. The standard samples were selected through visual colour fastness assessments of staining performed ratings 4, 3, 2 and 1.
Observers were requested to choose four samples having the same colour depth to the four achromatic standard colour samples from the sample groups of other 16 chromatic directions. The observers were students of 19 to 25 years old. The total number of the observers was 30 (15 males and 15 females).

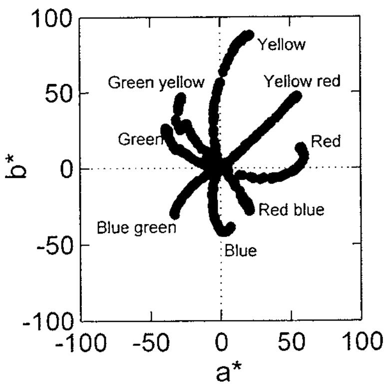

Figure 3: Colorimetric propertyes of vivid colour samples

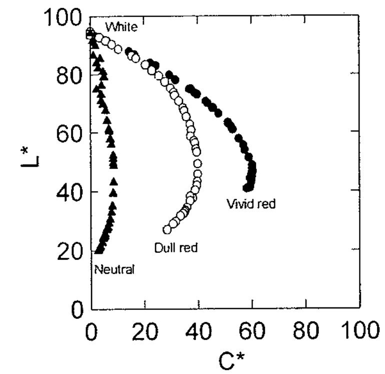

Figure 4: Colorimetric propertyes of the vivid red, dull red and achromatic colour samples

3.2 Estimated colorimetric value

The observers chose several colour samples for a standard colour from one direction group. Therefore, we firstly picked the two nearest colour samples having about the same colour depth to a standard colour. With L* and C* values of these two nearest samples, the estimatied values of the average colour depth of visual assessments were proportionally calculated. By the above method, the average values of 64 points (16 directions and 4 ratings) were obtained. As an example, the average values calculated from visual results in vivid red are shown in Table 1.

Table 1: Average value of L* C* computed from the visual result in vivid red (VR)

VR	R-1	R-2	R-3	R-4
L*	46.67	68.16	75.04	87.27
C*	60.52	46.02	37.27	15.88

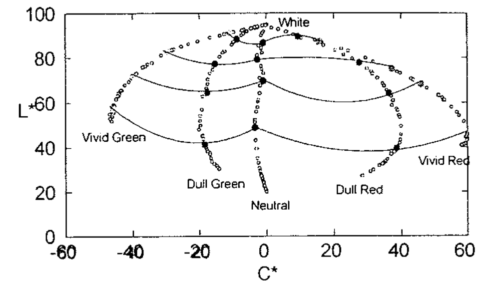

Figure 5: Iso colour depth lines drawn in the CIELAB colour space: Red - Green

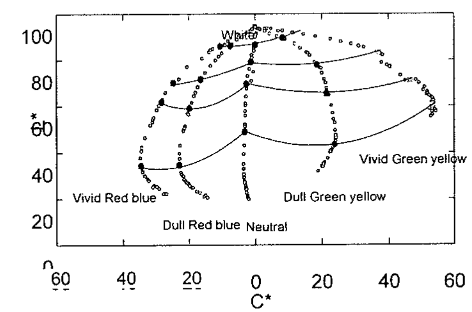

Figure 6: Iso colour depth lines drawn in the CIELAB colour space: Green yellow - Red blue

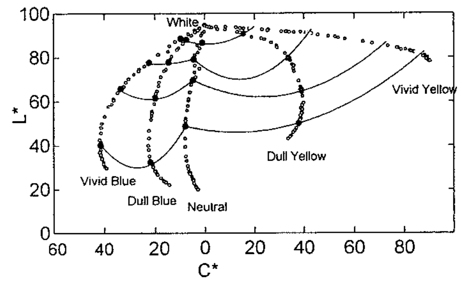

Figure 7: Iso colour depth lines drawn in the CIELAB colour space: Yellow - Blue

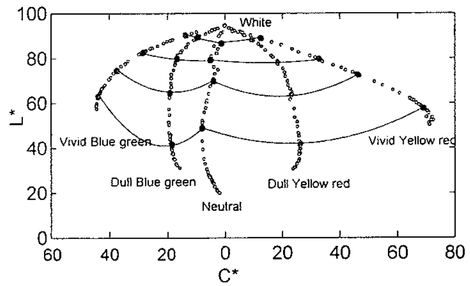

Figure 8: Iso colour depth lines drawn in the CIELAB colour space: Yellow red - Blue green

4. RESULTS

The estimated colour depth points corresponding to the colour depth of ratings 4, 3, 2 and 1 were plotted on the CIELAB L* C* plane including complementary colours. And the iso colour depth lines were drawn as polynomial curves on the same plane is shown in Figures 5, 6, 7 and 8. The figures show the colorimetric properties of colour depth in Red - Green, Green yellow - Red blue, Yellow - Blue, and Yellow red - Blue green, respectively.
Consequently, we found the followings.

1. The iso colour depth lines derived from visual assessments have a 'W' type curve. And the lines show the colorimetric properties of the colour depth. This means that colour depth is different from lightness.
2. Dull colours are relatively assessed as paler than achromatic colours, if they have same lightness. Vivid colours are relatively assessed as deeper than the dull colours. These means that colour depth has some contribution of chroma
3. Colour depth is also influenced by hue. The contribution of chroma in yellow area is the highest, but that in purple area is the lowest.

As further study, we need to investigate visual assessment data by various observer groups, which are different on age, job and country.

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Master course student, Mr. Gen Nishimura
Associate Professor, Dr. Tetsuya Sato, Department of Design Engineering and Management, Faculty of Textile Science, Kyoto Institute of Technology, Goshokaido-cho, Matsugasaki, Sakyo-ku, Kyoto 606-8585, Japan. Phone/Fax: +81 75 724 7578, E-mail: tsato@ipc.kit.ac.jp
Professor, Dr. Taeko Nakamura, Nara Saho College, 806 Rokuyaon-cho, Nara 630-8566, Japan.
Professor, Dr. Ronnier M.Luo, Colour and Imaging Institute, University of Derby, Kingsway House, Kingsway, Derby DE22 3HL, U.K

RAL SYSTEM RELIABILITY

Đ.Parac-Osterman,V.Šimić,A.Hunjet*,M.Joanelli
University of Zagreb, Faculty of textile Technology,Zagreb, Croatia
* Ministry of Science and Technology, Zagreb, Croatia

Abstract
In all technological branches that employs colour management and colour communication system, RAL colour system is used as mean of simple and quick choice and comparisement of desired colour.
However, practice proved RAL system as unsuitable in a processes of reproduction in comparison with visual evaluation as well as instrumental CIELab evaluation.
In this paper, reliability and suitability of RAL system was analysed by means of statistical evaluations and compared to computer based CIELab system.
Three groups of hue samples were chosen: H 080 – 090 (yellow), H* 350 – 360 (red), H* 200 – 210 (blue).*
Analysis were made based on Y tristimulus value that define true lightness value of one coloured surface. L, C* and H* colour values were calculated as well as dE value and statistical evaluation was performed according to "t" and "F" statistical test. Results obtained showed disagreement of RAL system in compare with CIELab system in the area of yellow and blue hues. This confirm lower reliability of RAL system for hues mentioned than for the are of red hues.*

Keywords: *RAL, reliability, CIE L*a*b*, statistic*

1. INTRODUCTION

In the beginning of the 20^{th} century, there has been an increased usage of a new dyestuff, which influenced a rapid development of standardized quality assurance systems, aimed with quality and reproducibility assurance in a production processes.

In the year of 1925, first set of standardized color patches was created for industrial use, named RAL system.
As the requests on reproducibility and preciseness were more and more accented, the first developed RAL system proved uncompleted, so extended version was created. In 1996, "RAL digital" system was created for use in computer based color systems and was accepted for professional use. This system is based on CIELAB color system of conversion from L*a*b* coordinates to polar LCH coordinates. Every color described through color coordinate terms can be reached through multimedia.
If computer database available over Internet does not provide satisfactory range of colors, requested color can be produced by system of color mixing.

Although the RAL system is based on CIE system very often it does not provide a satisfactory definition of requested color hue, as it was proved in practice.
Investigations were carried out with aim of pointing out the question of reliability of RAL system use and to indicate the degree of its acceptability and usefulness, although it may cause some disapproval among RAL efficiency defenders.

2. APPROACH

To provide satisfactory accuracy of results, all measurement of chosen color samples were performed in CIELAB mode as a base of RAL system, spectrophotometrically by means of "Data Color 3890" remission spectrophotometer, D_{65}, d/8°.

Analyses of RAL standard values and measured values of the chosen RAL colored samples was performed in a following relations:

- L*/C* for RAL standard values versus L*/C* measured values of the same samples
- L* measured values of the samples versus L* standard RAL values
- dE/dC* (differences calculated for RAL values versus measured values)
- da*/db*
- Statistical analysis in terms of "F" test and "t" test

3. RESULTS

Following mathematical expressions were used for a statistical analysis:

$$n = \sum_{i=1}^{k} f_i$$

$$s^2 = \frac{1}{n-1} \sum_{i=1}^{k} (x_i - \bar{x})^2 f_i$$

$$s_d^{\,2} = \frac{(n_1 - 1) s_1^{\,2} + (n_2 - 1) s_2^{\,2}}{n_1 + n_2 - 2} \cdot \frac{n_1 + n_2}{n_1 \cdot n_2}$$

$$F_{eksp} = \frac{s_1^{\,2}}{s_2^{\,2}}$$

$$t_{eksp} = \frac{\bar{x}_1 - \bar{x}_2}{s_d}$$

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{k} f_i x_i$$

Considering L* value, significant disagreement were noted for group of yellow hues; H 80° - 90°. Estimated variance (S) for the main group was:

	S_{RAL}	$S_{MEASURED}$
H 80 ^{0}	131,86	67,28
H 90 ^{0}	136,72	70,13

"F" test and "t" test proved significant disagreements for h 200° and h 350°, considering chroma C* value.

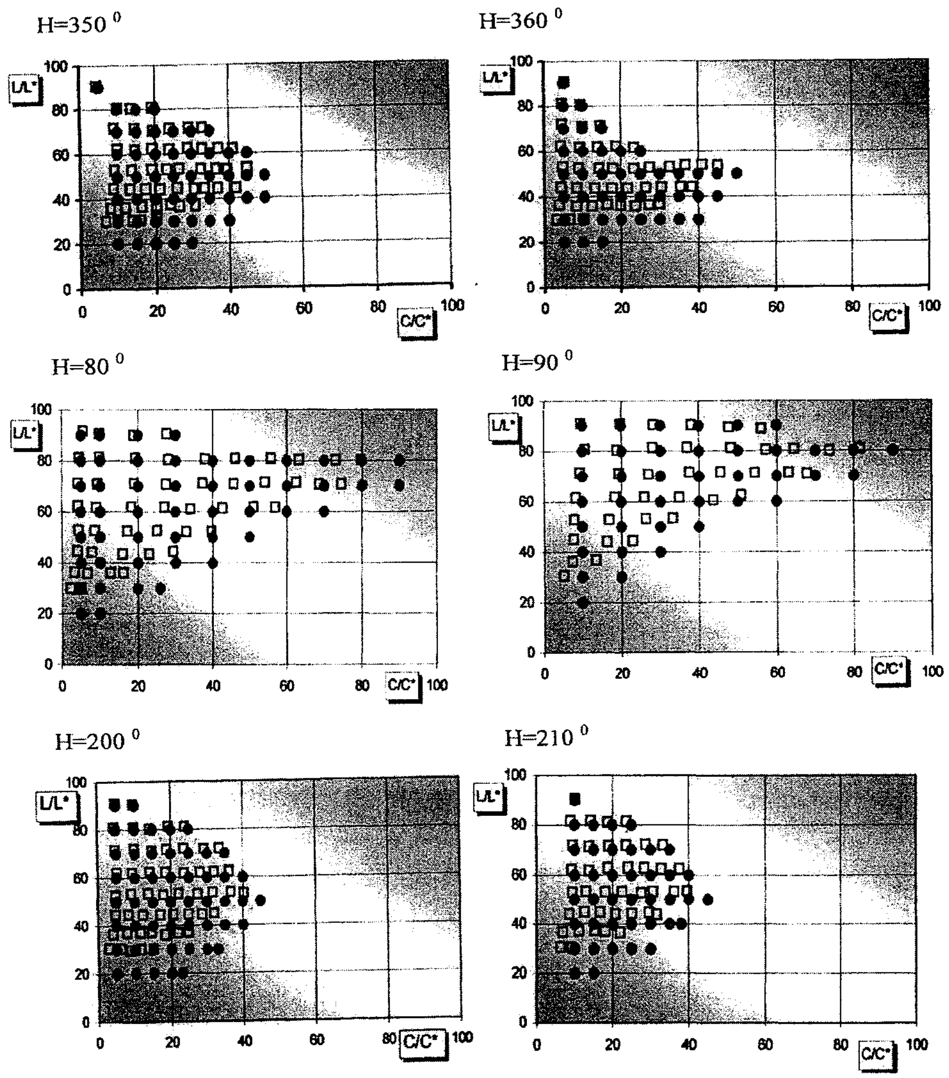

Figure 1: C/C* / L/L* relationship (RAL •, measured □)

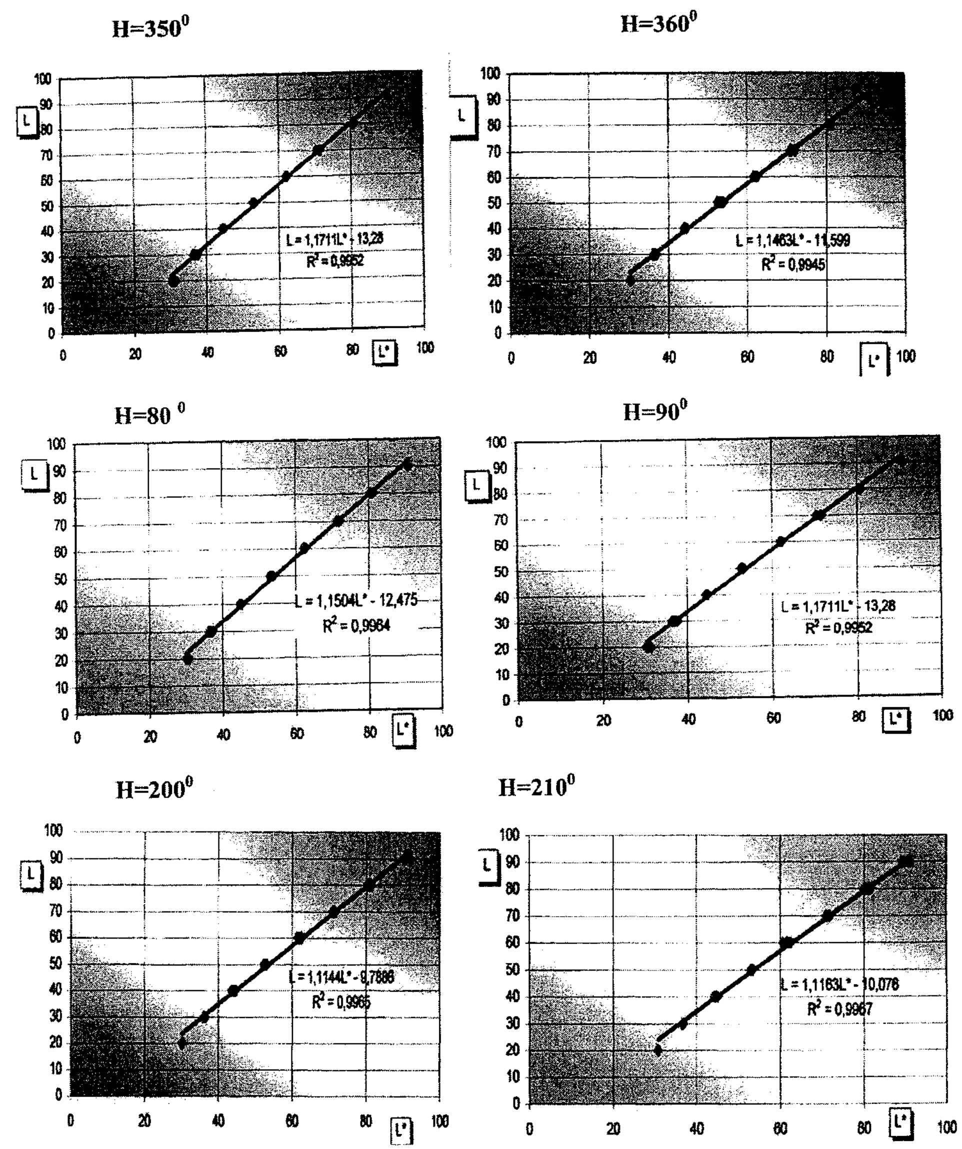

Figure 2: L*/L relationship

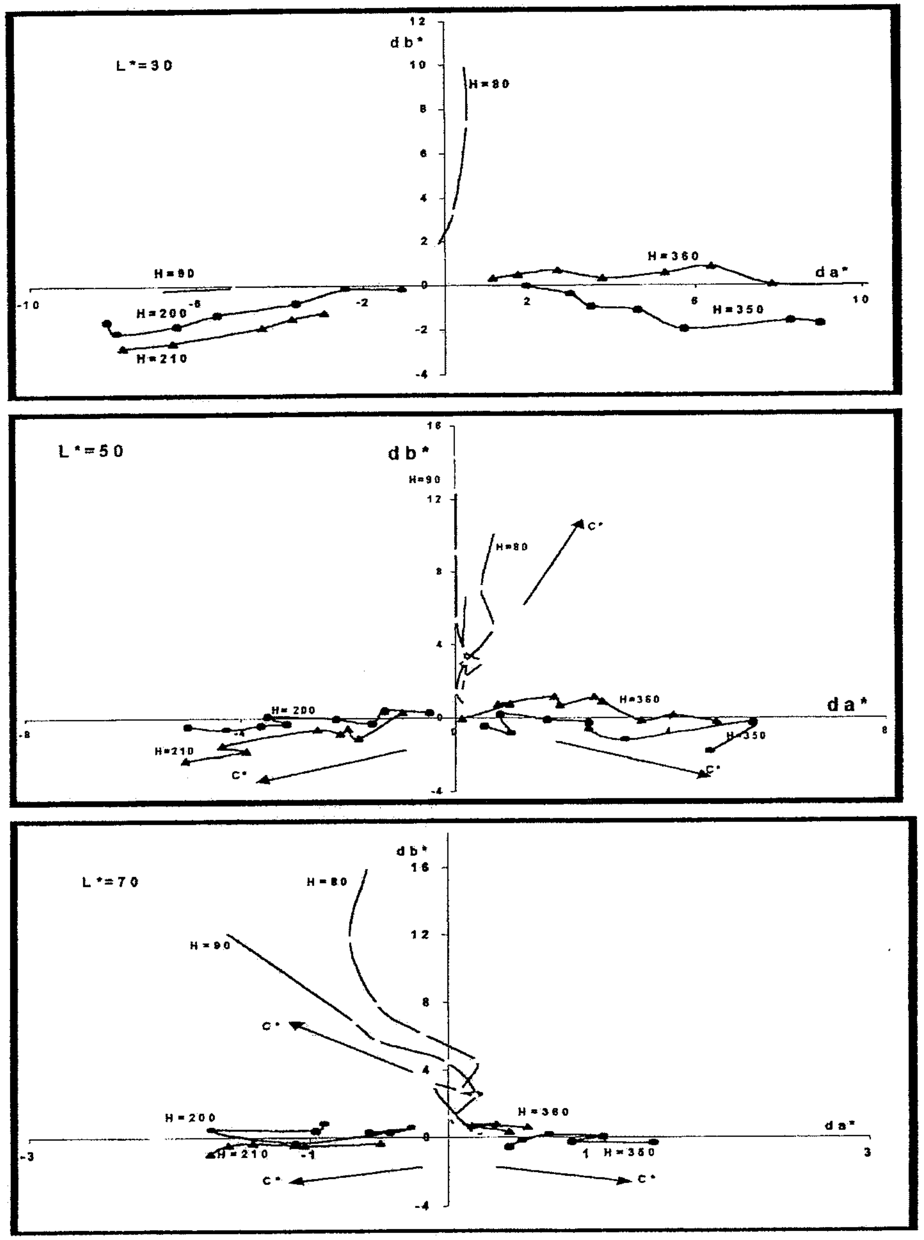

Figure 3: da*/db relationship between pair samples

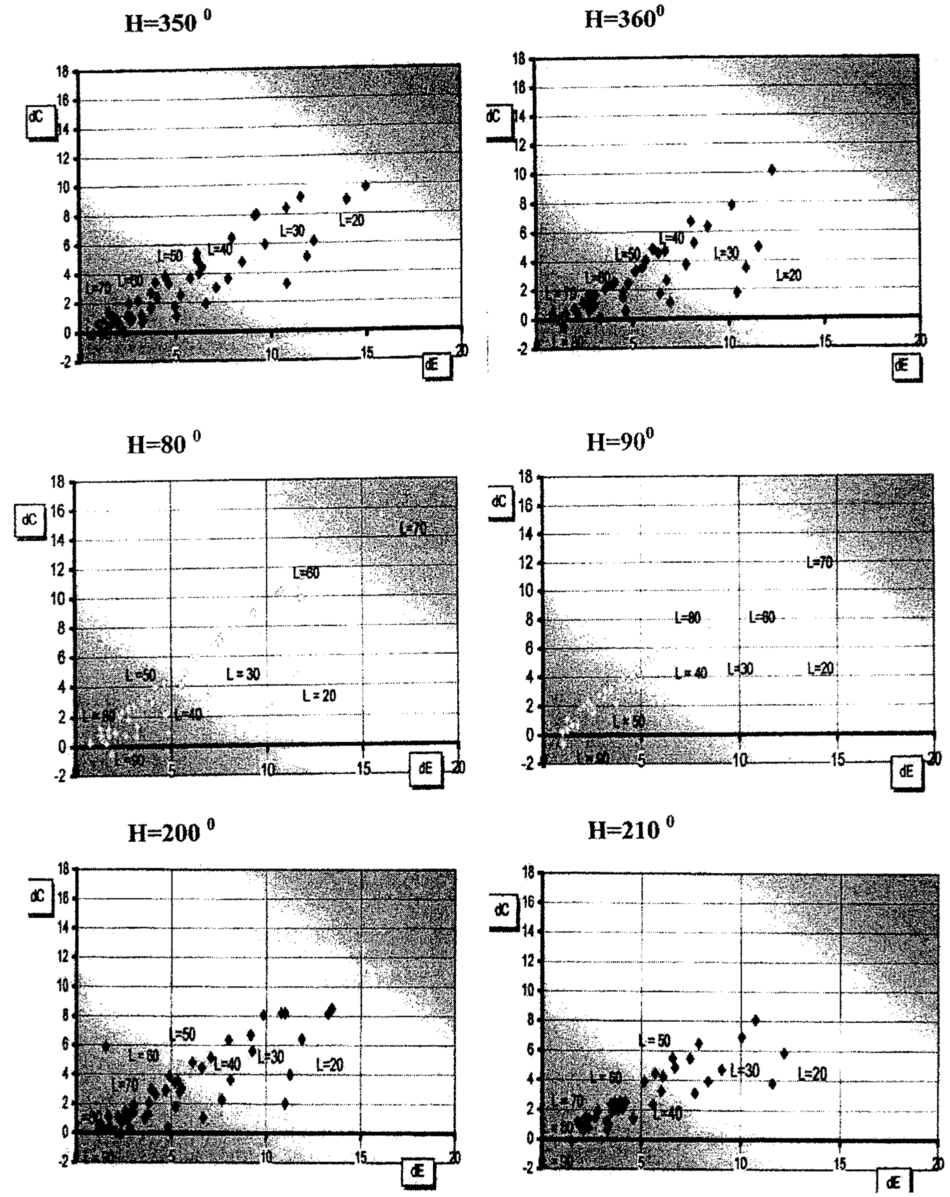

Figure 4: dE/dC relationship

4. CONCLUSION

γ Results obtained shows that standard lightness value (L) of a RAL samples are 10-13 units lower than the measured L* values for the same samples.

γ This fact point out the problem of unreliability for the samples of lower L* values (Fig. 1., 2.).

γ In the group of yellow hues standard RAL chroma value (C) is approximately 10 units higher than the measured chroma values of the same samples. In the group of longer wavelengths (red and blue) those differences were smaller (Fig.1.).

γ da*/db* relationship shows some changes in hue values for the group of yellow samples of higher C* value and for the L* value 70 (Fig.3.).

γ Based on a figure 4.. significant dependence of total difference value (dE) on a L* value can be seen.

γ Statistical analysis proved significant disagreements considering L* value for hue 80° and 90°."F" and "t" tests proved significant disagreements considering C* value for hue 200° and 350°.

γ Insufficiency of RAL system is unsuitability and unreliability for L* values lower than 30 units.

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Prof. Dr. sc. Đurđica Parac-Osterman, University of Zagreb, Faculty of Textile Technology, Pierottijeva 6, Zagreb, Croatia. Phone: +385 1 487 7359, Fax: +385 1 483 6058, E-mail: djparac@ttf.hr

QUALITY ASSURANCE IN DIGITAL PRINTING

Đurđica Parac – Osterman, Martina Joanelli,
Faculty of Textile Technology, University of Zagreb, Zagreb, Croatia

Abstract
The color phenomena forms an indispensable basis of textile printing which makes CAD operational system one of the greatest importance. This is also the source of the first and maybe the most important problem – lack of communication between design/coloration operations and printer/production processes. To print digital image, it is necessary to make the transformation from the monitor RGB color model into the printer CMY model, which results in a loss of information and can cause image distortion.. Analysis in this paper were carried out with aim of pointing out the importance of lightness value as one of the parameter of colour management that indicates the problem of loss of information. Printed samples of three hue groups were tested: h 080 – 100 (yellow), h* 260 – 280 (blue) and h* 000 – 010 and 350 – 360 (red). Results obtained, presented in a CIELab terms through Y/C*, a*/b* and dE/Y relationships, showed that problem can be expected in area of yellow hues due to a selectivity problem that occurs with increasing of lightness value. Importance of Y tristimulus value that uniquely defines lightness of one coloured surface, was also confirmed.*

Keywords: *digital printing, RGB, CMY, loss of information.*

1. INTRODUCTION

In the beginning of its development, digital printing could only be used for printing onto a paper substrate. Over the past 15 years there has been an increased interest in the application of digital printing technologies to textile substrates. This interest has been fuelled by the rapid advances made in digital printing technologies in computer printing systems. Major interests and research have been aimed at translation of ink jet printing technologies from paper application to fabric. The basis of such technological system are integrated into the general CIM (computer integrated manufacturing) concept, based on a computer operational processes CAD (computer aided design), CAM (computer aided manufacturing), CAP (computer aided planning) and CAQ (computer aided quality control). The colour phenomena forms an indispensable basis of textile printing which makes CAD operational system one of the greatest importance [1].

However, this is also the source of the first and maybe the most important problem – lack of communication between design/coloration operations and printer/production processes. It is a common knowledge that colour image on monitors is represented in accordance with the principle of additive colour mixing [2]. It means the systems for image coding on colour monitors are linear RGB systems. On the other hand, colour output devices (such as ink – jet printers) function on the principle of CMY non – linear colour system, using the three subtractive primary colours: cyan, magenta and yellow, plus black, which is used for higher quality shade productions [3].

To print digital image, it is necessary to make the transformation from the monitor RGB colour model into the printer CMY model, which results in a loss of information and can cause image distortion. The quality of the input (monitors) and output devices (printers) as well as the possibility of transforming digital image into a reproduction with a minimal loss of transformation, influences quality of the reproduction made.

Image quality can also be defined as a function of both resolution (dots per inch or dpi) and the number of levels of colour that can be achieved. Considering this, image quality can also be defined as function of precisely defined colorimetrical values (C*h*L*a*b*) of CMY color system of a printer. Any change in these particular coordinate values will result in image color distortion.

