Applications of colorimetry in industry and design
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A new method is described to calibrate tristimulus colorimeters for high accuracy color measurements. Instead of traditional lamp standards, high accuracy detector standards are suggested for calibration. After accurate absolute spectral response determination of the tristimulus receivers, color (spectral) correction and peak (amplitude) normalization can minimize uncertainties caused by imperfect realizations of the Commission Internationale de l'Eclairage (CIE) color matching functions. The calibration procedure can be applied to various measurement geometries (e.g., illuminance, luminance, luminous flux, or luminous intensity) depending on the units in which the absolute spectral responsivities are expressed. Also, existing tristimulus colorimeters can be calibrated, where the spectral response of the receivers can be measured. As a result of the corrections, stable light sources of different spectral power distributions can be measured with an accuracy dominated by the spectral response determinations. With 0.1 % relative expanded uncertainty (k=2) in response measurements, the chromaticity coordinate expanded uncertainties (not relative) will be less than 0.001. This corresponds to a color temperature measurement accuracy equal to or better than that of presently used primary lamp standards.
1. Introduction

Tristimulus colorimetry is based on light measurement using three or more receivers with spectral responsivities matched to the Commission Internationale de l'Eclairage (CIE) $x(\lambda)$, $y(\lambda)$, and $z(\lambda)$ color matching functions [1]. To achieve accurate measurements for a large variety of light sources, the spectral matches should be as close as possible to the color matching functions. The receivers are usually realized with silicon photodiodes and attached filter packages [2]. Usually, the spectral mismatch between the realized and the color matching functions give the dominant uncertainties in tristimulus color measurements.

At present, tristimulus colorimeters are calibrated with standard lamps. The calibration of the most frequently used color temperature standard lamps is derived from source-based spectral irradiance scales. NIST reported a 0.67 % relative expanded uncertainty ($k=2$) for the disseminated spectral irradiance standard lamps in the visible range and a relative 0.59 % long-term reproducibility [3]. Research is being conducted at NIST to decrease the 0.67 % uncertainty by a factor of three still using standard lamps [4]. The accuracy of the standard lamp influences the photometric (receiver matched to $y(\lambda)$) accuracy of the tristimulus colorimeter. The wavelength dependent (e.g. burning time caused) changes of the standard lamp influence the colorimetric accuracy of the tristimulus meter.

Several commercially available colorimeters were compared for accuracy by measuring nine different laser lines (saturated colors) by Berns et al. [6]. The differences between the theoretical and the measured chromaticity coordinates were reported. The lowest rms errors in $x$ and $y$ (0.0042 and 0.0051, respectively) were observed on a tristimulus colorimeter employing partial (mosaic) filters. The errors are expected to decrease to a large extent for

1 Throughout this paper uncertainties are given as relative expanded uncertainties with a coverage factor $k=2$, unless otherwise stated [5].
white light sources, such as tungsten lamps. The reported errors were dominated by spectral response deviations (mismatch) of the receivers relative to the CIE recommended color matching functions. The uncertainties of the calibrating standard lamps also contributed to the results.

In contrast to source standards, primary standard detectors (cryogenic radiometers) can measure optical (radiant) power with an uncertainty of $10^{-4}$ [7, 8]. Certain type silicon detectors, in a light-trap arrangement, can be calibrated against primary standard radiometers using several intensity stabilized lasers [9]. With interpolation between the laser lines, a 0.06 % uncertainty in spectral responsivity was reported on light-trap Si detectors between 406 nm and 920 nm [10]. This uncertainty is about one fourth of the uncertainties reported for traditional monochromator based detector spectral response measurements [11].

Achievable total uncertainty of spectral transmittance measurements on high quality color filters is reported to be $2 \times 10^{-4}$ [12].

A narrow-band filter-radiometer was calibrated for spectral irradiance response in the visible region against a trap detector with an uncertainty of 0.07 % [13] for measured irradiance. In that report, the dominant uncertainty components were the uncertainties of the trap detector response, 0.036 %, the area of the trap aperture, 0.034 %, and the wavelength reproducibility, 0.026 %.

If the uncertainties of the receiver response measurements are very small, the spatial response non-uniformities of the filter-detector packages could limit the accuracy of the tristimulus measurements. This problem can be avoided if apertures are used in front of the filter-detector packages and the apertures are overfilled with the uniform field of the (point) source to be measured. The area of the apertures was measured with an uncertainty of 0.026 % [14].
The motivation behind the development of a detector-based calibration method for tristimulus colorimeters was to utilize the significantly lower uncertainty of new detector standards compared with traditional lamp standards. The goal of the method described in this paper is to determine broad-band calibration factors for all tristimulus receivers to minimize measurement uncertainty. If the spectral response determination of the receivers is accurate, application of the calibration factors for different source distributions will result in high colorimetric accuracy. This multiple receiver method is an extension of the single receiver spectral mismatch correction used in our detector-based illuminance scale realization [15, 16].

2. Theoretical basis

In order to determine \( x, y \) chromaticity coordinates of a light source, the CIE tristimulus values of the source are to be obtained by

\[
X = k \int S(\lambda) \bar{x}(\lambda) \, d\lambda
\]

\[
Y = k \int S(\lambda) \bar{y}(\lambda) \, d\lambda
\]

\[
Z = k \int S(\lambda) \bar{z}(\lambda) \, d\lambda
\]

where \( S(\lambda) \) is the spectral power distribution of the source to be measured; \( \bar{x}(\lambda), \bar{y}(\lambda), \) and \( \bar{z}(\lambda) \) are the 1931 CIE color-matching functions; and \( k \) is a normalization factor. In practice, \( \bar{x}(\lambda) \) is realized by two receivers, \( \bar{x}_L(\lambda) \) and \( \bar{x}_s(\lambda) \):

\[ \bar{x}_s(\lambda) = 0 \text{ and } \bar{x}_L(\lambda) = \bar{x}(\lambda) \text{ if the wavelength is longer than 504 nm, and} \]

\[ \bar{x}_L(\lambda) = 0 \text{ and } \bar{x}_s(\lambda) = \bar{x}(\lambda) \text{ if the wavelength is shorter than 504 nm.} \]

(Note that the subscripts L and S mean long and short, respectively.)

The CIE tristimulus value \( X \) can be written as:

\[
X = X_1 + X_2,
\]

where

\[
X_1 = k \int S(\lambda) \bar{x}_L(\lambda) \, d\lambda, \text{ and}
\]

\[
X_2 = k \int S(\lambda) \bar{x}_S(\lambda) \, d\lambda.
\]
Y in Eq. (1) will give an absolute photometric quantity (e.g. in lux) [15] if

\[ k = K_m = 683 \text{ lm/W.} \]  

(3)

The measured photodiode output currents of the four separate receivers are

\[ I_{x1} = \int S(\lambda) s_{x1}(\lambda) d\lambda \]
\[ I_{x2} = \int S(\lambda) s_{x2}(\lambda) d\lambda \]
\[ I_y = \int S(\lambda) s_y(\lambda) d\lambda \]
\[ I_z = \int S(\lambda) s_z(\lambda) d\lambda \]  

(4)

where \( s_{x1}(\lambda) \), \( s_{x2}(\lambda) \), \( s_y(\lambda) \), and \( s_z(\lambda) \) are the absolute spectral responsivities of the color measuring receivers (channels).

When measuring a light source of known spectral power distribution \( S(\lambda) \), the receiver calibration factors can be determined from the ratio of Eq. (1) to Eq. (4):

\[ k_{x1} = \frac{K_m \int S(\lambda) x_1(\lambda) d\lambda}{I_{x1}} = \frac{K_m \int S(\lambda) s_{x1}(\lambda) d\lambda}{\int S(\lambda) s_{x1}(\lambda) d\lambda} \]
\[ k_{x2} = \frac{K_m \int S(\lambda) x_2(\lambda) d\lambda}{I_{x2}} = \frac{K_m \int S(\lambda) s_{x2}(\lambda) d\lambda}{\int S(\lambda) s_{x2}(\lambda) d\lambda} \]
\[ k_y = \frac{K_m \int S(\lambda) y(\lambda) d\lambda}{I_y} = \frac{K_m \int S(\lambda) s_y(\lambda) d\lambda}{\int S(\lambda) s_y(\lambda) d\lambda} \]
\[ k_z = \frac{K_m \int S(\lambda) z(\lambda) d\lambda}{I_z} = \frac{K_m \int S(\lambda) s_z(\lambda) d\lambda}{\int S(\lambda) s_z(\lambda) d\lambda} \]  

(5)

By normalizing the color matching functions to their peak values, the receiver calibration factors can be written as:
by introducing the color correction factors:

\[ F_{x1} = \frac{\int \lambda S(\lambda) \bar{X}_{L}(\lambda) \, d\lambda}{\int \lambda S(\lambda) \, d\lambda} \]

\[ F_{x2} = \frac{\int \lambda S(\lambda) \bar{X}_{2}(\lambda) \, d\lambda}{\int \lambda S(\lambda) \, d\lambda} \]

\[ F_{y} = \frac{\int \lambda S(\lambda) \bar{Y}(\lambda) \, d\lambda}{\int \lambda S(\lambda) \, d\lambda} \]

\[ F_{z} = \frac{\int \lambda S(\lambda) \bar{Z}(\lambda) \, d\lambda}{\int \lambda S(\lambda) \, d\lambda} \]

where \( s_{x1}(599) \), \( s_{x2}(442) \), \( s_{y}(555) \), and \( s_{z}(446) \) are the absolute responses of the realized receivers at the peak wavelengths of the color matching functions; and \( s_{x1}(\lambda) \), \( s_{x2}(\lambda) \), \( s_{y}(\lambda) \), \( s_{z}(\lambda) \) are the relative responses of the realized receivers normalized also at the
peak wavelengths of the color matching functions. The peak wavelengths of the realized receivers are not necessarily equal to the peak wavelengths of the color matching functions.

A color correction factor will be unity if the normalized channel response is equal to the normalized CIE color matching function.

Once the tristimulus colorimeter is calibrated for $k_{X_1}$, $k_{X_2}$, $k_Y$, and $k_Z$, the tristimulus values of a test light source can be measured as

$$X' = X_i' + X_2'$$
where $X_i' = k_{X_1} I_{X_1}'$ and $X_2' = k_{X_2} I_{X_2}'$

$$Y' = k_Y I_Y'$$

$$Z' = k_Z I_Z'$$

(3)

where $I_{X_1}'$, $I_{X_2}'$, $I_Y'$, and $I_Z'$ are the measured output currents of the tristimulus receivers.

The calibration procedure can be applied to various measurement geometries (e.g., illuminance, luminance, luminous flux, or luminous intensity) depending on the units in which $s_{X_1}(599)$, $s_{X_2}(442)$, $s_Y(555)$, and $s_Z(446)$ are expressed.

3. Achievable accuracy

In order to obtain the highest color measurement accuracy, the receiver calibration factors are to be redetermined for all $S(\lambda)$ source distributions to be measured. The spectral mismatch of the receivers, relative to the CIE functions, should be small to allow for relatively large uncertainties when determining $S(\lambda)$. It was shown in an earlier work [16] that the change of $F_T$ with a high quality spectral match of $\Delta T=1.43 \%$ [2], was 0.1 % for a color temperature change from 2600 K to 3200 K of a Planckian radiator. With a lower quality spectral match.
of $f_1^*=3.4\%$, which is typical for the red and blue receivers, the change in $F_\gamma$ would be larger, still allowing for a large enough uncertainty of $S(\lambda)$. The final $S(\lambda)$ for tungsten lamps, which are more or less similar to Planckian radiators [17], can be obtained by iterating the Planckian function (at different temperatures) and the tristimulus measurements, until the highest color measurement accuracy is reached. For other types of sources with smoothly varying spectral power distribution (e.g. many kinds of paints, color tiles, etc.), $S(\lambda)$ can be measured with a low accuracy spectroradiometer, and the color measurement accuracy still remains high.

According to the references in the Introduction, the presently achievable relative expanded uncertainty of absolute spectral response determinations is on the order of 0.1 %. The uncertainty of relative spectral response measurements can be lower because of the smaller number of uncertainty components. The uncertainties of the tristimulus values propagate to the uncertainties of the chromaticity coordinates. The chromaticity coordinates can be calculated from the tristimulus values via

$$
x = \frac{X}{X+Y+Z}, \quad y = \frac{Y}{X+Y+Z}.
$$

(9)

Now, assume that the relative uncertainties of $X$, $Y$, and $Z$ are all 0.1 %. For a Standard Illuminant A, where $x=0.4476$ and $y=0.4074$, the worst case scenario ($\Delta X=+0.1\%$, $\Delta Y=-0.1\%$, and $\Delta Z=0\%$) shows a chromaticity coordinate change of $\pm 0.0004$ for both $x$ and $y$, resulting in a $\pm 10$ K change in the correlated color temperature. These expanded uncertainties are similar to those reported for the source-based NIST color temperature scale [18]. With improvements of spectral response determinations (as suggested below), the accuracy of detector-based tristimulus color measurements can be further increased.
4. Suggested realizations

The described detector-based calibration method can be applied to the calibration of existing tristimulus colorimeters where the spectral response of the tristimulus receivers can be measured. The achievable color measurement accuracy will depend on the uncertainty of the spectral response measurements.

Standard quality tristimulus colorimeters can be constructed using high accuracy detector standards such as trap detectors. The advantage of using silicon trap detector standards is that the spectral response of the trap detector can be determined directly against a primary standard cryogenic radiometer [10]. Further advantages of trap detectors are relative response non-uniformities of less than 0.02 % [19] and very low reflectance in the visible wavelength range [9], especially for transmission type versions [20, 21]. The filter packages can be measured separately if they are used with transmission-type trap detectors because of zero back reflection from these detectors.

We have started developing a new facility to calibrate illuminance measuring photometers and tristimulus colorimeters against irradiance measuring trap detectors. These trap detectors will be calibrated against the cryogenic radiometer in the power (detector is underfilled by the laser beam) measurement mode. The trap detectors are equipped with precision apertures and will measure the well-collimated radiation (within the aperture) from point sources to obtain the highest accuracy. The point sources are being realized with small integrating spheres illuminated by tunable lasers. The aperture areas are also measured with point sources. The accuracy of our cryogenic radiometer is being improved to achieve radiant power measurements with an uncertainty of between 0.01 % and 0.02 %. The expected spectral irradiance response uncertainty of the irradiance trap detectors (for point sources) is about 0.03 %. Most of our existing illuminance-type meters can be calibrated against the irradiance trap detectors with substitution in the uniform field of the tunable monochromatic...
point source. After spectral response calibrations, the described correction method will be applied. A tristimulus colorimeter calibrated this way will have a chromaticity coordinate measurement uncertainty (expanded but not relative) of about 0.0003. The accuracy of matrix corrected tristimulus colorimeters [22, 23, 24] can also be improved if they are calibrated against the suggested response corrected reference tristimulus colorimeters. Further analysis is suggested to establish a relationship between the $f_i'$ of the receivers and the colorimetric accuracy when spectrally structured and changing source spectral power distributions (e.g. color TV monitors) are measured.

5. Conclusion

The significant decrease of uncertainties in detector spectral response measurements in the past five years motivated the development of a detector-based calibration method for tristimulus colorimeters.

A method for color (spectral mismatch) correction and peak (amplitude) normalization of color measuring tristimulus receivers has been developed. Broad-band calibration factors, based on spectral response measurements of the receivers, can be determined to minimize the color measurement uncertainties caused by the imperfect receiver response realizations. The method utilizes the lower uncertainty of new detector standards relative to traditional lamp standards. The calibration factors can be determined for sources of different spectral power distributions.

Application of the described detector-based calibration method will result in chromaticity coordinate expanded uncertainties (not relative) of less than 0.001. This corresponds to a color temperature measurement accuracy equal to or better than that of presently used primary lamp standards.
References


[23] E 1455-92, Standard Practice for Obtaining Colorimetric Data from a Visual Display Unit Using Tristimulus Colorimeters, ASTM Standards on Color and Appearance Measurement, 4th Ed. (Available from ASTM, 100 Barr Harbor Dr., Wet Conshohocken, PA 19428-2959.)

WORKING WHITES. THEIR INFLUENCE IN THE CIELAB VALUES

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Colour determination of an opaque surface implies obtaining its spectral reflectance and subsequent calculation of Tristimulus Values and Chromaticity Coordinates associated.

The values of the spectral reflectance for an opaque surface refers to a "perfect reflecting diffuser", but usually is obtained in relation with a calibrated item know as secondary standards, also called white standards, in order their determination.

In this work we evaluate, for different colour samples, how the use of the above mentioned white standards affects to CIELAB values and differences.

Two commercial white standards of different characteristics were used in order to measure the spectral reflectance for six different colour samples: a) Ceramic white tile  b) Polyfluoreed resin white standard. The first one is glazed, and the other unpolished. Both calibrated, with traceability to international standards.

Measurements of CIELAB coordinates of (cyan, blue, pink, red, yellow and green) colour standards tiles (certified values of L*,a*,b*) were carried out changing white reference (a,b) at the initial step of the setting process for a spectrophotometer device. The complete process is summarized in the following table.
The results presented in table 1 and graphics I-IV show the differences in the L*,a*,b* values, in relation with the samples values certified, obtained with a and b white standards, in terms of ΔE*, ΔL*, Δa* and Δb*.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Working White a</th>
<th>Working White b</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ΔE*</td>
<td>ΔL*</td>
</tr>
<tr>
<td>Cyan</td>
<td>0.6599</td>
<td>-0.15</td>
</tr>
<tr>
<td>Blue</td>
<td>1.2427</td>
<td>0.58</td>
</tr>
<tr>
<td>Green</td>
<td>1.2725</td>
<td>-0.19</td>
</tr>
<tr>
<td>Pink</td>
<td>0.3348</td>
<td>-0.04</td>
</tr>
<tr>
<td>Red</td>
<td>2.0410</td>
<td>1.03</td>
</tr>
<tr>
<td>Yellow</td>
<td>1.3530</td>
<td>-0.04</td>
</tr>
</tbody>
</table>

Table 1. Differences in terms of ΔE*, ΔL*, Δa*, Δb*
The interpretation of the results only can be made considering the uncertainty associated to reflectance values of white standards and colour samples (considering that other influence factors associated to the uncertainty of the equipment are constants).

In this occasion these values were:

<table>
<thead>
<tr>
<th></th>
<th>Values of uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>White standard a</td>
<td>Between 0.38 and 0.69%</td>
</tr>
<tr>
<td>White standard b</td>
<td>Less than 0.5%</td>
</tr>
<tr>
<td>Colour samples</td>
<td>Between 0.4 and 0.05%</td>
</tr>
</tbody>
</table>

Taking into account these values, the comparison between $\Delta E^*$, $\Delta L^*$, $\Delta a^*$, $\Delta b^*$ for the two methods don't permit select one of them as the best. Only for sample Red, coordinate $L^*$, the differences of $\Delta L^*$ between the two methods seem relevant, but these values are not very significant for industrial manufacturing.

![Graph 1. DE* in relation with certified values of L*,a*,b*](image1)

![Graph II. DL* in relation with certified values of L*](image2)

![Graph III. Da* in relation with certified values of a*](image3)

![Graph IV. Db* in relation with certified values of b*](image4)
As consequence and in agreement with another studies, the results show that for an industrial processes, the selection of a white standard, is conditioned better by the facility in the use (easy maintenance: clean, fragility...; other manufacturer facilities) than for their influence in the results.

**BIBLIOGRAPHY:**

- "Colorimetry" Public. CIE N° 15


- J.C.Soriano, N.Alcón "Evaluation of white standards in accordance with their characteristics in order to carry out measurements of colour characterization" 4th International Symposium “Colour and Colorimetry”. Maribor-Slovenia. 1994
DEVELOPMENT OF THE WHITE REFERENCE PLATE FOR THE COLOR MEASUREMENT CALIBRATION

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Abstract

The first primary standard of colorimetry is the absolute spectral diffused reflectance. White reference standard plate was developed for the foundation of the national color standard traceable system. In our laboratory, absolute reflectance measuring system has been developed. So the first primary standard of colorimetry has been established. White reference standard is a kind of standard reference materials (CRM: Certified Reference Material) which is used for reference calibration of color meters. Specially the white reference standard, we have developed, have been measured to have no specular reflecting components. This means it can be used as a geometry free reference.

1. Introduction

The importance of color is increased more and more with the development of the industrial technology and with up grade of the life qualities. Nowadays everybody is interested in color and they request more delicate and sensitive color. To satisfy these kinds of demand, factories's interest and effort about color have been greatly increased all over the industrial fields. To menage color more precisely, the technology of colorimetry became important. In this paper we are going the report the development of color reference standard, white reference standard. To construct the traceable system of color, it is necessary to develop white reference standard. White reference standard is the base of the colorimetry using the color meter.
2. Problems in color measurement with color meter

To objectify about color affairs, use of color meter increase in many industrial fields. The main application of color meter is color difference for the control of color within permissible region. But nowadays, accurate color coordinate is also important. We communicate about color not in color name but more precise color coordinate. And almost every standard document provides only with color coordinates, not with color samples. So now we need real color meter not color difference meter. To be a real color meter, it should be calibrated with accurate white reference standard.

There are two kinds of color meter, one is filter type and the other is spectrometer type. As for filter type color meter, it has three filter and detector in it which measure the brightness (Y), blueness (Z), and redness (X) separately. When we measure color with this type of color meter, we should calibrate with a white reference standard, which has color coordinate of its own.

The other type, color meter of spectrometer type, measure spectral reflectance of the color samples. And from the data of the spectral distribution of the CIE standard illuminations and the color matching functions of CIE standard observer, the color coordinates of the samples are calculated. But the spectral reflectance of the samples should be calibrated with the white reference standard which contains the absolute spectral diffused reflectance of its own.

The spectral reflectance of the sample is different from the measuring geometry. Due to the gloss of the surface of the color sample, the measured values of spectral reflectance are different. Generally the reflectance measured in 0/d geometry including specular reflectance component is the largest value and next is that in d/0 geometry and so on.

Fig 1. CIE recommended 4 geometries of the measuring reflectance.
Some kinds of color meters have ambiguous geometry, for example, between 45/0 and d/0 geometry. And in standard institute there are not all kinds of calibration system. Only one or two geometry is possible. So there can be often some discrepancy between the calibration values. The discrepancy will increase as the gloss of white reference standard plate is greater. So to eliminate these kinds of discrepancy, matt surface of the white reference plate is preferable.

3. White Reference Materials and the color standard traceable system

White Reference standard is a kind of Certified Reference Material (CRM) which is used as a standard for the color measurement. When we measure color with color meter, the sample colors are measured based on the color coordinates of white reference materials. The coordinates of White reference materials should be traceable to the national standard (absolute reflectance measuring system) which coincide with international standards. The national standard is compared with the international standard regularly.

Absolute reflectance measuring system is suitable for high reflectance (over than 80%) materials (white reference materials). The measured data transferred to the reference spectrometer. And with the reference spectrometer the white reference standards are calibrated. The calibrated white reference standards are used as working standards for the all kinds of color meters.

![Diagram of the national color standard traceable system](image)

**Fig 2.** The national color standard traceable system.
4. Manufacturing of the white reference standard

We have manufactured the white reference standard with the help of the staff of Hankook Chinaware Co. Ltd.

4-1. Selection of the materials of the white reference standard

White reference standard which is frequently used in measuring fields as a working standard, should satisfy following requirements.

(1) Should have flat and high (above than 80%) spectral reflectance within the visible range.

(2) Should not be fluorescent.

(3) Should be stable mechanically and chemically.

(4) Should have matt surface.

(5) It is preferable to be easy to clean and to maintain.

We have searched many materials which satisfy these requirements. And compared the spectral reflectance of those materials. Our final decision was New Zealand white and alumina. New Zealand white shows the highest reflectance of our tested materials. And alumina was need to improve the mechanical properties. Table 1 and 2 are the properties of the our selected materials.

**Tab. 1. Chemical analysis of Alumina**

<table>
<thead>
<tr>
<th>Chemical Analysis (%) of Alumina (Al₂O₃)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O</td>
</tr>
<tr>
<td>L.O.I</td>
</tr>
<tr>
<td>Fe₂O₃</td>
</tr>
<tr>
<td>SiO₂</td>
</tr>
<tr>
<td>Na₂O</td>
</tr>
<tr>
<td>Al₂O₃</td>
</tr>
<tr>
<td>Density: 3.95</td>
</tr>
<tr>
<td>Particle size : ~ 4.8 μm</td>
</tr>
</tbody>
</table>

**Tab. 2. Chemical analysis of New Zealand white**

<table>
<thead>
<tr>
<th>Chemical Analysis (%) of New Zealand white</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
</tr>
<tr>
<td>Al₂O₃</td>
</tr>
<tr>
<td>Fe₂O₃</td>
</tr>
<tr>
<td>TiO₂</td>
</tr>
<tr>
<td>CaO</td>
</tr>
<tr>
<td>MgO</td>
</tr>
<tr>
<td>K₂O</td>
</tr>
<tr>
<td>Na₂O</td>
</tr>
<tr>
<td>H₂O (moisture)</td>
</tr>
<tr>
<td>Density: 2.55</td>
</tr>
<tr>
<td>Fluoride ion: less than 0.01%</td>
</tr>
<tr>
<td>Cation exchange capacity: approx. 10 mEq</td>
</tr>
<tr>
<td>Linear shrinkage: 3.8% (at 110 °C), 10.8% (at 1300 °C)</td>
</tr>
<tr>
<td>Particle size: 0.2 - 2.0 μm</td>
</tr>
</tbody>
</table>
4-2. Manufacturing of white reference standard
New Zealand white and alumina mixed with pure water. And pressed with press to form. The formed wet plates are dried and baked in electric furnace at 1,100 °C - 1,150 °C. The temperature raising speed should not exceed 60 °C/h. After baking the surface of tile polished with the diamond mash of number 200.

4-3. Test of the white reference standard
The manufactured tiles were tested with reference spectrophotometer (Varian 5E). We measured the spectral reflectance of the sample in two methods of the specular included and the specular excluded in 0/d geometry. Comparing the results, we could not find out any difference between the two methods. This means that our sample has no specular component. This property will be useful to make the geometry free white reference standard.

![Spectral Reflectance of the White Reference Standard]

Fig 3. Measured results of the developed white reference CRM (Certified Reference Material). We have measured the sample in two different geometries of the specular included and the specular excluded. Comparing the results we could reach the conclusion that our new white reference standard has no specular component. This property will be useful to make the geometry free white reference standard.

Recently there are some kinds of color meters which are difficult to classify the geometry. Our developed white reference standard will be helpful in this case to decrease the
discrepancy of the color measurements due to the standard calibration with different geometries.

5. Conclusion and Discussion

Our new white reference standard will play key role in construction of the national standard traceable system of color. Non gloss property of our white standard will be helpful to decrease the uncertainty of the color standard.

We have a schedule for the foundation of the more complete traceable system of color standard. Till next year the international comparison of the absolute spectral reflectance will be performed within CCPR members. And end of this year we will finish to developing the standard color plates set. I hope we can show you our final products at next meeting of AIC in Seoul Korea.

Reference

STUDY OF REPRODUCIBILITY OF STATE-OF-ART OF SPECTROPHOTOMETER

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Hung Hom, Kowloon, Hong Kong

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e-mail: tcrachys@inet.polyu.edu.hk

ABSTRACT

In colour-related industries, reflectance spectrophotometers are the most important colour measuring equipment controlling the quality of colour. Because of the advance in electronic devices and machine design, the repeatability of spectrophotometer measurements becomes more and more accurate in practice. However, different manufacturers will have their own machine design and profile, thus the measurement result varies with different instruments. This paper reports on the results of the study of reproducibility of the commercial reflectance spectrophotometers. Both the Glossy and Matt type of the Ceramic Colour Standards – Series II were chosen in this study. The results of this study illustrate that the improvement of the communication among the instruments should be made in order to enhance the inter-instrument agreement.

1. INTRODUCTION

In the colour-related industries, textile coloration and printing or painting et al, objective colour difference specification for quantitative colour comparison is very important to promote quick response to the market place and efficient in-house colour quality control. In order to enhance such quantitative colour difference evaluation, reflectance spectrophotometers are one of the most important tools for controlling the quality of colour. Based on the advanced development in the electronic devices and the improvement of the machine design of the reflectance spectrophotometers, different manufacturers claim that the repeatability of measurements on the same instruments is lower than 0.01 CIELAB ΔE units.
Moreover, those manufacturers also claim that the inter-instrument agreement of the similar design spectrophotometer is lower than 0.15 CIELAB $\Delta E$ units, according to our present investigation, it was found that even the reflectance spectrophotometers produced from the same manufacturers, the reproducibility range from 0.526 to 0.611 CIELAB $\Delta E$ units. Concerning the machines produced from different manufacturers, the reproducibility range from 0.575 to 0.854 CIELAB $\Delta E$ units. Thus we can conclude that further investigation must perform in order to enhance the inter-instrument agreement and non-physical sample communication.

2. EXPERIMENTAL SAMPLES AND INSTRUMENTS

2.1 Experimental Samples

Up to the date BCRA-NPL Series II Ceramic Colour Standards (CCS-II)\cite{1,2} is one of the most common and popular used standards in the colour-related industries. CCS-II is mainly used to check the consistency of operation and the accuracy of colour-measuring instruments over long periods of time. CCS-II is commonly divided into “GLOSS” type and “MATT” type.

Although, CCS-II is very popular in the colour related industries, they are commonly affected by temperature change, so call “Thermochromism” or “Photochromism”\cite{3,4}. According to the past research result, the red and orange tiles show the significance change in temperature, and the colour difference was about 1.18 CIELAB $\Delta E$ units when the temperature increase from 25°C to 35°C.

2.2 Colour Measuring Instruments

The following spectrophotometers for colour difference measurements are used in this experiment.

- COLOR-EYE® 2180 (CE-2180) from GretagMacbeth®
- COLOR-EYE® 7000A (CE-7000A) from GretagMacbeth®
- Spectraflash® 600 PLUS-CT (SF-600) from Datacolor International
Totally there are a total of three spectrophotometers used in this research. Among three spectrophotometers, all of them are sphere type geometry but CE-2180 is a single-beam type while the other two are double-beam type. Table 1 describes the major features of these three instruments in terms of principle, illumination, optical geometry configuration, spectral range, aperture size, wavelength interval, dynamic range, baud rate and working environment.

Table 1: The comparison of three different types of spectrophotometer used in this research

<table>
<thead>
<tr>
<th></th>
<th>CE-2180</th>
<th>CE-7000A</th>
<th>SF-600</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Principle</strong></td>
<td>Single-beam</td>
<td>Dual-beam</td>
<td>Dual-beam</td>
</tr>
<tr>
<td><strong>Illumination</strong></td>
<td>Pulsed Xenon Flashlamp</td>
<td>Pulsed Xenon Flashlamp</td>
<td>Pulsed Xenon Flashlamp</td>
</tr>
<tr>
<td><strong>Optical Geometry Configuration</strong></td>
<td>Diffuse/8</td>
<td>Diffuse/8</td>
<td>Diffuse/8</td>
</tr>
<tr>
<td><strong>Spectral Range</strong></td>
<td>360 – 750 nm</td>
<td>360 – 750 nm</td>
<td>360 – 700 nm</td>
</tr>
<tr>
<td><strong>Aperture Size</strong></td>
<td>LAV – 14 mm, SAV 5 mm</td>
<td>LAV – 25.4 mm, MAV – 15 mm, SAV – 10 mm, USAV – 3 mm</td>
<td>LAV – 26 mm, SAV – 5 mm, USAV 2.5 mm</td>
</tr>
<tr>
<td><strong>Wavelength Interval</strong></td>
<td>10 nm</td>
<td>10 nm</td>
<td>10 nm</td>
</tr>
<tr>
<td><strong>Dynamic Range</strong></td>
<td>0% - 150%</td>
<td>0% - 200%</td>
<td>0% - 200%</td>
</tr>
<tr>
<td><strong>Baud Rate</strong></td>
<td>9600</td>
<td>9600</td>
<td>9600 / 19200</td>
</tr>
<tr>
<td><strong>Environment</strong></td>
<td>15 to 32°C, 0 – 80%RH, non-condensing</td>
<td>15 to 32°C, 25 – 80%RH, non-condensing</td>
<td>5 to 40°C, 20 – 85%RH, non-condensing</td>
</tr>
</tbody>
</table>

3. METHODOLOGY

3.1 Instrument Settings

The instrument settings should be set according to the following.

- large area of view;
- remove UV cutoff filter from the optical path;
- wavelength range: 400nm to 700nm at 10nm intervals

Since all the spectrophotometers are sphere type, the specular component excluded (SCE) or specular component included (SCI) should be specified.

3.2 Sample Conditioning

Because of the thermo-sensitivity of the CCS II tiles, all the CCS II tiles and reflectance spectrophotometer are well conditioned in our control laboratory to avoid the temperature and the humidity change which led to affect the measurement result.

3.3 Instrument Calibration

Before measurement of the tiles, all colour measuring instruments should be allowed to warm up for the period recommended by the instrument supplier. In addition follow the instrument set-up in section 3.1, the instrument should be well calibrated according to the manufacturer’s guide by using the black and white standards provided by the manufacturers.

3.4 Measurement Procedure

Each tiles should be measured once at the centre position for spectral reflectance factor from 400nm to 700nm at 10nm intervals. Report the average CIE ΔL*, Δa*, Δb*, ΔC* and ΔE*ab (Illuminant D65, 10° standard observer).