Based on its natural characteristics, lightness is confirmed as one of the most important parameter of color system based on color communication and its digital reproduction based on transformation from linear RGB system to non linear CMY system, and there are still questions about color hue and its reflected energy relations, which depend exactly on wavelengths of color.

It is important to note that reproduction of colour in computer systems of colour communication and colour management is provided by linear transformation of CIE XYZ values to RGB system [4]. The three major colour vision theories which are the basis of colour science and modern colorimetry are the trichromatic theory of Young and Helmholtz, Herring's opponent colour theory and the retinex theory put forward by Land. These theories generally defining colour as the result of the total amount of luminance energy reflected from the coloured surface, which stimulate photosensitive receptors for red, green and blue colour in human eye (RGB system), which is exactly the basic principle of digital colour reproduction [3]. CIE tristimulus values X, Y, Z uniquely defines the colour in numerals and precisely describes the colour. X, Y, Z values represent basic spectrophotometric data which are calculated into a different colour parameters through means of different mathematical models. "Y" tristimuls value, (1), uniquely define lightness of one coloured surface, which is given by the product of an illumination spectral power distribution and surface reflectance function, weighted by the factor "k" which defines Y tristimulus value of ideal white reflecting all the energy incident on it with reflectance value 100. "$d\lambda$" defines how finely spectrum must be divided to evaluate the integral from the equation (1), and for colour calculations of any product "$d\lambda$" is set as value 10 – 20 .

$$Y = k \int_{380}^{700} E_\lambda \bar{y}_\lambda R_\lambda d\lambda \qquad (1)$$

Investigations in this paper were carried out with aim of pointing out the real problem that needs to be solved aimed by development of more precise and functional model of color quantification in CAD processes and also in processes of color management and color communication.

Also the tests of four different printers, generally used in a paper printing technology, are presented with the purpose of defining the possibility of their use in the field of digital textile printing.

All commercial printers that have been developed for paper and industrial printing can be divided into two major categories; drop – on demand (DOD) and continuous ink – jets (CIJ). The DOD printers can also be divided into two groups, based on the type of technology: thermal ink jet printers and printers with piezoelectric technology. Piezo print heads are now in use in a number of printers for textile substrates, although there is no solid proof of preference for textile digital printing [5]. Based on the literature data, most of the researches in this field are aimed at digital

system which will assure the minimal loss of information (transformation of RGB to CMY system) and acceptable quality of prints.

2. APPROACH

Four commercial ink jet printers of two different types were chosen for test prints. Hewlett Packard DeskJet 660C-no.1 and Hewlett Packard DeskJet 820 Cxi-no.2 printers with thermal technology of printing head, as well as Epson Stylus Colour 660-no.3 and Epson Stylus Colour 1520-no.4 printers with technology of piezoelectric printing head. Testing was performed based on printer resolution and reproduction of three primary colours of subtractive colour mixing system: cyan, magenta and yellow. Primary colours were reproduced in a 100% concentration without mixing, in a square shape.

Three groups of hue samples were chosen; h* 080 – 100 (yellow), h* 000 – 010 ; 350 – 360 (red) and h* 255 – 285 (blue). In each hue group 70 coloured samples were measured. Samples were measured in CIELAB mode spectrophtometrically by means of <u>DataColor®</u> type *DC 3890* remission spectrophotometer. Results were obtained employing Y/C* and a*/b* relationships and were presented in a form of graph. Also dE/Y relationship were obtained.

3. RESULTS AND DISCUSSION

The judgment of lightness of an objects is one of the most important tasks in processes of visual perception. As it was noted earlier, lightness is defined as a total amount of light reflected from coloured surface, and surface under remission curve represent the true spectrophotometric colour information (flux of luminance). Those facts confirm lightness as one of the parameters of computer system based on colour communication. Some basis of colour and its digital reproduction based on transformation from CIE XYZ to RGB system, were mentioned in the introduction of the paper. Reproduction of an image is the only real indicator to show what kind of change took place in the process of reproduction. One of essential problem during the image reproduction is the loss of colour information, which happens during a process of transformation of the RGB system (input device - additive colour mixing) into CMY system (output device - subtractive colour mixing system).

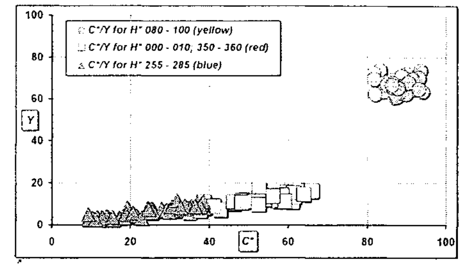

Figure 1: Y/C* relationship

Figure 1. shows high results obtained for Y tristimulus value for group of yellow samples (h* 080 – 100), which confirm high level of luminance energy. Also in this group of samples high C* values are obtained. Important fact for samples from this part of the colour space is that only with relatively high chromacity (C*) selectivity of yellow hue can be achieved. On the contrary, with decreasing chromacity hue values are translating towards achromatic white point while at the same time value Y is heading 100 (maximal value). The number of colours decreases with increasing lightness and finally at Y = 100 it becomes a point. This confirms the fact of problematic hue selection with increasing lightness. For group of red (h* 000 – 010; 350 – 360) and blue (h* 250 – 280) samples Y value obtained is less than 30 units, which confirm selectivity problem

also of hues with significant decrease of lightness. This was one of the most important reasons for mathematical model development, which would obtain more precise selection of these particular groups of hues.

Quality of colour reproduction of the prints of the chosen hues by ink jet printer was examined in colorimetric terms by calculating dE (total colour difference) value, having in mind that results of tested colours have to be inside the colour gamut. Figure 2., and 3. show a*/b* values of tested coloured prints, produced with the resolution of 300/360 (fig.2) and 600/720 (fig.3) dpi compared with theoretical CMY a*/b* values.

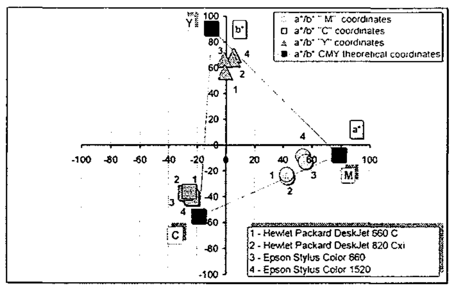

Figure 2: a*/b* relationship (300/360 dpi)

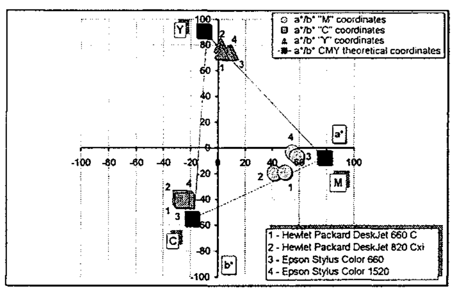

Figure 3: a*/b* relationship (600/720 dpi)

Disagreement between theoretical and measured data could be seen especially in the yellow and magenta region for the lower resolution results. For higher resolution, disagreements are not that significant considering that influence of lightness parameter is not defined. Relative agreement with theoretical CMY values showed in the colour space is achieved on printers no. 3. and 4. (Epson Stylus colours printers - piezoelectric technology). It is important to mention that a printer can produce all combination colours with the three subtractive primary CMY colours only in theory. In practice, a black (K) component is added to the CMY model in order to print 100 % black, but this was not the aim of the tests described in this paper.

The importance of the lightness parameter was pointed out in figures 4. and 5. where values of total colour differences (dE) are plotted versus Y values.

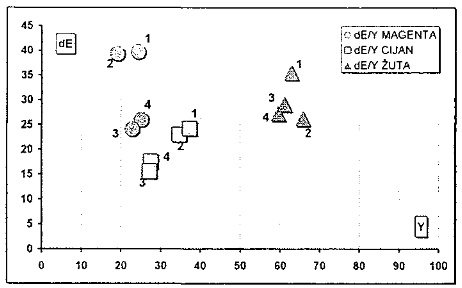

Figure 4: dE/Y relationship (300/360 dpi)

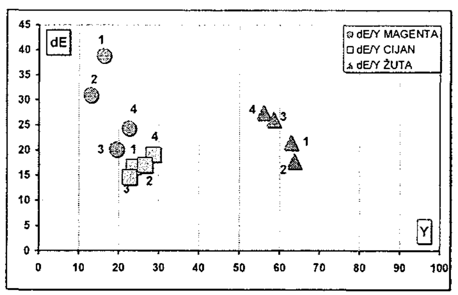

Figure 5: dE/Y relationship (600/720 dpi)

Using a theoretical CMY values as standard calculations were made of total colour difference (dE). With higher resolution, disagreements between results for Epson Stylus printers (piezoelectric head) were lower than between the results for Hewlett Packard printers (thermal head). dE values which shows higher disagreement in a magenta region, confirm the theoretical data explaining the greatest loss of information in the region of green light (magenta - conversion from green light). The tests confirmed that precise control is necessary in each phase of the reproduction to be able to minimize loss of information, regardless of the abilities and limitations of particular instruments.

4. CONCLUSION

The tests performed confirmed that precise control is necessary in each phase of the reproduction to be able to minimise loss of information and quality print assurance, regardless of the abilities and limitations of particular instruments. It was confirmed that quantification of color by lightness parameter causes hue selectivity problem in color management process. It is also confirmed that lightness evaluation as Y standard value does not give a satisfactory reliability for color samples of longer wavelengths such as red and blue hues. These results suggest that the influence of the yellow component would be of minor significance on the quality of the printouts (Figure 1.).

By defining colorimetric characteristics of printing inks by means of spectrophotometric measurements and presenting them in a CIELab terms and dE/Y relationship, information can be obtained on the acceptability of digital printing system (resolution, technology of ejection the ink onto the substrate) as well as of the ink system to ensure CMY colors position within gamut (Fig. 2 and 3). dE values which shows higher disagreement in a magenta region, confirm the theoretical data explaining the greatest loss of information in the region of green light (magenta - conversion from green light) (Fig. 4 and5).

It is suggested as a criterion, to take the difference between the best theoretical possible reproduction of the pure color presented by the point of the color solid (a*/b*) and really reproduced color presented by the point inside the color solid.

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Prof. Dr. sc. Đurđica Parac-Osterman, Mr. sc. Martina Joanelli, assistant, University of Zagreb, Faculty of Textile Technology, Pierottijeva 6, Zagreb, Croatia. Phone: +385 1 487 7359, Fax: +385 1 483 6058, E-mail: djparac@ttf.hr

COLORS AS LINGUISTIC ELEMENTS OF THE VISUAL COMMUNICATION SYSTEM

Vojko Pogačar
University of Maribor, Faculty of Mechanical Engineering, Slovenia

1. INTRODUCTION

The semantics of individual color shades has a specific symbolic value and a meaning of its own, like letters that we understand as the basic elements for words, which form sentences.
In a similar way, we can put together different shades of colors in a kind of semiotic note, bearing a new content. Out of this principal idea the tendency for a semantic classification of colors and shades is derived. This semiological classification of colors and shades is a symbolic codification of the color system, which has universal value, since it can be applied to any field of interest, though in this case it serves the purpose of a better articulation of elements of the visual language (1-3).
As centuries ago Gutenberg articulated the printed words, computer medium nowadays is allowing the articulation of visual language. The conclusion is that it is necessary to determine objectively the relation of meaning between a color and its semantic value. In this sense, I would like to create a surveyable correlative model, limited to the achromatic color scale. The chromatic color values are a too broad subject of discussion (4).
In 1994, Anton Trstenjak stated, that „specialised study leads the researcher to the knowledge to learn everything about nothing, and in the universal sense of learning nothing about everything" This statement is essential, since a specialised research of colors, due to broad and integrated phenomenon, exceeds the capabilities of only one specialistic optic view of the problem and the scientific research of colors includes all forms of basic philosophical questions as well (14).

2. THE EYE - A RECEPTOR, THE COLOR - AN ORGANIC CONVENTION OF THE HUMAN ORGANISM

The eye is the receptor organ for light or the energy of the luminous flux to the retina, from where visual data are further transformed to the visual centre in the brain, where the received data are interpreted as a picture and colors (Figure 1). At the end of the physiological pathway the dillemma appears: is subjectivelly experienced interpretation of colors during the centuries a slowly accepted visual convention of the language of images (17-19)?
In summary, talking about colors means a social and organic convention of humans, that physiologically interprets exactly defined energy quanta as exactly defined color experience. The social context is thought as a type of common visual code of the abstract communication system, which is accepted by common consent and internationally comprehensible (15-18).
While languages developed from a universal precode into a great number of linguistic interpretations that became individualized into dialects by small local communities, the „code to see colors" formed over thousands of years from a relatively mono-symbolic universal precode. According to communication, people undoubtedly used colors throughout history, but accuracy was always relative, optional and approximate,

depending on the sensibility of the intersubjective observational mechanisms. Today the objectve recording of colors is necessary (17-19).
In this paper I treat the color phenomenon as an integral hypothetical insight into the universal system of colors, as an encoded language of the present time that is linked to the development of our society (5,8,11).
From the physical point of view we are not able to see colors if there is no light, except for black. From the philosophical point of view, colors do not even exist if we have not seen them first. And if we have not seen them, we cannot be aware of their existence (15,16,19,20).

3. COMPUTER – VIRTUAL ENVIRONMENT OF COLORS

Computer programme tools have become an supportive and inevitable eye prothesis for more objective definition and repeated use of colors. Because of their non-material and etherial nature it is symptomatic for colors to be bound to this artificial, virtual environment, which offers the possibility for coding and objective standardisation of colors as the elements of visual communication among different consumers.

4. INTEGRAL INTERPRETATION OF COLORS

Color itself is not a material substance, but interpretation of the light in the brain, perceived by the eyes. Besides colors, a number of other accompanying information is recieved by the optic stimulus, that essentially blurs the mono-symbolic understanding of the encoded language. It is widely accepted, that colors always appear at least in pairs. Therefore, for the observed color shade its contrast, like a counterbalance, always appears.
Besides experiencing colors, the influence of other receptors is present, as that of sound, smell, taste, tactile perception or surface structure, temperature, linked to the accompanying conscious and unconscious patterns of mental criss-cross, associations, prejudices etc.
The complexity of color perception is an individual experience, which is difficult precisely correlate to perceptions of another observer. A part of informations to understand colors perception and experience can be gained through the analysis of the eye evolution, as well as from the work of color-perception researches in uncivilized cultures or out of the childrens perception developement (15,16,19).

5. LINGUISTIC NAMING SHOWS THE EVOLUTION OF COLOR PERCEPTION

Linguistic research of the basic expressions for colors is the most suitable method for understanding in detail human color reception through time.
Berlin and Kay (1) concluded in their comparative linguistics study, that some civilized societies were able to perceive colors objectively, when they became aware of their existence.
A preliminary condition to see a color at all is light. When we see the color and perceive it, the next stage is to become aware of it, that is to realize the individual color. Children are not aware of what they see. Usually, they interpret the luminous flux, but they are not able to identify the individual color consciously. To be able to do that, a certain stage of intelectual development is necessary. If a keyboard is given to a child, he would unconsciously type something, but wouldn't know what it means. The interpretation serves simply for orientation in space and for survival. It is probably the same with animals, but humans with their level of intelligence can be aware of the optic stimulus in a creative sense. During evolution humans became

aware of the numerous colors, became able to enjoy them and use them for communication at the same time (1, 15, 16, 19, 20).

It's assumed in thesis: **what we are not aware of, we cannot give a name (1)!**

According to this analogy, evolution of linguistic research shows us individual awarness of individual color existance, but the names of colors are only an approximation of lingustic denotations.

In 1879 Allen Grant (1) speculated that expressions in primitive cultures were not as abstract as today. The term *green* only abstractly encoded the idea for the green color. In the times of Homer the term *green* was understood as something *fresh, or young*. For Grant, primitive cultures named things by their predominant impression at a certain moment, as for example a tree in a shadow was a black tree. Later on, poets - like Swinburne in Poems and Ballads and Tennyson in Princes (21) – described colors in more sophisticated way.

Lazarus Geiger stated in 1867 (1), that the eye was not as fully developed and sensitive for colors thousands of years ago as it was in his times. For him, the evidences for this statement were ancient Greek, Veda and Zen writings. Today, these evidences are hard to believe, since the evolution of the eye was not this rapid. It is probably the conscious realization and awareness of color perception that was first mentioned in written words (17).

Geiger defines several stages of conscious realisation of colors. The earliest stage of conscious realisation of colors defines the non-material and indeterminable concept of a color, especially black, which summarizes all others, although Geiger does not think of it as a color (17). The next, second stage by Geiger defines red and black, which are considered as the first real percepted colors. At the third stage of perception, yellow appears, which is typically mistaken for green. The fourth stage of perception is represented by white.

Geiger observed, that Democritus and the Pythagoreans defined four basic colors: black, white, red and yellow. The same was proven by Cicero, Pliny and Quintilian, as the ancient Greek painters used the above-mentioned four basic colors up to the period of Alexander (17).

At the fifth stage of color perception, there is green and at the sixth blue. By Geiger, the term blue was often used and mistaken for green, and even more often for black (17). The afore mentioned Berlin and Kay determined in their study of comparative linguistics eight evolutionary stages for the development of terminological definitions for color perception.

5.01 If we re-capitulate, the conscious realisation of colors in the first stage was based on the difference between bright and dark. Consciously realized black probably included the whole palette of darker shades. Brighter colors and white on the other hand included all other bright ones. Some African and Australian tribes are still witnessing this phenomenon today. I am sure that the evolution of color perception can be verified also in children, who surpass all the evolutionary stages of civilisation in their growth (17,18).

In terms of the evolution of color perception the development of the eye in humans, primates and other mammals can be clearly traced (Figure 1). In evolutionary terms, approximately 1,5 billion years ago, the receptors for bright and dark light stimulus in animals appeared. From the original *primitive* receptor stem cells, approximately 800 million years ago, the eye developed as the receptor for light stimulus, as well as the pathways from the receptor to the visual center in the brain. At the same time receptors for taste and temperature developed as well. 500 millions of years ago, the receptors for short- and long-wave light developed. This made the first two-chromatic color perception possible (22).

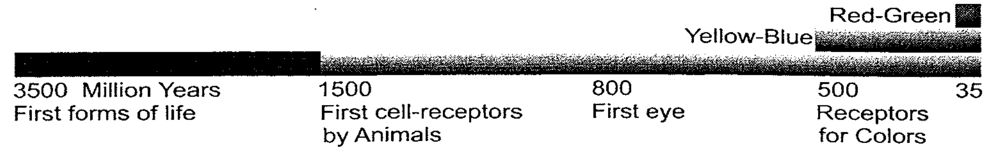

Figure 1: Appearance of Color perception

5.02 The next stage would be the occurance of the term red next to white and black. Due to inaccurate perception, the term red can cover anything, either orange, or even yellow. My conclusion would be, that this phenomenon is similar to the perception of warm and cold, that are also not precisely defined. I think, that this kind of preception is only a slight move out of the bright-dark, white-black towards cold-warm polarisation (18).

The explanation of the cold-warm polarisation makes sense in the next stage, when green is consciously realized and named. Magnus' sudies of African tribes show the perception of short-wave colors (green, blue, purple), where green is also mistaken for blue.

The long-wave orange and red probably occurred independently before the cold colors, because they are more invasive and aggressive, but black or dark colors acted as a cold antipode to the warm colors. Later, the red-green polarisation was realized.

In summary, the research of Berlin and Kay observed, that only two variants of the linguistic evolution appear. They can be differentiated only in the order of percieving yellow and green: in the first variant green is placed third and yellow fourth, in the second these colors change places (1).

Variantion A: 1-black/white, 2-red, 3-*green*, 4-*yellow*, 5-blue, 6-brown; and the group: 7-purple, 8-pink, 9-orange, 10-grey.

Variantion B: 1-black/white, 2-red, 3-*yellow*, 4-*green*, 5-blue, 6-brown; and the group: 7-purple, 8-pink, 9-orange, 10-grey.

However we interpret this evolutionary order in the way, that after green red-green polarisation occurs, and after yellow and later blue the yellow-blue polarisation appears.

To summarize: *the evolution of the eye is linked to the evolution of the sight and the conscious realisation of colors* (1,15,16,19). The physics of visual stimulus - the luminous flux as an energy is perceived by the eye and then transformed in the thalamus - is well defined. But from this point on, when decoding and screening –experiencing the color – is taking place, we know much less. Experiencing and realizing colors can be observed only indirectly through the different stages of the human evolution (15,16,19). (Figure 2)

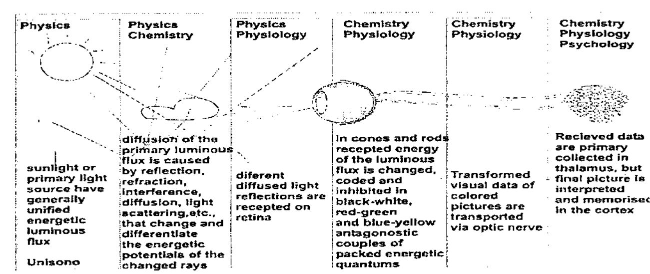

Figure 2: Color perception process

6. BRIGHT - DARK ACHROMATIC SCALE IN THE SENSE OF PSYCHOLOGICAL CORRELATION

The bright-dark pre-perception is a kind of anachronistic atavism, which in today's world of variegated colors has an effect of an elementary pre-category that is artificial, similar to the evolution in which humans become civilised and alienated from the nature. This polarising bright-dark achromatic scale stands in intensive correlation with typical elements of the civilisation that are reflected in psychological relationships in their lightness of beeing or heavy behaviours and manners (17).

Nowdays have the black and white movies similar abstract meaning opposed to colored ones. Generally, we can say for a movie, that it is a typical product of civilisation, but all attempts to come close to the perfect color reproduction of nature are only an approximation.

Jacobson in Halle defined the correlation between black and white as a stage of energetic quantum, white as the maximum and black as the minimum. In the span between the highest and the lowest energetic state is the whole palette of intermediate ones, which are in a social surroundings known as the unwritten civilisation codex of positive and negative norms of behaviour.

According to this definition, most of civilisation's achievements can be defined as virtualy created and completely new in comparison with naturally developed by evolution. The language as a form of communication is a characteristic of the human species. Animals communicate mostly in the sence to express their primal needs. On the opposite, humans beings can express wide palette of sofisticated feelings (1,21,23).

Today's diversity of languages is a proof of human innovation and capacity to learn, and through that, proof of surpassing the achieved stages of language knowledge.

We are also witnessing the process of *linguistic* color coding, made possible by computer technology. As this technology enables the simultaneous process of globalisation, this is a certain guarantee that *color linguistics* will develop mono-symbolically in the global sense, and the original communication code born by color itself will remain preserved. All seemingly diverse languages have a common code, but the linguistic process enabled by computer technology will be retrograde (11,23).

The evalutation of the bright-dark achromatic scale in concordance with a psychological model, places individual psychological conditions, behaviour, emotions and disturbances into the context of socially valued system.

Making the bright-dark achromatic scale more radical is demonstrated most expressively in drama. The theatre language contains exactly this vertical correlation, which includes the whole range of dramatic values by giving them all the characteristics that *drama* was named for: the serious, tragic and soul-stirring experience of the events, ranging from comedy to tragedy (5,9,11,12).

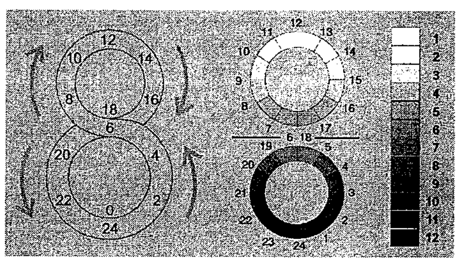

Figure 3: Acromatic bright - dark cyclus scale

The meaning of the horizontal direction around the color equator is represented in the dramatic language structure with a strongly emotional correlation, manifesting

itself typically in light genres, comedies, love stories, but also in dramas and operas with dramatic plots.

The bright-dark cycle is in correlation with the natural twelve-level time span between the brightest and the darkest point of the day, e.g. between white and black (Figure 3). The result is vertically symetrical system and represents the cycle of a day. The strongest light of the day is around midday, when the sun is in zenith. The sunsets describes the cycle of the night, but the deepest dark is around midnight (9,10).

The twelve-hours time span (10) of the day is the starting point for the hypothesis relating to the achromatic scale in correlation with dramatic values of behaviour (Table 1). According to the bipolar concept of the day and night cycle, behaviours are devided into the positive and negative pole and further each into six positive and six negative levels. Each part of this 12. stages scale is devided into five terminological definition of behaviours but the whole scale is devided into a four main complexes, groups with common general characteristics with declining tendency. It means that from part to part of the grey scale the energy values are constantly falling.

The table shows different stages of behaviour in correlation with the value of their psychological importance and experimentally comparative energy values (13). Besides, the conscious and unconscious levels of behaviour and emotions, the comparative achromatic bright-dark scale is presented with 12. and 60. stages scale with their percentages (%) of grey (1,5,8-12,24-29).

Table 1: Correlation between acromatic scale and psycho-dramatic modes of behaviour

Psycho-dramatic modes of behaviour	Concious / unconcious	(+/-)	Tone scale (12-st.)	(60-st.)	(%)
1. Vivid spiritual serenity	You know exactly what you want,	+			0
2. Postulates, creativity, ideas, goals, commitment	everything is clear, transparent	+			2
3. Games, deliberated playing	Future is not totaly clear	+			4
4. Action and engaged passionate working	To learn	+			6
5. Enthusiasm, excitement, exhilarations	To observe	+			8
6. Aesthetic		+			10
7. Thrill		+			12
8. Cheerfulness		+			14
9. Strong interests		+			16
10. Conservativism, status quo		+			18
11. Mild interests		+			20
12. Contented, satisfied		+			22
13. Desinterested		+			24
14. Boredom	Conciouss	+			26
15. Repeated monotony	Positive emotions	+			28
16. Antagonism	Negative emotions	-			30
17. Servility and humbleness		-			32
18. Hostility, unfriendly, unkind		-			33
19. Pain		-			34
20. Anger		-			35
21. Hate		-			36
22. Concealed anger, resentment		-			37
23. No sympathy, without compassion		-			38
24. Unexpressed resentment, full of covered anger		-			39
25. Covered hostility		-			40
26. Anxiety		-			41
27. Fear		-			42
28. Dispair, dissappointment		-			43
29. Terror, fear of war or darkness		-			44
30. Numb, loss of sensitivity		-			45
31. Sympathy, compassion		-			46
32. Propitiation, support		-			47
33. Mourn, grief, sorrow		-			48
34. Making amends, propitiation		-			49
35. Undeserving, worthless, can't withhold anything		-			50
36. Selfabasement, selfhumiliation, no one likes me, I am bad		-			61
37. Feel like a victim		-			62
38. Hopeless		-			63
39. Apathy		-			64
40. Useless, no sense		-			65
41. Dying		-			66
42. Body death, exaustion		-			67
43. Failure		-			68
44. Pity, sorrow		-			69
45. Shame (rather be somebody else, being other bodies)	Unconciouss	-			70
46. Accountable		-			72
47. Blame, accusation	Addiction	-			74
48. Selfpunishment		-			76
49. Controlling bodies, to take control over the others	Effort	-			78
50. Protecting bodies		-			80
51. Owning bodies, to posess	Think	-			82
52. Approval from bodies		-			84
53. Needing bodies, prostitution	Symbols	-			86
54. Worshipping the bodies, adore own or other's body	Eat	-			88
55. Sacrifice, to be offered as a victim	Sex	-			90
56. Hiding, selfconcealment	Mystery, secret	-			92
57. Being object, being an object of desire	To wait passively	-			94
58. Being nothing, nonexisting	unconscious	-			96
59. Can't hide, totally inactive	Total failure	-			98
60. Total failure	Unknowable	-			100

Legend: (+/–):positive/negative emotions, (12-st.): 12-stage tone scale, (60-st.): 60-stage tone scale

6.01 I. complex
I. complex represents the group of achromatic values with the strongest energy. Transmitted energy is equal to the recieved one. Further on, the reflection is declining and the absorption increasing. Acromatically, it ranges from fully white to the brightest grey shadows, expressed in percentages from 0 to 28% of grey. These shades of grey represent the complex of high conscious stage and positive emotions. It represents behaviours with positive psychological orientation and is resulting in successful human functioning. This complex of stages are full of energy in every respect, are creative, successful and socially correct. At these levels of energy the individual is aware how to act, behave, survive, understand limitations and be able to cross them, etc (Table 1).
The modes of behaviour of the first fifth are as follows:

6.1.1 First fifth of the I. complex:
1.1.01 Vivid spiritual serenity is the highest form of individual level of being. It is full of spontaneous, unlimited creativity. This nearly *devine* level is resumed in *the unbearable lightness of being and creativity*. Only few people in life make a durable approach to that stage, many spiritual innovators, thinkers, spiritualists reach it only in certain periods of time and under special conditions.
1.1.02 Behind the absolute peak follows the level of being, characterized by creativity, ideas, goals, commitment, highly placed noble aims, determination and positive manners.
1.1.03 The next, still highly esteemed level of being, the level best described as overcoming the obstacles, free games, deliberated game. This active and positive level is reached by broad number of people and the most often reached level for the majority of the population. Constructive approach by hyperactive education, training, etc. is the anticipated tool for this mode of behaviour.
1.1.04 Action and engaged passionate working.
1.1.05 Enthusiasm, excitement, exhilaration.

6.1.2 Second fifth of the I. complex includes highly appreciated forms of functioning:
1.2.06 Aesthetics as a principal of life – to be beautiful, ordered, surrounded by beautiful things, loving beauty in every way, either artificial, or natural.
1.2.07 To be thrilled about anything positive and openly showing enthusiasm towards people, animals, events, things…
1.2.08 Cheerfulness means a noble, broad-minded attitude...
1.2.09 Strong interests for anything positive.

6.1.3 Third fifth of the I. complex includes the last forms of positive life principles:
1.3.10 Conservativism, status quo;
1.3.11 Mild interests;
1.3.12 Contented and satisfied;
1.3.13 Disinterested is still considered to be positive;
1.3.14 Boredom;
1.3.15 Repeated monotony, at the very edge of positivism, is the last mode of positive behaviour.

In this way the I. complex of positive forms of functioning, behaving and feeling is concluded.

6.02 II. complex
II. complex of achromatic values represents the from declining strength and increasing energy absorption. From the achromatic point of view, this complex ranges from the brightest grey shadows to medium grey, in percentages this is from 28 to 45% of grey, representing decreasing energy quantums and behaviour modes, gradually declining to negative emotional states with a similtaneous diminishing of consciousness. This complex is a field of relatively neutral grey and monotony. Gradually, every fifth of this grey complex becomes more intense and passing deeper into the negative sphere of behaviour and emotions (Table 1).

6.2.1 First fifth of the II. complex:
2.1.16 Antagonism;
2.1.17 Servility and humbleness,
2.1.18 Hostility, unfriendliness, unkind;
2.1.19 Pain;
2.1.20 Anger.

6.2.2 Second fifth of the II. complex:
2.2.21 Hate;
2.2.22 Concealed anger, resentment;
2.2.23 No sympathy, without compassion;
2.2.24 Unexpressed resentment full of hidden anger;
2.2.25 Covered hostility – kind praising.

6.2.3 Third fifth of the II. complex:
2.3.26 Anxiety;
2.3.27 Fear;
2.3.28 Dispair, dissappointment;
2.3.29 Terror, fear of war or darkness;
2.3.30 Numb, loss of sensitivity.

6.3 III. Complex of achromatic values is at the breaking of diminishing strength, where the absorbing energy overcomes the giving level of energy. Achromatically, it ranges from middle grey shades toward dark grey, in persentages from 45 to 72% of grey. This represents the complex of declining energy, negative behaviour and emotions with totally diminished conciousness. The III. complex is overwhelmed by severe grey and depression, which becomes deeper with every fifth of the complex. In the zero point in the next fifth, the negative emotional sphere moves into extremities of the critical state (Table 1).

6.3.1 First fifth of the III. complex:
3.1.31 Sympathy, compassion;
3.1.32 Propitiation, support;
3.1.33 Mourning, grief, sorrow (if somebody dies);
3.1.34 Making amends, propitiation (to agree with somebody about everything, also when damage is done);
3.1.35 Serving, feeling worthless, can't withold anything (I'm not worthy…);

6.3.2 Second fifth of the III. complex:
3.2.36 Self-humiliation, no one likes me, I am bad;
3.2.37 Feel like a victim;
3.2.38 Hopeless;
3.2.39 Apathy (you are not present, quiet, passive)
3.2.40 Useless, no sense.

6.3.3 Third fifth of the III. complex:
3.3.41 Dying (spiritually);
3.3.42 Body death, exaustion;
3.3.43 Failure (surrendering, renouncing, failing exams, being defeated);
3.3.44 Pity, sorrow;
3.3.45 Shame (rather be somebody else, being other bodies).

6.4 IV. complex of achromatic values is the last one and represents complete absence of strength. The absorbing energy is much higher than the giving one. The achromatic range is from dark grey shades to black, in percentages from 72 to 100% of grey. This complex lacks energy quantums and is reigned by negative behaviour modes and emotions, as death, failure, exaustion, shame, pity and finally, total loss of conciousness. Human behaviour through each fifth of this complex becomes more dramatic and ends with unconscious state. It is an extremely depressive field representing the most miserable images of living and the lowest possible state of the human being (Table 1).

6.4.1 First fifth of the IV. complex:

4.1.46 Accountable;
4.1.47 Blame, accusation (punish someone);
4.1.48 Self-punishment (take guilt upon oneself and assume responsibility for others, world weariness);
4.1.49 Controlling bodies, to take control of others;
4.1.50 Protecting bodies (to protect someone, to have him/her imprisoned);

6.4.2 Second fifth of the IV. complex:

4.2.51 Owning bodies, to posess;
4.2.52 Approval from bodies;
4.2.53 Needing bodies, prostitution;
4.2.54 Worshipping the bodies, adore own or other's body;
4.2.55 Sacrifice, to be offered as a victim.

6.4.3 Third fifth of the IV. complex:

4.3.56 Hiding, selfconcealment;
4.3.57 Being an object, being an object of desire (in prostitution);
4.3.58 Being nothing, non-existence;
4.3.59 Can't hide, totally inactive, you can't hide within yourself anymore;
4.3.60 Total failure, state of complete resignation and not even being aware of it.

8. CONCLUSION

Similar to Mendeleyev's system of classification of chemical elements, color shades need to be systematized according to their characteristics and semantic values. Computer technology offers a global visual communication, but demands at the same time a more objective articulation and coding of the elements of visual linguistics, which form the basis of the universal semiotics of global language. As colors are among important components of visual linguistics, the necessity for their semiotic and semantic articulation is becoming a very important task, which may need to be carried out on a long-term basis.
Though, the presented classification model for achromatic scale is purely informative, the main purpose, however, is to point out how it may be organised in future in respect to different modes of behaviour, emotional states and energy levels.

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Assist. Prof. Dr. Vojko Pogačar, University of Maribor, Faculty of Mechanical Engineering, Smetanova 17, 2000 Maribor, Slovenia. Phone: 386-0-31-661306, Fax: 386-0-2-220-7990, E-mail: vojko.pogacar@uni-mb.si

COLORIMETRICAL EVALUATION OF COLORS IN FOUR - SEASONAL TYPOLOGY

Vojko Pogačar[1], Majda Kuzmič[2], Vera Golob[1]
[1]University of Maribor, Faculty of Mechanical Engineering, Maribor, Slovenia
[2]Secondary Textile School, Maribor, Slovenia

Abstract
The advanced approach to textile color consultation for selecting appropriate wardrobes and home-furnishing colors is based on four-seasonal personal color palettes. In nature, each season offers various palettes of harmonious color combinations and personal coloring should be in harmony with one of these palettes. Various four-seasonal color palettes were developed as guides for personal colors by adapting Itten's theory on fashion.
Determining personal colors is still subjective, depending on the adviser's intuition or experience, therefore a more objective method using colorimetry needs to be developed. In this research the natural skin coloring of selected individuals was colorimetrically evaluated and classified according to seasonal types. Systematization of color tones surely makes personal color consulting more logical and predictable. Such an objective color evaluation will result in a more logical method of projecting personal fashion colors.

Keywords: *color consulting, color design, seasonal color theory, four-season color palettes*

1. INTRODUCTION

The advanced approach to textile color consultation for selecting appropriate wardrobes and home-furnishing colors is based on the typology of four-seasonal personal color palettes. The seasonal color theory has already been proposed by artist and colorist Johannes Itten who after years of working with his art students discovered that they consistently chose personal colors, which were complementary to the natural coloring of their skin, hair and eyes. By adapting Itten's theory on fashion various four-seasonal color palettes were developed as guides for personal colors [1, 2, 3].
In nature, each season offers various palettes of harmonious color combinations and personal coloring should be in harmony with one of these palettes. The whole color gamut varying in shades and intensity is contained in each palette. Spring and autumn types of colors have yellow undertones, meanwhile summer and winter ones have blue undertones.
Each person is born with specific individual coloring of skin, hair and eyes. Natural human coloring is based on genetic heredity: brown eyes, dark hairs and darker skin are inherited dominantly, but blue eyes, fair hair and pale skin by recessive line.
Determining personal colors is still subjective, depending on the adviser's intuition or experience, therefore a more objective method using colorimetry needs to be developed. In this research the natural skin coloring of selected individuals was colorimetrically evaluated and classified according to seasonal types.
Systematization of color tones surely makes personal color consulting more logical and predictable. Such an objective color evaluation will result in a more logical method for projecting personal choice of colors. The basis for the objective evaluation of colors are the specific characteristics of each seasonal type that give us objective arguments and tools for understanding the principles of harmonious seasonal color selections.

2. PREDEFINITION OF THE SEASONS

Itten [3] introduced four basic seasonal types, but this general classification had to be completed by intermediate periods. Each main or dominant period has an entering and closing part for adaptation, in regard to previous or next period [6, 7, 9]. Therefore, besides four main seasons, eight intermediate periods exist, classified together in twelve different periods. Such division is also in accordance with our meteorological calendar but not exactly with each month's diversity [4]. A variety of different calendars exists, but the differences among them are not always logical and in accordance with present color theory, and nowadays practice for choosing colors.
These basic preconditions have specific influences on color appearance and perception, and, therefore it is necessary to classify basic circumstances, which result from certain reactions. It is necessary to describe the physical conditions first, then other physiological and psychological reflexes, which lead to a more logic and objective basement for seasonal color selections [8].
One of the first basic preconditions of the four-seasonal phenomenon can actually be explained by the mathematical geometry of correlations between Earth and Sun. Only the Sun is actually the main source of the light for this purpose (Figure 1). Different angles of the sunlight's flux to the Earth, have different influences on the brightness, color appearance, etc [4, 5].
The various angles of sunlight flux result in plenty of consequences at different levels, which will be briefly explained later. The bright-dark cycle is in correlation with the natural twelve-level time span, between the brightest and the darkest points of the day, between essentially white and black (Figure 2). The result is a vertically symetrical 12 hour system and represents the whole cycle of the 24-hour day [6, 7, 9].

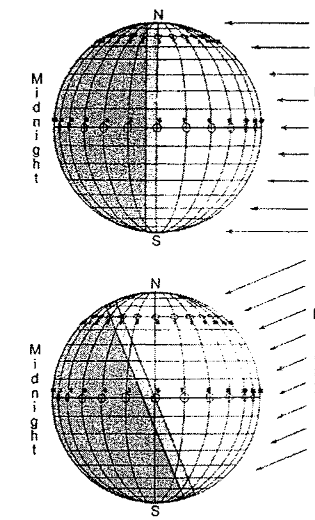


Figure 1: Effect of the light-flux on Day-cycle

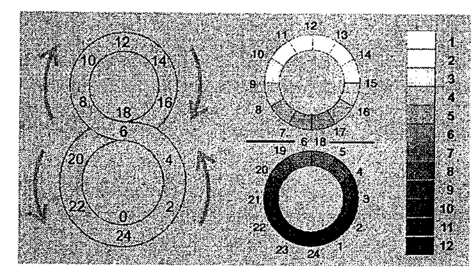


Figure 2: Bright-dark scale of the Day-cycle

The strongest light of the day is around midday, when the sun is in zenith. The sunset describes the cycle of the night, but the deepest darkness is around midnight.

This Cycling system has an important influence on the Earth's energy balance. The sun spreads large quantums of light-energy to the Earth. Its warming function has inevitable side effects. Earth has an enormous capacity of mass material to accumulate that heat. In a Day-cycle the warming effect has two to three hours delay after the highest peak of the light cycle. This has a certain influence on atmospheric conditions, but also on our perception of colors.
This warming-delay of a Day-cycle has similar consequences as the Year-cycle [6, 7, 9], but the amount of energy is larger and the time period is broader. Warming-delay varies from two to three months and this again has a certain effect on atmospheric conditions and our perception of colors. For instance humidity in atmosphere results as a barrier for the light, but in addition it is also a kind of color filter, which sometimes creates special conditions: for instance a glorious picturesque sunset.
The Year-cycle (Figure 3) has certain similarities with the Day-cycle, but the year consists of 12 months, symmetrical only in five common sequences plus two extremes.

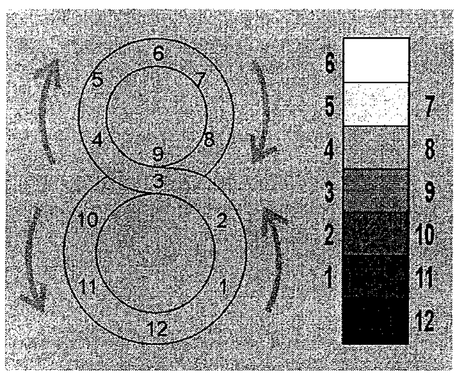


Figure 3: Bright-dark scale of the Year-cycle

Different types of seasons are formed out of the different positions of the Sun towards the Earth (Figure 4), which generally have common characteristics [4] (Figure 5).
Spring is between the 20th of March and the 21st of June, Summer is between the 21st of June and the 23rd of September, Autumn is between the 23rd of September and 21st of December and finally, Winter is between the 21st of December and the 21st of March. (Figure 5)

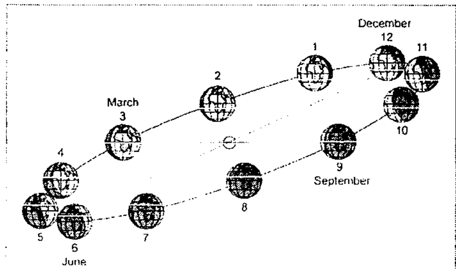


Figure 4: White line denotes the parallels on the Earth, when the Sun is in Zenith

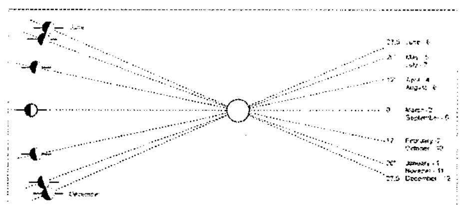


Figure 5: Different angles of the Sun-flux in correlation with Seasons and Months

Equinox is in March and September and correlates with Green and Red in color system. Winter Solstice in December is in correlation with Blue, but Summer Solstice in June is in correlation with Yellow [4, 6, 9]. Such a system does not mean direct connection with the abovementioned colors, but merely a basis to explain and interpret the different psychological principles of color perception. Colors are only received and differentiated quantums of light energy, interpreted in the cortex [10]. Light energy at the same time has side effects, like warming, cooling, dampness, snowing, etc., which on the other hand have a tremendous influence on our perception of colors.

3. INTERPRETATION OF SEASONAL TYPOLOGY SYSTEM

Itten's four-seasonal theory is based on his Color star (Figure 7), which was developed by Adams already in the year 1862 (Figure 6).

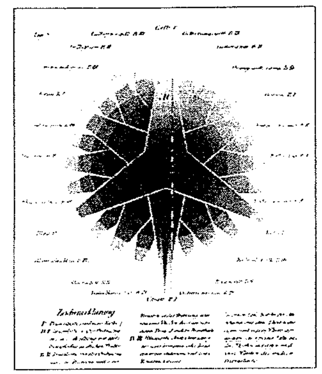


Figure 6: Adams's Color star (1862)

Instead of Itten's star and his idea we find it more suitable to use the Color sun table, which was developed by Harald Küppers [10] (Figure 8), but we also made some transformations in color sequences to bring it in accordance with the Color-Cycling system and partly with the CIELAB system for possible further evaluation [11].

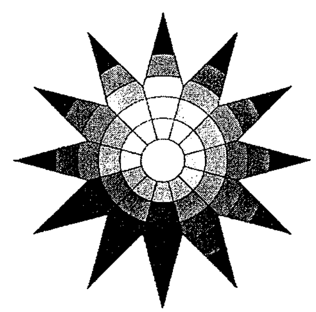


Figure 7: Itten's Color star (1962):

We find it to be a more suitable basis for the explanation of harmonious color selections for seasonal typology. The white line in Figure 8 shows the elapse of symbolic color values in certain periods. It doesn't mean any preferred or suggested seasonal color, but only the basic standpoint for the seasonal color selection.

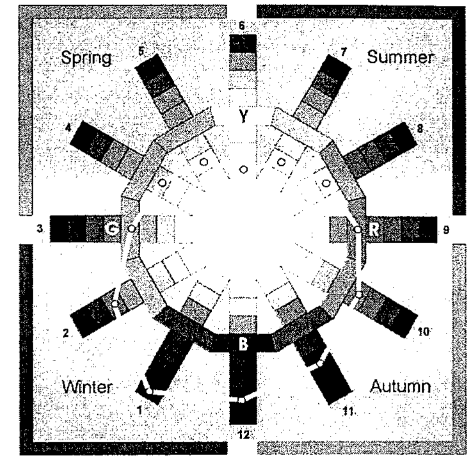


Figure 8: Transformed Küppers's Color sun (1989)

Each season period is associated with certain colors, feelings, emotions and energetic states. It means that a particular season possesses a palette of selected colors, which are in accordance with each other. For this type of selection it is possible that potentially any chromatic color from the color wheel can be included, but selection has to be focused on specific characteristics of the chosen colors. Afterwards, it is more important, that the chosen colors are in accordance among themselves. This second criteria is one of the most important, because it means that one selected color has to be in balance with another.
Therefore, our personal colors are in accordance with the color patterns of a particular season and each seasonal type is

in harmony with this particular selection of colors [6, 7, 8, 9].
This comprehension is based on a belief, that all color combinations in certain seasonal period are in harmony. In each natural environment, the color combinations and contrasts are balanced and result in a specially defined aesthetic of the surroundings and of the time.
Selected color combinations for seasonal typology also depend of various optical misleads, psychological effects, basic color variances, dynamic characteristics of color cycling system etc. We may conclude, that all mentioned elements are in very complex correlations.

4. SEASONS' MAIN FEATURES

4.1 Spring and Autumn - technical description

Basically, Spring and Autumn are in a similar position: the angles of light-flux are the same, the amount of perceived energy is similar, but in reverse orientation. This means, that in Spring the light energy is rising, in Autumn it is falling. At the same time, in Autumn a huge amount of energy, accumulated during Summer is disposed of and slowly vanishes over a two or three month time period. In contrast, Spring starts with a lack of energy after Winter and by slowly heating up it grows until Summer.
Generally speaking it is important, what our point of view on the Earth is by means of geography in order to observe this phenomenon. From a neutral Equatorial point of view the highest peak of light flux is attained on the 20th of March and 23rd of September. In our specific regional geographical position, this is only in summer solstice, that's on 21st of June, at the beginning of Summer [4, 5, 6, 9].

4.2 Winter and Summer - technical description

These two seasons are in total opposition, which means that almost all of their characteristics have the exact opposite meaning.
In Winter, Earth is reached by the minimum of light energy. The angles of light-flux are widest in the winter solstice, reflection of light flux is maximal, but at the same time this minimal light energy is optimally spread and seems to be quite rationally used in nature.
The very specific of Wintertime is snow, covering the Earth. The White of the snow reflects most of the Sunlight-flux, which increases common brightness in the atmosphere. This has several effects on color perception. First, white color causes that all middle and darker color look even darker because of the light-dark contrast. In the sense of Chromaticity, White – due to neutrality and maximal brightness, increases the chromaticity characteristics of any color, resulting in the vivid, fresh and very extended appearance of the majority of colors during Winter. More snow surfaces cause small parts of visible colors to intensify them. These special Winter effects achieve specific conditions for the perception of colors, which are substantially different from other seasons.
In Summer maximum light energy is reached on Earth. The light-flux in the summer solstice is under 90° angle, the accumulation of energy is maximal, but it also depends on vegetation and type of surroundings. There are a lot of side effects, like overheating, evaporation, that produce more humidity, moisturing and other physical, as meteorologic effects [5].
These effects have specific influences on color appearance and perception, like: physical, physiological, psychological, etc. Describing seasonal conditions is necessary to classify basic circumstances resulting in certain reactions, first physical conditions, then other physiological and psychological reflexes [4, 5, 6, 9].

5. EXPERIMENTAL

Determining personal coloring according to the four-season typology is based exclusively on subjective color evaluation of skin, hair and eyes. In this research work colorimetry was used as an objective method for skin color evaluation. 14 local (mid-European) candidates of different sexes and ages were selected for colorimetric determination of the natural skin coloring. They were first subjectively tested and classified to certain season-types. The skin on the forehead was measured using a Datacolor Microflash 200 d portable spectrophotometer and evaluated using the CIELAB system [12,13].
Human skin contains three pigments, yellow-red carotene, brown melanin and red hemoglobin, which influence the natural skin tones. Various combinations of these three pigments determine inherited skin tones, which do not change significantly, but deepen with a tan and fade with ages. Lightness values L* of the evaluated skin lie between 62 (winters) and 55 (autumns). Chromaticity values of the skin are graphically presented in a*/b* diagram in Figure 9.

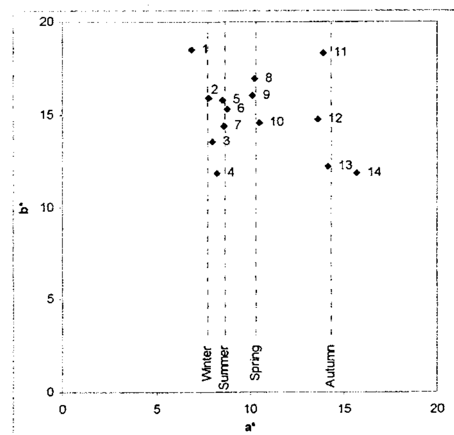


Figure 9: Position of skin colors in a*/b* diagram

From Figure 9 great differences in skin coloring are evident:

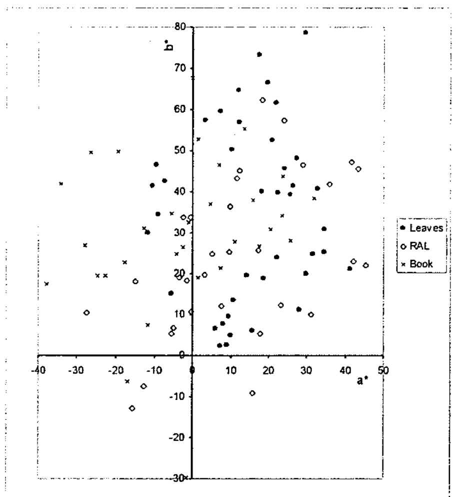
- Winter types (1-4) have the lowest a* value, which means less red component in skin color than others; b* values vary considerably and give a sallow, more or less yellow appearance of the skin, depending on subtypes.
- Summer types (5-7) lie close to winter types with a* values about 8.5 and b* values about 15.
- Spring types (8-10) have higher a* and b* values appearing as a golden undertone of the skin color.
- Autumn types (11-14) have the highest a* values, but depending on b* value the color of the skin ranges from medium copper to peach.

Most winter types have dark hair and fair complexion with cool undertone creating strong contrast. Although their skin tones vary considerably, cool and clear saturated colors with a blue undertone are well suited to their contrasting natural coloring.
Summer types usually have a visible pink in their skin and have blonde, brunette or dark ash-brown hair. Soft colors with a blue undertone are recommended for summer types.
Typical skin colors of the spring types are ivory, peach and golden beige. Their skin is usually finely textured and of a most delicate quality with freckles or clear as glass. The color of hair is blond, red or golden brown. The spring palette contains clear, warm colors with yellow undertones, which positively underline the face color.
Characteristic hair colors of autumn types are dark brown with red shine, red and honey. Skin colors are usually peach to golden-yellow often covered with freckles. Warm and earth colors smooth their complexion, therefore, color palettes of the

autumn type consist of rust brown, warm red and all earth tones.
In Figure 10 the positions of various autumn colors in a*/b* and C*/L* diagrams are presented, determined by the measuring of:

- Various tree leaves in autumn season,
- RAL design autumn color palette consisting of 32 colored paper samples,
- Suggested autumn seasonal palette of 30 colors in the book "Color me beautiful"[14].

Autumn leaf colors in nature vary from green to golden yellow, from orange to orange-brown, red to red-brown and dark brown. The majority of RAL palette colors are in accordance with the natural colors of leaves. Suggested "Color me beautiful" palette of autumn colors is wider and lighter and includes more green colors and also deep blue.



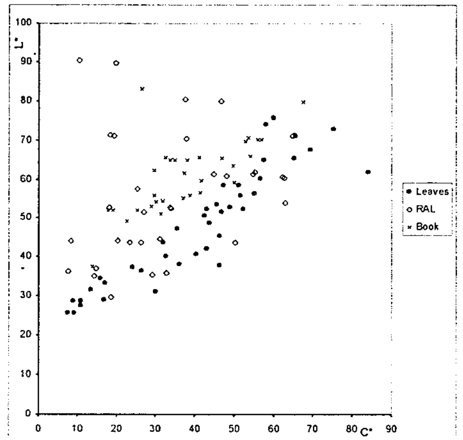


Figure 10: Color position of autumn's colors in a*/b* and C*/L* planes

6. CONCLUSION

Four distinct seasons exist in nature, Spring, Summer, Autumn and Winter, each with its unique and harmonious colors. Hereditary human natural coloring of skin, eyes and hair is complemented by one of these seasonal palettes.
We observed that all known selections of the seasonal colors are subjective and are very roughly defined with lack of logical selection system. Therefore we tried to define more objective basis for selection of seasonal colors.
There are also observed some discrepancies among color theory and known selections of the seasonal colors in practice. In this way we noticed that all known selections of the summer seasonal colors are cold with cold undertones, generally in analogy with winter season, what seems unlogical for summer, being a hot season. Explanation of this paradox is based on hypothesis that summer seasonal colors are in fact antagonistic selected. Cold colors act like substitutes for the hot summer weather conditions.

In that way each selection of the seasonal colors has to be interpreted separately and in correlations with general principles of the color theory, seasonal characteristics of certain geographical areas, perception of the specific seasonal color appearance and psychological principles of color perception.
In this paper we presented only few basic points of the seasonal typology with some colorimetric skin analysis.
Skin color analysis, using colorimetry, is an objective method to determine the personal seasonal type and corresponding seasonal colors, that are in accordance with personal skin coloring. Colorimetrical systematization of seasonal types makes the appropriate personal color consulting more predictable in projecting personal fashion colors.