4. RESULTS AND DATA ANALYSIS

The colorimetric data[9] (e.g. L*, a* and b*) based on D65 standard illuminant and 10° standard observer were computed for all the CCS-II tiles of the experimental samples specified in section 2.1 for each spectrophotometer. Computing the CIELAB colour differences formula can assess the reproducibility performance of colour difference measurements among the various instruments. The average absolute L*, a*, b* and the CIELAB colour difference are summarised in the table 2 to table 5.
Table 2: The summarised table of the average absolute $L^*$ difference among the three spectrophotometers

<table>
<thead>
<tr>
<th>Tiles</th>
<th>CE-7000A vs CE-2180</th>
<th>CE-7000A vs SF-600</th>
<th>SF-600 vs CE-2180</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GE$^1$</td>
<td>GI$^2$</td>
<td>ME$^3$</td>
</tr>
<tr>
<td>Pale Grey</td>
<td>0.133</td>
<td>0.151</td>
<td>0.397</td>
</tr>
<tr>
<td>Mid Grey</td>
<td>0.151</td>
<td>0.184</td>
<td>0.376</td>
</tr>
<tr>
<td>Diff. Grey</td>
<td>0.060</td>
<td>0.101</td>
<td>0.302</td>
</tr>
<tr>
<td>Deep Grey</td>
<td>0.110</td>
<td>0.091</td>
<td>0.269</td>
</tr>
<tr>
<td>Deep Pink</td>
<td>0.204</td>
<td>0.273</td>
<td>0.362</td>
</tr>
<tr>
<td>Red</td>
<td>0.452</td>
<td>0.320</td>
<td>0.395</td>
</tr>
<tr>
<td>Orange</td>
<td>0.286</td>
<td>0.414</td>
<td>0.569</td>
</tr>
<tr>
<td>Bright Yellow</td>
<td>0.404</td>
<td>0.457</td>
<td>0.654</td>
</tr>
<tr>
<td>Green</td>
<td>0.105</td>
<td>0.091</td>
<td>0.255</td>
</tr>
<tr>
<td>Diff. Green</td>
<td>0.120</td>
<td>0.101</td>
<td>0.479</td>
</tr>
<tr>
<td>Cyan</td>
<td>0.145</td>
<td>0.151</td>
<td>0.146</td>
</tr>
<tr>
<td>Deep Blue</td>
<td>0.054</td>
<td>0.043</td>
<td>0.256</td>
</tr>
<tr>
<td>Average</td>
<td>0.485</td>
<td>0.196</td>
<td>0.372</td>
</tr>
</tbody>
</table>
Table 3: The summarised table of the average absolute a* difference among the three spectrophotometers

<table>
<thead>
<tr>
<th>Tiles</th>
<th>GE</th>
<th>GI</th>
<th>ME</th>
<th>MI</th>
<th>GE</th>
<th>GI</th>
<th>ME</th>
<th>MI</th>
<th>GE</th>
<th>GI</th>
<th>ME</th>
<th>MI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pale Grey</td>
<td>0.079</td>
<td>0.021</td>
<td>0.070</td>
<td>0.053</td>
<td>0.003</td>
<td>0.051</td>
<td>0.002</td>
<td>0.059</td>
<td>0.090</td>
<td>0.033</td>
<td>0.091</td>
<td>0.008</td>
</tr>
<tr>
<td>Mid Grey</td>
<td>0.033</td>
<td>0.037</td>
<td>0.034</td>
<td>0.026</td>
<td>0.008</td>
<td>0.007</td>
<td>0.035</td>
<td>0.010</td>
<td>0.039</td>
<td>0.035</td>
<td>0.005</td>
<td>0.017</td>
</tr>
<tr>
<td>Diff Grey</td>
<td>0.073</td>
<td>0.096</td>
<td>0.064</td>
<td>0.057</td>
<td>0.052</td>
<td>0.048</td>
<td>0.003</td>
<td>0.009</td>
<td>0.039</td>
<td>0.048</td>
<td>0.074</td>
<td>0.079</td>
</tr>
<tr>
<td>Deep Grey</td>
<td>0.068</td>
<td>0.120</td>
<td>0.065</td>
<td>0.086</td>
<td>0.079</td>
<td>0.086</td>
<td>0.065</td>
<td>0.069</td>
<td>0.006</td>
<td>0.027</td>
<td>0.009</td>
<td>0.055</td>
</tr>
<tr>
<td>Deep Pink</td>
<td>0.233</td>
<td>0.321</td>
<td>0.250</td>
<td>0.302</td>
<td>0.007</td>
<td>0.058</td>
<td>0.027</td>
<td>0.104</td>
<td>0.248</td>
<td>0.244</td>
<td>0.222</td>
<td>0.177</td>
</tr>
<tr>
<td>Red</td>
<td>0.400</td>
<td>0.824</td>
<td>0.418</td>
<td>0.592</td>
<td>0.178</td>
<td>0.667</td>
<td>0.425</td>
<td>0.565</td>
<td>0.252</td>
<td>0.135</td>
<td>0.007</td>
<td>0.009</td>
</tr>
<tr>
<td>Orange</td>
<td>0.025</td>
<td>0.077</td>
<td>0.092</td>
<td>0.004</td>
<td>0.921</td>
<td>0.777</td>
<td>0.636</td>
<td>0.608</td>
<td>0.962</td>
<td>0.735</td>
<td>0.761</td>
<td>0.647</td>
</tr>
<tr>
<td>Bright Yellow</td>
<td>0.487</td>
<td>0.505</td>
<td>0.464</td>
<td>0.475</td>
<td>0.512</td>
<td>0.329</td>
<td>0.456</td>
<td>0.509</td>
<td>0.039</td>
<td>0.054</td>
<td>0.012</td>
<td>0.074</td>
</tr>
<tr>
<td>Green</td>
<td>0.370</td>
<td>0.394</td>
<td>0.317</td>
<td>0.294</td>
<td>0.247</td>
<td>0.182</td>
<td>0.269</td>
<td>0.180</td>
<td>0.626</td>
<td>0.553</td>
<td>0.595</td>
<td>0.474</td>
</tr>
<tr>
<td>Diff Green</td>
<td>0.354</td>
<td>0.401</td>
<td>0.405</td>
<td>0.402</td>
<td>0.206</td>
<td>0.136</td>
<td>0.183</td>
<td>0.081</td>
<td>0.561</td>
<td>0.524</td>
<td>0.589</td>
<td>0.452</td>
</tr>
<tr>
<td>Cyan</td>
<td>0.371</td>
<td>0.380</td>
<td>0.236</td>
<td>0.289</td>
<td>0.880</td>
<td>0.809</td>
<td>0.699</td>
<td>0.688</td>
<td>0.530</td>
<td>0.426</td>
<td>0.495</td>
<td>0.394</td>
</tr>
<tr>
<td>Deep Blue</td>
<td>0.341</td>
<td>0.173</td>
<td>0.168</td>
<td>0.194</td>
<td>0.161</td>
<td>0.350</td>
<td>0.413</td>
<td>0.359</td>
<td>0.065</td>
<td>0.165</td>
<td>0.227</td>
<td>0.154</td>
</tr>
<tr>
<td>Average</td>
<td>0.236</td>
<td>0.279</td>
<td>0.234</td>
<td>0.231</td>
<td>0.271</td>
<td>0.306</td>
<td>0.268</td>
<td>0.270</td>
<td>0.288</td>
<td>0.248</td>
<td>0.257</td>
<td>0.208</td>
</tr>
</tbody>
</table>
Table 4: The summarised table of the average absolute $b^*$ difference among the three spectrophotometers

<table>
<thead>
<tr>
<th>Tiles</th>
<th>CE-7000A vs CE-2180</th>
<th>CE-7000A vs SF-600</th>
<th>SF-600 vs CE-2180</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GE</td>
<td>GI</td>
<td>ME</td>
</tr>
<tr>
<td>Pale Grey</td>
<td>0.045</td>
<td>0.042</td>
<td>0.062</td>
</tr>
<tr>
<td>Mid Grey</td>
<td>0.002</td>
<td>0.004</td>
<td>0.051</td>
</tr>
<tr>
<td>Diff. Grey</td>
<td>0.047</td>
<td>0.023</td>
<td>0.009</td>
</tr>
<tr>
<td>Deep Grey</td>
<td>0.022</td>
<td>0.001</td>
<td>0.004</td>
</tr>
<tr>
<td>Deep Pink</td>
<td>0.474</td>
<td>0.458</td>
<td>0.355</td>
</tr>
<tr>
<td>Red</td>
<td>0.211</td>
<td>0.573</td>
<td>0.221</td>
</tr>
<tr>
<td>Orange</td>
<td>0.405</td>
<td>0.650</td>
<td>0.371</td>
</tr>
<tr>
<td>Bright Yellow</td>
<td>0.049</td>
<td>0.149</td>
<td>0.239</td>
</tr>
<tr>
<td>Green</td>
<td>0.479</td>
<td>0.426</td>
<td>0.303</td>
</tr>
<tr>
<td>Diff. Green</td>
<td>0.456</td>
<td>0.385</td>
<td>0.150</td>
</tr>
<tr>
<td>Cyan</td>
<td>0.545</td>
<td>0.565</td>
<td>0.488</td>
</tr>
<tr>
<td>Deep Blue</td>
<td>0.599</td>
<td>0.296</td>
<td>0.261</td>
</tr>
<tr>
<td>Average</td>
<td>0.278</td>
<td>0.290</td>
<td>0.213</td>
</tr>
</tbody>
</table>
Table 5: The summarised table of the average CIELAB colour difference among the three spectrophotometers

<table>
<thead>
<tr>
<th>Tiles</th>
<th>CE-7000A vs CE-2180</th>
<th>CE-7000A vs SF-600</th>
<th>SF-600 vs CE-2180</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GE</td>
<td>GI</td>
<td>ME</td>
</tr>
<tr>
<td>Pale Grey</td>
<td>0.172</td>
<td>0.165</td>
<td>0.415</td>
</tr>
<tr>
<td>Mid Grey</td>
<td>0.168</td>
<td>0.197</td>
<td>0.385</td>
</tr>
<tr>
<td>Diff. Grey</td>
<td>0.133</td>
<td>0.158</td>
<td>0.314</td>
</tr>
<tr>
<td>Deep Grey</td>
<td>0.266</td>
<td>0.218</td>
<td>0.292</td>
</tr>
<tr>
<td>Deep Pink</td>
<td>0.617</td>
<td>0.653</td>
<td>0.575</td>
</tr>
<tr>
<td>Red</td>
<td>1.106</td>
<td>1.112</td>
<td>0.630</td>
</tr>
<tr>
<td>Orange</td>
<td>0.672</td>
<td>0.515</td>
<td>0.701</td>
</tr>
<tr>
<td>Bright Yellow</td>
<td>0.736</td>
<td>0.745</td>
<td>0.847</td>
</tr>
<tr>
<td>Green</td>
<td>0.653</td>
<td>0.618</td>
<td>0.519</td>
</tr>
<tr>
<td>Diff. Green</td>
<td>0.635</td>
<td>0.596</td>
<td>0.654</td>
</tr>
<tr>
<td>Cyan</td>
<td>0.695</td>
<td>0.718</td>
<td>0.564</td>
</tr>
<tr>
<td>Deep Blue</td>
<td>1.204</td>
<td>0.384</td>
<td>0.415</td>
</tr>
<tr>
<td>Average</td>
<td>0.588</td>
<td>0.533</td>
<td>0.526</td>
</tr>
</tbody>
</table>

Note:

1. The GLOSSY CCS-II tiles measured under the condition of the specular component excluded
2. The GLOSSY CCS-II tiles measured under the condition of the specular component included
3. The MATT CCS-II tiles measured under the condition of the specular component excluded
4. The MATT CCS-II tiles measured under the condition of the specular component included
5. DISCUSSION

5.1 CE-7000A vs CE-2180

Considering the average $\Delta E_{ab}$, the MATT tiles measured under the condition of the specular component excluded shows good reproducibility. The mean average colour difference is 0.526 $\Delta E_{ab}$ unit between these two spectrophotometers. Among the four different measurement mode, the CE-7000A and CE-2180 show better reproducibility because these two products manufacture under the same company. And the machine design of the CE-7000A is based on the machine design of the CE-2180, the main difference between is that CE-7000A is a dual-beam type spectrophotometer while CE-2180 is the single-beam type spectrophotometer.

5.2 CE-7000A vs SF-600

Concerning the average $\Delta E_{ab}$, the MATT tiles measured under the condition of the specular component included shows good reproducibility. The mean average colour difference is 0.575 $\Delta E_{ab}$ unit between these two spectrophotometers. Among the four different measurement mode, the CE-7000A and SF-600 show average reproducibility because these two products manufacture under the different company. And the machine design of the CE-7000A is different from that of the SF-600, but these two machines are dual-beam type spectrophotometers.

5.1 SF-600 vs CE-2180

Considering the average $\Delta E_{ab}$, the GLOSSY tiles measured under the condition of the specular component included shows good reproducibility. The mean average colour difference is 0.614 $\Delta E_{ab}$ unit between these two spectrophotometers. Among the four different measurement mode, the SF-600 and CE-2180 show poor reproducibility because these two machines manufacture under two different company. And the machine design of the SF-600 is different from that of the CE-2180, besides the main difference between is that SF-600 is a dual-beam type spectrophotometer while CE-2180 is the single-beam type spectrophotometer.
Among these three spectrophotometers, during the colorimetric measurement, an additional variable known as “sphere efficiency” enhances the measurement variation.

6. CONCLUSIONS

In general, the reproducibility among the three selected spectrophotometer is not satisfactory because the average colour difference is larger than 0.5 $\Delta E_{ab}^*$ units. The results imply that the origin of the errors and also the improvement should be investigation, such as mathematical models for inter-instrument agreement, should be applied in order to improve the reproducibility. Once the reproducibility among the spectrophotometers can improve, the inter-instrument agreement and non-physical sample colour communication can further enhance.

ACKNOWLEDGE

The authors wish to acknowledge a studentship received from The Hong Kong Polytechnic University Postgraduate Research Grant.

REFERENCE

VISUAL AND COLORIMETRIC EVALUATION OF METAMERIC TILES

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ABSTRACT

Psychophysical experiments were carried out to measure perceptual colour differences of the metameric and non-metameric pairs of tiles developed in the NPL by grading them against a fine grey scale difference under the simulated D65 and A sources (daylight and tungsten sources, respectively) to compare them with the color differences based on colorimetric values calculated using the color difference formulae of the CIELAB, CIE94, BFD, and CMC. Visual field of the pair of tiles was set to either 10° or 2° and that of the grey scale was 4° constant. Mean absolute difference between ΔEs of colorimetric and visual-assessment values and correlation coefficient between them were calculated. Mean absolute difference was the largest in the 2° field under tungsten sources for all the formulae except CIE94. CIELAB showed the lowest correlation coefficients for all the conditions. Among the colour difference formulae examined in this study, CIE94 showed the best performance as a whole.

1. INTRODUCTION

To extend the range of colour standard available to industry, NPL developed six pairs of metameric ceramic tiles. Each pair of tiles has been designed to form an instrumental match, in terms of CIELAB ΔE under CIE illuminant D65 for the 1964 10 deg standard observer and an instrumental mismatch under CIE illuminant A for the same observer.

Purpose of this study is to measure perceptual colour difference of the metameric tiles under the CIE illuminants D65 and A, and then to examine which colour difference formula can best fit the results of visual assessment. Therefore we carried out the experiment assessing perceptual colour difference of the tiles using difference matching method under 6500K daylight and a tungsten sources, instead of the above CIE illuminants. Colour differences
using the CIELAB$^1$, CIE94$^2$, BFD$^3$, and CMC$^4$ formulae were calculated and the results based on colorimetric measurement and visual assessment were compared with each other.

2. EXPERIMENT

2.1 Test Stimuli and Illuminants

Test stimuli were six coloured pairs of metameric tiles (green, grey, orange, pink, yellow1, and yellow2) and 2 coloured pairs of nonmetameric ones (CCS Green and CCS Grey). Fig.1 (a) and (b) show the spectral reflectance curves of metameric Orange pair and nonmetameric CCS Grey pair, respectively. Instead of the CIE illuminant D65, daylight fluorescent lamp of which correlated color temperature is 6500K, and instead of the CIE illuminant A, a tungsten light was used, respectively. Their spectral radiant distributions plotted together with those of the illuminants D65 and A are shown in Fig.2.

\[ \text{Fig.1. Spectral reflectance of (a) Orange metameric pair and (b) CCS Green nonmetameric pair.} \]

\[ \text{Fig.2. Spectral radiant power distribution of the CIE illuminants and the sources used in this study.} \]
2.2 Visual Field, Procedure, and Observers

The experiments were carried out in a viewing cabinet (Macbeth Judge II) with illumination at 0° onto the samples and a viewing angle of 45° as indicated in Fig.3. Inside wall of the cabinet was a grey of nearly Munsell 7. Diagrams of visual field for the test size of 10° and 2° are demonstrated in Fig.4 (a) and (b), respectively. In order to compare visually assessed results of both test sizes directly, the diameter of matching field was fixed at 4° for both conditions.

The left half of the matching field was fixed to Munsell N6.75 and the right side was varied from N5.5 to N7.5 with 0.25 step. Observer was instructed to adjust the variable grey so that the lightness difference is perceptually same as the color difference of the test pair of tiles. For each of the test pairs, one judgment was done in the position lighter than N6.75 and one judgment in the position darker then N6.75. In one session, all of 8 pairs of tiles were tested. Experiments were conducted in four different conditions such as 10° and 2° test field sizes under each of the daylight and tungsten illumination. For one observer, three sessions were carried out for each of the four conditions.

Three males and one female, all were Japanese and tested color normal on Farnsworth-Munsell 100 hue test, participated as observers.

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**Fig.3. Side view of experimental apparatus.**

**Fig.4. Diagram to demonstrate relative sizes of the viewing fields: (a) and (b) represent 10° and 2° test field, respectively. The 4° grey scale matching field is shown below each one.**
3. RESULTS

In Figs. 5 to 10, the following abbreviations are commonly used. DAY10: daylight source with 10° field, TUN10: tungsten source with 10° field, DAY2: daylight source with 2° field, TUN2: tungsten source with 2° field. In these Figs, „Experimental Value” (open square) represents the term of the measured ΔE for the grey scale difference selected by the observer, and „Calculated Value” (filled circle) is ΔE for each pair of tiles calculated using each of colour difference formula, respectively. Vertical bars of the experimental values indicate the standard deviations among four observers’ results. Although the colour difference formulae examined in this study are recommended to be used under the illuminants not far from daylight sources, we applied them to the tungsten light condition in this study as the first approximation. For the results under the tungsten light, the effect of chromatic adaptation should be taken into consideration, and thus colour differences of the corresponding colours under the 6500K daylight should be tested in the next step using some kind of method.

Fig.5 is the results calculated using CIELAB formula. As can be seen, visual assessments for both 10° and 2° field showed significantly larger values for tungsten than those for daylight. Disagreement between visually assessed and colorimetric values are the largest in 2° field under tungsten sources as expected.

Fig.6 is the results calculated using CIE94 colour difference formula. Disagreement between experimental and calculated values looks smaller than those for CIELAB in all the conditions.

Fig.7 and Fig.8 show the results calculated using BFD (l : c) and CMC(l : c) formulae, respectively. We used l =1.0 and c =1.0 in the calculation. In both Figs, disagreements between visual evaluation and colorimetry are most significant in 2° under tungsten light.
Fig. 5. Color differences based on visual evaluation ("Experimental Value", ○) and colorimetry ("Calculated Value", ●) calculated using CIELAB color difference formula under four different conditions. Vertical bars denote standard deviation among four observers' results.