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Assist. Prof. Dr. Vojko Pogačar, University of Maribor, Faculty of Mechanical Engineering, Smetanova 17, 2000 Maribor, Slovenia. Phone: 386-0-31-661306, Fax: 386-0-2-220-7990, E-mail: vojko.pogacar@uni-mb.si
Assoc. Prof. Dr. Vera Golob, University of Maribor, Faculty of Mechanical Engineering, Textile Department, Smetanova 17, SI-2000 Maribor, Slovenia. Phone: +386 2 220 7891, Fax: +386 2 220 7990, E-mail: vera.golob@uni-mb.si

INFLUENCE OF TRAINING SET SELECTION ON PREDICTION ABILITY OF MODELS FOR THREE COLOUR PROPERTIES OF A TITANIUM DIOXIDE PIGMENT

Karmen Rajer - Kanduč[1*], Jure Zupan[2], Nineta Majcen[3],
[1]Cinkarna Celje, d.d., Celje, Slovenia
[2]National Institute of Chemistry, Ljubljana, Slovenia
[3]Metrology Institute of the Republic of Slovenia (MIRS),
Ministry of Education, Science and Sport, Celje, Slovenia

Abstract

In order to improve the quality control of pigments, several models for pigment's properties as lightness (L), whiteness (W_{10}) and hue (b*) were built. In all variations of data selections and modelling, the same set of 132 samples of white pigment produced in a six months period was employed. Each of 132 samples is characterised by 17 independent and three dependent variables. Models were built by linear and non-linear techniques: a standard multiple linear regression (MLR) as a linear method and radial basis function (RBF), error-backpropagation (EBP-ANN), counter-propagation (CP ANN) as non-linear methods, employing different learning strategies.*

Training and test sets, each containing exactly 66 samples, were obtained by four different strategies: time-dependent selection, random selection, Kennard-Stone maximal distance approach and sampling from Kohonen self-organised top-maps. The 66 testing samples were further divided into the test (53 samples) and the control set (13 samples).

It was established that the prediction ability is importantly influenced by different modelling techniques, while different division methods do not influence significantly on prediction capability.

Keywords: *Modelling, Sample selection, White pigment, Training set, Whiteness*

1. INTRODUCTION

Titanium dioxide is the most widely used white pigment or colouring agent. It is one of the few chemical compounds in the pigment area that can not be replaced for the present. The optical properties of titanium dioxide pigment are based principally on its high unselective scattering power. The key factors are the difference in refractive index ($n_{pigment}$ -n_{binder}), the particle size and chemical composition.

In the Quality Control Department lightness (L*), whiteness (W_{10}) and hue (b*) of titanium dioxide pigment are daily spectrofotometricaly determined. In order to improve the quality control of pigments, several models for pigment's properties as lightness (L*), whiteness (W_{10}) and hue (b*) were built.

It is well known that for building of any model in general, and for models that are aimed for applications in the routine quality control processes in particular, the selection of the samples upon which the training or building the model is performed, is the crucial step. In order to apply most of the standard chemometric modelling methods the data set should be split into the training (learning) and the test set. Although several

studies and experiences about the training and test sets selections and their influence on the model's prediction ability already exists [*1,2,3*], a preliminary investigation of this problem on a case by case basis is always recommended. Our study aims to point out to some aspects of the data set selection and the choice of the modelling technique when applied for the prediction of the characteristic properties for the white pigment.

It is hard to decide which modelling method to chose for a given data. Each modelling technique has it own advantages and disadvantages. Linear models require evenly distributed samples over the entire measurement space, while the non-linear ones are more sensitive on local curvature of the response surface, meaning that a particular and/or problem specific distribution of samples might lead to better models. Therefore, four different modelling methods, namely, the multiple linear regression [*4*], radial basic functions [*5,7*], error-backpropagation learning strategy in feed-forward artificial neural networks [*3,8,9*] and counterpropagation neural network learning [*11*] were used. As the division of the data set into the training and test sub-sets, the following four selections of the samples were employed:

1. random selection,
2. selection based on a self-organised Kohonen top-map,
3. selection made on the Kennard-Stone maximal intra-distance criterion, and
4. each second sample taken from a time-of-production-ordered series.

2. METHODS

2.1 Selection of the training set

Each procedure for the selection of the training set was applied on the same set of 132 samples. 66 samples have been selected for the training and the rest for testing each time.

The first method we have applied was the *random selection (RS)*. It should be kept in mind that the random selection does not guarantee the representativity of the training set, except for an adequate number and distribution of objects in the data set. The advantage of it is its simplicity and the property that a group of data randomly taken from a larger set retains the population distribution of the entire set. However, if for some reason the original population distribution is not adequate for the sought model, the random selection should be avoided.

Kohonen self-organisation maps (KOH) [*2,10*] are obtained by a projection of multi-dimensional objects (17-dimensional samples) into a 2-dimensional plane (top-map). In the 2-d map the points (the mapped objects) as are not evenly distributed. The obtained 2-d map is divided into several areas of equal size representing different areas in the measurement space. According to objects' features each segment has different population. In order to ensure a balanced training set from each segment an equal number of samples is picked out for training. For the projection of all 132 samples the Kohonen network consisting of 9 x 9 neurons has been used. Due to the non-uniform distribution of the 132 samples in the measurement space 11 neurons out of 81 were not excited by any object. On the other side, 36 neurons were excited by more than one, two of them by as much as six samples. In order to assure a more balanced selection of the training set the 81 cells of the top-map were grouped into nine rectangular square areas each consisting of 9 (= 3 x 3) cells. From each of the nine areas it was possible to select seven samples, i.e. 63 (= 7 x 9) samples altogether. Each of the selected samples was exciting a *different* neuron, thus assuring the largest possible uniformness of the sample selection within each 3 x 3 area. Because 66 samples were needed for a complete training set, the remaining three samples were drawn one from each of the three most populated 3 x 3 areas.

Kennard - Stone selection (K-S) is based on an algorithm [*1,11*] which first finds the two most distant objects in the entire set of objects and forms a group / at the beginning it is a group of two objects). Next it looks among the rest of objects and adds to the group the one that has the largest minimal distance to objects in the group.

The last selection was called *time-dependent (Odd/Even or O/E)*. The samples were taken from the production line on the daily basis through several months In the period of the investigation altogether 132 samples were controlled. Therefore, for the *time-dependent selection* each second one was assigned to the training set of 66 samples.

The final test set was chosen very simple. Because all four test sets obtained by different division methods are different we have pulled out of them all 13 objects that were common in all of them. In this way we did not interfere with the initial division methods for the selection of the training set and have at the same time obtained an independent small final test set of data that can is the same for all test. The prediction results obtained from different models can thus be confidentially compared and evaluated by such a set.

2.2 Modelling methods

As the modelling techniques standard multiple linear regression (MLR), radial basis functions (RBF) model, and two artificial neural networks (ANNs) learning strategies: error-backpropagation (EBP ANN) and counter-propagation (CP ANN) were used.

Multiple linear regression (MLR) is the most widely used modelling method. First the relevant variables x_1, x_2, ...x_m are selected and the appropriate polynomial consisting of either only linear or higher power of variables or combinations of them is established. For this study we have decided to compare the true linear model (linear in all 17 factors) with 18 coefficients. Once the form of the polynomial is determined (i.e. the form of each factor is defined) the evaluation of coefficients, including the free one, is a task that can be carried out by most of the standard statistical software packages. Using this particular method [*4,7*] 18 models were built for the prediction of three properties of titanium white pigment for four different divisions of samples into the training and test set.

Counter propagation neural network (CP ANN) is in a way a hybrid modelling method with both *supervised* and *unsupervised* features. The CP ANN consists of two layers: a Kohonen and output layer. The detailed information about the CP-ANN training procedure can be found in the literature [*2,10*]. In order to find the optimal CP ANN training parameters, several models were built applying different architectures of CP ANN and different number of epochs. Altogether about 240 different CP ANN models were build.

Radial basis functions (RBF) as a modelling technique combines the non-linear features of neural network transfer function and linear feature of MLR for the calculation of coefficients at each transfer function. RBF training or generation of the model is not an iterative procedure like other ANNs, but a straightforward two-step procedure.It could be said that the RBF method in essence is a sort of a MLR procedure with highly non-linear factors (all factors are in fact RBFs in equivalent form). For the detailed information on the RBF modelling see [*5*]. For this purpose 312 RBF models were built [*6,7*].

Error back propagation (EBP ANN) is the most widely known and most commonly used ANN method (*2,8,9*). It is iterative supervised learning with a feedback

correction method based on the steepest descent approach. The correction is different for the output layer weights and for hidden layer weights. The detailed mathematical procedure can be found in any textbook on ANNs. 288 models were built using the EBP ANN method in a homemade program according to [2].

3. EXPERIMENTAL DATA

For the present investigation of the influence of training sets variations on different models' prediction ability 132 samples were employed. Each sample is characterised by 20 variables. Among them seventeen variables are representing input data: *chemical composition*, *particle size distributions*, and *pH value* while the remaining three are response variables whiteness (W_{10}), lightness (L^*) and hue (b^*) [*12,13*]. The response three variables called in the training or model building procedure the targets, describe the pigments' colorimetric properties.

4. RESULTS AND DISCUSSION

Altogether more than 600 different models were built. In the final selection for each of the three different properties we have 16 models. This means that for each property four different modelling techniques (MLR, EBP, RBF, and CP) were employed while for each of this four techniques four models were made using four different selections of the training and test sets (time sequence, random, Kohonen, and Kennard-Stone). Out of the entire pool, 48 models showing the best prediction ability in each category were picked out and tested once again with the *final test* set containing 13 samples. In Table 1 the correlation coefficients (*r*) [*14*] between the experimental data on each of the three properties and the predictions yielded by the corresponding models obtained by one of the training set divisions are represented.

Table 1: Statistical evaluation of linear and non-linear models using various sample selections. The model having the largest correlation coefficient for each property is shown in bold.

Predicted property	Division of the training set	Correlation coefficient *r*			
		MLR	RBF	EBP	CP
W_{10}	time	0.62	0.85	0.89	0.78
	random	0.70	0.90_5	0.86	0.77
	Kohonen	0.82	0.91	0.93	0.87
	K –S	0.79	0.88	**0.94**	0.67
L^*	time	0.48	0.74	0.76	0.76
	random	0.58	0.76	0.73	0.62
	Kohonen	0.70	0.77	0.79	0.65
	K –S	0.61	0.75_8	**0.80**	0.71
b^*	time	0.55	0.79	**0.89**	0.70
	random	0.57	0.56	0.84	0.42
	Kohonen	0.79	0.85	0.87	0.77
	K –S	0.74	0.75	0.86_8	0.29

Although the models were obtained by a very different methodologies and on different sets of data it has to be stressed again that each and every model of the selected 48 best ones made was tested with the same set of 13 compounds. The use of the third, completely independent set of data, which was never used in any estimation of the prediction ability or correction of models *before* this final evaluation of correlation coefficients, has enabled us to make a sound inter-category comparison.

The results in Table 1. show that the error back-propagation is clearly the best suited method for modelling W_{10}, L^*, and b^* regardless which division method was applied for the selection of the training and the test set.

5. CONCLUSION

The general conclusion in our study was that the best predictions were achieved in most cases with error backpropagation neural networks and with Kennard-Stone division method. Of course, it is recommended that for each specific case the entire procedure is made.

The detailed study of various sample selections and modelling techniques shows that careful examination and testing of various ways to generate the models is important for find the best model for a property which does not correlate strongly with to the measured variables. The worse the correlation with the measured variables more care has to be paid in inspecting various aspects and possibilities of model generation. For such a study it is of paramount importance to keep aside a third independent final test set using which the models can be validated. In our study it happens several times that we found models yielding very good responses on the test sets, however, when tested with the final tests set they perform much worse.

The second experience we have learned from our study is the fact that sometimes valuable information can be extracted when comparing the models of different qualities obtained by different means. With other words, even the models with less favourable performance can yield valuable information when inspected in the context of a series of trials.

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M.Sc. Karmen Rajer Kanduč, Cinkarna Celje, d.d., Kidričeva 26, SI-3000 Celje, Slovenia. Phone: +386 3 427 6 185, E-mail: karmen.kanduc@cinkarna.si
Prof. Dr. Jure Zupan, National Institute of Chemistry, Hajdrihova 19, 1000 Ljubljana, Slovenia.
Prof. Dr. Nineta Majcen, Metrology Institute of the Republic of Slovenia (MIRS), Ministry of Education , Science and Sport, Tkalska 15, 3000 Celje, Slovenia.

ANALOG AND DIGITAL ISO/IEC-COLOUR CHARTS FOR DIFFERENT COLOUR REPRODUCTION TESTS AND FOR THE EFFICIENT USE OF COLOUR IN DESIGN

Klaus Richter

Federal Institute of Materials Research and Testing (BAM), Berlin, Germany

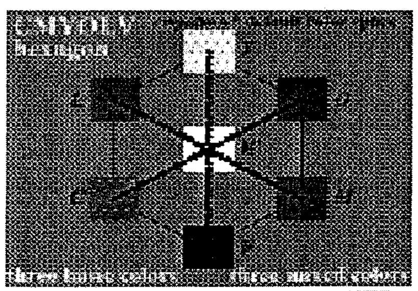
Abstract

The device output of ISO/IEC-test chart files which include colours defined in the CIELAB colour space and the corresponding device dependent colour spaces shows a lot of problems. The correponding colours produce very different output or no output difference on monitors and printers. Sometimes for the present standard software the monitor output is very different and there are no output differences on printers or vice versa. If a PostScript MTL code (Measurement, Transfer and Linearization) is added to the code of an ISO/IEC-test chart (the NP file) then the output of the new FP file produces the same output as expected by users and CIE colorimetry if CIELAB colours and related device dependent colours are used for input. For this intended output property the definition of the Colour Workflow (CW) and the Output Linearization (OL) is included in all ISO/IEC-test charts of the FP form.

Remark: The output of this paper produces large color differences (often 20 CIELAB) for the NP files on most printers and monitors. The large colour differences for corresponding colours of different colour spaces are not intended by users and CIE colorimetry. The output of the FP files produces no colour differences as intended.

1. VARIETY OF COLOUR SPACES WITH CORRESPONDING INPUT PS OPERATORS

There is a variety of colour spaces which can be used for input and output. Any user has to spend a lot of time to learn about the different spaces and to train the relationship of the different spaces which depends on application.



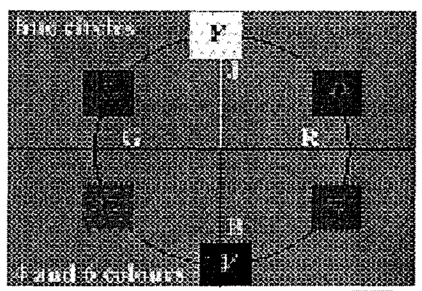


Figure 1: Six reproduction colours CMYOLV and four unique hue colours RJGB according to ISO/IEC 15775 defined in CIELAB colour space

Fig. 1 shows the six chromatic colours CMYOLV and Black N (=noir) and White W of standard offset printing (left). The four unique hue colours RJGB are different from the six reproduction colours. Standard non fluorescent offset paper was used to produce the analog ISO/IEC-test charts which are equally spaced in CIELAB coordinates. There are productions of DIN and JBMA (Japan Business Machines Association) in reflective and transparent mode. The German DIN production has been measured with the 45/0 measuring geometry for standard illuminant D65 and the CIE 1931 standard observer at BAM *(Laboratory S.13)* . The mean colour difference of CMYOLV compared to the standard data is 2.5 CIELAB, see the standard DIN 33866-X [1] and the International Standard ISO/IEC 15775 [2].

Remarks: According to the International Standard ISO/IEC 15775 the letters *j* (=jeanne=yellow), *r* (red), *g* (green), and *b* (blue) are reserved for the unique hues and the letters *olv** (orange red, leaf green, violet blue) are used with a star to indicate the linear relationship to CIELAB. The *olv** coordinates are used for the reflective colours and are used in a similar way as the coordinates *rgb* of the luminous television colours. The *cmy** coordinates are alternate coordinates compared to *olv** (see Fig. 1 and Table 1 and 2).

All the 16 step colour series between white and the six chromatic colours CMYOLV (see Fig. 1) and black are equally spaced in the CIELAB colour space. Laser printers produce the six chromatic colours by between 3 and 6 (e. g. a printer of the company Océ) colorants. The result is very similar compared to the six colours CMYOLV of the present analog ISO/IEC-test charts which has been produced by standard offset printing.

The halftone screening of laser printers (or of offset printing) produce colours which are approximately on a line e. g. between White W and Cyan C in the CIELAB space. This is one basic assumption of the model colour space. In practice the 16 colours between White and Cyan may slightly deviate by less then 3 CIELAB from the line in CIELAB space. This is much less compared to the spacing differences along the line W - C of 20 CIELAB which printers often produce. For the office applications it was therefore the basic task to reduce the spacing differences along the 16 step series C - W below 3 CIELAB. Then all Landolt-rings in the ISO/IEC-test chart output are recognized. A naive user requires that along the line W - C only the cyan coordinate of *cmy** changes between 0 and 1 in 15 digital steps of 1/15. The other coordinates are cero. In the alternate coordinate system *olv** the Orange red coordinate is cero and the other two change by equal amounts from cero to 1 in steps of 1/15 (see Table 2).

There were two task to solve: Linearization (equal CIELAB spacing) of the seven series W to CMYOLVN and calculation methods of the coordinates *cmy** and *olv** from the CIELAB data of the standard (and the analog samples) and vice versa. Both tasks have been solved by a PostScript MTL code (MTL=Measurement, Transfer and Linearization). If a device is linearized along the lines in CIELAB space then there are linear relationships between the coordinates *cmy**, *olv**, and *LAB** of the CIELAB colour space. The linear relations (and as a result a linear additive metric in CIELAB space in each of the six sectors of Fig. 1) are used in the PS MTL code. Either the *olv**, *cmy**, or *LAB** data can be used in an ISO/IEC-test chart file to get the same output on a printer or monitor. There is a lot of additional material on the web site (http://www.ps.bam.de)

Table 1: Colour data of the 5 step colour series N - W for six input PS operators in six colour spaces

Colour series Black - White (N - W) of ISO/IEC-test chart 3 (5 steps)						
Six colour spaces and coordinates	CMYN (CMYK) (000n*)	GREY (w*)	CMYN (CMYK) (cmy0*)	OLV (RGB) (olv*)	CIELAB relative (lab*)	CIELAB absolute (LAB*)
six input PS operators	000n* setcmykcolor	w* setgray	cmy0* setcmykcolor	olv* setrgbcolor	lab* setcolor	LAB* setcolor see ISO/IEC 15775, Table H6
data for black N	0.00 0.00 0.00 1.00	0.00	1.00 1.00 1.00 0.00	0.00 0.00 0.00	0.00 0.00 0.00	18.01 +0.50 -2.48
data for dark grey D	0.00 0.00 0.00 0.75	0.25	0.75 0.75 0.75 0.00	0.25 0.25 0.25	0.25 0.00 0.00	37.36 +0.13 -0.84
data for mean grey Z	0.00 0.00 0.00 0.50	0.50	0.50 0.50 0.50 0.00	0.50 0.50 0.50	0.50 0.00 0.00	56.71 -0.24 -2.15
data for light grey H	0.00 0.00 0.00 0.25	0.75	0.25 0.25 0.25 0.00	0.75 0.75 0.75	0.75 0.00 0.00	76.06 -0.61 -3.46
data for white W	0.00 0.00 0.00 0.00	1.00	0.00 0.00 0.00 0.00	1.00 1.00 1.00	1.00 0.00 0.00	95.41 -0.98 -4.76

Table 1 include six input *PostScript* (PS) operators which define the same achromatic colours black, three greys and white. Between one and four input data are necessary for the complete definition of the achromatic colours depending on the colour space.

Table 2: Colour data of 5 step colour series C - W for three input PS operators in three colour spaces

Colour series Cyan blue - White (C - W) of ISO/IEC-test chart 2 (5 steps)			
Three colour spaces and coordinates	CMYN (CMYK) (cmy0*)	OLV (RGB) (olv*)	CIELAB absolute (LAB*)
Three input PS operators	cmy0* setcmykcolor	olv* setrgbcolor	LAB* setcolor see ISO/IEC 15775, Table H2
1.00 C + 0.00 W (Cyan blue C)	1.00 0.00 0.00 0.00	0.00 1.00 1.00	58.62 -30.62 -42.74
0.75 C + 0.25 W	0.75 0.00 0.00 0.00	0.25 1.00 1.00	67.82 -23.21 -30.16
0.50 C + 0.50 W	0.50 0.00 0.00 0.00	0.50 1.00 1.00	77.02 -15.80 -18.58
0.25 C + 0.75 W	0.25 0.00 0.00 0.00	0.75 1.00 1.00	86.21 -08.39 -07.01
0.00 C + 1.00 W (White W)	0.00 0.00 0.00 0.00	1.00 1.00 1.00	95.41 -00.98 +04.26

Table 2 includes three input *PostScript* (PS) operators which define the same chromatic colour series between Cyan blue and White. There are ISO/IEC-test chart files which use the different PS operators of Table 1 and 2.

2. FIGURES OF ISO/IEC - TEST CHART FILES (NP AND FP FORM) IN DIFFERENT COLOUR SPACES

Main and important software products on *Windows* and *Mac* fail to produce the same colours as required by any user and CIE colorimetry for many of the following files. The first four different PS operators of Table 1 are used to reproduce a 16 step grey scale by the NP file.

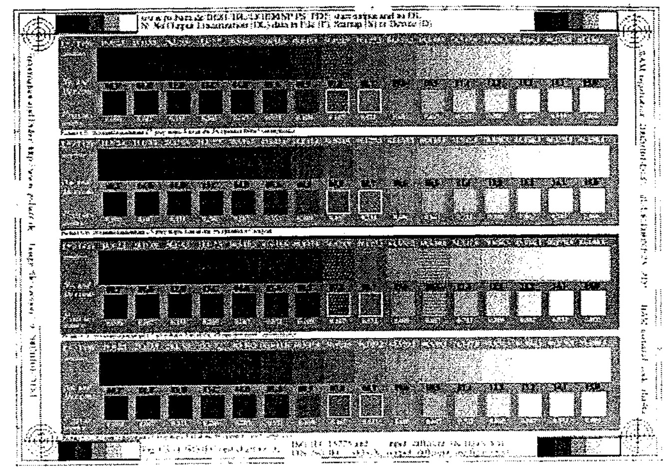


Figure 2: Fig. C3 of ISO/IEC-test chart 3; the corresponding colours are defined by four input PS operators without any transfer; original NP file see web (click to go always on the left (blue) part of the web address) (http://www.ps.bam.de/DE81 /10L/L81E00 NP .PDF)

Fig. 2 is called the start output which is produced always by an NP file. The monitor output shows at least 2 different grey scales by the software *Adobe Reader* but *Mac Preview* shows no difference for the four scales. The output on a few printers shows no difference but most printers show up to four different scales. Any user requires the same output which must be independent of the input PS operator used. The required identical output of the four identical grey scales is produced by the FP file which differs from the NP file by the additional PostScript MTL code .

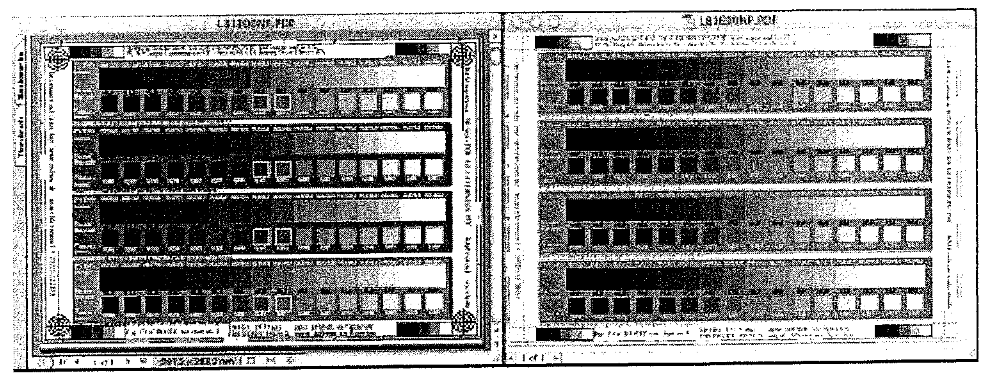


Figure 3: Fig. C3 of ISO/IEC-test chart 3; the corresponding colours are defined by four input PS operators without any transfer; see for the original screen photo: (http://www.ps.bam.de/DE81 /10L/L81RP0 NP.tiff)

Fig. 3 shows a screen photo on the computer operating system *Mac OS X 10* which shows the same NP file (shown already in Fig. 2) by both the software *Adobe Reader (left)* and by the software *Mac Preview (right)* . Is is obvious that *Mac Preview* agrees with the user requirement and CIE colorimetry.

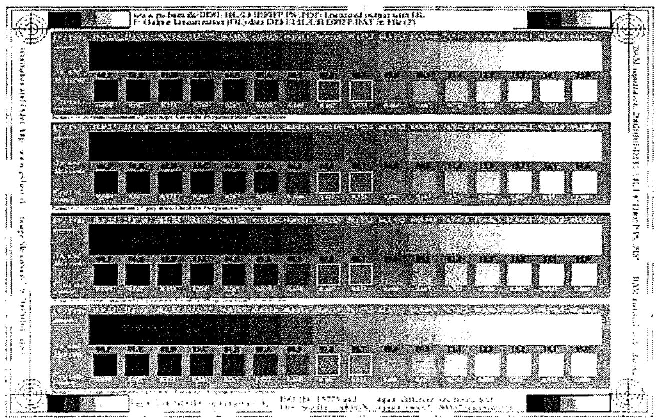


Figure 4: Fig. C3 of ISO/IEC-test chart 3; Transfer from four input to one output PS operator, see for the original FP file (*http://www.ps.bam.de/DE81* /10L/L81E00 FP.PDF)

Fig. 4 shows the PF file output. The four input PS operators are transferred to one output PS operator. For a mean grey instead of the CIELAB lightness L^* =57 often the lightness L^* =37 or 77 is reproduced (see Table 1, last column, colour difference 20 CIELAB). But the tolerance range is only 57+/-3 for office devices according to ISO/IEC 15775.

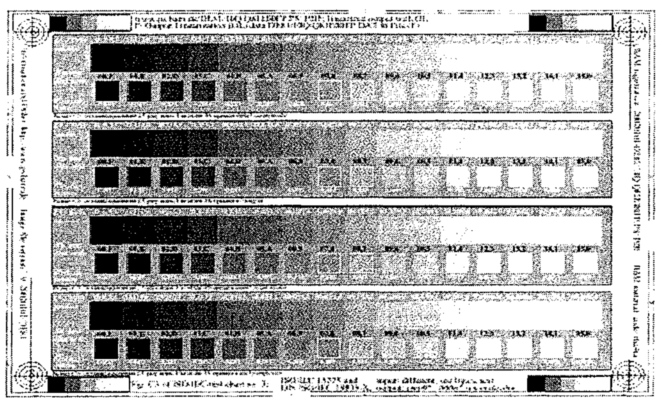


Figure 5: Fig. C3 of ISO/IEC-test chart 3; Transfer to *lighter* colours compared to the standard colours (Fig.2) from four input to one output PS operator, see for the original FP file *http://www.ps.bam.de/DE81* /10Q/Q81E00 FP .PDF

Fig. 5 shows a lighter FP file output which may look on some devices more equally spaced. The required 16 step standard output which is equally spaced in CIELAB is produced if a user measures the *LAB** data of the NP file output and if he replaces the L=Linear default output *LAB** data by the *LAB** measurement data in the MTL code of the FP file. The PostScript or PDF interpreter prints the corrected FP file and uses the *LAB** data to produce the required 16 step output which is equally spaced in CIELAB for any device.

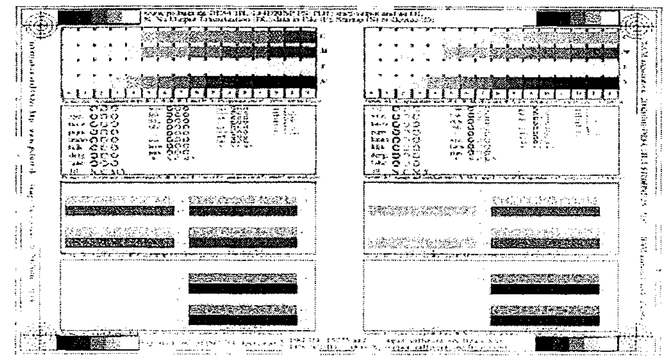


Figure 6: Fig. B4 to B7 of ISO/IEC-test chart 2; corresponding colours are defined by two input PS operators without transfer; there are output differences; see for the original NP file (*http://www.ps.bam.de/DE84* /10L/L84E00 NP.PDF)

Fig. 7 shows again (compare Fig. 2) for two different input PS operators (see left and right in the figure) a different output by the software *Adobe Reader* and equal output by the software *Mac Preview* as required by naive users.

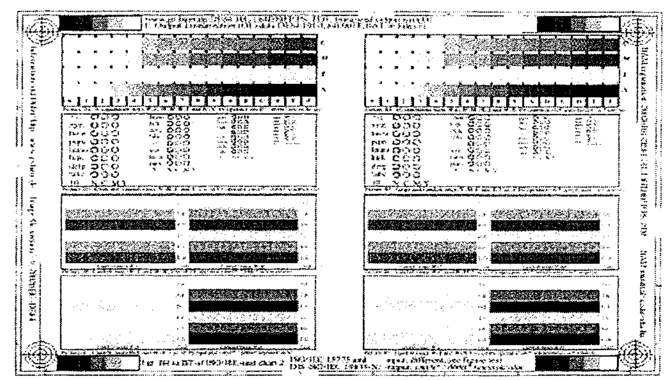


Figure 7: Fig. B4 to B7 of ISO/IEC-test chart 2; corresponding colours are defined by two input PS operators which are transferred to one output PS operator *cmy0* / 000n* setcmykcolor* ; see for the original FP file (*http://www.ps.bam.de/DE84* /10L/L84E00 FP .PDF)

Fig. 7 shows again an FP file output (compare Fig. 3). The two input PS operators are transferred to one output PS operator. The MTL code in the FP file again produces the same output (compare Fig. 3) for the different input PS operators used on one page for any software used *(Adobe Reader or Mac Preview).*

All the different input PS operators of Table 1 and 2 are used in the improved ISO/IEC-test charts (NP files) no. 2 to 4 and allow to test the colour reproduction of the different devices and the different software. The ISO/IEC-test charts (FP files) which include the PS MTL code (Measurement, Transfer and Linearization) produce the same output for any of the six input operators of Table 1 used. If with ISO/IEC-test charts the Output Linearization (OL) is applied then the output is within the CIELAB tolerance range of 3 CIELAB which is intended for colour office devices according to ISO/IEC 15775. The Colour Workflow (CW) which is the transfer from the input to the output PS operators and the Output Linearization (OL) is done by the PS MTL code (Measurement, Transfer and Linearization) which is included in the ISO/IEC-test charts (FP files).

Remark: The PS MTL code determines the output in the same direction if stored at one of the following places

1. the file (Remark: If the MTL code is added to the ISO/IEC-test chart 4 (NP-file) then this file is called the FP file)
2. the PostScript Printer Memory
3. the PPD file (PostScript Printer Description)
4. Adobe Distiller Startup Directory
5. Display PostScript Memory

Remark: For screen photos and the application of no. 4 there are examples at http://www.ps.bam.de/DE81 /DE81D.HTM

3. ISO/IEC -TEST CHART FILES (NP AND FP FORM) IN DIFFERENT COLOUR SPACES

The more important and complete NP and FP files of the ISO/IEC-test charts are shown in the following.

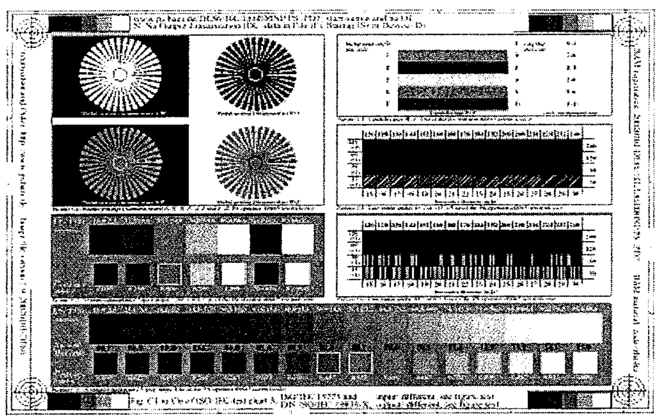


Figure 8: Fig. C1 to C6 of the ISO/IEC-test chart 3; colours are defined by the input PS operator *000n* setcmykcolor* without any transfer; see for the original NP file (http://www.ps.bam.de/DE86 /10L/L86E00 NP .PDF)

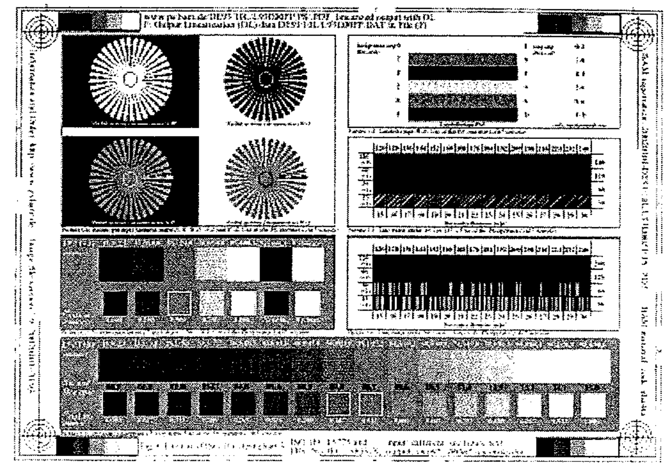


Figure 9: Fig. C1 to C6 of ISO/IEC-test chart 3; colours are defined by the input PS operator *LAB* setcolor* and transferred to the output PS operator *000n* setcmykcolor* ; see for the original FP file (http://www.ps.bam.de/DE93 /10L/L93E00 FP .PDF)

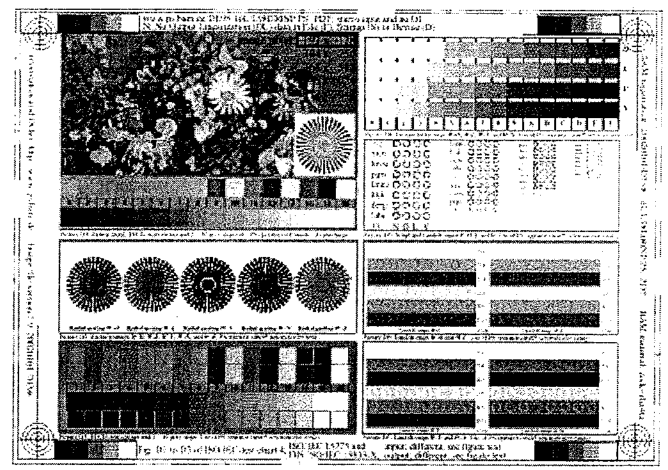


Figure 10: Fig. D1 to D7 of ISO/IEC-test chart 4; colours are defined by one input PS operator *cmy0* setcmykcolor (only)* without any transfer; see for the original NP file (http://www.ps.bam.de/DE98 /10L/L98E00 NP .PDF)

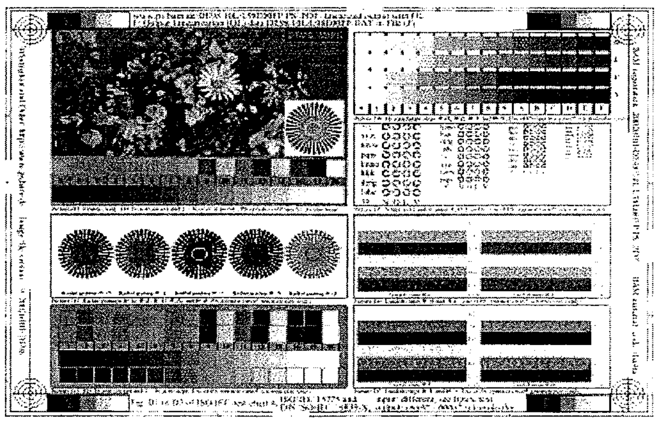


Figure 11: Fig. D1 to D7 of the ISO/IEC-test chart 4; colours are defined by the input PS operator *cmy0* setcmykcolor (only)* which is transferred to the one output PS operator *cmy0* / 000n* setcmykcolor* ; see for the original FP file (*http://www.ps.bam.de/DE98* /10L/L98E00 FP .PDF)

For instance the output of the grey changes by the software *Adobe Reader* from brownish to neutral on the monitor.
The ISO/IEC-test charts no. 3 (GREY) and no. 4 (OLV colours) in the NP form are proposed for the tests according to DIS ISO/IEC 19839-X. The ISO/IEC-test chart file 3 in the FP form allow to linearize the output on different printers. Then the letter A, O, T is used instead of L on the web site for three different printers. The *LAB** data of the start output are included in these FP file and the FP files are only useful if the corresponding printer or device is present.

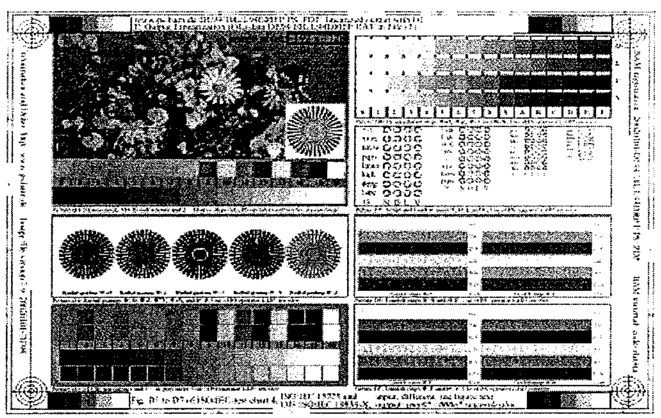


Figure 12: Fig. D1 to D7 of the ISO/IEC-test chart 4; colours are defined by the PS operator *LAB* setcolor* which is transferred to the one output PS operator *cmy0* / 000n* setcmykcolor;* see for the original FP file (*http://www.ps.bam.de/DE94* /10L/L94E00 FP .PDF)

4. NP FILES FOR THE START OUTPUT AND THE MEASUREMENT OF THE *LAB** DATA

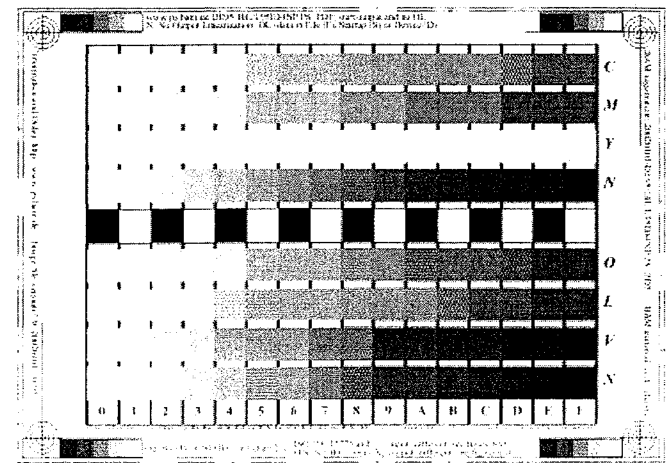


Figure 13: Fig. B4 and D4 of the ISO/IEC-test chart 2 and 4; colours are defined by the input PS operator *cmy0* / 000n* (B4) and cmy0* (only) setcmykcolor (D4)* without any transfer; see for the original NP file (*http://www.ps.bam.de/DE95* /10L/L95E04 NP .PDF)

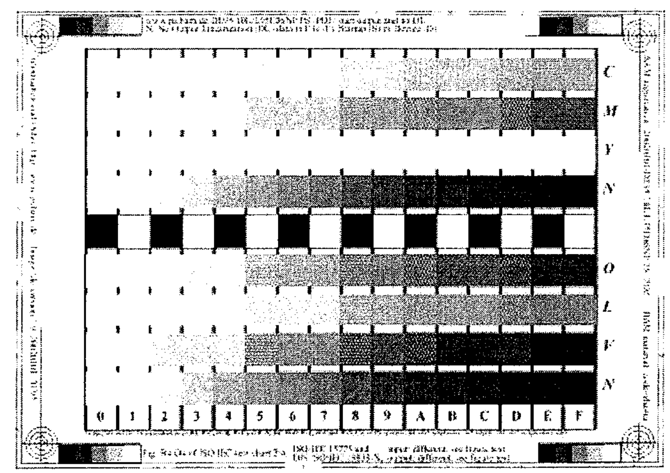


Figure 14: Fig. B4 and D4 of the ISO/IEC-test chart 2 and 4; colours are defined by the input PS operator *olv* setrgbcolor / w* setgray (B4)* and *olv* setrgbcolor (only, D4)* without any transfer; see for the original NP file (*http://www.ps.bam.de/DE95* /10L/L95E06 NP .PDF)

For CIELAB measurement the colour patches of ISO/IEC-test charts (7 mm square) are often too small. The following files produce larger patches (14 mm square) which can be used to measure the *LAB** of the start output. It is required to include the *LAB** data at the appropriate place in the FP files within the MTL code.

If for output the PS operator *cmy0* / 000n* setcmykcolor* is preferred, then it is required to measure the 128 colours of the following file.

Remark: Software which is in agreement with CIE colorimetry produce the same output on printers and monitors for the NP files of Fig. 13 and 14 and then there is no need to measure the output twice.

5. CONCLUSION

The standard digital ISO/IEC-test charts (NP files) are useful to test the colour output on the different devices. If different results of the different software products on the different devices appear on output then the user can make the appropriate decision according to his technical requirements.

If DIS ISO/IEC 19839-X is accepted as International Standard then new optional device drivers according to ISO/IEC 18839-X are expected. If the MTL method is used then the present large output differences usually reduce by a factor 3 to 5. If the coordinates in the corresponding colour spaces are used, then equal output on devices is expected. The example solutions with the FP files of the ISO/IEC-test charts help users and manufacturers and will appear in an ISO/IEC technical report (already approved in ISO/IEC JTC1/SC28) with K.Richter as Editor.

Remark: The method with the MTL code is not intended to replace colour management methods of professional graphics but it may be used to improve the output, e. g. to adapt the results to output paper and other variations.

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- DIN 33866-3, Edition:2000-07; Part 3: Method for 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
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Prof. Dr. Klaus Richter, Federal Institute of Materials Research and Testing (BAM), Head of Project Group: Visual Methods and Image Reproduction for NDT, Unter den Eichen 87, D-12200 Berlin, Germany. Phone: +49 30 8104 1834/1839, Fax: +49 30 8104 1809, E-mail: klaus.richter@bam.de, internet: http://www.ps.bam.de or http://www.ps.bam.de/AICMAR.PDF

ENVIRONMENTAL COLOR DESIGN 'PERCEPTIVE TEXTURES IN THE ENVIRONMENT'

Silvia Rizzo,
Liceo Artistico Barabino, Genoa, Italy

Abstract
The proposed experiment intends to follow up the work presented at the AIC 2001 Conference in Rochester "Work on Color Design Installed in an Urban Environment". Those who were present, will remember the large canvasses matching the surrounding environment of the city of Genoa through a bi-dimensional expression of color. With their soft surfaces, they would link up with architectural volumes. What was then painted surface, now becomes more complex: it is now texture, or rather a search for diversified texture obtained through the interlacing of colored fabric strips to form some sort of macroscopic cloth. While the previous work would offer a primary perception of colors in the environment, some sort of visual signs, with this work a more complex reaction is sought, brought about by the intertwining of colors crossing each other through never-ending interferences, still with a constant reference to the surrounding environment: perhaps, signals again.
2) When thinking about a project for children, long strips of cloth could be designed with colored portions based on space measurements, to be spread over streets and squares.

Keywords: *Genoa, texture, strips, environment, colors.*

1. INTRODUCTION

This research work aims to explore new environmental perception experiences through color installations. It follows up the project presented in Rochester "Works on Color Design Installed in an Urban Environment" which featured large canvasses on the city of Genoa to express the relation between the bi-dimensional nature of color and the three-dimensional character of the various types of urban spaces.
Now, also prompted by the topic of this congress, the canvas surface is no longer a painted substratum but it is replaced by a mesh proper of intertwined colors, sort of perception points which refer to the environmental colors, in which vision dynamics becomes richer and more complex.

2. METHODOLOGY AND CONTENTS

The project features large regular surfaces - with either a square or rectangular shape - formed by cloth stripes of different colors referred to the environment which becomes the background of our work.
Therefore, the "symbolic mesh" is not an end in itself.
Different geographic points in the city are selected, having diversified history, life, and work situations; they become sites for analysis and suggest the very colors of the various works, a sort of chromatic scale; they act as points of visual concentration which, at the same time, expand into environmental colors.
The tones of colors are investigated, with the attitude of artists who paint and wish to detect chromatic shades and tones as suggested by their intuition. Each and

every chromatic point is intertwined like in a textile weft and, together with the other spots, it leads to different traces, to structural variations, like in a pictorial paradigm.
These color wefts can be viewed only within their reference area: old frescos (historic paint and time) or the city landscape are composed together playing as object and subject at the same time, as a spatial perception of color, and overcoming the real limits of a project that cannot be visually codified owing to its very unique role visavis reference points.
The weft itself becomes dynamic research of rhythms and itineraries; it is a unique expression as if it were a pictorial work of art.

3. CONCLUSIONS

It is not by chance that this project refers to Genoa. As I have already pointed out several times, the city of Genoa throughout its history has had a major encounter with colors in which the tradition of fully frescoed facades of old palaces has developed, whereby colors were living in their own city spaces.
My research brings colors back to the urban space, within the context and diversification of our contemporary world.
The objective is also for ECD -by means of spatial and environmental synergies - to take up the role of an overall aesthetic vision, thus joining the environment to the color project. It represents an artistic composition without physical limitations, which goes beyond the concept of open work of art, irrespective of the surrounding environment, be it a historic, suburban , industrial, or contemporary landscape. The direct encounter with citizens aims to harmonize people with their environment, thus suggesting again the democratic role of work in art and in design.

PROJECT FOR CHILDREN COLOR MEASUREMENTS

The project presented entitled "Color Meshes" intends to target children as well, developing a spatial project of educational and at the same time pedagogic Environmental Color Design: the awareness of the environment spatial extension. In this case, stripes are arranged flat or at a suitable height for children; they are divided into chromatic scans which correspond to metric measurements. The purpose is to have children feel the extension and dimension of the environment through color scans. It is a game to walk through and a maze to invent, all together.

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Prof. 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

SECOND SKINS AND NEW MATERIALS: THE "CHROMO-TACTILE" RANGE

Stéphanie Sagot
IUP Arts Appliqués, University Toulouse / Le Mirail, France

Abstract
We are nowadays witnessing a reasonned approach of design in witch the object, its nature, its function and its relationship with the user are submitted to multiple questioning, that goes for beyong mere technological rationalism. The object would therefore develop another value of use, other than its function, which would convey all the sphere of the relationships it has whith the world and then whith other territories it is crossed by. This territories call the intimaey of the object, currently favored by a work on texture.
In such a context, the development of matters named « second skins » which we can find again in all fields of design (architecture, packaging, fashion and so on) encourages new logics of differenciation, variation, suggesting an opportunity : before, chromatic ranges related to an object were suggested ; today, the game is opened on several composents, one of which is the couple color / texture that allows multiple choice equations, « chromatactile colour charts ».

Keywords : *texture, color styling, color design, matters design, differenciation*

INTRODUCTION

Industrial aesthetics evolved significantly in the 1980's. Designers put themselves on the fringe of industry, and a sensible approach to design took place. The object, its nature, function and relationship to the user are submitted to multiple questioning that goes far beyond mere technological rationalism.
The object would thus develop a use other than that of its simple function. It would give an account of the whole sphere of relationships it is maintaining with the world, and then, with the other territories it is related to. These territories call the intimacy of the object which is shaping thanks to the relationship its user establishes with it.
These last years, we are witnessing a new approach to surfaces favoring proximity with the object, more particularly exemplified by the "second skins" textures. It is already in line with the process, and it opens up the form/function game to more individualistic approaches to it. Its seizure is specific to what constitutes it, and to what the user makes of it in their relationship, taking into account the appeal of the plastic properties of the object.
Thus, it only gains its identity in its unique and single relationship to its user. The handling and contact actualize what is at stake in it. The question is no longer how to use the object, but how to understand it as a subject of knowledge in the networks.
Therefore the development of these materials in all fields of design favors a new approach of textures, linking color and tactile sensation, sight and touch. Such a step favors new logics of differentiation and variation, proposing an opportunity: chromatic ranges were formerly proposed in relationship with an object; now, the play is opened to several components, one of

which is color/texture, which allows multiple-choice equations, "chromo-tactile ranges".
In that context, during the process of creation and the choice of materials, how to handle data which seem variable ad infinitum? How to plan and conceive that relationship to surface, which would start from plurality and go to singularity? How can that process be combined with industrial production?

I. STANDARD RUPTURE

Industrial design brings social progress in essence. Mass production of standardized articles aimed to mass markets is called for universal model. Standardization rules the design network – conception/achievement/ production - and impose a specific way to grab the object. It has models and systems we can identify: they are depending on each other and thus regulate the methodology of the project.
That productivity device has been in crisis since 1968 in France. The inevitability of a mass-production industrial system has been challenged. The production circuit isn't aimed at an egalitarian majority anymore. The right to different individual behaviors has been affirmed and functionalistic design suffers from a sudden rejection by the public. Profound mutations within society lead to new attitudes in the "creation, production, consumption" process. We need to understand the importance of cultural data in order to enhance the prestige of the world of mass-production, to make it more attractive. A return to craft industry can be seen in the United States and Great Britain. Furniture resembling the creations of Art Nouveau are set out to get the market. This rejection of functionalism reveals a change concerning behaviors regarding the object. The user wants to be different by getting closer to it, getting more intimate and emotional. Besides, Yves Deforge [1] analyzes this when he explains that contrarily to mass production, craft industry puts feelings and some kind of humanity in its creation.
That fracture, which takes into account a great number of circumstances, is combined with the designer's will. It ensures to signal breaking points in the production chain. Researches on diversification of produced items based on standardized elements are appearing. Let's remember for instance Marc Held's shelves which allowed an endless number of variations from an asymmetrical modular element. In the late 1970, in Milano, the Memphis group calls for return to ornamentation and useless elements. That trend goes ahead with architectural Post Modernisme which rejects the cult of sobriety advocated by the Moderne movement from the 1920's too.
More recently, Gaetano Pesce has shown how to evolve inside of the mould with his plastic furniture - the Samson and Dalila table and chair. Plastic is injected into closed moulds, creating unpredictable shapes. He then makes unique industrial objects. His models are never the same and they show the genesis of the article, the very moment material congeals. Man is at the center of his issue thanks to these varied series. That is to say that the uniqueness of his products is the mirror of the uniqueness of their owners, and of the diversity of particular differences. Such an approach plays a very large part in the connection between the user and his object, which he very easily appropriates since he sees it as unique, at least in its shape.

II. SINGULARITY AND INDUSTRY

Therefore production doesn't obey a logic of conception and programming anymore, but instead proposes new logics of differentiation and variation. That approach

[1] Yves Deforge, *Work and Product*, Seyssel, Editions Champ Vallon, 1990.

favors an opportunity: before, chromatic ranges were proposed in relation to an object; since the 1980's, designers have been using any of its components, offering multiple-choice equations. The logics of experimentation through variability gains acceptance in the production chain. New behaviors towards objects are then required. Paradoxically, the very question of the model arises again. New standards are perfected: they contribute to the development of new typologies, but don't content themselves with it. What is important is to always go beyond the idea of standard. Besides, according to Italian designer Andrea Branzi[2], great mass markets have a tendency to be replaced by polycentrical area markets, organized around social groups with very diversified languages, cultures and behaviors.
Christine Colin[3] explains that nowadays the world of design seems to be subject to this double contradictory movement:
- the first one can be observed at firms with a high level of industrialization. The process of standardization of production is now thwarted by two combined effects. On the one hand, the necessities for a thinner and thinner segmentation of markets by distribution. On the other hand, an information of production itself. Here, the very notion of standard product disappears in profit of an infinite multiplication of references.
- the second movement can be seen at firms with a strategy focused on design. They offer what is known as "shape fundamentals", centered around ranges.
It seems that this double movement hinders our presuppositions: while the industry was supposed to produce standardized, indistinct articles, design seeks the production of difference and breaking points. However, at the back of complete uniqueness, plurality resurfaces.
Systematization produces standard, just as much as the industrial mould. Beneath the question of archetype lies what links us, what we have in common, and not what makes us different.
What can these "shape fundamentals" , these common denominators be? They constitute today's standard - taking in charge new parameters and attitudes - and they will be the subject of a mass contribution, if not a mass production. What's their definition?

III. THE FANTASY OF A COMMON SKIN

One of these common denominators seems to aim at a quest for the sensitive which began in the 1980's with the Nouveau Design. The creation of objects refers to a wider project culture that integrates the symbolism of ideas. This is akin to the heart of the current problem of industrial production: "the necessity to find again, including within great consumption models, that "inspiration of objects" Wittgenstein was talking about embodied by the quest of a soul"[4], able to rekindle the former relationship between man and material universe. A more intelligent, more likeable product must be conceived, a real advantage of extra use, a greater respect based on the meaning of the product and an intellectual, economical or physical access should be looked for.
The status of the designer is evolving. He is at the same time a sociologist, an ethnologist, a psychologist, and a politician in the initial meaning of the word: "the one that cares about collective and individual good."

[2] Andréa Branzi, foreword to *Affective Objects: new table design*, by Brigitte FITOUSSI, Paris, Hazan, 1993, 7-10.
[3] Christine COLIN, « Archetype is a dream » in Type Objects and Archetypes, journal of French Furniture Trade, Paris, Hazan, 1997, 19-37.

[4] Andrea BRANZI, op.cit., 7.

According to Philippe Starck[5], the most interesting work nowadays is the semantic fine tuning of the archetype. Beginnings or endings of conversations which are "our common memory"[6] must be found.
He means a sentimental language. The issue of archetype allows objects which are more discreet for the eyes, and richer for our feeling. The archetype comes from the greatest collective memory, from the number, the multiplication. That makes it a standardized product also.
How then to create that sensitive interface between industrial production and a technology that will meet a shape fundamental allowing a privileged contact between user and object?

Advocated by Luigi Colani in the 1960's, bio-design[7] partially meets that demand, and will become obvious thirty years later. The body becomes a source of inspiration for creators, and allows the object to establish itself as a social link. The technical performance isn't enough to satisfy the consumer anymore, so domestic appliances with suggestive shapes attract our senses. Objects adopt physical lines and are easily recreational, so much that we love and sport them. As Philippe Starck declares, "they like people" and "serve the human"[8]. They sometimes become so human than they're given names, as Zoé, the washing machine created by the Italian Roberto Pezzeta for Zanussi. "Today (...) the connection with the object is stronger, they are no longer shown,they are lived" says Xavier Dixsant, design director at Vuitton[9]. The object thus integrates his owner's circle of acquaintances, following the example of a close relative or friend.
These last years, we notice a craze for materials named "second skins". This is fixed in the same quest for a connection between user and item. They can be found in all the fields of design (packaging, object design, space design...). Their intensification and expansion seems to favor a new approach to surfaces, which itself creates a new proximity with the object: "proximity in the strict sense, touch for instance, but also in a broad sense, as a favorable connection for the elaboration of sensory messages."[10] In the same direction, we are witnessing today a renewal of the work on material. Indeed, the Matières Proches[11] workshop has been specializing its activity in the "design of material" from the 1990's. Creations are gathered under the generic term of "rodalège" (from the Greek word "rodalegein" which meant "saying sweet things"). Whether it be new or transformed materials, what matters most is the pleasure to discover new sensations through the voluptuousness of touching.
The skin model thus seems to be defining a link with the world which favors emotion, affect. "Feeling everything, by every possible way" as Portuguese poet Fernando Pessoa says. It is particularly obvious in architecture. The Fob Association group of architects thus proposes "Aura"[12], a tent-

[5] Philippe STARCK, « Archetype and Mass Market », in *Type Objects and Archetypes*, journal of French Furniture Trade, Paris, Hazan, 1997, 50-63.
[6] ibid., 52.
[7] see Mike Jones, « Bio-design », in *Design, Mirror of a Century*, under the direction of Jocelyn de Noblet, Paris, Flammarion/APCI, 1993, 283-291.
[8] See Odile FILLION, « Philippe Starck, the Right Product", *Villages, Modernity and Modesty*, journal of French Furniture Trade, Liège, Mardaga, 1993, 53-63.