Fig. 6. Same as Fig. 5, but using CIE94 color difference formula.
In order to compare the performance of the four color difference formulae quantitatively, we calculated the following two values. First, the mean absolute difference of ΔEs between
visually assessed and colorimetric values among eight pairs, and secondly, correlation coefficient between them. Fig.9 shows the mean absolute difference of ΔEs resulted from the four color difference formulae. In this figure, the smaller ordinate value, the better performance. As can be seen, CIE94 shows a good performance for all the conditions. Correlation coefficients are plotted in Fig.10. In this case, the larger the better, and the CIELAB shows the worst while the results of other three conditions are about the same.

4. SUMMARY

Perceptual colour differences of the metameric and non-metameric pairs of tiles were evaluated by difference matching method using fine grey scale under the daylight of 6500K and tungsten sources. Visual field of the pair of tiles (test field) was set to either 10° or 2° and that of the grey scale (matching field) was 4° constant. Results of the visual evaluation
were compared with color differences based on colorimetric values calculated using the color difference formulae of the CIELAB, CIE94, BFD, and CMC. For all the results of different colour difference formulae, visual assessments under tungsten source showed larger values than those under daylight for both 10° and 2° field. Mean absolute difference between ΔE of colorimetric and visual-assessment values and correlation coefficient between them were calculated. Mean absolute difference was the largest in the 2° field under tungsten sources for all the formulae except CIE94. CIELAB showed the lowest correlation coefficients for all the conditions. Performance of BFD and CMC markedly worse for 2° field under tungsten source than other conditions. Among the colour difference formulae examined in this study, CIE94 showed the best performance as a whole.

REFERENCES

1) CIE Supplement No.2 to CIE Publication No.15 : Recommendations on uniform colour spaces, colour-difference equations, psychometric colour terms. CIE, 1978.
SPECTRAL AND SPATIAL REFLECTED LIGHT DISTRIBUTIONS OF REFERENCE MATERIALS AND PRACTICAL SAMPLES

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Abstract

Spectral and spatial reflected light distributions of reference materials and practical samples were measured by goni-spectrophotometric color measuring system and spectrophotometer with integrating sphere. Reference materials were white working standards (matt and glossy surfaces) and chromatic working standards (BCRA tiles, Evercolor and Spectralon), and practical samples were painted panels and ink jet printings both with various color and gloss grade.

Goni-spectrophotometric reflected light distributions of reference materials are not always uniform. Therefore, when using these materials for instrument calibration, the geometric and spectral conditions of the measuring devices should be carefully considered.

Paint panels were prepared as adding the delustering agent gradually to base paint. The diffuse components of reflected light from glossy solid paint are distributed considerably uniform, but spatial and spectral distributions from semi-glossy or matt paint panels change largely with the viewing condition.

Ink jet hard-copies were printed on two types (matt and glossy) of ink-jet-grade paper and art paper, using cyan, magenta and yellow inks. When using the same ink by the same printer, color of ink jet hard copy changes largely by the liquid absorption behavior of paper and the characteristics of ink.

Now most of paper is treated by the fluorescent whitening agent. Fluorescence from paper remains after ink jet printing, then ultraviolet part of irradiation should be examined, when polychromatic illumination type instrument is used.
1. Introduction

In the former report\(^1\), we studied on gonio-spectrophotometric analysis of white and chromatic reference materials. Spatial distributions of reflected light from these materials are not always uniform. Then, colorimetric values of these materials are strongly affected by the geometric condition of measuring instruments.

In this report, as practical samples, painted panels and ink jet hard-copies, both with various color and gloss grades, were measured in a same manner. For painted panels, spatial and spectral distributions of reflected light change with viewing angle, except high-glossy solid paint. For ink jet hard-copies, spatial and spectral distributions of reflected light are strongly affected by the characteristics of printed paper. Furthermore, for ink jet hard-copies, the effects of fluorescence from printed paper were separately examined.

2. Specimens

For these experiments, the following specimens were used:

(1) White surfaces
   (a) Matt surfaces
      a-1: barium sulfate, pressed by Zeiss powder press.
      a-2: polyvinyl alcohol (PVA) coating of barium sulfate.
      a-3: Spectralon, white, by Labsphere, USA.
      a-4: Ever-white, roughened surface, by Evers, Japan.
   (b) Glossy surfaces
      b-1: Ever-white, polished surface.
      b-2: white ceramic tile, by INAX, Japan.
   (c) Paint surfaces
      c-1: white paint, glossy.
      c-2: white paint, semi-glossy.
      c-3: white paint, matt.

(2) Chromatic surfaces
   (a) Matt surfaces
      a-1: Spectralon, blue.
      a-2: Spectralon, green.
      a-3: Spectralon, yellow.
      a-4: Spectralon, red.
(b) Glossy surfaces (polished)
   b-1: Ever-color, blue.
   b-2: Ever-color, green.
   b-2: Ever-color, yellow.
   b-4: Ever-color, red.

(c) Glossy surfaces (glazed)
   c-1: BCRA ceramic color standard, pale gley.
   c-2: BCRA ceramic color standard, deep blue.
   c-3: BCRA ceramic color standard, green.
   c-4: BCRA ceramic color standard, bright yellow.
   c-5: BCRA ceramic color standard, red.
   c-6: BCRA ceramic color standard, deep pink.

(d) Paint surfaces
   d-1: green paint, glossy.
   d-2: green paint, semi-glossy.
   d-3: green paint, matt
   d-4: yellow paint, glossy.
   d-5: yellow paint, semi-glossy.
   d-6: yellow paint, matt.

(3) Ink jet printings, using EPSON MJ-930C ink jet printer

(a) Gonio-spectrophotometric analysis

   Printing ink:  Cyan
                 Mazenta
                 Yellow

   Printed paper:  ink jet-grade paper, matt   EP
                   ink jet-grade paper, glossy  GF
                   art paper              GP

(b) Effect of fluorescence

   paper  concentration of ink  symbol
          (mazenta)         
                      no      EP-1
                      low     EP-2
                      medium EP-3
                      high    EP-4
3. Instruments and measuring conditions

Measurements of spatial and spectrophotometric characteristics of samples were made with two kinds of instruments, both by Murakami Color Research Laboratory, one was the Model GCMS-4 gonio-spectrophotometric color measuring system, and the other was the Model CMS-3SSP spectrophotometer with integrating sphere. Both instruments use the same polychromator with concave grating and photodiode array detector.

Using the GCMS-4, the spectral directional reflectance factor was measured. Measuring conditions were as follows:

Incident angle: -45°, -7°, 0°, polychromatic illumination.

Viewing angle: from -70° to 70°, except for area obstructed by light source.

Source and receiver aperture: ca. 2°.

Using the CMS-3SSP, the spectral diffuse reflectance factor was measured. Measuring conditions were as follows:

Geometric conditions: Polychromatic diffuse illumination, 7° viewing.

Integrating sphere: 200 mm dia., with or without light trap.

Aperture angle of light trap: ca. 9° in dia.

In both cases, the wavelength range was from 390 to 730 nm, and the wavelength interval was 10 nm with a 10 nm bandpass.

For measurement of fluorescence, the Model BFC-450, bispectral fluorescence colorimeter by Labsphere was used.
4. Measured results and discussion

For all specimens, the spectral directional reflectance factor for $-45^\circ$ incidence were measured by the GCMS-4, and tristimulus values and trichromatic coordinates for CIE III. D65, 2° field, were calculated. Specimens were also measured by the CMS-3SSP spectrophotometer, using integrating sphere, with or without a light trap, and colorimetric values were obtained. For examining the effects of fluorescent whitening agent, mazenta ink jet printing samples were measured by BFC-450 fluorescence colorimeter, using two-monochromator method.

In measurements of white reference surfaces, when illuminated from $-45^\circ$, spatial distribution of reflected light is not always uniform. Then, when these white surfaces are used for instrument calibration, geometric conditions of the instrument should be precisely reported.

For chromatic reference surfaces or practical samples, angular dependence of spectral reflectance factor is more larger. In measurement of diffuse reflectance, in many cases the light trap is used in the integrating sphere, to reduce the specular component. In case of highly polished or glazed surfaces, specular components are concentrated within 5° of the specular direction, but in the case of paint surfaces, glossy, semi-glossy or matt, specular components are spreaded up to 25° from the specular direction. Therefore, diffuse reflectance is strongly affected by the size of the light trap. When diffuse reflectance measurement is made, the size and shape of the light trap should be recorded.

From the measured results for ink jet hard copies, not only luminous reflectance but also chromaticity coordinates change with bi-directional geometric conditions, and the tendencies are strongly affected by the characteristics of paper.

Most of paper for ink jet printings are treated by fluorescent whitening agent. The effect of fluorescence of paper remains after ink jet print. Then, ultraviolet part of irradiation should be examined.

Reference

Cyan

-45° incidence

Fig. 1 Goni-spectrophotometric distributions of cyan ink-jet printings on EP, GP and GF printed paper.

-45° incidence

Fig. 2 Chromaticity changes of cyan, magenta and yellow ink-jet printings on EP, GP and GF printed paper.
Fig. 3 Fluorescent component and reflected light component of tristimulus values for magenta ink-jet printings on EP, GF, and GP printed paper.
Fig. 4 Spectral total radiance factor of printed paper, measured by different irradiation.
BASIC CATEGORICAL COLORS IN THE CIECAM97s SPACE

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Abstract

In order to allocate the basic color name regions in a viewing-condition independent color space, we employed the CIE Color Appearance Model (CIECAM97s). Subjects were asked to sort 292 Munsell color samples under 9 illurninants into eleven basic colors. The lightness $J$, the chroma $C$ and the hue angle $h$ defined by the CIECAM97s were calculated for all color samples sorted consistently in a same color name under each illuminant. The basic color name regions were plotted in the CIECAM97s space. Each color name region was determined with an OR-region for all illuminants. It is found that the eleven basic color name regions are clearly separated in the CIECAM97s space with each other. This means that the CIECAM97s model provide a good prediction of basic color names under various light sources.

1. INTRODUCTION

Color name is used to communicate color information in every day life. Berlin and Kay\(^3\) have mentioned that in fully developed languages there are precisely eleven basic color names. Boynton and Olson\(^3\) provided quantitative information concerning the locations of basic colors in the OSA space. Color appearance of the object is, however, influenced by viewing conditions such as the illumination, the surround and viewing size, etc. On the other hand, color appearance itself, such as brightness, hue, colorfulness, and color names should be independent of the viewing condition. The color name map in a viewing-condition-independent color space would be very useful for many application field of color industry. The purpose of this study is to provide the locations of basic color names in the color space by the CIE Color Appearance Model (CIECAM97s).
2. EXPERIMENTS

In order to specify the regions of basic color names, categorical color naming experiments were carried out using many color chips under various viewing conditions.

Experimental Materials

The set of JIS (Japanese Industrial Standard) color chips specified with the Munsell Color Order System is used for the experiment. We used 292 color samples which consist of all samples found at even value levels, even chroma levels, and hue labeled 5 and 10. The size of each color chip was 5.5 x 7 cm, and it was horizontally put on an N5 gray background. The stimuli were observed at an angle of about 45° at a distance of 50 cm.

Light sources

The nine light sources used for the present study were fluorescent lamp (D65) as a simulator of CIE standard illuminant D65, cool white fluorescent (W), three-band type fluorescent warm white (EX-L), three-band type fluorescent neutral (EX-N), halogen (IL), high pressure sodium (NH), metal halide (MHL), high pressure mercury (H), and fluorescent high pressure mercury lamp (HF). The illuminance was 1000 lux for all illuminants.

Categorical Color Naming

Subjects were asked to sort samples into eleven basic color categories specified by Berlin and Kay1. These colors are red, green, yellow, blue, orange, pink, purple, brown, white, gray and black. Sorting of color samples under each illuminant was repeated three times for each subject in different experimental sessions.

Subjects

Four subjects with normal color vision checked by the Ishihara plates participated in the experiment.

3. RESULTS

Color samples sorted into the same color category consistently for all three trials under each illuminant are selected for each subject. Color samples selected from four subjects were not much different from subject to subject. In order to examine consensus colors, we extracted color samples named with a same color by at least three out of four subjects. Figure 1 shows these color samples in the Munsell hue circle under the D65 fluorescent lamp, the high-
pressure mercury lamp H, and the halogen lamp IL. The distributions of color category for the fluorescent lamps EX-N, EX-L, W, the metal halide lamp MHL were very similar to the results from the D65 fluorescent lamp. On the other hand, color categories for high-pressure sodium NH and high-pressure mercury H were different from one illumination to another.

Figure 1. Color samples consistently sorted into the same category of color name for typical three illuminants: D65, H and IL.

4. CIECAM97s SPACE

In order to allocate the basic color name regions in a viewing-condition independent color space, we applied the CIE Color Appearance Model (CIECAM97s)[3] to our data. The lightness J, the chroma C and the hue angle $h$ of the CIECAM97s output were calculated for all color samples which were consistently sorted in a same color name under each illuminant. Figure 2 shows the basic color name regions in the hue circle at four different lightness levels of the CIECAM97s space. Since the color appearance coordinate $(j, h, C)$ of a color chip varies with the illuminant, each color name region was determined with an OR-
region for all illuminants. It is found that the eleven basic color name regions are clearly separated in the CIECAM97s space with each other. This means that the CIECAM97s provide a good prediction of color names under various light sources.

![Regions of eleven basic color names in the CIECAM97s space.](image)

**Figure 2.** Regions of eleven basic color names in the CIECAM97s space.

**References**


PARAMETRIC EFFECT FOR INVESTIGATING COLOUR DIFFERENCE

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Abstract

Parametric effect may significantly change the performance of the advance colour difference formulae, as those formulae were derived from a set of standardised conditions, such as high luminance level with hairline separation surrounded by medium grey background. This study investigated the parametric effects of sample size, sample separation. Four colour difference formulae, viz., CIEL*a*b*, CMC, CIE94, BFD were also tested using the visual results obtained. Grey scale method was adopted for assessing colour difference. 107 pairs of samples in five colour centres with the mean colour difference of 5.01 CIELAB unit were used in visual assessment. The experiments have been divided into four phases: reference phase (3x3 inches square sample pairs viewed upon neutral grey background with hairline separation), large gap phase A(3x3 inches square sample pairs viewed upon neutral grey background with 3 inches gap separation for both grey scales and sample pairs), large gap phase B(3x3 inches square sample pairs viewed upon neutral grey background with 3 inches gap separation for sample pairs and hairline for grey scales), and small size phase (0.6x0.6 inches square sample pairs viewed upon neutral grey background with hairline separation). The parametric effect is obtained by the ratio of the visual colour differences of one viewing condition to those of the reference condition. It varies from 0.92 to 0.88 in this study. When the visual data were used to test the colour difference equations, it was found that CIEL*a*b* colour difference formula gave better results than others.

Introduction

Colour difference formula is an essential part of instrumental colour assessment. It is used for quantifying the colour difference and assisting the colour quality control decisions. Many colour difference formulae have been published so far. The so-called advanced
formulae are CMC(l:c) [Clarke1984], BFD(l:c) [Luo1987] and CIE94 [CIE1995]. However, differences do exist among those formulae in both the structures of those formulae and the results of quantifying the same pair of sample. Moreover, these formulae were developed under reference viewing conditions, such as under high luminance level with hairline separation surrounded by medium grey background. Nevertheless, in practical situation, there are cases that colour difference assessment of a sample pair may not be under reference conditions, i.e., the parameters for visual assessment may be different from those of the reference condition. These parameters could significantly influence the colour difference perception and hence cause discrepancies between the formula prediction and visual assessment. This study investigated the effects of some of the important parameters to the visual assessment of colour difference in comparison to those of the reference viewing conditions so that the parametric effect can be identified and quantified.

Experiments

Five colour centres were selected for this study. The colour centres were selected based on the previous investigation of the three colour difference formulae, i.e., CMC, BFD and CIE94[Heige 1996]. Around those five colour centres, the three colour difference formulae have the highest disagreement. The average L*, a* and b* under D65 illuminant are given in table 1.

Table 1: The average of L*, a* and b* for the selected five colour centres under D65.

<table>
<thead>
<tr>
<th>Colour centre</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>C*</th>
<th>h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orange centre</td>
<td>49.25</td>
<td>11.15</td>
<td>17.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow centre</td>
<td>76.87</td>
<td>-0.55</td>
<td>18.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grey centre</td>
<td>48.44</td>
<td>-0.88</td>
<td>-0.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green centre</td>
<td>28.84</td>
<td>-13.42</td>
<td>-1.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue centre</td>
<td>25.45</td>
<td>9.02</td>
<td>-19.42</td>
<td></td>
<td></td>
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</table>
Sample pairs were produced using cotton fabric with very fine surface texture and dyed with reactive dye. Sample pairs for each of the five colour centres were prepared in such a way that the colour difference for each pair are from 4.5 to 5.5 CIELAB units. In this way the visual assessment results would be around Grade 2.5 to 3 in grey scale assessment. For each of the colour centres, sample pairs would have only chroma differences ($\Delta C^*$) or hue differences ($\Delta H^*$) as well as mixture of chroma and hue differences. And a few pairs would have only lightness differences. Orange, yellow, grey, green, and blue centres had 14, 10, 29, 27, and 23 pairs of samples respectively. Additional 4 pairs of samples with only lightness differences were also prepared at the grey centre with the lightness ($L^*$) centre points of 70 to 80 and 25 to 35. All together 107 pairs of samples were dyed.

Grey scale method [Luo1986] was adopted for the visual assessment of colour difference. Hence, a set of grey scale was also prepared, which were in the same size and material as those of the sample pairs. Specification of the grey scale was produced according to the ISO1006: A02 Grey Scale for assessing change in colour. The ratios of CIE $\Delta L^*$ and $\Delta E$ values were very close 1.0, which indicated the colour differences were mainly in lightness attributes.