[9] *Intramuros*, n°86, dec/jan 2000, 29.
[10] Ezio Manziani, *Matter of Invention*, Paris, Editions du Centre George Pompidou, 1989, 135.
[11] It is the workshop I have started my work within. It is based in Bordeaux and it researches and perfects materials aimed at fashion design, space and object design. Matières Proches is exhibiting at the moment at the Musée d'Aquitaine in Bordeaux: "Beyond textile: dreaming material by Jacques Bernar," from 29/11/2001 to 13/01/2002.
www.matieresproches.com
[12] *Aura*, Fob Association, Tokyo, 1995.

building conceived as a temporary shelter on a thin plot of land. The translucent membrane on the roof provides a steady light: an aura of diffuse light. That thin skin stretched between the walls of the building serves as an interface, as a transition between the outside and the inside, indoor and outdoor. That creation of sensory , introverted spaces allows the personalization of our environment from a sensory point of view. Sloanism[13] is pushed to its climax in order to create a product faithful to our own image. Home becomes an "inner-home", an intimate nest, a place where we live in our dreams and our fantastical projections.
The development of "second skins" therefore seems to be developing with the fantasy of a common skin. It is individual and collective at the same time, and each one seizes the identity of the object as he pleases, in order to seize its own world. Indeed, we do know that skin is peculiar to each individual and that it shows its identity (sex, race...) and its uniqueness (fingerprints). Paradoxically, the Greek etymology "kutos" implies that the word "skin" means envelop, or entirety. Besides, every human being has a skin[14] .
Skin is also the organ of touch, the only one that is essential for man, and the only one that provides both passive and active sensations: it gets the information of the skin of the hand that strokes the cheek, and that of the skin of the touched face. During an interview with a doctor[15], he explained to me that a lot of pathologies were appearing nowadays because people didn't touch each other anymore. It would be one of the reasons for the success of balneotherapy and physiotherapy. Patients would be looking for the tactile contacts they reprimand in their everyday life. In an article on new technologies, Paul Virilio expresses his fears concerning the disappearance of contact in our "over-computerized" societies. Connection with the remote instead of the fellow man would provoke a degradation of the human sensitive system, long-term. That threat would result in "a loss of natural motricity and in a loss of the body substance"[16]. The extension of "second skins" would therefore seem to be symbolically compensating for that lack, proposing materialistic solutions of the extension of its own body, and thus presenting another connection with space, a change of scale organized around a more matrix environment.
Moreover, as it shows the immediately visible aspect of the individual, the skin has inevitably embodied the characteristics of relational and social life[17]. Organ of touch, surface, interface, the skin takes on many functions[18]. Besides many expressions make reference to the joined activities of the skin and the self[19]. "Avoir quelqu'un dans la peau" which means to be crazy about somebody, expresses the feeling that through the skin, we can reach the place where our feelings dwell, that is to say our brain[20]. Through metonymy or synecdoche, the skin designates the whole person, hence the expressions "to save one's skin" or " to be in his skin (shoes in English)". "Skin is the most profound" as Paul Valery liked to say.
Work on material and its symbols favors the connection between user and object. The model of skin would then be the basis to help find back that collective memory. "Second skins" would allow to reconcile the individual with the collective. They effectively question man's territories and their limits within a sphere going far beyond the body strictly speaking. They develop along with current political and economical affairs and their globalization. Following the example of a world market, we are witnessing the constitution of an universal skin exemplified by interbreeding and cultural cross-fertilization.
Like the varieties of skins we can find from one person to another (speaking of their texture as well as their color), "second skins" materials can be found in several versions and ranges. They favor "chromo-tactile" researches and allow multiple-choice equations as far as texture and color are concerned. Paradoxically, uniqueness strives for a new plurality.

IV. POIETICS OF THE RANGE

We already knew musical scales and chromatic ranges. Designers and industrials give endless references nowadays, in order to fulfill more and more personalized expectations. They often organize themselves around a unique variable: colors, materials, sizes, finishings and so on. The multiplication of these characteristics gives endless possibilities, following the example of natural history and the evolution of species. Besides designer Alessandro Mendini notices some analogies between range and species: " One can think of a system of object similar to that of a natural species. An industrial aesthetic system has similarities with a biological organism: its rhythm, its mechanism, materials, colors signs on the skin. (...) What matters here as much as the signification of single individuals, is the continuity of their cosmos conceived as a jig-saw puzzle[21] ."
Range also imposes itself as concept in the design project. " *Romeo*", Philippe Starck explains, "only exists because it's a range. It doesn't exist as drawing, it's an accumulation of commonplaces. It only exist as a proposition which tries to be exhaustive in doing favors and helping. An object from the *Romeo* range on its own doesn't mean much. Some objects only have some value because they are aiming at an exhaustive answer[22]." Range therefore seems to be existing on a catalog, in a shop. The isolated object taken from a range becomes a quote. It can not be apprehended alone and it exemplifies its belonging to a universe. Range relates back to something universal, and its importance becomes obvious in the development of "second skins" textures.
The research work conceived from petrochemical material led at the Matières Proches workshop works that way. Some sorts of plastic, among which PVC and silicones are the starting point of all

[13] From Alfred Sloane, CEO of General Motors between 1925 and 1949. He has introduced the idea of range within industry.
[14] or a bark, a peel, a shell, a membrane, a pleura and so on.
[15] Doctor Marc Elman, Toulouse, 7/11/2001.
[16] Paul Virilio, « From Secular to Sacred Body », in *Art Press* special feature on new technologies, n°12, 1991.
[17] *La peau de chagrin* by Honoré de Balzac (Paris, classical contemporary editions, 1950, 2 volumes) highlights that social function. The *peau de chagrin* becomes a sort of mirror for his own life, a symbol for a generation.
[18] In the *Robert* dictionary, the paragraphs devoted to the words "skin", "hand" and "touch" are among the longest. The "touch" paragraph is the longest in the *Oxford English Dictionary*.
[19] We are referring to Didier Anzieux's works in *The Skin-Me*, Paris, Dunod, 1985.
[20] The human embryo is made of two layers – ectoderm and endoderm- at the gastrula stage. The first one represents at the same time brain and skin, including sense organ. Brain and skin can therefore be seen as surface beings, and thought is the relationship between these two surfaces. Psychiatrist Didier Anzieux (op. cit., 10) speaks of "invagination" in the language of anato-physiology to qualify the paradoxical relationships between surface and depth.
[21] Alessandro Mendini, *100 % Make-up, Alessandro Mendini and... La Fabbrica estetica*, Crusinalo (Italy), Alessi Tendentse, 1992, 17, quoted by Catherine Colin, "The Origin of Ranges" in *Design and Ranges*, French Furniture Trade, *Villages*, Paris, 2001, 22.
[22] Conversation between Philippe Starck and Catherine Colin, quoted by Catherine Colin, "The Origin of Ranges" in *Design and Ranges*, French Furniture Trade, *Villages*, Paris, 2001, 17.

practice. Color and drawing are coming along. The application of rodalèges, on hotplates for instance, varies depending on the amount of pigment (color-material) we choose. The strong or weak viscosity resulting on the hand gesture and the weight that draws a line, determines the drawing and pattern. The dynamism of the line depends on that, and then becomes itself one of the vectors of the range. On the other hand, the viscosity of the matter mixed with the amount of pigment in the paste infer the matt or brilliant aspect, the opacity and transparence dear to the color/material binomial.

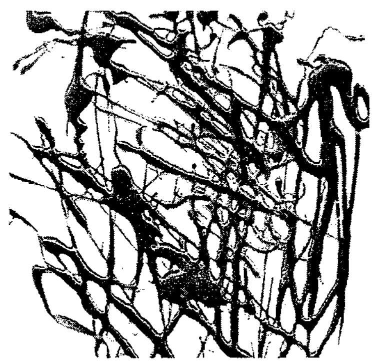


Figure 1 : Rodalège texture, Stéphanie Sagot, 2001

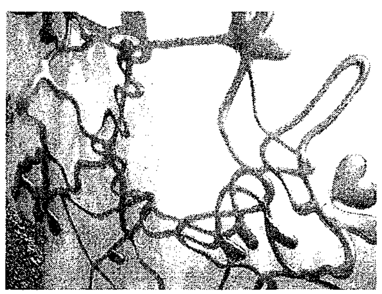


Figure 2 : Rodalège texture, Matières Proches, 2002

Such a practice reveals a poïetics of the range. Coupling within a range creates new parameters, new aspects. The graphics of a sample depends on the joint action of texture and color and generates new parameters. Color and drawing become material. They provoke different touching and take part in what we could call a "chromo-tactile range".

CONCLUSION

The philosophy of the post-industrial project has split into a series of devices directed to partial and precise markets, more and more personalized in their semiotic frames, and strongly different from one another. The aimed-at-everybody standardized product has been replaced by the interactive one able to stimulate its owner, able to launch a number of sensitive reactions and specific behaviors on a certain kind of users.

Design has taken the paradoxical path of plural uniqueness. It refers to the skin model, which appears as a real collective memory, unique and universal at same time, allowing maximal proximity with the object, creating a quasi organic intimacy with the user.

The multiplication of these sensations has paradoxically introduced immaterial criterions such as value, emotion, feeling, in the ranges of products. That phenomenon goes along with the development of design practices in which material, color and drawing become inseparable elements, hence the emergence of chromo-tactile ranges.

Stéphanie Sagot, University of Toulouse / Le Mirail, IUP Arts Appliqués, 116 bvd Montauriol, 82000 Montauban, France. E-mail : sagot.Stephanie@wanadoo.fr

COLOR PREFERENCE STUDY ON AUTOMOTIVE EXTERIOR IN HONG KONG AND JAPAN

Izumi Satake[1)], Tetsuya Sato2[)], John H Xin [3)], Kenji Ando [1)], Koichi Kuwano[1)], Kanji Kajiwara[2)]
1) Nippon Paint Co., Ltd., Tokyo, Japan
2Kyoto Institute of Technology, Kyoto, Japan
3) The Hong Kong Polytechnic University, Hong Kong, China

Abstract

We elucidated color preference for automotive exterior in Hong Kong Poytechnic University (HPU), Kyoto Institute of Technology (KIT) and Nippon Paint Co. (NP) by using a set of questionnaire and painted panels. The results were compiled from the subjects of 50 Hong Kong observers and 168 Japan observers. In prior to this experiment, we have selected 12 colors from 104b Color Chart produced by Japan Color Enterprise Co., Ltd., according to the results of like-dislike tests of 101 people in two countries.

These emotional assessments revealed that preference for purple significantly differed in each country. The statistical analysis performed by Factor Analysis calculated that the parameter consisted of two factors affected color preference.

These data suggest that the selection of automotive exterior colors is different between Hong Kong and Japan, possibly indicating from the image of the color and/or automobile. We will discuss further characteristics of color preference in each country.

Keywords: *Color Evaluation, Color Preference, Paint and Coating, Asian Study, Automotive Exterior*

1. INTRODUCTION

Asian color taste is drawing the attention of the whole world in the field of the product design, similar to European taste. Owing to the popularity of multimedia and Internet, local information or cultural background is instantly spread and easily accessed. Color communication networks nations, and local culture is becoming less characteristic. Previous studies of color preference were performed to contrast the object from standardized sensibility in comparative anthropology, and particularly, the report for automotive exterior color in East Asia was scarce. To clarify color preference for automotive exterior color based on identical and/or common culture, the present study was designed to analyze the elemental factor of color preference obtained from the observers in Japan with various ages and backgrounds and from Hong Kong using a set of questionnaire and painted panels.

2. METHODS

2.1 Preliminary experiment

Using pieces (12×17.4 cm) of 104b Color Chart obtained from Japan Color Enterprise Co., Ltd., the like-dislike tests were performed with 101 observers in two countries. The subjects were the students of HPU (Hong Kong Polytechnic University); 20.7 ± 0.86 years old (mean±SD, n=40) including 24 males; 20.7 ± 0.92 years old and 16 females;

20.6±0.81 years old, and those of KIT (Kyoto Institute of Technology); 21.4±1.25 years old (n=40) including 20 males; 21.7±1.53 years old and 20 females; 21.0±0.79 years old, and the researchers of NP (Nippon Paint Co.,); 38.3±10.4 years old (n=21) including 11 males; 43.2±11.4 years old and 10 females; 32.3±4.44 years old.

The observers were inquired to select the most favorite automobile in 15 monochromatic side shapes shown in figure 1, and categorized the 104 pieces of Color Chart under suitable, unsuitable or ambiguous color to the selected automobile shape. Figure 2 shows the condition for this preliminary experiment. Briefly, the piece of color chart was put on the desk covered with the gray color cloth facing north window under fine weather and sunlight. In addition, the observers cited suitable and unsuitable adjectives to the specified automobile shape. The experiment was performed with the completely equal condition in 3 regions of Hong Kong and Japan using the local language; Cantonee in Hong Kong and Japanese in Japan.

According to the results, 12 colors of painted panels and 16 pairs of emotional words were selected.

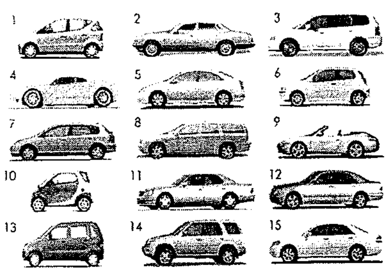


Figure 1: Image shapes of automobiles used in the present study

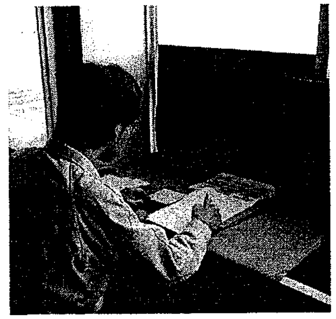


Figure 2: Condition for selecting of pieces of 104b Color Chart in the Preliminary experiment

2.2 Emotional assessments of painted panels for automotive exterior

The subjects were the students of HPU; 21.8±1.30 years old (mean±SD, n=50) including 29 males; 21.5±1.09 years old and 21 females; 22.3±1.45 years old, and those of KIT; 21.5±1.63 years old (n=75) including 54 males; 21.5±1.72 years old and 21 females; 21.5±1.44 years old, and the researchers of NP; 41.7±10.5 years old (n=93) including 68 males; 41.4±10.4 years old and 25 females; 42.6±10.8 years old.

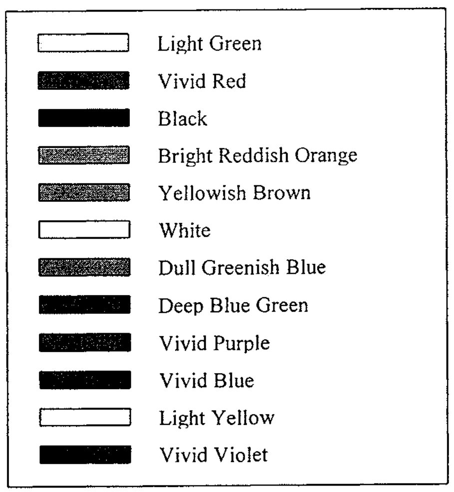


Figure 3: Color of painted panels for automotive exterior

Color emotional assessment was performed by a set of questionnaire and painted panels (30.5x 38 cm) with 12 colors specified by the preliminary experiment as shown in figure 3. Figure 4 shows the condition for the emotional assessment.

Figure 4: Condition of the sensory evaluation for 12 painted panels of automotive exterior parts

Here, the painted panels were hanged on the gray colored boards at 1.5m height, and placed weather in the order by the same table of random numbers in the open air under sunlight and fine in 3 regions. The observers assigned suitable or unsuitable to the each painted panels, cited suitable and unsuitable adjectives in 16 pairs as shown in table 1, and using a 7-point scale method. By referring to the automobile in 15 monochromatic side shapes (6 SUVs, 5 sedans, and 4 compact cars) shown in figure 1, the observers specified the pained panels for automotive exterior. The experiment was performed with completely equal condition in 3 regions in Hong Kong and Japan, and using the local language; Cantonee in Hong Kong and Japanese in Japan.

Table 1: Sensory words of the impressions induced by each painted color

bright	-	dark
fast	-	slow
light	-	heavy
gaudy	-	plain
clean	-	dirty
feminine	-	masculine
up dated	-	out dated
pretty	-	ugly
pointed	-	dull
young	-	old
cheerful	-	melancholic
like	-	hate
decent	-	indecent
settled	-	unsettled
luxury	-	cheap
good taste	-	bad taste

2.3. Statistical analysis

Statistical analysis was performed by the Semantic Differential method and the normal varimax test of Factor Analysis.

3. RESULTS AND DISCUSSION

3.1 According to the result in the preliminary experiment using pieces of 104b Color Chart pieces, 12 colors of painted panels were specified.

The colors liked by the highest percentage of the observers chosen from 104b Color Chart in 3 regions are shown in table 2. Typical suitable color to the image shape of automobile for the observers in NP were Pale Violet (52.4%) and White (52.4%), those in HPU were Vivid Red (70.0%) and White (70.0%), and those in KIT were Dull Greenish Blue (52.5%) and White (52.5%), respectively. Typical unsuitable color in NP were Deep Yellow Green (85.7%), Yellowish Pink (85.7%) and Pale Yellowish Pink (85.7%), those in HPU were Yellowish Brown (90%), and those in KIT were Dull Red (82.5%) and Vivid Purple (82.5%), respectively.

In the assessment, 2 was assigned to a suitable color, 0 to an unsuitable color, and 1 to an ambiguous color. Then the average values to number of observers for 104 color charts were calculated. The maximum and minimum differences between any two regions were as follows: the minimum difference compared with any regions in the suitable color was White, that in the unsuitable color was Bright Reddish Orange in HPU/KIT and HPU/NP, Vivid Purple in KIT/NP, respectively, and the maximum difference as suitable and unsuitable color was Vivid Red in HPU/KIT, Dull Greenish Blue in KIT/HPU, Vivid Blue in HPU/NP, Light Green in NP/HPU, Vivid Violet in KIT/NP, and Yellowish Brown in NP/KIT, respectively. Following the results of this color assessment, 12 colors were selected to be used for preparing painted panels in the succeeding experiments. Those colors are shown in figure 3.

Table 2: Like /dislike ratio for pieces of 104b Color Chart in the prior experiment

Nippon Paint			
% of Like		% of Dislike	
Pale Violet	52.4	Deep Yellow Green	85.7
White	52.4	Yellowish Pink	85.7
Deep Blue Green	47.6	Pale Yellowish Pink	85.7
Dark Green	47.6	Deep Purple Pink	81.0
Grayish Violet	47.6	Vivid Purple	81.0
Pale Beige	47.6	Bright Purple	81.0
Dark Gray	47.6	Deep Violet	81.0
Dark Brown	47.6		

Hong Kong Polytechnic University			
% of Like		% of Dislike	
Vivid Red	70.0	Yellowish Brown	90.0
White	70.0	Yellowish Pink	82.5
Black	60.0	Pale Pink	82.5
Vivid Blue	57.5	Deep Yellow	80.0
Light Green	57.5	Pink	80.0

Kyoto Institute of Technology			
% of Like		% of Dilike	
White	52.5	Dull Red	82.5
Dull Greenish Blue	52.5	Vivid Purple	82.5
Bright Blue	50.0	Yellowish Brown	77.5
Dull Blue	47.8	Deep Purple	77.5
Light Blue	47.8	Yellowish Pink	77.5
		Graysh Pink	77.5

3.2 Taste assessments of painted panels for automobile exterior

The percentages of 'like' for the 12 colors of painted panels in 3 regions are shown in terms of percentage of observers in figure 5. Suitable colors for the painted panel in NP were White (81%) and Deep Blue Green (77%), those in HPU were Black (84%), White (84%), and Vivid Blue (76%), and those in KIT were Black (83%), Vivid Blue (83%), and White (80%), respectively. These results indicate that the tendency of the suitable colors for automobile exterior identical for the observers in HPU and KIT as the age matched and with a similar curriculum, and that different that in NP. Unsuitable colors in NP were Bright Reddish Orange (86%) and Yellowish Brown (79%), those in HPU were Bright Reddish Orange (90%) and Yellowish Brown (90%), and those in KIT were Bright Reddish Orange (79%) and Yellowish Brown (75%), respectively. The tendency of unsuitable colors was found similar in NP, HPU and KIT, indicating that unsuitable color may not depend on age, education, nation and other factors. Remarkable results in the present study were that Vivid Purple was favorite in the observers of HPU, whereas it was disliked in NP and KIT, and that Light Green was favorite in NP and KIT and disliked in HPU.

3.3 Emotional assessments of painted panels for automotive exterior

Figure 6 summarizes the strength of sensory words allocated to 12 pained panels of automobile exterior parts as calculated from the factor loadings of the Factor Analysis using the normal varimax test. These results suggest that the first factor was worth and the second factor was cheerful.

The highest value to the first factor (worth) specifies was Yellowish Brown in NP, Vivid Blue in HPU, and Vivid Red in KIT, respectively, whereas the lowest value Deep Blue Green in NP, Dull Greenish Blue in HPU, and Yellowish Brown in KIT, respectively. Resulting from the age matched observers in HPU and KIT, the highest or the lowest of factor loading were almost identical. Therefore, the present

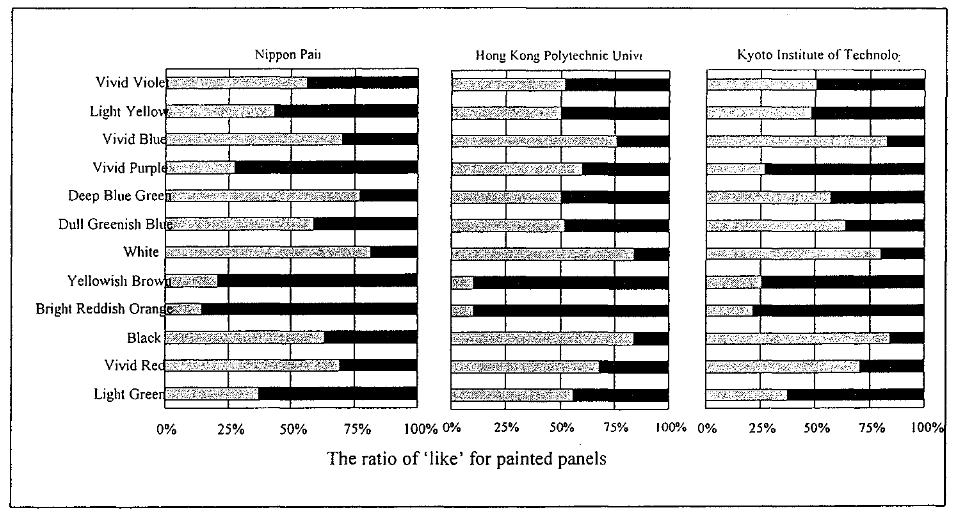


Figure 5: The ratio of 'like' for color of painted panels for the automotive exterior in observers of NP, HPU, and KIT, respectively

result may possibly indicate that an important factor is the age in the sensory of worth to the color, and suggest that the growing older tends to have a different opinion of worth for a color.

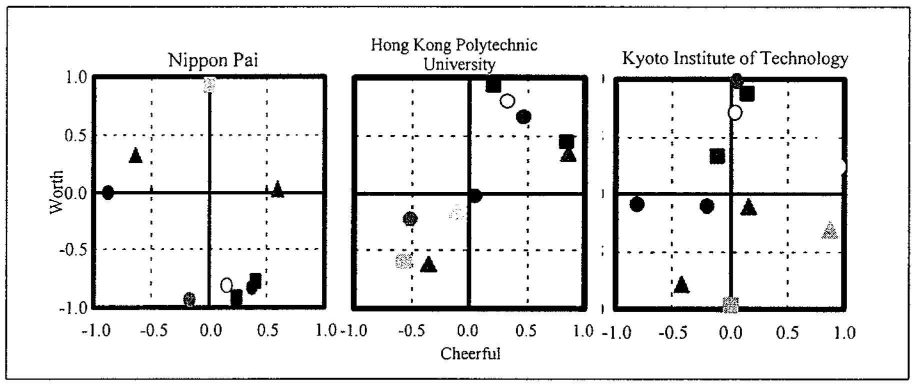
The highest value specifies Light Green and Light Yellow in NP and KIT, and Vivid Purple and Vivid Violet in HPU, respectively, in the second factor of cheerful, whereas the lowest value Black in NP and KIT, and Yellowish Brown and Deep Blue Green in HPU, respectively. The value of factor loading for cheerful was clearly different between that in HPU and those in NP and KIT. The sensuousness to the color with regard to cheerful, therefore, may possibly indicate the significance of geographical locations.

4. CONCLUSION

These data suggest that the color choice for automotive exterior is markedly different between Hong Kong and Japan. The analysis in this study could assist the proper use of color for automobile exterior in different regions and for different age groups.

5. ACKNOWLEDGMENTS

We thank Mr. H. Hattori of Kyoto Institute of Technology for carrying out the statistical analysis and the questionnaires in Japan, Ms. C.F.J. Wong of the Hong Kong Polytechnic University for the questionnaires in Hong Kong, and Ms. Y. Miki and Ms. N. Usumoto of Nippon Paint Co., Ltd. for performing for the questionnaires in Japan.



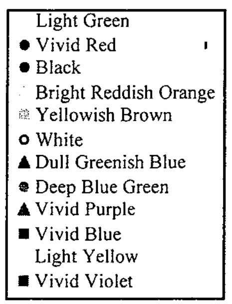


Figure 6: Profiles of the factor loading for worth and cheerful with sensuousness to the painted color parts in NP, HPU and KIT, respectively, performed by Factor Analysis.

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M. A. Izumi Satake, Ph. D. Kenji Ando, M.S. Koichi Kuwano, Nippon Paint Co., ltd., Design Center, 4-1-15, Minami-shinagawa, Shinagawa-ku, Tokyo 140-8675, Japan. Phone: +81 3 3740 1355, Fax: +81 3 37401359
Associate Prof. Dr. Tetsuya Sato, Kyoto Institute technology, Faculty of Mechanical Engineering, Faculty of Textile Science, Matsugasaki, Sakyo-ku, Kyoto, 606-8585, Japan. Phone/Fax: +81 75 7247578
Associate Prof. Dr. John H. Xin, The Hong Kong polytechnic University, Institute of Textile & Clothing, Hung Hom, Kowloon , Hong Kong, China
Prof. Dr. Kanji Kajiwara, Kyoto Institute technology, Faculty of Engineering and Design, Matsugasaki, Sakyo-ku, Kyoto, 606-8585, Japan. Phone: +81 75 724 7567, Fax: +81 75 724 7564

COLOUR - STRUCTURE RELATIONSHIP IN PET FIBRES

Majda Sfiligoj Smole, Kristina Stakne, Vera Golob
University of Maribor, Textile Department, Maribor, Slovenia

Abstract

Two different types of PET fibres were studied for this presentation, i.e. a normal wool-type and a low pilling modification. A detailed fibre structure was determined and the correlation is given between the fibre structure and its colour. The structural morphology and crystalline orientation of the fibres were investigated by means of wide-angle x-ray scattering (WAXS), density measurements and IR spectroscopy. WAXS studies were made to determine the degree of crystallinity, crystallite orientation and apparent crystallite dimensions. The acoustic investigations and measurement of birefringence were used to study the average molecular orientation and the orientation of macromolecular chain segments in the amorphous regions. The microvoid system was studied by means of small angle x-ray scattering (SAXS). PET samples were conventionally dyed and the effect of the structure on colour was followed using colorimetry.