The experiments have been divided into four phases as seen from table 2. The reference phase (phase I) follows CIE guideline with medium grey ($L^* = 50$) background, direct contact of sample pairs forming hairline separation. The sample size was 3 by 3 inch square, which is equivalent to $10^4$ viewing field. Phase II (large gap A) uses 3 by 3 inch square samples viewed on the same medium grey background with 3-inch gap separation for both grey scales and sample pairs. Phase III (large gap B) uses 3 by 3 inches square samples viewed on the same background with 3-inch gap separation for sample pairs and hairline for grey scales. Phase IV uses small size sample of 0.6 by 0.6 inches square sample viewed on the same background with hairline separation.

Table 2. Description of phases in visual assessments

<table>
<thead>
<tr>
<th>Phase</th>
<th>Background</th>
<th>Sample Size</th>
<th>Sample Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (Reference 10°)</td>
<td>Medium Grey</td>
<td>3 inch square</td>
<td>Hairline</td>
</tr>
<tr>
<td>II (Large gap A)</td>
<td>Medium Grey</td>
<td>3 inch square</td>
<td>3 inches (3-inch gap for grey scale)</td>
</tr>
<tr>
<td>III (Large gap B)</td>
<td>Medium Grey</td>
<td>3 inch square</td>
<td>3 inches (hairline for grey scale)</td>
</tr>
<tr>
<td>IV (Small size 2°)</td>
<td>Medium Grey</td>
<td>0.6 inch square</td>
<td>Hairline</td>
</tr>
</tbody>
</table>
All observers had been tested as having normal colour vision using Ishihara test. Before starting the experiment, observers were asked to adapt the viewing condition for about 2 minutes. There was also a training session for each of observers. The sequence of samples being assessed was in random order. The position of sample pair and grey scale pair swapped alternatively after each individual assessment. The effect of orientation can be averaged out by such arrangement [Sugiyama and Wright 1963].

All the visual assessments were carried out in Verivide viewing cabinet under D65 simulator. 0/45-viewing geometry was used. A panel of 10 observers was used and they were invited to repeat all the assessment after about a week.

The arrangement of the sample and grey scale pairs are shown as follows:

![Diagram of sample and grey scale pairs]

Fig.1 Arrangement of visual assessment without gap for grey scale method

Observers were encouraged to provide a intermediate steps, e.g. 2.4, 2.7 etc. if colour difference is in between two neighboring grey scale steps. The grey scale rating (GS) for each pair was recorded. The GS values are not proportional to the difference seen, but the corresponding ΔE values should be. Thus an equation was required to relate the Grades and ΔE values, using a computer curve-fitting package. A smooth curve of transforming GS to ΔE was obtained and given as the following:

\[ ΔE = 21.572 - 10.702GS + 2.22GS^2 - 0.188GS^3 \]

Therefore, individual observer grey scale rating (GS_i) of each pair of sample would be transformed into the visual colour differences ΔVi using the above equation:

\[ ΔVi = 21.572 - 10.702GS_i + 2.22GS_i^2 - 0.188GS_i^3 \]
In order to test the observer precision and the correlation of colour difference formulae, a performance factor (PF) is used. The PF developed by Luo (1987) was combined several measures of fit: Gamma Factor \( \gamma \), Coefficient Variation \( CV \), \( V_{AB} \).

\[
PF = 100[\gamma + CV/100 + V_{AB} - 1]
\]

The PF so obtained are then divided by 3, i.e. PF/3, to give an indicator for the performance. The calculation of \( \gamma \), \( CV \), and \( V_{AB} \) are given as the following:

\[
\ln(\gamma) = \{1/N\Sigma[\ln(\Delta E/\Delta V) - \ln(\Delta E/\Delta V)]\}^{1/2}
\]

\[
CV = [\Sigma(\Delta E - f\Delta V)^2 / N]^{1/2} / \Delta E, \; f = \Sigma(\Delta E\Delta V) / \Sigma\Delta V^2
\]

\[
V_{AB} = [1/N\Sigma[\Delta E - (F\Delta V)]^2 / \Delta E(\Delta V)]^{1/2} \; \text{Where} \; F = [\Sigma(\Delta E/\Delta V) / \Sigma(\Delta V/\Delta E)]^{1/2}
\]

For perfect agreement, \( \gamma \) would be equal to 1 and \( CV \) and \( V_{AB} \) would be equal to 0.

**Results and Discussion**

1. Observer precision

The observer precision in terms if PF/3 is given in table 3. It is calculated using all 107 pairs of sample of all 4 different phases.

<table>
<thead>
<tr>
<th>Phase Observer</th>
<th>Reference</th>
<th>I Large Gap(A)</th>
<th>II Large Gap(B)</th>
<th>III Small size</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>29.20</td>
<td>28.44</td>
<td>19.26</td>
<td>23.60</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>22.65</td>
<td>23.94</td>
<td>19.55</td>
<td>23.39</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>33.35</td>
<td>30.06</td>
<td>19.45</td>
<td>27.22</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>19.83</td>
<td>21.60</td>
<td>27.94</td>
<td>23.32</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>34.79</td>
<td>36.43</td>
<td>20.87</td>
<td>23.36</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>26.91</td>
<td>25.23</td>
<td>14.90</td>
<td>22.02</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>14.50</td>
<td>23.09</td>
<td>12.06</td>
<td>15.07</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>21.64</td>
<td>28.23</td>
<td>25.29</td>
<td>21.67</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>20.13</td>
<td>16.36</td>
<td>13.58</td>
<td>19.78</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>20.96</td>
<td>14.80</td>
<td>13.27</td>
<td>18.67</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>20.39</td>
<td>28.94</td>
<td>18.10</td>
<td>17.65</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>19.22</td>
<td>19.04</td>
<td>21.90</td>
<td>23.84</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>21.46</td>
<td>23.97</td>
<td>24.75</td>
<td>24.76</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>22.62</td>
<td>14.31</td>
<td>24.33</td>
<td>20.27</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>29.28</td>
<td>29.06</td>
<td>17.27</td>
<td>16.87</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>27.93</td>
<td>23.25</td>
<td>27.30</td>
<td>15.47</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>12.43</td>
<td>17.83</td>
<td>24.80</td>
<td>15.07</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>17.48</td>
<td>26.27</td>
<td>17.13</td>
<td>22.52</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>16.60</td>
<td>24.87</td>
<td>18.72</td>
<td>15.38</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>14.44</td>
<td>17.43</td>
<td>14.25</td>
<td>17.27</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>22.30</td>
<td>23.56</td>
<td>19.74</td>
<td>20.40</td>
<td></td>
</tr>
</tbody>
</table>

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It can be seen from table 3 that the observer precision is satisfactory. The best precision is found in phase III which was carried out last. This could be due to the experience built by observers during the experiments. The overall results are comparable with previous researches using grey scale assessment method.

2. Performance of colour difference formulae

The performance of various colour difference formulae was also tested using PF/3. The results are shown in table 4.

<table>
<thead>
<tr>
<th>Formulae</th>
<th>CIEL<em>a</em>b*</th>
<th>CMC (2:1)</th>
<th>CMC (1:1)</th>
<th>CIE94 (2:1)</th>
<th>CIE94 (1:1)</th>
<th>BFD (1.5:1)</th>
<th>BFD (1:1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase I</td>
<td>21.50</td>
<td>33.39</td>
<td>26.12</td>
<td>29.25</td>
<td>26.02</td>
<td>31.89</td>
<td>26.50</td>
</tr>
<tr>
<td>Phase II</td>
<td>23.28</td>
<td>32.68</td>
<td>26.35</td>
<td>28.90</td>
<td>27.65</td>
<td>31.27</td>
<td>26.7</td>
</tr>
<tr>
<td>Phase III</td>
<td>20.74</td>
<td>34.82</td>
<td>28.71</td>
<td>29.75</td>
<td>27.99</td>
<td>33.24</td>
<td>28.56</td>
</tr>
<tr>
<td>Phase IV</td>
<td>25.51</td>
<td>37.25</td>
<td>30.78</td>
<td>32.96</td>
<td>30.36</td>
<td>34.57</td>
<td>29.71</td>
</tr>
</tbody>
</table>

In all 4 phases, it is very clear that CIEL*a*b* gives best performance, about 3 - 8 PF/3 units smaller than those of CMC(1:1), CIE94(1:1) and BFD(1:1) in all four phases. The lightness weight of 1 gives better results than 2, which is reasonable since the results are perceptibility in nature. In general, the results obtained from reference phase are better than other phases for all colour difference formulae. This indicates that the formulae can not correlate the visual results well if no modifications are applied.

The results obtained in this work contradict with previous studies[ Luo 1987]. However, the average size of colour differences in this work is about 5 CIELAB unit whereas the previous studies have smaller (about 3 CIEL*a*b* unit). Therefore, the size of the colour difference plays an important role for the formulae performance. For large colour difference (10 CIEL*a*b* unit), CIELAB also shown better performance[Guan1997]

3. Evaluating Parametric Effects

In this study, the parametric effects are assessed by direct comparison of the visual colour differences of one viewing condition against those of the reference condition (phase I). A K factor was calculated to describe the parametric effect: \( K = \Sigma (\Delta V_i / \Delta V_r) / N \)
Table 5. The K values for phase II, III, and IV in comparison to the reference phase

<table>
<thead>
<tr>
<th>Phase</th>
<th>Phase II</th>
<th>Phase III</th>
<th>Phase IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.92</td>
<td>0.89</td>
<td>0.88</td>
</tr>
</tbody>
</table>

This K value indicates how much the perceived colour difference changed compared with the reference phase. K equaling to 1 this represents that there is no parametric effect. The higher the degree of deviation from 1 for K value, the higher the parametric effect. It can be seen from table 5 that the perceived colour differences of the small size sample pairs in phase IV have 12% deviation from those of the reference phase. And the perceived colour difference for the phase III has about 11%. The result for phase II has only 8% deviation from those of the reference phase. These results can also be seen from fig 2 to fig 4 in which the points for phase II are more close to the 45° line whereas phase III and phase IV are less close to 45° line.

**Fig 2.** The visual colour difference results of phase II vs. phase I.

**Fig 3.** The visual colour difference results of phase III vs. phase I.

**Fig 4.** The visual colour difference results of phase IV vs. phase I.

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Conclusion

CIEL*a*b* colour difference formula has better agreement to the visual colour difference results in this study, in which the average colour difference is about 5 CIELAB units for all 107 sample pairs. All other formulae give worse correlation about 3 - 8 PF/3 units worse than those of from CIEL*a*b*. When parametric effects are considered, small samples with 2° viewing angle and large sample with a 3-inch gap between them (whereas the grey scales have hairline separation) show 12% and 11% deviation from the reference viewing conditions.

Reference


Color can appear in two different modes. Color of light presented in a small hole in the dark surround is called aperture mode. It changes from dark to bright. Color appearing as a surface of an object is called surface or object mode. It changes from black to white. Specification of color of CIE system, such as \(x, y, Y\), is mainly concerned with aperture colors. Systematization of surface colors, such as Munsell and NCS, is sometimes called color order system. This presentation is focused on appearance and differences in surface color. Traditionally, color scientists are concerned with color difference at differential threshold level, jnd (just-noticeable difference). The main concern of this presentation is suprathreshold difference between surface colors. When we see an orange color, we feel "redness" and "yellowness" in it. These are called principal hue components. When we see two colors, we feel "similarity" or "difference" between the two. Let us denote a principal hue component \(\alpha\) in a color \(j\) by \(\gamma_{\alpha}(j)\), and the difference between colors \(j\) and \(k\) by \(\delta_{jk}\). These are experiences of an observer and can not be observed by anybody else. In this sense, \(\gamma_{\alpha}(j)\) and \(\delta_{jk}\) are latent variables. Hence, we have to convert these to observable data. This process is called scaling and obtained variables are denoted as \(\xi_{\alpha}(j)\) and \(d_{jk}\) respectively.

1. Scaling of color difference \(\delta\) and prediction from Munsell solid (Indow, 1999a)

Under the standard observing condition, pairs of colors \((j, k)\) were presented one by one, and the observer evaluated the size of \(\delta_{jk}\) in the following way. The observer had a series of Munsell grays, \(N_1, N_2, \ldots, N_{12}\) with a step size smaller than 0.5\(V\). With a pair \((j, k)\), a gray \(N_{\alpha}\) is specified and the task of observer was to select such a \(N_{X}\) that the lightness difference between \(N_{\alpha}\) and \(N_{X}\) appeared to match \(\delta_{jk}\) in size. With each pair \((j, k)\), such matchings were repeated \(N_{R}\)
times by N_s observers. Several grays were used as the standard gray N_A. Then, the average of
\[ |V_A - V_X| \]
was defined to be \( d_{jk} \), where \( V \) means Munsell Value that ranges from 0 to 10. In other
words, \( d \) is converted to \( d \) in terms of matched \( V \) unit. If two colors are too different, e.g.,
saturated red and green, it becomes difficult for human to realize the size of difference. Hence,
pairs evaluated were limited in the range that can be matched by \( d < 4.0V \). The detailed
explanation of the data \( (d_{jk}) \), \( N = 730 \), is in Table 1 of the original article.
### Predictors of Euclidean Distance in Munsell Solid

<table>
<thead>
<tr>
<th>Predictors</th>
<th>RMS in terms of matched V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euclidean distance in Munsell solid</td>
<td>0.30 – 0.63</td>
</tr>
<tr>
<td>Adams-Nickerson (NBS)</td>
<td>0.70</td>
</tr>
<tr>
<td>Modified Judd (NBS)</td>
<td>0.77</td>
</tr>
<tr>
<td>CIE 1976 (L* u* v*)</td>
<td>0.71</td>
</tr>
<tr>
<td>CIE 1994 (L* C* H*)</td>
<td>0.58</td>
</tr>
</tbody>
</table>

These sizes of RMS in terms of the matched V-unit should be evaluated from the viewpoint that the just-noticeable difference in V-scale is in the order of 0.15.

### 2. Scaling of Principal Components $\Delta \lambda$ and Prediction from Munsell Solid (Indow, 1999b)

This scaling was tried in various ways. The most representative procedure was to ask the observer to make marks on a given line segment for a given color $j$. First, the line, defined to be 0-10, was divided into two parts in proportion of the chromatic impression and the achromatic impression, $\zeta(j)$ and $N(j) = 10 - \zeta(j)$. Then, $\zeta(j)$ was divided into two, sometimes three, parts according to the degree of $\Delta \lambda$, $\xi_{an}(j)$. For instance, if a color $j$ is saturated orange, $\zeta(j) = 0.9$, $\xi_{an}(j) = 0.50$, and $\xi_{an}(j) = 0.40$. Namely, $0 \leq \zeta(j) \leq 10$, $0 \leq \xi_{an}(j) \leq \zeta(j)$, and the sum of two or three $\xi_{an}(j) = \zeta(j)$. These assessments were repeated $N_8$ times by $N_9$ observers with each of $N = 641$ colors (Table 1 in the original article), and mean values were denoted as $\zeta(j)$ and $\xi_{an}(j)$.

Information on the stability of these assessments is given in Table II. Let us call $\xi_{an}$ absolute principal hue components $\alpha$ and $\eta_{an} = \xi_{an}/\zeta$ relative principal hue components $\alpha$. With some
colors j, the observer matched the grayness of the achromatic part N(j) with Munsell V. The mean result was denoted as \( \hat{V}(j) \).

Data \( \xi_a(j) \) were related to \( \hat{\xi}_a(j) \), the coordinate of \( P(H_j \ V/C_j) \) on the hue vector \( \xi_a \), where \( P(H_j \ V/C_j) \) is the orthogonal projection of point \( P(H_j \ V/C_j) \) in the Munsell solid to the plane \( (H, C) \), and \( \xi_a \) were defined in this plane so as to minimize

\[
RMS_a = \sqrt{\frac{\sum_{j}^{N_a} (\xi_a(j) - \hat{\xi}_a(j))^2}{N_a}}
\]

\( \hat{\xi}_a(j) = A_a(A, H) \xi_a(j) B_a(H, V) \).

The variables to be optimized are directions of \( \xi_a, A_a(H, V) \), and \( B_a(H, V) \). The range of data \( \xi_a(j) \) is from 0 to 10 and the general level of RMS\( _a \) was 0.3 ~ 1.4 in this unit. The exponents \( B_a(H, V) \) were 0.5 ~ 0.9. Namely, when \( \xi_a(j) \) were plotted against \( \hat{\xi}_a(j) \), the scatter of \( N_a \) points is not linear but clearly convex upwards in each \( a \). All assessments were made in two ways, with four hue names \( (\alpha = R(\text{red}), Y(\text{Yellow}), G(\text{green}), \text{and } B(\text{blue})) \) and with five names in Munsell notation \( (\alpha = R, Y, G, B, \text{and } P(\text{purple})) \). Principal findings are as follows.

1. It became clear that the hue name \( P \) is redundant. (A) The observer had no difficulty to specify principal hue components of all colors without using \( P \). (B) When plotted as functions of \( H_p \), the curve \( \xi_a(j) \) can be divided exactly into two curves, \( \xi_R(j) \) and \( \xi_B(j) \). Hence, in the discussion to follow, only four hue names are used.

2. Directions of \( \xi_a, \xi_y \), and \( \xi_0 \) were very close to the directions of 5R, 5Y and 5G of Munsell notation. However, irrespective of whether four or five names were used, \( \xi_0 \) was in between 5PB and 2.5PB (Fig. 5 in the original article).

3. It was tried to predict data \( d_{jk} \) by \( \Delta \xi_a(j, k) \) defined from \( \Delta \xi_a(j, k) = |\xi_a(j) - \xi_a(k)| \), where \( \alpha \) represent hue names relevant to the two colors \( j \) and \( k \), and \( \Delta V_{jk} = |V_j - V_k| \). The prediction was not quite satisfactory.

3. Prediction of color difference scale, \( d \), from principal hue curves \( \xi_a(H \ V/C) \)

This is the new part of this presentation. Now, it appeared as the third article (Indow, 1999c). By plotting \( \xi_a(j) \) against \( H_p \) we can a curve for principal hue \( \alpha \). It was found difficult to define a curve for each hue \( \alpha \) that is independent of \( V \) and \( C \). Hence, curves were defined separately.
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according to V/C. We can have the similar curves from NSC system and two curves were synthesized. As an example, curves on the hue-circle at (4V/4C) are shown below.

These curves \( \bar{e}_\alpha (H | V/C) \) thus defined are called principal hue curves and given in Fig. 5 of the original article, \( \alpha = R, Y, G, B, V = 4 \) to 7 and \( C = 2 \) to 10.

The color difference \( d_{jk} \) between \( P(H_j V_j/C_j) \) and \( P(H_k V_k/C_k) \) must be related to the differences in components; \( \Delta V = |V_j - V_k| \), and \( \Delta \bar{e}_\alpha = |\bar{e}_\alpha (H_j | V_j/C_j) - \bar{e}_\alpha (H_k | V_k/C_k)| \). for \( N = 899 \) pairs \((j, k)\), various functional relationships were tested, e.g., linear, logarithmic, power, and Minkowski metric. It became apparent that the best predictor \( \bar{d} \) is the linear regression with the intercept \( d_0 \),

\[
\bar{d} = a_V \Delta V + \left( d_0 + \sum a_x \Delta \bar{e}_x \right)
\]

\( a_V = 0.459, d_0 = 0.610, a_R = 0.199, a_Y = 0.031, a_G = 0.098, \) and \( a_B = 0.136. \)

The discrepancy RMS between \( d_{jk} \) and \( \bar{d}_{jk} \) was 0.34 in the matched V unit. This value should be compared with the values in Section 1.

In contrast to predictions stated in Sections 1 and 2, this prediction is not based on any metric interpretation of Munsell solid. What is used is Munsell notation of color \((H V/C)\) only. If the current Munsell color spacing is altered, the forms of \( \bar{e}_\alpha (H | V/C) \) must be adjusted. Except cases in which interpolation is necessary, this change does not affect the result stated herein.
4. Appearance of colors

Principal hue curves tell us how a color \( P(H | V/C) \) appears. For example, the peak of \( \bar{v}_{H}(H | 4/4) \) is not at 5B but at 5PB. The same is true in other V/C colors. This is the reason that \( f_{\text{I}} \) did not coincide with the Munsell notation of 5B ((2) in Section 2). The same fact was mentioned, e.g., by Kuehni (1999).

We can see brown only in surface color mode. If a brown surface is observed through a reduction tube, the color we see in the aperture is not brown but dark desaturated red. The Munsell notation for the most representative brown is (SYR 4/4). The relative principal hue components \( \eta_{H}(5YR V/C) \) remains at about 0.6 and \( \eta_{V}(5YR V/C) \) at about 0.4 all through V/C. As stated in Section 2, the observers matched the lightness of \( N(j) \) part with the Munsell V level \( (V(j)) \). In general, \( V(j) \) is linear functions of \( V_{j} \) in \( (H_{j} V_{j}/C_{j}) \) with the same slope but slightly difference intercepts according to \( H_{j} \) (Fig.2 in Indow (1999b)). Interesting enough, \( V(5YR 4/4) \) was found considerably blacker compared with this general trend (Fig.15). In order for a color to appear brown, the black component must be apparent. It is an open question, the fact that \( V(5YR 4/4) \) was matched particularly dark is whether the cause for (5YR 4/4) to appear brown or the result of that (5YR 4/4) looks brown.

References


COLORIMETRY PROBLEMS RELATING TO COLOR RENDERING AND COLOR PREFERENCE
William Thornton and Nick Hale
Prime-Color Inc., Cranford NJ USA and Hale Color Consultants Inc., Naples FL USA

Abstract

Both CIE Standard Observers report that some visually white lights appear to the Standard Observers as grass-green [1]. These, and many other data [2], show that the CIE color-matching functions are not characteristic of the normal human observer, when they are used as weighting functions on the spectral power distributions of viewed lights. But color-rendering, under any illumination, is analyzed by using the CIE color-matching functions. It is therefore to be expected that CIE-computed chromaticities will be in error. Deane Judd[3]—and others, have shown that colors of familiar objects (complexions, fruit, vegetables, meat, grass) are preferred considerably different from CIE-computed chromaticities. For that reason it has been believed that "preferred" colors can be quite different from "true" colors (CIE-computed). We show here that substitution, of color-matching functions [4] taken directly from normal human observers, immediately shifts the colors of those familiar objects at least approximately to their "preferred" chromaticities. The tentative conclusion is that "true" color and "preferred" color are the same. They are the colors that the normal human observer always sees, and SO (in the case, for example, of complexions and foods) they are the colors he prefers and expects. Thus we may look forward to a more satisfactory color-rendering index developed on this basis.

Literature


The full text has not been received by editor
MULTI-ANGLE SPECTROPHOTOMETERS FOR METALLIC, PEARLESCENT 
AND SPECIAL EFFECTS COLORS

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The matching and quality control of color components has always been an ever challenging task. With the introduction of higher quality standards and consciousness it has became even more critical to accurately measure and reproduce color. Added to the quality issue has been the introduction of new special effects colors that change appearance with viewing angle. The use of these special effects along with metallic and pearlescent colors has generated a need for an instrumental means of quantifying these effects. This has been especially true in the automotive exterior colors.

Designers has used these special effects in new and innovative designs which has forced quality engineers to search for more consistent and accurate means of quantifying color in the manufacturing process. When evaluating exterior automotive color differences with instrumentation, there are a number of variables that need to be considered, most importantly is instrument geometry. Other areas of focus are color standards, paint technologies, part configuration, part orientation and of course, visual comparison.

While older existing instrument geometries such as diffuse/8, commonly known as sphere and 0°/45°, can give same indication as to what kind of color difference exist, neither provides the correlation to visual assessment nor correlation to process parameters needed to make adjustments. Utilizing recent technology, one can now accurately monitor and control automotive colors with the use of multi-angle spectrophotometer.

The full text has not been received by editor
COLOR APPEARANCE NOT EXPLAINED BY x AND y BUT BY THE RECOGNIZED VISUAL SPACE OF ILLUMINATION

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It was shown that the color property of the recognized visual space of illumination, RVSI was controlled by changing the initial visual information by arranging objects in the room all orientating toward a certain direction. We constructed two miniature rooms, D and I both illuminated by the same fluorescent lamps of daylight type but arranged with furniture of different color, those in the room I shifting toward colors as if they were illuminated by an incandescent lamp. Subjects perceived the room I as if it was illuminated by a incandescent lamp. A test patch was placed in midair of each room and its apparent color was judged. When the test patches were placed in the room I their colors were all perceived orientated toward greenish blue compared to those of test patches placed in the room D in spite of the fact that the test patches had same chromaticities whether they were placed in the room D or I. The results imply that the apparent color of an object is determined not by its chromaticity coordinates x and y, but in relation to the color property of the RVSI of the room where the object is observed.

KEYWORDS: color, color appearance, color constancy, interior, illumination, recognized visual space of illumination

1. INTRODUCTION

The present experiment is based on the recognized visual space of illumination, RVSI\textsuperscript{1,2,6} in short, and the concept of the RVSI is first explained. When a person enters a room, he/she immediately understands how the space is illuminated, brightly or dimly, or, whitely or a little bit reddishly, for example. This situation is expressed as that the recognized visual space of illumination for the room was constructed in his/her brain. For the construction he observed and utilized the appearance of objects in the room, luminaires and windows, if any, as the first information, and they are called the initial visual information.

Hereafter, the person perceives the color of any object in the room in relation to the RVSI\textsuperscript{1,6}. In other words, the appearance of the object and the property of the RVSI should coordinate with each other within the person. The initial visual information can be controlled, for example, by changing the light source, from a daylight lamp to an incandescent lamp. Consequently the chromaticity of the object changes toward orange. At the same time, however, the color property of the RVSI also changes from that of daylight to incandescent lamp, shifting toward orange by an almost same amount as in the object chromaticity. The perception for the object should not change, remaining white if the object started with white.

In this paper, yet another way to change the color property of RVSI is introduced. The same daylight lamps were used for both two rooms, but the colors of furniture were changed among
the two rooms. The colors in one room were chosen so that they appeared as if the furniture were placed under an incandescent lamp although in fact they were illuminated by the daylight lamp. By this way the observer's RVSI can be shifted toward orange similarly as the room with an incandescent lamp. If this happens, we can predict that a white test patch placed in the room appears a little bit greenish blue as it is still illuminated by the daylight lamp and some other orange test patch should appear white. By measuring the color appearance change of the test patch toward the greenish blue, we can confirm the shift of color property of the RVSI toward orange.

2. EXPERIMENT

The two miniature rooms, D and I, were constructed and placed side by side as shown in Fig.1. Both rooms had the same dimensions: 38 cm wide, 50 cm deep and 40 cm high and were illuminated by the same fluorescent lamps of daylight type, FL, through the opal glasses as the ceilings. Both rooms were arranged with furniture of different colors. A subject observed inside the room in turn through an opening shown by thick lines and judged the color of the test patches indicated by T. They were papers of 3 × 3 cm square and attached at the top of poles projecting from the back walls so that the subject could see the patch in midair of the rooms. The side view of the apparatus is shown in Fig.2. The test patch was tilted toward the ceiling so that it was illuminated by the ceiling light. An experimenter E could change the test patch by opening the back walls as shown by an arrow. The subject's booth was kept dark so that he/she could see only inside of the miniature rooms.

The colors of furniture in the room D were properly selected to cover various colors. Then the colors of the room I were determined in the preliminary experiment as follows. A color paper of

![Diagram of two miniature rooms](image-url)
the corresponding furniture in the room D was placed in a box illuminated by an incandescent lamp. It was observed through a small square opening made on the box and was matched by a subject with a reference color chart placed at the subject’s hands and illuminated by a daylight lamp. By this way the color paper in the box appeared as if it was attached on the small square and recognized by the subject as an object in the subject’s space illuminated by the daylight lamp. The matched color in the reference color chart was used as the color of the furniture in the room I.

The colors in the room I were all oriented toward orange compared to the room D as shown in Table 1. For example, walls were N5 in the room D but they were 7.5YR5/6 in the room I. The color shifts of corresponding furniture from the room D to I are shown by solid arrows in Fig.3, tails showing the colors in the room D and heads in the room I. All the arrows direct toward orange.

3. PROCEDURE

A subject was asked to judge the color of the test patches of various chromaticities by color naming method using one or two hues from four unique hues, Red, Yellow, Green and Blue. The subject was instructed to view only one room at a time so that only the RVSI for the room was constructed in his/her brain at the color judgment. When the subject observed inside the room, he/she could not see the ceiling and it could not become the initial visual information. An experimenter changed the test patch randomly every time after the subject’s judgment.

The chromaticity coordinates of the test patches used for the color judgment, when illuminated
by a daylight lamp, are shown by small open squares in Fig. 4. Nineteen of them were prepared to cover colors of the range from greenish blue (10BG8/1.0) to yellowish red (7.5YR8/3.5) including a white N8 with 0.25 step in Munsell Chroma. Large circles labeled D and I will be explained later.

Five subjects, HY (21 years old, male), TT (21, male), NO (22, male), RY (23, female) and YM (24, female) participated in the experiment. All had normal color vision. HY and TT were naive subjects in this kind of experiment.

4. RESULTS AND DISCUSSION
First of all it should be emphasized that all the subjects felt two rooms were illuminated differently, namely by white light and orange light in spite of the fact that both rooms were illuminated by same white light. Even the subjects who knew that both rooms were illuminated by same white lamps had the same impression. This clearly shows that the color property of the recognized visual space of illumination in the subject's brain was different for the two rooms.

The results of color naming for the test patches for the five subjects are shown in Fig. 5. The abscissa shows the nominal color of the test patch from 10BG to 7.5YR. The ordinate shows the percentage of responses of R, or Y, or R and Y. Consequently the rest of the percentage indicates the percentage of responses of G, or B, or G and B.

The open symbols indicate the responses for the room D. The color perception for the test patch changes...
from greenish blue to yellowish red in accordance with its nominal color. By taking the test patch color at the 50% percent response, it can be seen that the subject YM, for example, perceived a neutral white for the test patch N8 as expected. The filled symbols indicate

![Graphs showing color perception](image-url)

Fig. 5. The percentage of the response of R, or Y, or R and Y.

Results of five subjects; HY, TT, NO, RY, YM, and the average. Open symbols, room D; filled symbols, room I.
responses for the room I. All the curves shifted toward orange direction. That is, they are now perceiving greenish blue for the N8 patch and neutral white for an orange patch. The subject YM, for example, perceived the neutral white for the patch of 7.5YR8/1.6. The right bottom section shows the average of the five subjects. The shift found for the neutral white perception at 50% response is from 0.28 in Chroma in the room D to 2.0 in the room I. The chromaticities corresponding to these Chroma are shown by large circles, D and I in Fig. 4. The subjects perceived the orange patch I as a neutral white in the room I arranged with furniture all shifted toward orange direction, though the ceiling light is unchanged from the room D.

The shift of the perception of neutral white is shown by an open arrow in Fig.3, superposed on the arrows of the color shifts in furniture. The shift of the neutral white is along the same direction as the furniture change. That is, the subject's RVSI shifted toward orange direction by only the color of furniture as predicted. It is interesting to note that the amount of the shift is clearly smaller than the color shift of furniture. This should imply that the change in the color property of the RVSI is smaller than the shift of the color of the initial visual information.

5. CONCLUSION

It was shown that the color property of the recognized visual space of illumination, RVSI, of a room changed toward orange by changing only the color of furniture placed in the room, though the room was in fact illuminated by daylight lamps. In other words, the apparent color of an object is determined, not by its chromaticity coordinates x and y, but in relation to the color property of the RVSI of a room where the object is observed. The color property of the RVSI can be estimated by the chromaticity of a colored patch perceived as neutral white.

REFERENCES

APPARENT LIGHTNESS OF AN OBJECT DETERMINED BY THE IMMEDIATELY SURROUNDING RECOGNIZED VISUAL SPACE OF ILLUMINATION

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When a person enters a room, he/she immediately understands how the room is illuminated. The state is expressed as the person constructed the recognized visual space of illumination, RVSI in his/her brain for the room. For the construction of the room the person must observe the objects, luminaire, and windows in the room, which are called the initial visual information. In the present experiment it was investigated how much initial visual information was needed to construct a RVSI. A test room was moderately illuminated by a ceiling light and a test target was placed in the air supported by a stick. Beside the ceiling light another light came from above so that it illuminated a limited area covering the test target. If there existed only a test target, a subject could not recognized the illumination at all because he/she observed the test room through an aperture. Hence we called the illumination the hidden illumination. In this case the lightness of the test target was judged by the RVSI made up with only the main ceiling light and the additional light on the test target given by the hidden illumination was transferred to the apparent lightness to raise it up. Then some objects were inserted gradually to the area of the hidden illumination so that the subject could gradually understand that the area was additionally illuminated. The apparent lightness of the test target was measured as a function of the number of objects illuminated by the hidden illumination by matching with a gray scale. The apparent lightness decreased for more objects in the hidden illumination area implying that it was judged by the new RVSI made by the hidden illumination, but it did not fall down to the physical lightness even when there were as many as ten different objects in the area.

KEY WORDS: apparent lightness, initial visual information, hidden illumination, spot light, lightness matching, recognized visual space of illumination

1. Introduction

When one comes to a room, he/she can immediately understand how the room is illuminated, such as brightly or dimly. This situation is expressed as that he/she constructed the recognized visual space of illumination, RVSI, for the room in his/her brain based on the appearance of all the objects in the room, which work as the initial visual information for construction of the RVSI. We use a circle to schematically exhibit the RVSI, R1 as shown by a solid circle in Fig. 1. When we consider an object in the room it can be expressed in the scheme by a certain point along the radius as shown by a solid square in Fig. 1.
Now, once a RVSI is constructed the lightness of any object in the room is determined in relation to the size of the RVSI. In other words it is determined by the distance of the object from the center of the circle compared to the radius of the circle to represent the size of brightness of the RVSI.

Let us consider that a spot-light is employed to cast light on an object in the room without being noticed by the observer. The location of the object shifts outward in the RVSI circle as indicated by an open square. Because the observer still has to judge the lightness of the object in relation to the already established R1, the elevated luminance on the object is then counted into its lightness. It is naturally judged higher. The illumination in this case is called the hidden illumination because it is not noticed by the observer.

If the area covered by the spot-light is enlarged, the observer now can see other objects within the spot-light and the objects work as new initial visual information for the area. He/she begins to construct another RVSI, R2 for the spot lit area beside the already existing R1. The size of brightness of R2 is larger than R1 and it is shown by a larger dotted circle in Fig. 1. The location of the object does not change from the open square and its lightness is judged lower as the location comes to nearer to the center relative to the dotted circle.

In the present experiment we will show the change of the apparent lightness of a test target placed in the spot light as a function of the size of the spot lit area.

2. Experiment
2.1 Apparatus

The apparatus is shown in Fig.2. T indicates a test target for which a subject judges the lightness by matching with a gray scale GS. It was supported by a stick projecting from the back wall so that the subject could see the target in the air without seeing the supporting stick. The test target is illuminated by ceiling light FL together with other objects in the room. In addition the target is also illuminated by a hidden illumination coming from the above by using a slide projector P and a mirror as shown by unshadowed area. The objects in the room are illuminated by the ceiling light only.
For the objects various colors were chosen to cover the most of the main hues. The illuminance of the hidden illumination can be controlled by a circular neutral wedge density filter placed in front of the projector.