Keywords: *PET fibres, structure, colour, colour measurement*

1. INTRODUCTION

Poly(ethylene terephthalate) (PET) is commercially one of the most important polymers. It is widely used in fibreforms for textile applications and technical purposes. The properties of PET fibres may be modified over a range that is limited by the inherent characteristics of the polymer. By chemical modification variants were developed, which exhibited low pilling, cationic dyeability, etc. The formation-mode and history of a fibre determine the fibre structure and, thereby, the physical properties of the fibres.
The importance of this man made fibre has, consequently, generated much basic research concerned with the relationship between processing, morphology and physical properties. There have thus been extensive investigations concerning the crystalline structure and orientation of PET over a range of thermal, stress and deformation conditions in order to achieve a qualitative and quantitative understanding of the effects of the structure and properties of the polymer, e.g. [1-5]. Two different types of PET fibres were analysed for this presentation, i.e. a normal wool-type and a low pilling modification with significantly lower molecular weight. The influence of the structural differences on the fibre dyeing properties was then studied.

2. EXPERIMENTAL

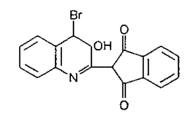
2.1 Materials used

Commercial poly(ethylene terephthalate) staple fibres of standard woollen type (linear density 3,6 dtex and length 75 mm) and a variety with lower pilling tendencies of the same fineness and length were investigated. The molecular mass of the pill resistant fibres (A1) was approximately 40% lower in comparison to the woollen type (W1).

2.2 Dyeing of the samples

A high temperature exhaustion method at T=130°C was used for the fibre dyeing

processes. The dyeing of both types of fibres was performed simultaneously in the same dyebath at liquor ratio 10:1, using a Labomat BFA laboratory machine (produced by W.Mathis AG). The dyeing process started at 50°C with the addition of dispersant (1g/L) and buffer agents (pH = 5.5). After 10 minutes the dyes were added and the temperature was raised at a gradient of 1.5°C/min, until it reached 130°C and then maintained for 45 minutes. The reduction after-clearing at T = 70°C was performed with the addition of NaOH (1.0 g/L) and $Na_2S_2O_4$ (1.0 g/L).
The applied dyestuff concentrations were 0.1, 1 and 3%, respectively. Two dyestuffs, C.I. Disperse Yellow 64 (1) and C.I. Disperse Blue 183 (2) were used, respectively, with structures as shown in Figure 1:



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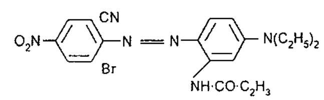

(2)

Figure 1: Dyestuffs used

2.3 Analytical methods

2.3.1 Fibre structure determination

The structural morphology and crystalline orientation of the fibres was investigated using wide angle x-ray scattering (WAXS), FTIR spectroscopy and density measurements. WAXS studies were performed to determine the degree of crystallinity, crystallite orientation and apparent crystallite dimensions [6,7]. A two-circle goniometer equipped with a position sensitive detector and a Siemens D 500 diffractometer were used. Scattering was registered on the equator between $2\theta = 10°$ to $35°$ on the diffractometer and azimuthal scan of the meridional $(\bar{1}05)$ reflection was performed to study the crystalline orientation [8,9]. A modified Kratky SAXS camera was used for the registration of the equatorial and meridional distribution of the small angle x-ray scattering (SAXS). To study the micro void system the measurements were carried out on a Kratky camera with slit collimation (elongated slit of 40 μm width) and with a proportional counter. Measurements in the equatorial direction were carried out in the angular range of $2\theta = 0.95$ mrad to $2\theta = 115$ mrad. The data were subjected to an absorption correction and to background subtraction. The orientation of the fibres was parallel to the longitudinal direction of the primary beam during the measurement. This method is described exactly in [10,11]. The characteristic SAXS parameters were obtained from the scattering curves. A two-phase fibre model, consisting of polymer (crystalline and amorphous domains) and empty holes was accepted for analysing the equatorial SAXS curves. It was assumed that phase 1 (polymer) and phase 2 (voids) have different electron densities and that within each phase the electron density is constant. For the two-phase system the microvoid system was evaluated by means of equations given in literature [12].
A same Kratky camera was used for meridional SAXS measurements.
Transversal scattering curves were obtained by measuring the SAXS intensity along the meridian on the angular range of $2\theta = 0.95$ mrad to $2\theta = 65$ mrad. The orientation of the fibres was perpendicular to the longitudinal direction of the primary beam during the experiment. The experimental data were corrected for absorption and background scattering. The position of the (first) scattering maximum when evaluated according to the Bragg's law gives an estimation of the size of the long period, i.e., the average distance between crystalline regions which alternate with

amorphous domains in the two-phase fibre model [6,10,11].

FTIR measurements were carried out using a Perkin Elmer 1600 FTIR spectrometer. Each spectrum was obtained with a resolution of 4 cm^{-1}. The ratio between intensities was determined directly from the spectra, using a pseudo-base line. An average of 100 scans was recorded in the absorbance mode.

The absorption band at 973cm^{-1} was used as a measure of trans content (O-CH_2 stretching of the trans conformer of the ethylene glycol fragment), the 898 cm^{-1} absorption as a measure of gauche content (CH_2 rocking of the gauche conformer) and the 793 cm^{-1} band as the reference band. Since only trans isomers can exist in the crystalline regions, the content of trans in ordered zones can be estimated as equivalent to the crystallinity obtained by another independent technique [1,13].

Additional measurements of fibre birefringence and acoustic measurements were performed to determine average orientation functions, i.e. $f_{\Delta n}$ (average molecular orientation determined by birefringence), f_a (average molecular orientation determined from the velocity of ultrasound propagation) and to calculate the orientation of amorphous macromolecular segments $f_{\Delta nA}$ (amorphous orientation determined by birefringence) and f_{aA} (amorphous orientation calculated from acoustic measurements) [2,7,17].

The mass fraction of crystallinity was calculated from fibre density measured at 23°C using a density gradient column according to ASTM procedure D 1505-85 [15]. The density of fully crystalline and amorphous PET is taken to be 1.455 g cm^{-3} and 1.335 g cm^{-3}, respectively [16].

Determinations of intrinsic viscosity were made in 50/50 phenol / 1,1,2,2-tetrachloro-ethane at 20°C using an Ubbelohde dilution viscosimeter. All samples were cut in pieces of 5mm, washed and dried in an oven at 105°C prior to viscosity measurements. Sample concentrations of 1g/100ml were used. Dissolving was carried out over 12 hours at 20°C and afterwards additionally 30 min at reflux. The relationships between intrinsic viscosity and molecular mass ($\overline{M}_n$, $\overline{M}_w$) using the above conditions were used according to Griehl and Neue [17]

2.3.2 Colorimetric analyses

Reflectance values of dyed samples were measured using a SF 600+ spectro-photometer - Datacolor and CIELAB colour differences were determined according to the following equations [18]:

$$\Delta E_{ab}^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + \Delta b^*)^2]^{1/2}$$

$$\Delta E_{ab}^* = [(\Delta L^*)^2 + (\Delta C^*)^2 + (\Delta H^*)^2]^{1/2}$$

where ΔE_{ab}^* is the Euclidean distance between batch (B) and standard (S) in CIELAB colour space, . calculated as a Pythagorean sum of the component differences L*- lightness, a*- red(+a*) /green (-a*) axis and b*- yellow(+b*)/ blue(-b*) axis or C*- chroma and h - hue, respectively, given by:

$$\Delta L^* = L^*_B - L^*_S$$
$$\Delta a^* = a^*_B - a^*_S$$
$$\Delta b^* = b^*_B - b^*_S$$
$$\Delta C^* = C^*_B - C^*_S$$
$$\Delta H^* = C^* \Delta h\,(\pi/180) \text{ or}$$
$$\Delta H^* = [(\Delta E_{ab}^*)^2 - (\Delta L^*)^2 - (\Delta C^*)^2]^{1/2}$$

3. RESULTS

The two dimensional x-ray scattering patterns of both samples represent crystalline reflections with three sharp intensity maxima on the equator (Fig. 2, 3). The intensity distribution on the WAXS photographs reflects the same picture of highly oriented and crystalline structure. The crystallinity index was determined

from the WAXS scattering curves, FTIR spectra and density measurement and the

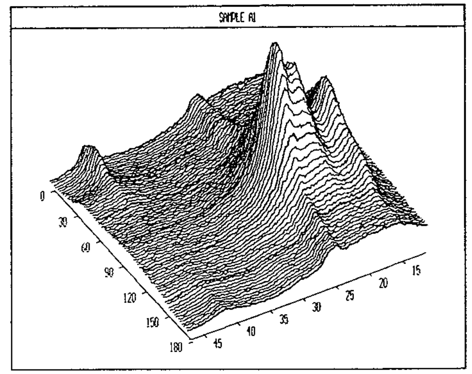

Figure 2: Two dimensional WAXS pattern of low-pilling wool type PET fibre A1

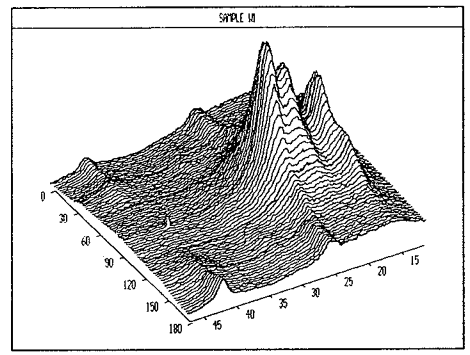

Figure 3: Two dimensional WAXS pattern of normal wool type PET fibre W1

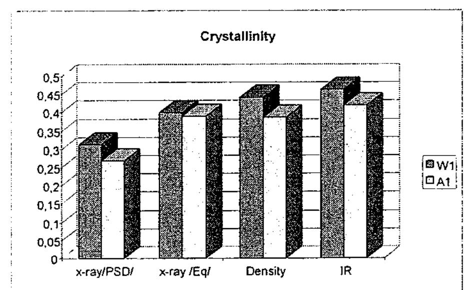

Figure 4: Crystallinity index determined from different analytical methods

results are collected in Table 1 and Figure 4. The same relationship between pill-resistant and standard wool PET fibres are observed regardless of the evaluation method although different experimental techniques lead to different results. The degree of crystallinity determined from the equatorial x-ray scan (2θ=10°-35°) agrees with the values obtained from the density measurements and IR spectroscopy, but the crystallinities determined from the two-dimensional x-ray intensity distributions (two-circle goniometer 2θ = 10°-35°) are considerably lower. Higher crystallinity, evaluated by means of all the measuring methods, was determined for standard wool type fibre (Fig. 4, Table 1).

Table 1: The structural parameters of standard and low-pilling wool PET fibre types

Structural parameter	W1	A1
Crystallinity index $x_{ray\ PSD}$	0.31	0.27
Crystallinity index $x_{ray\ Eq}$	0.40	0.39
Crystallinity index x_p	0.44	0.39
Crystallinity index x_{FTIR}	0.46	0.42
Dimensions of crystallites $L_{(010)}$ [nm]	3.13	2.48
Dimensions of crystallites $L_{(1\text{-}10)}$ [nm]	2.31	2.45
Dimensions of crystallites $L_{(100)}$ [nm]	2.63	1.80
Long period [nm]	7.76	6.91
Density [g.cm^{-3}]	1.3855	1.3790
Degree of polymerisation	19 600	12 300

The apparent sizes of crystallites normal to the planes (010), ($1\bar{1}0$) and (100) are slightly influenced by the length of the molecular chain. The crystallite sizes L(hkl) were found to be larger when the crystallites are formed from longer polymer chains in both directions perpendicular to the fibre axis. This fibre type is also characterized by the higher orientation of crystallites in the direction of the fibre axis (determined from the azimuthal profile of near meridional ($\bar{1}$05) reflection) (cf.Table 2) and a larger long period (cf Table 1).

Table 2: Orientation factors of standard and low-pilling PET fibres' modification determined by different methods, i.e. WAXS (crystalline orientation f_c) birefringence determination (average orientation $f_{\Delta n}$ and amorphous orientation $f_{\Delta nA}$), and acoustic investigations (average orientation f_a and amorphous orientation f_{aA})

Hermans orientation functions	W1	A1
Crystalline orientation f_c	0.927	0.982
Average molecular orientation $f_{\Delta n}$	0.540	0.534
Average molecular orientation f_a	0.681	0.741
Amorphous orientation $f_{\Delta nA}$	0.395	0.369
Amorphous orientation f_{aA}	0.486	0.646

In Table 3 characteristic SAXS parameters of standard wool- type PET fibre and a low pilling modification are given. Volume fraction of the voids is w and the relative inner surface of the system S_s, i.e. interfacial area between the two phases. Another parameter is obtained from the ratio of Porod's invariant Q and Porod's constant K_p, i.e. the reduced intersection length l_r and the additional correlation length l_c is determined. O_r represents the relative inner surface of the voids system and f the form factor. Both types of PET fibres develop the same part of voids during the fibre formation process, but the voids in the pill-resistant fibre type are smaller and comprise a bigger area. The fibre structure containing a greater number of smaller voids contributes to the more inhomogeneous structure.

Table 3: Microvoid system of standard and low-pilling wool PET fibre types

SAXS parameter	W1	A1
w (%)	1.9	1.9
l_c (Å)	227.6	244.1
O_r (Å^2)	0.28	0.30
l (Å)	14.2	13.4
S_P (m^2/g)	38.5	39.9
f	8	9.1

The effect of the fibre structure on colour differences is graphically presented in Figures 5 and 6. Observed CIELAB colour difference DE* and its components depends both on the chemical structure and concentration of the used dyestuffs, which yield a specific fibre colour under defined dyeing conditions.

The pill-resistant PES fibres (A1) dyed using C.I.Disperse Yellow 64 (Fig. 5) exhibits maximal colour difference DE* at 1% dye concentration in comparison to the woollen type (W1-standard); they are redder (a*), yellower (+b*) and have a higher chroma (+C*). No perceptible colour difference occurs at low dye concentration (0.1%) between both types of the fibres (DE*≤1). The lightness L* and value a* only slightly change with an increasing concentration of the yellow dye, but value b* and, consequently, chroma C* increase significantly, therefore, these colour

components also have a significant effect on the total colour difference DE*. At higher dye concentrations (4%) the fibres are saturated which reduces the effect of the fibre structure on colour difference.

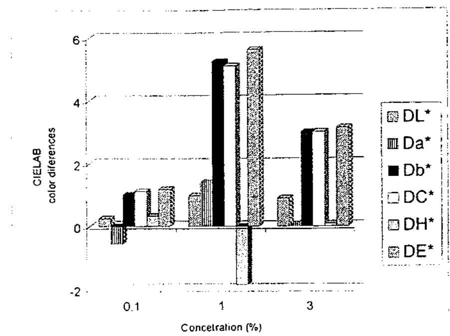

Figure 5: CIELAB colour differences for C.I. Disperse Yellow 64 (standard W1)

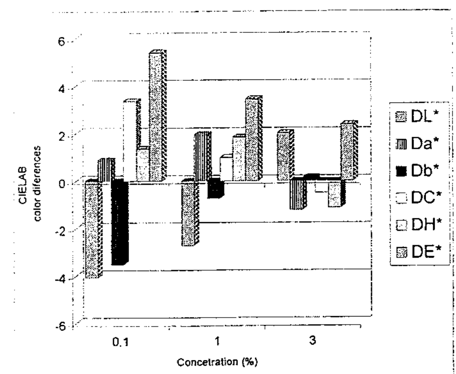

Figure 6: CIELAB colour differences for C.I. Disperse Blue 183 (standard W1)

The structural differences between PET fibres cause the maximal colour differences at low dye concentration (0.1%) when dyed with C.I.Disperse Blue 183 (Fig.6); the pill-resistant PES fibres are darker (-L*), bluer (-b*) and have a higher chroma (+C*) than woollen type (W1-standard). The colour differences decrease with any increase of dye concentration; the difference in lightness DL* remains the most significant, but positive value at higher concentration (4%) indicates a darker colour for woollen type PET fibres.

4. CONCLUSIONS

The physical/chemical modification employed in fibre production such as modification of spinning conditions or the use of shorter molecular chains alters the fibre structure, thereby modifying the dyeability and pilling performance of the fibre. Despite large differences in the molecular masses of the samples, leading to significant differences in the mechanical properties [19], only slight differences are observed in the supramolecular structure of the pill-resistant and normal wool-type fibre. The crystallinity in the wool-type is higher, although the differences are very small, the crystallites are slightly larger and better oriented, long periods are larger and all this points to a better developed microfibrillar structure for this type of fibre. There are also some differences in the microwoid system of the two types of PET fibres.

Nevertheless, the less perfect supra-molecular structure observed with the pill-resistant type of PET fibre, and a bigger inner surface leads to better accessibility for dyes. Significant colour differences were observed in all dyeing experiments, although the effect of the structure differences on the sample colour is not the same in the cases of the blue and yellow dyes, respectively. Only negligible colour differences at low dye concentrations were observed using C.I. Disperse Yellow 64, however with the concentration increase the colour differences are increased as well. In the case of the blue dye the colour differences decrease with any increase of dye concentration.

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Assist. Prof. Dr. Majda Sfiligoj Smole, Associate Prof. Dr. Vera Golob, Kristina Stakne, B.Sc., University of Maribor, Faculty of Mechanical Engineering, Textile Department, Smetanova 17, SI-2000 Maribor, Slovenia. Phone: +386 2 220 7883, Fax: +386 2 220 7990, E-mail: majda.sfiligoj@uni-mb.si, vera.golob@uni-mb.si, kristina.stakne@uni-mb.si.

DETERMINATION OF THE DYEING LEVELNESS BY COLORIMETRIC MEASUREMENTS

Barbara Simončič, Mateja Kert
Department of Textiles, Faculty of Natural Sciences and Engineering,
University of Ljubljana, Snežniška 5, 1000 Ljubljana, Slovenia

Abstract
The paper presents the investigation of different approaches used to determine the levelness of dyed textile substrates. For this reason the microfibre nylon 6,6 knitted fabric was dyed by anionic dye C.I. Acid Red 88 under different conditions. The reflectance values of different points on the same dyed samples were measured, from which the corresponding K/S values and CIE L^*, a^*, b^*, C^* and h^o co-ordinates were calculated at λ_{max} of the dyeing. K/S values were statistically analysed and the deviation as well as the variance of the K/S values was considered as a measure for dyeing levelness. The differences between the uniformity of different dyeings were calculated with F-test. These results were compared to the values of color difference ΔE^*, which acts as a measure for the dyeing levelness, if ΔE^* value is calculated from the differences between CIE L^*, a^*, b^* co-ordinates of the representative points on the same sample. It can be concluded from the results that the calculation of the ΔE^* value itself is not sufficient to determine the dyeing levelness, and that the K/S value, its deviation and the variance have to be taken into account.

Keywords: *dyeing levelness, colorimetry, color strength, color difference, statistic analyse;*

1. INTRODUCTION

Levelling dyeing is still one of the most important objectives in any dyeing process. It strongly depends on the physical and chemical uniformity of textile substrate as well as on the dyeing process procedure. Unlevel dye sorption on the fibre is usually obtained when dyes with high affinity and low migration propensity are used. In this case it is very important to control the rate and the extent of dye uptake by regulating dye bath pH, the rate of heating, added electrolyte and in the presence of levelling agents. Surfactants, which act as levelling agents in dye bath, slow down dye sorption and reduce dye exhaustion at equilibrium. The two actions increase uniform dye distribution on textile substrate [1, 2].

To determine the dyeing levelness the colorimetric method is widely used. In accordance with this method the uniformity of dye distribution on the textile substrate can be evaluated by different means. A very important one is the determination of color differences ΔE^* between representative points on the same sample of the dyed substrates. On the other hand, dyeing levelness can also be estimated by the deviation of the colour strength (K/S value) obtained for any dyed sample since the K/S value is proportional to the dye concentration to the first approximation. The aim of research work was to investigate different approaches used to determine the levelness of dyed textile substrate and to discuss the results obtained by the used methods.

2. METHODS

2.1 Materials

The microfibre nylon 6,6 knitted fabric was generously provided by Julon (Slovenia).

The anionic azo dye C.I. Acid Red 88 (AR88), the anionic surfactant sodium dodecylsulphate (SDS) and the nonionic surfactant Triton X-100 were commercial products produced by Aldrich Chemical Company. AR88 was purified with the re-crystallization from N,N-dimethylformamid - acetone mixture and SDS with the re-crystallization from acetone. TX100 was used in the same form as supplied without further purification.

2.2 Dyeing

Samples of scored nylon 6,6 fabric (2,0 g) were dyed with 2 % omf dye AR88 with and without added surfactants SDS and TX100 of different constant concentrations and mixture ratios. Since the concentration of TX100 was higher than its critical micelle concentration (c.m.c) and of the same time equal to $1\cdot10^{-2}$ mol/kg, the concentration of SDS was varied from $1\cdot10^{-4}$ to $1\cdot10^{-3}$ mol/kg and was below its c.m.c. The dye and the surfactant solutions were prepared in water which was purified by ion exchange. All dyeing processes were carried out in Launder-Ometer at pH value of 4, at liquor ratio 1 : 150 at different temperatures in the range from 60 to 80 °C for 360 minutes until the equilibrium was reached. The dyed samples were rinsed in warm and cold tap water and dried in open air.

2.3 Color measurements

The reflectance values of the dry, dyed nylon 6,6 samples were measured at twenty different points on each sample by the use of Datacolor Spectraflash SF 600 Spectrophotometer. From the reflectance (R) values the corresponding color strength (K/S values) and CIE L*, a*, b*, C* and h° co-ordinates were calculated at λ_{max} of the dyeing.

3. RESULTS AND DISCUSSION

To be able to analyse and discuss the results obtained by different approaches used to determine dyeing levelness, it is necessary to consider all R values, the corresponding K/S values and CIE L*, a*, b* co-ordinates which are obtained at twenty points on the same dyed nylon 6,6 sample. K/S value, which is proportional to the absorbed dye on the fibre, was calculated according to Kubelka-Munk equation [3,4]:

$$\frac{K}{S} = \frac{(1-R)^2}{2R} = ac \qquad (1)$$

where K is the coefficient of absorption, S the coefficient of scatter, a the absorption coefficient and c the dye concentration. In Tables 1 and 2 the colorimetric parameters measured on two representative samples A and B, which are dyed under different conditions, are selected. Table 3 shows the calculated mean values of these colorimetric parameters for both dyeings.

Measurements of CIE L*, a*, b* co-ordinates enable the calculation the color difference ΔE* between two representative points on the same sample [4, 5]:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad (2)$$

where one of the points is chosen as the standard and the other as the trial. If ΔE* > 1 then the total colour difference is perceptible. Since the color difference is calculated between two points on the same sample the value of ΔE*, which is higher than unity, indicates the dyeing unlevelness. Color differences calculated for the studied samples A and B are selected in Table 4.

Table 1: Colorimetric parameters for the nylon 6,6 sample (marked A) dyed with 2 % omf dye AR88 at 80 °C without added surfactants.

Point	L*	a*	b*	R (%)	K/S
1	34,76	53,63	22,81	2,05	23,40
2	34,49	53,45	22,68	2,02	23,76
3	34,58	53,38	22,62	2,06	23,28
4	34,57	53,79	22,94	2,02	23,76
5	35,10	53,58	22,51	2,15	22,27
6	34,50	53,37	22,54	2,06	23,28
7	34,33	53,53	22,86	1,98	24,26
8	34,67	53,64	22,84	2,04	23,52
9	34,32	53,68	22,99	1,96	24,52
10	34,96	53,53	22,65	2,13	22,48
11	34,64	53,51	22,82	2,08	23,05
12	35,03	53,70	22,79	2,15	22,27
13	34,19	53,72	22,36	1,94	24,78
14	34,50	53,90	23,48	1,97	24,39
15	34,29	53,38	23,08	2,01	23,89
16	34,31	53,40	23,21	2,02	23,76
17	34,68	53,53	23,11	2,08	23,05
18	34,73	53,69	23,17	2,07	23,16
19	34,31	53,62	23,45	1,97	24,39
20	34,52	54,02	23,51	1,96	24,52

Table 2: Colorimetric parameters for the nylon 6,6 sample (marked B) dyed with 2 % omf dye AR88 at 80 °C in the presence of SDS/TX100 surfactant mixture (the concentration of TX100 is $1\cdot10^{-2}$ mol/kg and of SDS is $1\cdot10^{-4}$ mol/kg).

Point	L*	a*	b*	R (%)	K/S
1	36,38	53,94	21,19	2,27	21,04
2	36,53	53,89	21,11	2,33	20,47
3	37,04	54,40	21,24	2,36	20,20
4	36,78	54,37	21,43	2,29	20,85
5	36,64	54,00	21,43	2,30	20,75
6	37,42	55,10	21,89	2,37	20,11
7	36,75	54,19	21,53	2,30	20,75
8	36,70	53,92	21,30	2,33	20,47
9	36,83	54,03	21,47	2,35	20,29
10	36,75	53,92	21,31	2,35	20,29
11	36,89	54,79	21,74	2,29	20,85
12	37,24	54,85	21,71	2,35	20,29
13	37,11	54,79	21,66	2,33	20,47
14	37,21	55,10	21,95	2,32	20,56
15	37,51	55,33	21,86	2,31	20,66
16	37,52	55,16	21,84	2,37	20,11
17	37,51	55,16	21,85	2,31	20,66
18	37,69	55,50	21,91	2,32	20,56
19	37,28	55,00	22,06	2,32	20,56
20	37,42	55,28	22,20	2,31	20,66

Table 3: The mean values of colorimetric parameters calculated for samples A and B.

Sample	L*	a*	b*	R (%)	K/S
A	34,57	53,60	22,92	2,04	23,59
B	37,06	54,64	21,63	2,32	20,53

Table 4: Color differences (ΔE*) calculated for samples A and B.

Sample	Standard	ΔE^*_{mean}	ΔE^*_{max}
A	point 1	0,45	0,78
	point 5	0,77	1,24
	mean values	0,40	0,72
B	point 1	1,16	2,16
	point 18	1,19	2,16
	mean values	0,68	1,10

It can be seen from Table 3 that the addition of the surfactants SDS and TX100 into the dye bath reduces the concentration of the dye on the substrate at the equilibrium. The result of this is lower K/S value of sample B in comparison with sample A dyed in the absence of the surfactants. The statistical analysis shows that the deviation of the K/S value is much lower in sample B (s = 0,26) than that in sample A (s = 0,75). That means that the uniformity of dye distribution on sample B is higher compared to sample A, which confirms our previous assumption that surfactants act as levelling agents in dye bath. The difference between the uniformity of the studied dyeings was confirmed by F test, where the ratio of the variances is calculated as follows [6]:

$$F = \frac{s_A^2}{s_B^2} = \frac{0,568}{0,066} = 8,61 \qquad (3)$$

This is based on 19 and 19 degrees of freedom. Based on the critical $F_{0,01} = 4,7$ value, we found out that the difference between the variances of dyed samples A and B is statistically significant.

To investigate the dyeing levelness from the color difference ΔE*, which is calculated from the CIE L* a* b* co-ordinates between representative points on the same dyed sample, we found out that the value of ΔE* is directly dependent on the position of the chosen standard in the color space. As a result of this its value can vary to a great extent at the same measured points. If the co-ordinates of the first measured point are taken as the standard and the other points are treated as the trials, the mean value ΔE^*_{mean} as well as the maximum value ΔE^*_{max} of color differences can be much more different compared to those obtained when the standard co-ordinates L*, a* and b* represent the mean values of all measured points (collected in Table 3). The second approach is used for comparison of the color difference between two dyed samples. It can be seen from Table 4 that when the standard co-ordinates are very similar to the mean values of all measured points (point 1 on sample A) the calculated ΔE^*_{mean} and ΔE^*_{max} values are much lower than those which are obtained when the co-ordinates of the chosen standard are extremely high or low (point 5 on sample A and points 1 and 18 on sample B). It is also seen from the results in Table 4 that the levelness of sample A is higher compared to sample B. This is in contrast with the results obtained on the basis of statistical analysis of the K/S values.

These results enable the conclusion that the calculation of the ΔE* value itself is not sufficient to determine the dyeing levelness, and that the K/S value, its deviation and the variance have to be taken into account.