The subject looks at the test room through an opening of the size 40cm high and 50cm wide, but he/she can't know the hidden illumination if only the target is within the hidden illumination. Fig. 3 shows the subject's view of the test room. T shows the test target. The objects shown by black figures are the initial visual information to be inserted into the space of the hidden illumination. They are composed of about ten different objects such as green potted plants, black grapes, red dolls, white and yellow cards, blue papers, a table cross and others in one case. Some of them were removed in another case to reduce to about six objects.

They are mounted on a platform movable sideways as shown by an arrow. When the platform is gradually inserted into the hidden illumination area, some objects on the platform are gradually illuminated by the hidden illumination. When the inserting objects come in the middle of the hidden illumination area they completely surround the test target, and subject can clearly see that this area is additionally illuminated. The hidden illumination is in fact no longer hidden illumination.

The subject's task was to judge the lightness of the test target by matching it with the gray scale.

2.2 Condition

Three different patches, N2, N3, and N4 were employed. The hidden illumination was kept constant at 400 lx, and the illuminance of the ceiling light were 60 lx and 150 lx. Both illuminance were measured at a level 30 cm below the test target. The subject's room was illuminated at the same illuminance as the test room.

Two arrangements of the inserting objects were prepared, composing of six objects and ten objects as shown in Fig.4.
The movable platform was placed at seven positions, -17cm, 4.5cm, 8.5cm, 15.5cm, 19.5cm, 21.5cm, 28.5cm. At -17cm the inserting objects are not illuminated by the hidden illumination at all, at 4.5 cm only small right portions of the objects are inside of the illumination, and at 21.5cm the most of the objects are within the hidden illumination. Those three cases are shown in Fig. 5 where the clear area indicates the illuminated portion by the hidden illumination.

Four subjects, SI (24 years old, male), YM (24, female), RY (23, female), and NO (22, male) participated in the experiment.

3. Result

Raw data taken from the subject YM for the 60-400 lx combination and for the dense inserting objects are shown in Fig.6. The ordinate indicates the apparent lightness of a test target in \( L^* \) and the abscissa the position of the movable platform or amount of initial visual information. The three curves are for test target, N2, N3 and N4. At each condition ten determinations of the apparent lightness were carried out. Some of them were completely overlapped and fewer points than ten are seen in the figure at some conditions. The solid curves indicate their means.

At the position of -17cm, the lightness of the test target was determined without any inserted objects. In other words,
the subject could not ever construct the RVSI, R2 for the space illuminated by the hidden illumination, and the subject should judge the lightness in relation to the RVSI, R1 constructed for the test room. All the added hidden illumination on the test target must be converted into the lightness. The apparent lightness became very large compared to its original lightness. The apparent lightness gradually decreased to return to its original lightness when the inserted objects were increased implying that a new RVSI, R2 for the hidden space was being established gradually.

To see the variation among the subjects the results of all the four subjects are plotted together in Fig.7 for the same condition as for Fig. 6. There exists some variation but the property that the apparent lightness of the test target gradually decreases to return to its original lightness is quite clear. Fig.8 is the average of these four subjects.

The results from other conditions are not shown here but they are more or less same as the above results, though the decrease of the lightness was somewhat small.

4. Discussion
When the inserting objects or the initial visual information is increased for the hidden illumination, the apparent lightness decreased, implying the restoration of the lightness of the test target to its original value. The restoration implies the construction of the RVSI, R2 for the space of the hidden illumination beside the RVSI for the test room, R1. It should be noticed, however, that the apparent lightness did not completely restore the to the original lightness, namely L*:20 of N2, 30 of N3, 40 of N4 as shown in Fig.8.

We can think of two reasons for that. Firstly there existed a large illuminance difference between the hidden space and the subjects’ room where he/she was

![Fig.7 Result of four subjects for the condition same as Fig.6: ○,YM ; ●,SI ; ▽, NO ; △, RY.](image)

![Fig.8 Mean of four subjects for the condition of 60 lx of ceiling light and 400 lx of hidden illumination from the subject YM, and for 10 inserting objects.](image)
matching the lightness of the test target with the gray scale, namely 400 lx for the hidden space and 60 lx or 150 lx for the subjects' room. The difference was in fact larger because the vertical position of the test target and the inserting objects was 38 cm higher than the position where the illuminance was measured to increase the illuminance. The difference might have caused to elevate the apparent lightness of the test target. Secondly there were no walls nor floor in the inserting objects to construct an ordinal room illuminated by the hidden light. It might be necessary to have a room to construct a complete RVSI for the space.

To check the first reason we conducted an additional experiment where the apparent lightness of the test target was measured as a function of the illuminance of the test room illuminated by the ceiling light only while keeping the illuminance of the subject's room constant at 60 lx. Fig. 9 shows the result from two subjects by dotted lines and the average by the solid line. The apparent lightness indeed increased gradually as the illuminance of the test room was increased from 10 lx to 350 lx. The illuminance difference influences the judgement. The curves in Fig. 8 should be reinterpreted and the conclusion may be that the restoration of the lightness to the original value was accomplished fairly well.

References
COLOUR APPEARANCE IN A TEXTILE PATTERN

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ABSTRACT

Various textile patterns are divided by techniques of production and by other textile technology specifications, that determine also visual and tangible quality of textile materials. Historically we distinguish woven, knitted, printed, embroidered, quilted and other textiles produced with modern technology. Colour appearance in a pattern differs significantly whether a textile material was dyed before the weaving or knitting or it was ennobled by dyeing and printing or embroidering afterwards.

Beside technology parameters visual variability influences effectively colour appearance in textile patterns. These are rhythm, contrast, orientation, scale, number of colours and shapes involved in a certain pattern. Distance of observation, illumination and pattern's surrounded colours are also very important for true colour comprehension.

In the following paper I will represent a design research of blue colour variability in various textile patterns. A project is based on a design of different textiles for a fashion collection, that reflects blue. Textiles involved vary in material qualities, patterns and surface feelings. Separated blue reflections form combined compositions in a group of clothes.
1. INTRODUCTION

Textile patterns are closely related to textiles themselves. Depending on the way of their production we distinguish various scales of patterns. The latter is closely affected by pattern's surrounded colours embodied also in other materials, light or reflection, not only in textiles.

Beside traditional ways of production now-a-days textile patterns are produced with various mixed techniques that employ quilting, interlacing, printing, dyeing, felting, finishing, joining, pressing, ageing and others. More and more specialised intentions of use cause also a wide range of interventions into textiles' micro structures. Development of technical textiles widely influenced also the image of fashion textiles. Colours' and other surface's effects depend on types of applied yarns, technique of textile's construction and finishing methods. All together compose textile as a whole. We express them as cool, smooth, liquid, matt, fresh, dense, creamy, undulating, waxed, patinated, transparent, sharp, organic, filmy, glazed, delicate, crisp, recycled, news print, deep, rich, dark, luxury, frothy, dusted, light as air, burnt, coated and others.

Pattern could appear traditionally all-over or as a sign located on a certain position. All-over patterns repeat equally in various scales. Depending on composition's density they tend to various monochrome impressions from a certain distance at the same illumination of samples. They behave as visually textured surfaces in combination with other textures and colours. On the contrary a located single sign or a group of signs focuses viewer's attention on a certain visual effect. It represents a stronger visual contrast in the whole composition. It stresses pattern's scale of colours and its literature approach.

2. EXPERIMENTS AND RESULTS

Textiles reflected in a blue colour are very often in a textile design. Blue textiles are beside brown and grey tones also traditionally the most common. The represented project is dedicated to a blue denim quality for clothing. Thinner and heavier denims were printed with pigment prints of different covering, shine and thickness. They materialised characteristically basic textiles' surfaces. Blue tones changed significantly as they were printed onto a certain colour basis. Various blue combinations with background colours were
created. Blue reflections were combined with other surface effects. They were produced with discharge, reserve and burn-out printing technique. Three-dimensional surfaces were created by expanded pigment pastes and extreme shrinking of thinner types.

Patterns were designed in various scales to provide different visual relationship to a human body. This becomes obvious in a following apparel design. A motif of dolphin was installed into some all-over patterns of a smaller and medium scale. The same motif was applied also individually or in a located group. In this case it was noticeably enlarged to provide a unique symbiosis with a dress designed later.

All-over patterns of various scales, mostly bicolour, pour together into monochrome reflections from a certain distance. Patterns loose their distinctness. They become textures, blue halftones. Described separated tones of textures close with the smallest scale of a plain denim. Typical denim’s twill weave provides two equal, darker and lighter, faces of a cloth.

The design project developed visual variability in textile patterns. They were synchronised in rhythm, scale, orientation and number of applied basic elements. Consequent richness of colours was created by various combinations of patterns. They were proved by numerous clothing inspirations.

3. CONCLUSION

Textile designers’ work is so combined on many levels. They have to define separated colours of employed yarns or ready made textiles. They have to visualise further colour compositions in various textile techniques considering all yarns’ visual and tangible qualities. Not finally they have to place newly designed textile into a synchronised collection of textiles. They have to be aware of different visual consequences of a new design on other surrounded elements. They create not only new visual compositions but also a new textile functionalism and behaviour habits. These are related either to cultural tradition either to developed modernity. New patterns of living in bigger communities inspired with new media of communication and textiles’ production are mixed with a traditional inheritance. Industrial production is largely influenced by craft and art. The latter fund an experimental basement of industrial innovation. A lot of modern textiles for fashion and interior still embody a high level of craft’s elements. On the contrary art fabrics only use traditional
techniques for their experimental background to be able to figure out certain human's decisions and social tendencies. Therefore we could finally declare the whole variety of colour compositions in textile patterns as art installations that move from hermetic galleries into an every day life.
EVALUATION OF APPEARANCE BY MEANS OF COLOR AND CESIA: VISUAL ESTIMATION AND COMPARISON WITH ATLAS SAMPLES

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1. Introduction

The concept of visual appearance includes such aspects as shape, texture, color, and cesia of objects. Of these four attributes, shape and texture are constructed by perceived spatial discontinuities, while color and cesia are the result of perceived light distribution. By color we mean the perception of spectral distributions and intensities of light, producing the sensations of yellowness, redness, blueness, greenness, whiteness, blackness, and any intermediate degree. Color is described by three parameters: hue, value, and chroma (according to the Munsell system); hue, blackness, and chromaticness (according to the Natural Color System). By cesia we mean the perception of spatial distributions and intensities of light, causing the sensations of matt opacity, mirrorlike appearance, translucency, transparency, darkness and any intermediate degree. Cesia is also described by three parameters: permeability, absorption, and diffusivity.

¹ The word "cesia" designates with a single term an aspect that is close to what Richard Hunter calls "geometric attributes of appearance" (Hunter and Burns 1969). The origin of the term and the subsequent developments are described in Caivano (1991, 1994, 1994a).
To describe appearance with certain accuracy one must quantify the mentioned variables, and this implies some kind of measurement. Basically, one can make instrumental or visual measurements. Usually, instrumental measurement is more applied in industry, while visual assessment is more applied in design.

There are two basic kinds of apparatus for instrumental measurement: spectrophotometers measure spectral distribution and intensity of visible radiation, the physical stimuli for color, while goniophotometers measure angular distribution and intensity of visible radiation, the physical stimuli for cesia.

The usual techniques for visual measurement involve comparison between the specimen under evaluation and some reference standard. Color atlases are developed with the purpose of having standard color samples. An atlas of cesia is under development with the aim of having standard cesia samples (Caivano and Doria 1997). But even without an atlas one can make somehow accurate estimates by using mental points of reference both in color and cesia perception. I will present an overview of known techniques for the visual assessment of color, and will describe procedures -that can be easily used by designers- for the visual appraisal of cesia.

2. Visual assessment using standard samples

Having an atlas with standard samples, the observer chooses the chip that better resembles the specimen under evaluation and gets the corresponding notation, i.e., the values for the three parameters.

2.1. Modalities of observation for color evaluation

For color evaluation, it is important to use geometries of observation that avoid the perception of gloss, transparency, and texture.

A geometry of 0/45 or 45/0 degrees between the direction of illumination and observation with respect to the normal to the surface is usually employed to avoid gloss (Figure 1).
Transparency is avoided by placing an opaque white surface under the specimen, which in this way can be adequately compared with an opaque sample. That is to say, if we need to assess the color of a transparent specimen, and we have opaque standard color samples (as it is the case with samples in the Munsell and NCS atlas), the white opaque surface under the specimen provides the standard background that allows for the comparison. For better results, this surface should be a white sample of the atlas we are using. The same procedure can be employed with translucent specimens.

With texture, the problem is more complicated. Sometimes, one wants to include texture in the overall color assessment. For instance, if one wants to evaluate the color of a certain area in a large printed announcement made with the process of four colors reproduction (which results in superimposed screens of yellow, magenta, cyan, and black dots), it is absurd to make the comparison by getting close to the announcement and placing the standard sample on it, because one is interested in the resulting color as perceived from a certain distance, not in the color of every printed dot. In this case, the best method is to take an adequate distance from the specimen so that a uniform color is perceived. This color is the visual synthesis of the different colored dots in the textured surface. In this way, one is able to compare it with the uniform color of a standard sample. This method is similar to the one described by Karin Fridell Anter (1997) to evaluate perceived color of facades, that is, the color seen in a specific situation. But sometimes, when the material is uniformly pigmented and the texture
is produced by surface's relief only, one may want to exclude texture in order to reproduce the color of the material independently of the surface's discontinuities. In this case, the specimen should be illuminated from a suitable angle to avoid shadows, usually at zero degrees to the normal. The observation should be made at 45 degrees, with sample and specimen close to each other. This method ensures that one is evaluating what Fridell Anter (1997) calls inherent color, that is, the color presented by the object when it is observed under the same standardized conditions by which the samples of the atlas are in accordance with their notations.

2.2. Modalities of observation for cesia evaluation

In order to evaluate cesia using standard samples for comparison, the geometries of observation are also very important. Cesia is not an intrinsic quality of materials and surfaces. It is the visual sensation resulting from the physical characteristics of the material, the kind of illumination and the viewing conditions. The perceived cesia changes with the intensity of illumination and the side from which it comes, so that a common window can be seen as transparent, half mirror or full mirror depending on those conditions. Cesia also changes with the quality of lighting, whether it is diffuse or concentrated, so that the same object may appear matt or glossy. It also changes with the angle of the surface with respect to the direction of illumination and observation.

Thus, the same categories of inherent and perceived can be applied to cesia. Inherent cesia is the cesia that the object presents when it is viewed under the same standard conditions by which the samples of the atlas are in accordance with their notations. Perceived cesia is the appearance that the object presents at a given situation. Stripes cut out from the same sheet of polyester film have an inherent degree of diffusivity which is the same for all of them. But placed at different distances from the background they produce different degrees of diffusivity, and consequently the perceived cesia changes.

For visual comparisons with standard samples, it is critical to hold the same geometry and conditions for specimen and sample. I am not going to enter into details here about the standard conditions of illumination and observation for the samples in the atlas of cesia, but let me just say that a special arrangement is needed for each page of different permeability. For permeability near 100 % (transparent or translucent), the right geometry of observation
is shown in Figure 2. For opaque specimens, with 0 % permeability, there are the two possibilities: 1) diffuse lighting and the face of the observer used as reference, according to how is it reflected on the samples; 2) diffuse lighting, a grid that is reflected on the samples, and observation from the direction of specular reflection (Figure 3).²

![Figure 2. Geometry of observation for cessa assessment: permeability near 100 % (transparent and translucent specimens).](image)

![Figure 3. Geometries of observation for cessa assessment: permeability 0 % (glossy or matt opaque specimens).](image)

² This arrangement is similar to the one described by the ASTM (1990).
There are also some hints to avoid the other variables entering into the visual perception and making the comparison difficult. In this case, one usually wants to exclude color and texture. For instance, suppose that we need to assess the cesia of a yellow translucent specimen, but we have achromatic standard cesia samples. This case is symmetrically opposite to the case of evaluating a translucent colored specimen with the usual opaque color samples of an atlas.

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<tr>
<th>SPECIMEN</th>
<th>STANDARD SAMPLE</th>
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<td>yellow translucent</td>
<td>yellow opaque</td>
<td>color (yellowness)</td>
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<tr>
<td>yellow translucent</td>
<td>achromatic translucent</td>
<td>cesia (translucency)</td>
</tr>
</tbody>
</table>

In the first case, we have seen, the solution is to put a white opaque sheet under the translucent specimen. In the second case, it is not possible to turn a chromatic specimen into achromatic in order to evaluate translucency without the disturbing color difference. The only possible solution is to look for the samples that match the specimen in lightness (or absorption). For instance, in the case of a yellow translucent specimen, the matching samples would be the lighter translucent grays in the absorption scale of the cesia atlas. Then, one is able to compare specimen and sample in terms of permeability and diffusivity.

3. Visual assessment without having standard samples

How is it possible to assess color without having standard samples? In a paper presented at the AIC Meeting 1997 in Kyoto (Caivano, Mattiello, and Biondini 1997), this experience is described. Students were confronted to the task of evaluating hue, value, and chroma (according to the Munsell system), and hue, blackness, and chromaticness (according to the Natural Color System), only by using mental points of reference and a description of the system. They were not allowed to see the atlas.

With regard to cesia, it is relatively easy to make visual assessments in terms of permeability, absorption, and diffusivity, without having the atlas at hand. A person normally has an exact idea or mental representation of transparency, translucency, matt opacity, mirrorlike appearance, and blackness. In addition, some of these five reference points of cesia can be easily contrasted with physical situations that are found everywhere. Clean air can be used as a sample of perfect transparency. Thus, the image of an object or
background seen without the interposition of any other object (just clean air in between) can be compared with the image of the same object or background seen through the specimen under evaluation. The pattern of letters in a book or newspaper provides a good background-object for this. As diffusivity changes with different distances among observer, specimen, and reference background, the best way to evaluate translucent specimens is to put them close to the eyes and at a certain distance from the background. The same physical point of reference can be used to assess the degree of diffusivity of an opaque specimen.