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Associate Prof. Dr. Barbara Simončič, University of Ljubljana, Faculty of Natural Sciences and Engineering Department of Textiles, Snežniška 5, 1000 Ljubljana, Slovenia. Phone: +386 1 200 3231, Fax: +386 1 425 3175, E-mail: barbara.simoncic@ntftex.uni-lj.si
Mateja Kert, M.Sc., Assistant, University of Ljubljana, Faculty of Natural Sciences and Engineering Department of Textiles, Snežniška 5, 1000 Ljubljana, Slovenia. Phone: +386 1 200 3233, Fax: +386 1 425 3175, E-mail: mateja.kert@ntftex.uni-lj.si

THE INFLUENCE OF SUPERMOLECULAR STRUCTURE ON DYEING PROPERTIES AND COLOR OF PA 6 FIBRES

Simona Strnad, Slava Jeler,
Laboratory for Characterization and Processing of Polymers, Faculty for Mechanical Engineering, University of Maribor, Maribor, Slovenia,
Sonja Malej
Department of Textiles, Faculty for Natural Sciences and Engineering, University of Ljubljana, Ljubljana, Slovenia

Abstract

This research focused on investigating the relationships between the structural and dyeing properties of PA 6 fibres. PA 6 monofilament yarn samples having different crystallinity degrees and different content of alpha, respectively gamma crystalline modifications were applied. The diffusion coefficients of two different acid dyes and the content of dyes absorbed by fibre samples were determined. In the second phase of the investigation the samples were dyed with the two above-mentioned acid dyes in a conventional dyeing process. The dyeability of differently modified PA 6 fibre samples was determined colorimetricaly (reflection measurements and calculation of L, a*, b*, C*, h coordinates of CIELAB color space) and color differences determined between untreated raw samples and structurally modified samples.*

The dyeability of PA 6 fibres does not always decrease with an increased degree of crystallinity because it also depends on the way in which crystallinity has been achieved, i.e. on the material's history. Fibres that contain only alpha or only gamma crystalline modifications show different sorption properties and dyeability. The diffusion of dyestuff and dyeability starts to lower after the crystalline degree starts to increase. Contrary to expectations, dyeability is being strongly increased when the crystalline level is significantly increased presumably owing to the formation of bigger voids in the structure..

Keywords: *Fibres, Polyamide 6, Structure, Dyestuff Diffusion, Colorimetry*

1. INTRODUCTION

Research into structure/diffusion interdependence was, for a long time, based on the cognition that fibres are two-phase systems, built from dense packed crystalline regions (non-accessible for water media), and from tie-molecules, loose chain loops and ends of macromolecules composed amorphous regions (accessible for water media). Consequently the simplest (two-phase) model for the description of diffusion processes into partly crystalline polymers discusses non-arranged amorphous regions as only one phase. Analyses of the swelling and absorption processes of oriented polymers, however, gave more complex results. The ordering level of amorphous regions changes and cannot be exactly evaluated at the moment. It should be considered, because of this, that diffusion processes also occur in non-crystalline phases at different local speeds. The fibres' structure can, therefore, be spoken about in regard to at least three phases [1].

Fibre dyeability can be treated as one of the most important absorption properties.

Structural differences have a large influence on dyeing kinetics, dyeability and the color of fibres. Some of them have a grater influence on dye diffusion into the fibre, whilst others have a grater influence on dye uptake at the equilibrium [5,6]. The influence of polymer structure on dye absorption has been mainly researched from the viewpoint of different orientation (stretching) of the polymers' structural elements [2,3,7-10].

In the field of structure/dyeability interdependence analyses two basic models of oriented polymer structure generally still predominate – the so-called 'pore-model' and the 'free-volume-model'. Both of them represent only a simplified image of the actual conditions, however, they result from a large amount of research work on this field [6,7,9,11].

In each fibre/dyestuff dyeing system both of the two models (pore- or free-volume) effect with different intensities [13]. It depends on the polymer chemical structure, crystallinity degree, amount of stable voids, flexibility of segments and on the dimensions of the diffusive molecules or ions, which model will prevail. It was stated, that dye diffusion into acrylic fibres runs below the glass transition temperature in accordance with 'pore-model' and above it in accordance with 'free-volume-model' [14]. On the basis of such statements a new 'dynamic-network model' was proposed [2,15]. The latter combines both very different former models: temperature-dependent flexibility of the chain segments and dye diffusion (free-volume model), and the pore-model [4].

The complexity of a textile fibres' structure and the complexity of dye-molecules, generates a large amount of phenomena, the majority of which still cannot be explained. In some dye/fibre systems and dyeing processes there many different influences and impacts appear, which do not enable an exact mathematical evaluation. In any case the main reason for obscurities in this field is the fact that the ordering level of the regions inside a fibre, which are accessible for dye-molecules, still cannot be defined exactly using only one direct method [6]. There are many publications, therefore, about the introduction of new methods for this research field [4,16-19].

Colorimetry is a very well known method for color evaluation in the wide field of color and dyestuff application [21,22]. Estimation of this method in regards to sensitivity for the detection of structural changes in fibres has, however, not yet been carried out.

In this investigation PA 6 monofilamet samples with different crystalline structures were applied e.g. degree of crystallinity, amount and perfection of crystalline modifications. Two acid dyes with similar molecular structure but different molar mass were applied to evaluate any interdependence between the structural differences (especially the content of different crystalline modification) of fibre samples, dyestuff structure and dyestuff absorption. Since the influences of the supermolecular structure of oriented polymers on the sorption of smaller molecules (iodine) has been investigated previously [20], we now wanted to explain the behavior of a similar system but with absorption of much more complex molecules.

2. METHODS

PA 6 monofilament yarn (22dtex, d=57 µm) was used as an origin sample. Monofilament samples with different super-molecular structure were produced using different annealing procedures and treatments in solutions. Applied samples and their structural properties are listed in table 1.

Table 1: Sample preparation methods and some thermal and structural properties of PA 6 samples: orientation factor ($f_{(\Delta n)}$), glass-transition temperature (T_g [°C]), crystallinity degree (X_c), amounts of alpha and gamma crystalline modification (X_α, X_γ), volume of unit cell (V [nm^3]) and crystalline perfection index of alpha modification (CPI_α)

Sample	Micro-scopy.	DSC	*X-ray*				
	$f_{(\Delta n)}$	T_g [°C]	X_k	X_α	X_γ	V [nm^3]	CPI_α
Std: PA 6 monofilament yarn 22dtex	0.732	56.4	0.34	0.30	0.03	1.321	73.2
V: Std - vacuum at 195°C [23]	0.795	72.1	0.41	0.40	0.01	1.289	83.6
Sio: Std - silicone oil at 210°C [24]	0.781	79.7	0.53	0.53	0.00	1.282	92.8
Vph: V - 4% phenol solution;[23]	0.759	83.9	0.53	0.53	0.00	1.274	95.6
VI: V - iodine solution; [25]	0.737	62.3	0.23	0.03	0.20	1.345	58.4

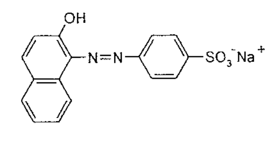

Figure 1: Structure of the dye ACID ORANGE 7 (C.I. 15510) with a molar mass of 350.3 g/mol

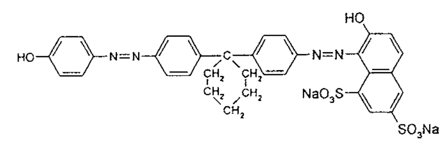

Figure 2: Structure of the dye ACID ORANGE 33 (C.I. 24780) with a molar mass of 730.7 g/mol

2.1 Determination of dye diffusion

Two purified acid dyes with different molecular structures were used (fig.1 and fig. 2) to investigate the dyeing kinetics of structurally modified PA 6 fibres. Diffusion coefficients (D [cm2/s]) and the concentration of the dye in the fibre at the equilibrium ($c_{f\infty}$, [mol/kg]) were determined by isothermal rate-of-dyeing curves relating to the total concentration of the dye in the fibre ($c_{f\infty}$,) to time of dyeing (t) followed by dye-bath absorbance (A) measurements.

The diffusion coefficients were determined on the basis of presumption that the dyeing is performed in the so-called infinite bath i.e. very large volume of liquor and that fibres are infinitely long cylinders of radius r. Under these conditions the solution of Fick's second law is simplified to the following equation [13]:

$$F = \frac{M_t}{M_\infty} = \frac{c_t}{c_\infty} \cong 4\left(\frac{Dt}{\pi r^2}\right)^{\frac{1}{2}} \qquad (1)$$

where:
F – degree of dye absorption or dyeing rate
M_t/M_∞ - degree of absorption
D – diffusion coefficient [cm^2/s]
t – time of diffusion [s]
r – fibre radius [cm]

Diffusion coefficients (D) were determined experimentally from the gradient of the linear region of a plot of c_t/c_∞ against $t^{1/2}$ at the early stages of dyeing (when F<0.05). Diffusion experiments were performed under the following conditions: temperature T=40°C (below glass-transition temperature), pH=3.8 (with CH3COOH), liquor ratio = 1:1470 (where the dye concentration decrease was negligible). To remove all dye molecules, which were deposited on the fibre surface through weak dye-fibre interactions, after the diffusion experiment a fibre sample was immersed into 250 ml of water and shaken for 1 hour at 25°C. The amount of non-bounded dyestuff was determined spectrometrically.

2.2 Dyeability and color evaluation

Samples were dyed with both acid dyes in an Ahiba Turbomat apparatus with six working places in the same thermostatic bath. To detect structure differences, the dyeing system was simplified (composed only of water, dyestuff and electrolyte) and the dyeing temperature (40°C) was below the samples' glass-transition temperature. The other dyeing conditions were as follows: dyeing time t=150 min, liquor ratio = 1:300, pH=3.8 (with CH3COOH).

The color of the dyed samples was determined using colorimetry on the basis of the samples' reflectance measurements. The CIELAB color space coordinates (L*, a*, b*, C* and h) were calculated together with the color differences between the standard monofilament sample and the structurally modified samples (ΔL*, Δa*, Δb*, ΔC*, ΔH* and ΔE*).

The dyeing results were evaluated using Datacolor equipment for color determination and color differences calculation.

3. RESULTS AND DISCUSSION

In the table 1 some structural properties of applied samples are listed. It can be seen that during the treatments orientation of fibres' structural elements were not changed. Fibre samples were processed in stretched conditions, thus the changes in dyestuff absorption were not influenced by different orientation.

In the table 2 the diffusion coefficients (D [cm^2/s]) and the concentration of the dye in the fibre at the equilibrium (c_f, [mol/kg]) for both applied dyestuffs are represented.

Table 2: The diffusion coefficients (D [cm^2/s]) and the concentration of the dye in the fibre at the equilibrium (c_f, [mol/kg]) for both applied dyestuffs Acid Orange 7 (AO7) and Acid Orange 33 (AO33)

Sample	AO7		AO33	
	c_f [mol/kg]	D [cm^2/s]	c_f [mol/kg]	D [cm^2/s]
Std	0,0154	1,26E-10	0,0102	9,17E-11
V	0,0029	7,67E-11	0,0029	6,12E-11
Sio	0,0141	1,08E-10	0,0081	4,59E-11
VPh	0,0219	3,11E-10	0,0177	8,29E-11
VI	0,0117	1,42E-10	0,0084	7,07E-11

After vacuum treatment (Vac sample) the concentration of dyestuff in the fibre drastically decreases in comparison with the untreated sample, despite the relatively small structural differences (tables 1 and 2). This sample absorbed the same amount of both dyestuffs. It can be stated that on the inside of the Vac sample the majority of voids or capillaries, respectively, are too small for diffusion by both relatively big dyestuff molecules.

The sample treated in silicone oil (Sio) has a larger mount of ordered regions in comparison with the Std sample (by about 57%). In the sample Sio crystalline regions have only alpha-monoclinic symmetry with a high ordering level. All the differences are also reflected in the samples' glass-transition temperatures (table 1). Larger differences in dyestuff uptake would be expected on the basis of the listed structural properties in comparison with the Std sample. The concentration of dyestuff in the Sio fibre sample at the equilibrium is in comparison with the Std sample smaller by less than 1 %. The accessibility for dyestuff is, by means of the dye uptake, obviously unchanged to a great extent despite of huge alterations in the crystalline and amorphous regions. The same tendency in the Sio sample can also be observed whit the VPh sample. The VPh sample has the same structural properties as the Sio sample, but the dyestuff concentration in the fibre at the equilibrium is higher by about 50% for the

Acid Orange 7 and by up to app. 100% in comparison with the Std sample for Acid Orange 33. It can be assumed that the re-ordering of macromolecules and re-crystallization which occur during the treatments in a vacuum, and phenol solution produce large amounts of crystaline regions and consecutively smaller amounts of amorphous parts. However, owing to the incorporation of the loose loops and ends of macromolecules (from the amorphous regions) into the growing crystallites, smaller amounts of amorphous regions in the VPh sample are 'emptier' and in such a way accessible to bigger dyestuff molecules.

The sample VI is structurally the most different from the other samples. It has a lower degree of crystallinity than the Std sample (by app. 30 %), lowest content of monoclinic alpha modification and a large amount of gamma crystalline modification. These differences in the crystalline structure evidently signify large differences in accessible non-ordered regions in comparison with the Std sample. Despite the lower degree of crystallinity (larger content of accessible regions) the sample VI absorbs smaller amounts of both dyestuffs in comparison with the Std sample. It can be assumed that in sample VI there are a larger amount of amorphous regions, which are less accessible for big dyestuff molecules (in water media at 40°C) than those in the sample Std.

An increase in the crystallinity degree causes changes in diffusion coefficients but, the interdependence is, however, non-linear. The same tendency for both dyestuffs can be observed, bigger differences, however, for smaller dye molecules.

Sample VI indicates a higher diffusion coefficient than samples Std and V. The accessible regions in sample VI are able to receive smaller amounts of both dyestuffs in comparison with STD and V, but with a higher velocity. The diffusion coefficients of the Acid Orange 33 dyestuff in samples STD, V and VI indicate no differences.

Color lightness (L*), color saturation (C*) and the hue (h) were chosen as the most appropriate parameters to describe the dyeability of the dyed samples. In the Table 3 the color lightness, color saturation and the color hue of the dyed samples are presented.

Table 3: Lightness (L*), saturation (C*) and the hue (h) of the samples dyed with dyestuffs Acid Orange 7 (AO7) and Acid Orange 33 (AO33)

Sample	AO7			AO33		
	L*	C*	h	L*	C*	h
Std	56,57	71,56	54,17	60,31	42,96	39,27
V	69,44	33,98	42,72	69,16	25,55	23,47
Sio	55,32	73,94	56,14	61,15	43,25	39,89
VPh	40,94	47,99	48,78	52,99	57,59	39,20
VI	66,07	46,59	45,75	68,35	33,98	27,12

The lightness (L*) of the samples with an increased degree of crystallinity and amount of alpha modification (V, Sio and VPh) changes according to dyestuff absorption (tables 1 and 2). The color lightness of sample V is the highest and the sample color is the least saturated (table 3). There are no differences between the L* values of the V samples dyed with AO7 or AO33, the color saturation C* of the sample, dyed with AO33 is, however, lower. The negative color difference in hue (ΔH* - table 4) indicates that the color of both V samples is more bluish in comparison with the Std samples.

The Sio sample has the same L* values (for both dyes) as the Std sample as well as the same C* and h, therefore the two samples can be said to have the same color. It can be concluded that despite the huge structural differences between the Sio and Std samples, both samples have similar dyeing properties (all the color differences are smaller or close to 2, which means that the differences are no longer detectable with an unaided eye). It can be stated that despite the large structural differences between the samples, after the dyeing procedure the same sample color is reached.

For a more accurate representation of the differences in the samples' dyeing properties, the color differences between the structurally modified samples and the standard untreated sample are listed in table 4.

Table 4: Color differences (ΔL*, Δa*,Δb*, ΔC*,ΔH*, ΔE*) between samples after dyeing with the dyestuffs Acid Orange 7 (AO7) and Acid Orange 33 (AO33) – standard sample: STD

SAMPLE	AO7						AO33					
	ΔL*	Δa*	Δb*	ΔC*	ΔH*	ΔE*	ΔL*	Δa*	Δb*	ΔC*	ΔH*	ΔE*
STD												
V	12,9	-16,9	-35,0	-37,6	-6,8	40,3	8,8	-9,8	-17,0	-17,4	-7,0	20,8
Sio	-1,2	-0,7	3,4	2,4	2,5	3,7	0,8	-0,1	0,5	0,3	0,5	1,0
VPh	-15,6	-10,3	-21,9	-23,6	-4,5	28,6	-7,3	11,4	9,2	14,6	-0,1	16,4
VI	9,5	-9,4	-24,6	-25,0	-6,8	27,6	8,0	-3,0	-11,7	-9,0	-7,2	14,0

The sample VPh expresses smaller L* values after dyeing with both dyestuffs in comparison with the Std sample. This is in accordance with the dye uptake - this sample absorbs most of the dyestuffs. The color saturation (C*) of the sample dyed with AO7 is, however, smaller in comparison with the Std sample and the color hue of the sample is also more bluish (table 3 and 4). It can be stated that during the dyeing process the positioning and bounding of the AO7 molecules was not the same in both samples. Electrostatic dyestuff/fibre interactions are prevalent during the dyeing of PA 6 fibres with anionic dyes. Because of the increased affinity of anionic dyestuff with an increase of their molecular mass and according to Giles [5], however, other types of interactions can appear (Van der Waals, hydrophobic). In the case of different interactions of dyestuff/fibre, different colors can appear.

In the case of AO33 dyestuff, there are smaller differences in L* between the samples VPh and Std. The color of the sample VPh is darker and more saturated, but in color hue there is no difference. In comparison with the Sio sample, VPh has the same degree of crystallinity, amount of alpha crystalline modification and ordering level. In dyestuff absorption, however, both of the samples have very different properties. It can be stated that the way in which some structural properties are attained has the biggest influence on the conditions inside the amorphous regions, which has an influence on the dyeing properties of the fibres.

The crystalline structure of sample VI is different in comparison with the other samples. It has the smallest degree of crystallinity, and contains only gamma crystalline modification with a low ordering level. These differences are also reflected in the dyeing properties and color of the sample. In comparison with sample Std, the color of sample VI is lighter, less saturated and more bluish. The color differences are in accordance with the differences in dye absorption. Despite the lower degree of crystallinity and, therefore, grater amount of accessible non-ordered regions, sample VI cannot absorb as many complex dyestuff molecules as the Std sample. It can be concluded, that the 'channels', which build

accessible regions in the sample, are too small to accept relatively large dyestuff molecules.

4. CONCLUSIONS

The complexity of textile fibres' structure and the complexity of dye-molecules, generates large amounts of phenomena, the majority of which as yet cannot be explained. Many different influences and impacts appear in some dye/fibre systems and dyeing processes there, which do not enable an exact mathematical evaluation. In any case the main reason for obscurities in this field is the fact that the ordering conditions of accessible regions in the swollen state (wet state) cannot be defined exactly using only one direct method.

There is no linear correlation between the dyeability of the fibres and their degree of crystalliniy. If the range of crystallinity degree increases by 20% (sample V) the dyestuff concentration in the fibre at the equilibrium decreases by app. 80% and the velocity of the dyestuff absorption (diffusion coefficient) by app. 40%. When the diffusion of smaller and larger dyestuff molecule is compared, the differences in the amounts of dyestuff absorbed are smaller for bigger dye molecules but the differences in diffusion coefficient are larger by 20% (bigger dyestuff molecules penetrate slower). The increased amount of crystalline regions in the sample causes a decrease of amount of accessible regions, the arrangement of which (density) is unchanged to a grate extent. Accessible inner places are composed by: ends of macromolecules, loose loops and tie molecules. They have, below the glass transition temperature, enough free volume to accept only a small amount of large dyestuff molecules.

The dyeing properties of the samples with high crystallinity indices of about 0.53 (increase of app. 60% in comparison with Std) depend on the treatment by which the structure was achieved. The Sio sample, treated for a short time in silicone oil at 210°C, shows, despite large structural differences in comparison with untreated sample, practically no difference in dyeing properties with small dyestuff molecules. The sample, however, absorbs smaller amounts of bigger dyestuff molecules (by app. 20%) and the diffusion coefficient of such molecules is lower (by 50%). Structural changes in the samples' accessible regions, which appear during the short treatment at high temperature, are influenced only by the absorption of larger dye molecules. Otherwise, the sample VPh, has a structure similar to sample Sio, but its treatment is longer and terminates after two stages. In comparison with the other samples VPh absorbs the largest amount of both dyestuffs with the highest velocity, despite of the highest amount of very well ordered non-accessible regions. It can be assumed that the re-ordering of macromolecules and re-crystallization, which occurs during the treatments in a vacuum, and phenol solution produces a large amount of crystaline regions and a consecutively smaller amount of amorphous parts. During the relatively long treatment in stretched conditions, loose loops and the ends of macromolecules (from amorphous regions) have enough time to incorporate themselves into the growing crystallites. It appears there are smaller amounts of amorphous regions, which are, however, unoccupied ('emptier') and in such a way also accessible for bigger dyestuff molecules.

The sample with predominantly gamma crystalline modification (VI) has lower crystallinity degree than the standard sample but dyestuff absorption is, however, contrary to expectations lower.

All the listed differences in dyestuff absorption are very well reflected in color values and color differences between the samples. Colorimetry is a very sensitive method for color evaluation and also detects all the structural differences of fibres, which have an influence on their dyestuff absorption.

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Assist. Prof. Dr. Simona Strnad, Laboratory for Characterization and Processing of Polymers, Faculty for Mechanical Engineering, University of Maribor, Smetanova 17, 2000 Maribor, Slovenia, Phone: +38622207882, Fax: +38622207990, E-mail: simona.strand@uni-mb.si,
Prof. Dr. Slava JELER, Faculty for Mechanical Engineering, University of Maribor, Smetanova 17, SI-2000 Maribor, Slovenia, Phone: +386 2 220 7540, Fax: +386 2 220 7990
Prof. dr. Sonja Malej, Department of Textiles, Faculty for Natural Sciences and Engineering, University of Ljubljana, Snežniška 35, SI, Slovenia, Phone: +386 125 686 49

PSYCHO-PHYSICAL STUDY OF COLOUR MEMORY

T. Tarczali, P. Bodrogi, Colour and Multimedia Laboratory, Department of Image Processing and Neurocomputing, University of Veszprem, Veszprem, Hungary

Abstract

Colour memory plays an important role in many practical tasks related to the choice, identification, and assessment of colours. Long-term memory colours or colour prototypes of familiar objects frequently seen in the past are often preferred by the customers of colour imaging products. Colour memory is also one of the factors responsible for the phenomenon of colour constancy. These facts motivated the authors to construct two different psycho-physical methods to characterise human colour memory on a computer-controlled monitor. The "short-term memory method" and the "abstract method" were compared. The "short term memory method" had two phases: an observation/memorisation phase and a mixing phase. The subject had to mix a just memorised "original" colour by controlling the hue, chroma, and lightness of a colour patch by the aid of three control elements of the user interface at the top of the screen. The abstract method provided more freedom: no original colours were shown. The observer was given only a greyscale photo to mix a uniform colour stimulus on a part of the photo representing an object identifiable in the photo. That colour stimulus is an estimate of the subject's colour prototype for the object. The short term memory of just-seen original colours often moved toward colour prototypes.

Keywords: *cognitive colour, colour memory, colour prototype*

1. INTRODUCTION

Colour memory plays an important role in many practical tasks related to the choice, identification, and assessment of colours. Long-term memory colours or colour prototypes of familiar objects frequently seen in the past are often preferred by the customers of colour imaging products. Colour memory is also one of the factors responsible for the phenomenon of colour constancy. These facts motivated the authors to try to extend their previous results [1-2] and to compare two psycho-physical methods experimentally. The so-called "short-term memory method" and the "abstract method" have been compared in the presence of greyscale image backgrounds depicting familiar objects.

2. METHOD

All experiments were carried out on a well characterised colour monitor by using computer based experimental programs.

The "short-term memory method" had two phases: an observation-memorisation phase and a mixing phase. After memorisation, the original colour disappeared. The colour memory effect was ensured by applying a pause of 4 seconds between the two phases. A full-screen medium grey was displayed in the pause. The subject had to mix the memorised original colour by controlling the hue, chroma, and lightness of a colour patch by the aid of three control elements of the user interface at the top of the screen. The subject could mix any colour that she/he wanted inside the monitor's colour gamut. Greyscale photos were used as background.

The original colour and the variable colour were uniform colour patches placed into a typical and identifiable part of the picture. The role of the greyscale image context was to promote the recall process of colour prototypes and therefore greater memory shifts were expected than without image context.

The "abstract method" provided more freedom for the subject: no original colours were shown. The observer was given only a greyscale photo to mix a uniform colour stimulus on a part of the photo representing an object identifiable in the photo e. g. "green grass". The mixed stimulus can be considered as an estimate of the subject's colour prototype.

3. RESULT AND DISCUSSION

Circles in the CIELAB *a*-b** diagram of Figure 1 show the original colours in the memorisation phase of the short-term memory method when "grass" type greyscale pictures were seen with the uniform colour patch. Crosses indicate the mean colours found by a subject in the mixing phase. There were no significant lightness differences between the original colours and the findings of the observers. Therefore lightness is not shown. Figure 2 contains results from the "abstract method". Triangles represent all colours mixed by the same subject as for the case of Figure 1. This subject carried out the abstract method *after* the short-term memory method (2 weeks later). Circles in Figure 2 are the same as in Figure 1 shown only for the reason of comparison with Figure 1. As can be seen, crosses in Figure 1 are shifted in the direction of the triangles in Figure 2. (Memory shifts are related to the original colours). Therefore it was concluded that the short term memory for just-seen original colours moved toward the colour prototype already existing in the observer's mind. The colour prototype was built during the whole lifetime of the subject as an average of many colour perceptions corresponding to a certain object e. g. green grass. Seeing a familiar object or even a standalone uniform colour patch displayed in several slightly different colour shades after each other during a long "short-term memory" session with many original colours may also lead to building a *new* colour prototype from these original colours. The new prototype would be presumably the average of all original colours (circles in Figures 1 and 2). As can be seen from Figure 2, this was obviously not true in the case of the "abstract method".

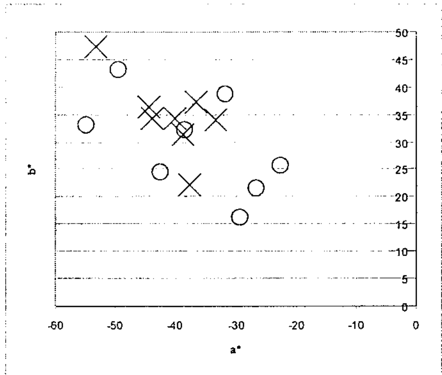

Figure 1: Short-term memory method. "Green grass" original colours (circles) and mean findings of a subject (crosses). L*=50 for all original colours

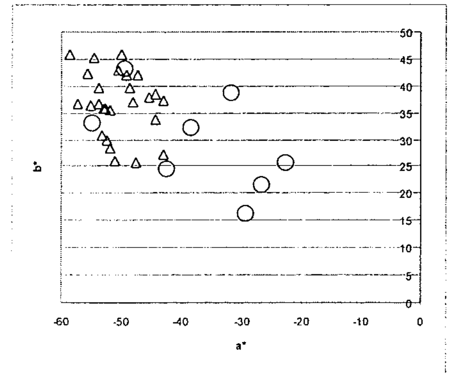

Figure 2: Abstract method. "Green grass" original colours taken from Fig. 1 (circles) and the findings of the same subject as in Fig. 1 (triangles).

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Tünde Tarczali ME, Colour and Multimedia Laboratory, Department of Image Processing and Neurocomputing, University of Veszprém, Egyetem u. 10, H-8200 Veszprém, Hungary. Phone: +36 88 422 022 4603, Fax +36 88 422 022 4606, E-mail: jane@ond.vein.hu
Peter Bodrogi Ph. D., same address and fax, Phone: +36 88 422 022 4609, E-mail: bodrogi@almos.vein.hu

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