A mirror is another physical point of reference that is easily found (as a matter of fact, any woman carries a mirror in her handbag). It provides a sample for 0 % permeability and near 0 % diffusivity and absorption. Thus, the degree of diffusivity and absorption of an opaque specimen may be visually assessed by evaluating how does it reflect some background object in comparison with a mirror.

4. Conclusion

In conclusion, it is necessary to have a clear idea of what one wants to assess. If one is asking for the “inherent” cesia of an object, then the geometries of observation should be the standard ones, and it is better to use the atlas for comparison. But if one is interested in the perceived cesia at a given situation, it is quite possible to evaluate just what one is seeing by using mental points of reference. As with the experience with color, the cesia notations given by various observers to specimens having different cesia (once they have understood the system) do not differ too much.

Acknowledgement

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References


THE VISUAL EFFECT OF DIFFERENT SPECTRAL DISTRIBUTION IN THE INTERIOR

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1. INTRODUCTION

The quality of light in the interior has recently been considered as an important factor in the architectural environment within a three-dimensional architectural space. The effect of spectral distribution within a room and its influence on people's body and emotions must be reconsidered because buildings demanding a specific functional light such as a Yellow Room which is necessary to produce semiconductor products are increasing these days. But this kind of research has not been widely carried out until now despite its necessity. Additionally, it is difficult to locate materials about the psychological and physical influences of light source color and their effects on the sense of color. And, the light in the interior of buildings must be researched through more systematic experiments and theories.

The aim of this study therefore is to examine spectral distribution's psychological and visual properties and workability, and analyze the colorimetric shift of light source color in the interior.

The methods and process are as follows:

1) Measuring the spectral distribution of 9 light sources: Red(630-680nm), Yellow-Red (580-630nm), Yellow(540-610nm), Yellow-Green(540-600nm), Green(530-580nm), Bluish-Green(520-580nm), Blue(470-570nm), White and Daylight,
   Calculating the color temperatures and color rendering index
   Analyzing the peculiar properties of colorimetric shift in light sources to establish their properties.

2) Carrying out the evaluation experiment of light sources as to their psychological stability, visual fatigue, and work efficiency in the Scaled Model Space.
3) Reevaluating the validity of this experiment in the Scaled Model space in the same way as enforced in the Mock-Up.

In this experiment, flourescent lamps are utilized because they are used as common architectural light sources.

2. THE PROPERTIES OF SPECTRAL DISTRIBUTION AND COLORIMETRIC SHIFT

The spectral distribution which is the basic factor deciding light source color was measured with a Monochrometer, and calculated the color temperatures of the light sources and their color rendering index.

1. The Properties of Spectral Distribution

The spectral distribution of light sources is clearly distributed in the main domain of wavelength, and they are suitable as sample lights in this experiment.

![Graph of Spectral Distribution](image)

**Fig 1. The Examples of Relative Spectral Distribution**

2. The Color Temperature and Color Rendering Index

The color temperatures according to light source and color rendering index are as follows (Table.1):

---

*Footnote:* The figure shows the radiative rate of Yellow-Red compared with those of various mixed lights in the domain of visible rays. As shown, the light in the wavelength of Yellow-Red, 580-630nm is radiated, but the light below 500nm is not radiated. Therefore, Yellow-Red is used in a Yellow Room due to this property of wavelength.
Table 1. The Color Temperature and Color Rendering Index of Light Sources

<table>
<thead>
<tr>
<th>Light Source</th>
<th>Chromaticity Coordinates</th>
<th>Color Temperature ((K^b))</th>
<th>Color Rendering Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIE Standard (Daylight)</td>
<td>0.3079 0.3188</td>
<td>6879</td>
<td>97</td>
</tr>
<tr>
<td>White</td>
<td>0.3776 0.3814</td>
<td>4107</td>
<td>61</td>
</tr>
<tr>
<td>Red</td>
<td>0.5380 0.2819</td>
<td>1250</td>
<td>59</td>
</tr>
<tr>
<td>Yellow-Red</td>
<td>0.5163 0.4669</td>
<td>2428</td>
<td>62</td>
</tr>
<tr>
<td>Yellow</td>
<td>0.4660 0.5137</td>
<td>3200</td>
<td>66</td>
</tr>
<tr>
<td>Yellow-Green</td>
<td>0.3650 0.5829</td>
<td>5010</td>
<td>68</td>
</tr>
<tr>
<td>Green</td>
<td>0.2830 0.5530</td>
<td>6380</td>
<td>69</td>
</tr>
<tr>
<td>Blush-Green</td>
<td>0.1840 0.2960</td>
<td>50000</td>
<td>68</td>
</tr>
<tr>
<td>Blue</td>
<td>0.1840 0.1960</td>
<td>High Temperature</td>
<td></td>
</tr>
</tbody>
</table>

3. The Properties of Colorimetric Shift

The chromaticity coordinates of light sources were measured with Color Meter(CS-100) after choosing 8 standard colors among the similar color groups. They were compared one to another and analyzed. The results indicate that the colorimetric shift in chromaticity coordinates was significant in R, YR, Y, B, but it was not significant in Green. The influence of light source color was significantly outstanding in R, YR, Y, B, but it was not outstanding in Green compared with the color temperatures.

In this experiment, the light intensity was constant at 750lx.
3. THE EVALUATION EXPERIMENT OF LIGHT SOURCES

1. The Evaluation Experiment in the Light Cabinet

1) The Contents and Methods of the Experiment

Adaptation time as a factor influencing the sense of color was investigated according to 6 levels of times: immediate, 5min, 10min, 20min, 30min, 40min. Light sources were evaluated in the 1/15 Scaled Model, The Light Cabinet of 1,300mm×610mm×510mm in terms of psychological stability, visual fatigue, and work efficiency. 25 colors of metal panels were selected. That size was 300mm×300mm. In this experiment, subjects were 6 graduate students who were professionals carrying out the experiments on lights and colors for over 2 years.

Fig. 3. The Summary of Light Cabinet

2) The Results of Evaluation Experiments according to Adaptation Time in Light Sources

Results indicate that it takes 10-20 minutes to be accustomed to certain light source color. The degree of adaptation was increased significantly in Daylight, White, and Green with time, but it was not significant in other light sources. This means that the colors similar to Daylight and Green give psychological stability and decrease eye fatigue.

Fig. 4. The Shift of Stability according to Adaptation Time in Light Sources
3) The Results of the Psychological Evaluation of Light Sources

25 different color samples derived from 8 major colors were used in the experiment. R, Y in Daylight and White, G, BG, PB in Yellow-Red, and R, Y, PB in Green scored well in the psychological evaluation. Especially Green, Daylight and White were evaluated high. Therefore, the experiment supported the claim that these colors and lights make people feel comfortable and relaxed, and they could decrease eye fatigue.

Table 2. The Average of SD in stability

<table>
<thead>
<tr>
<th>Light Source Color Sample</th>
<th>CIE (lx)</th>
<th>W</th>
<th>R</th>
<th>YR</th>
<th>Y</th>
<th>G</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.3 R 7.3/0.1</td>
<td>5.14</td>
<td>5.20</td>
<td>4.83</td>
<td>5.20</td>
<td>5.50</td>
<td>5.67</td>
<td>5.40</td>
</tr>
<tr>
<td>7.5 YR 8.2/0.6</td>
<td>4.43</td>
<td>4.40</td>
<td>4.14</td>
<td>4.33</td>
<td>4.80</td>
<td>4.83</td>
<td>4.20</td>
</tr>
<tr>
<td>9.0 YR 8.1/3.1</td>
<td>3.57</td>
<td>3.80</td>
<td>3.57</td>
<td>3.33</td>
<td>3.67</td>
<td>3.50</td>
<td>4.00</td>
</tr>
<tr>
<td>1.2 Y 8.7/0.9</td>
<td>4.30</td>
<td>4.40</td>
<td>4.17</td>
<td>4.17</td>
<td>3.33</td>
<td>4.50</td>
<td>3.80</td>
</tr>
<tr>
<td>2.3 Y 9.2/1.9</td>
<td>4.30</td>
<td>4.75</td>
<td>3.14</td>
<td>2.83</td>
<td>3.50</td>
<td>4.33</td>
<td>3.20</td>
</tr>
<tr>
<td>3.3 Y 8.9/1.5</td>
<td>4.71</td>
<td>4.00</td>
<td>3.29</td>
<td>3.50</td>
<td>3.00</td>
<td>4.83</td>
<td>4.60</td>
</tr>
<tr>
<td>4.7 Y 9.0/2.3</td>
<td>4.20</td>
<td>4.10</td>
<td>3.43</td>
<td>3.00</td>
<td>3.17</td>
<td>5.00</td>
<td>4.20</td>
</tr>
<tr>
<td>5.2 Y 9.0/0.6</td>
<td>4.20</td>
<td>4.30</td>
<td>3.29</td>
<td>2.83</td>
<td>2.83</td>
<td>4.67</td>
<td>2.40</td>
</tr>
<tr>
<td>5.5 Y 8.0/0.5</td>
<td>4.30</td>
<td>4.40</td>
<td>4.43</td>
<td>4.20</td>
<td>4.30</td>
<td>5.00</td>
<td>3.60</td>
</tr>
<tr>
<td>7.7 Y 8.0/0.8</td>
<td>5.43</td>
<td>5.00</td>
<td>5.17</td>
<td>4.67</td>
<td>4.83</td>
<td>5.14</td>
<td>4.50</td>
</tr>
<tr>
<td>7.7 Y 9.0/1.4</td>
<td>4.14</td>
<td>4.30</td>
<td>3.29</td>
<td>3.33</td>
<td>2.83</td>
<td>4.17</td>
<td>4.30</td>
</tr>
<tr>
<td>8.4 Y 7.7/1.1</td>
<td>5.00</td>
<td>5.20</td>
<td>5.00</td>
<td>5.20</td>
<td>5.17</td>
<td>5.17</td>
<td>4.80</td>
</tr>
<tr>
<td>0.2 GY 8.0/1.5</td>
<td>4.86</td>
<td>4.80</td>
<td>4.86</td>
<td>4.67</td>
<td>4.33</td>
<td>4.50</td>
<td>4.60</td>
</tr>
<tr>
<td>1.2 GY 9.0/1.0</td>
<td>4.43</td>
<td>4.10</td>
<td>3.43</td>
<td>3.17</td>
<td>2.83</td>
<td>4.00</td>
<td>2.80</td>
</tr>
<tr>
<td>5.2 GY 9.2/0.3</td>
<td>4.10</td>
<td>4.00</td>
<td>2.71</td>
<td>3.17</td>
<td>2.53</td>
<td>4.30</td>
<td>2.80</td>
</tr>
<tr>
<td>7.2 GY 8.2/4.4</td>
<td>4.00</td>
<td>4.30</td>
<td>3.86</td>
<td>3.50</td>
<td>3.40</td>
<td>4.67</td>
<td>5.20</td>
</tr>
<tr>
<td>9.0 GY 8.8/1.7</td>
<td>4.20</td>
<td>4.00</td>
<td>4.50</td>
<td>4.67</td>
<td>4.80</td>
<td>4.83</td>
<td>3.80</td>
</tr>
<tr>
<td>0.4 G 7.6/0.4</td>
<td>4.86</td>
<td>4.80</td>
<td>4.86</td>
<td>5.00</td>
<td>5.17</td>
<td>5.20</td>
<td>4.60</td>
</tr>
<tr>
<td>4.8 G 8.9/0.7</td>
<td>4.17</td>
<td>4.00</td>
<td>3.57</td>
<td>4.50</td>
<td>4.67</td>
<td>4.80</td>
<td>2.60</td>
</tr>
<tr>
<td>8.0 G 8.1/1.6</td>
<td>4.57</td>
<td>3.90</td>
<td>4.33</td>
<td>4.50</td>
<td>4.67</td>
<td>4.67</td>
<td>4.20</td>
</tr>
<tr>
<td>3.9 BG 8.3/0.7</td>
<td>4.71</td>
<td>4.60</td>
<td>4.43</td>
<td>4.67</td>
<td>4.50</td>
<td>5.17</td>
<td>4.00</td>
</tr>
<tr>
<td>4.4 BG 7.3/4.1</td>
<td>3.14</td>
<td>3.60</td>
<td>4.00</td>
<td>4.17</td>
<td>4.17</td>
<td>4.67</td>
<td>3.80</td>
</tr>
<tr>
<td>6.8 B 8.7/1.3</td>
<td>4.00</td>
<td>4.00</td>
<td>2.83</td>
<td>3.33</td>
<td>4.00</td>
<td>4.00</td>
<td>2.33</td>
</tr>
<tr>
<td>1.6 PB 7.6/0.4</td>
<td>4.57</td>
<td>4.40</td>
<td>5.00</td>
<td>5.17</td>
<td>5.17</td>
<td>5.00</td>
<td>4.20</td>
</tr>
<tr>
<td>2.5 PB 6.9/3.0</td>
<td>4.29</td>
<td>4.50</td>
<td>3.71</td>
<td>5.29</td>
<td>5.29</td>
<td>5.33</td>
<td>4.30</td>
</tr>
</tbody>
</table>

2. The Reevaluation Experiment of the Validity

1) The Contents and Methods of the Experiment

A real model space of 6,000mm×3,000mm×3,000mm was employed in the same way as enforced in the Scaled Model to reevaluate the validity of the results. But only 2 light sources which caused significant results in the Scaled Model, were used.

2) The Results of the Experiment

The results in the real model space, Mock-Up were the same with those in the Scaled Model space, Light Cabinet. Stability and work efficiency were decreased in Yellow-Red. Visual fatigue was serious, but these were contrary in Green just as in the results from the Light Cabinet. This experiment showed that stability and work efficiency were apt to be improved in each color with an increase of adaptation time.

In the experiment of color samples, Green highly evaluated with low visual fatigue and work efficiency, although there was no outstanding feature in the aspect of stability. R and Y had
very high scores for stability. Y and G, PB also had high scores for visual fatigue. These results indicate that these colors can decrease the sense of eye fatigue. And the experiment showed that Y and G, BG, PB were excellent in terms of work efficiency.

3) The Reevaluation of the Validity

Through T-Test, Yellow-Red was reevaluated as the color sample causing significant result within 1% in psychological stability. Green was reevaluated as the color sample causing significant result within 5% in stability and work efficiency. The reevaluation experiment in the Light Cabinet substantiated the results of the Mock-Up. It supports the Light Cabinet results' validity.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Light Source</th>
<th>Stability</th>
<th>Visual Fatigue</th>
<th>Work Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow-Red</td>
<td>0.006**</td>
<td>0.002**</td>
<td>0.05*</td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>0.018*</td>
<td>0.085</td>
<td>0.022*</td>
<td></td>
</tr>
</tbody>
</table>

* Significant Level: * Below 0.05, **Below 0.01

4. CONCLUSION

In this study, it was analyzed the visual effect of spectral distribution in the interior in terms of psychological stability, visual fatigue, and work efficiency. The results are as follows:

1. The changes of color coordinates were the smallest in White and Green, and they were the largest causing a major difference from the original color in Red.

2. It took 10-20 minutes for test subjects to adapt themselves to each light source. White and Green had the highest evaluation figures in the sections of psychological stability, visual fatigue, and work efficiency.

3. According to the results of the experiments, R, Y in Daylight and White, and G, BG, PB in Yellow-Red and Yellow, and R, Y, PB in Green were the most suitable as interior light sources.

4. Through T-Test, the reevaluation experiment in the Light Cabinet substantiated the results of the Mock-Up. It supports the Light Cabinet results' validity.

Encouraged by this conclusion, I would like to further study in detail spectral distribution and the physical and psychological effects in interior spaces by intensities of lights.
RELATIONSHIP BETWEEN VISUAL IMPRESSION OF A CITY LANDSCAPE AND ITS CHARACTERISTICS OF COLOR
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ABSTRACT
Colors of a city landscape significantly influence our visual impression. This study examined relations between human visual impressions of a city landscape and its characteristics of colors. The visual impressions examined in this study were comfortableness (Kaisekisa) and busyness (Nigiyakasa). In the experiment 1, ten subjects viewed fifty scene slides taken from large cities in Japan and evaluated their visual comfortableness and busyness with the magnitude estimation method. It was found that the subjects could judge both impressions, and the evaluated values obviously changed with the scenes. Moreover, the evaluations made by the subjects were closely correlated, indicating their judgements were based on some common criteria. In the experiment 2, to see the effect of colors themselves, fifteen slide images were digitized and were transformed into the two-dimensional color arrays (color mosaic). The subjects evaluated the comfortableness and busyness of the color mosaics using the paired comparison method. We found that the evaluation for the color mosaics correlated to those for the scene slides. Especially the busyness showed high correlation, indicating it was mainly determined by some characteristics of colors. The colors of the scenes were transformed into the CIELAB color space for analysis, and color statistics that correlated the evaluated impressions were inquired. It was indicated that statistics about spatially gradual changes of colors affect comfortableness, and spatial diversity of colors strongly influences busyness of the city landscape.

1. Introduction
When we look a city landscape, we have a certain visual impression. Colors must be one of
significant factors that affect our impression. The interest of this study is how and to what extent our impressions of a landscape are determined by colors. We examined relations between visual impressions of city landscapes evaluated by human observers and color statistics of the images.

This study consists of two experiments and analysis of the results. In experiment 1, subjects evaluated visual impressions of city landscapes projected on a screen. Visual impressions examined here are visual comfortableness and busyness. Actually, Japanese words, Kaitekisa and Nigiyakasa were used in the experiments. Although it is difficult to translate whole meaning of the words, Kaitekisa may correspond to comfortableness, pleasant, or calm, and Nigiyakasa may correspond to busyness, liveliness, or noisy. The question to be considered in experiment 1 is whether the evaluations of the impressions are consistent among subjects.

In experiment 2, to exclude the context effect of the landscape and to test the effect of colors per se, color mosaic images were used for the evaluation. The question to be asked is to what extent the evaluations are determined by colors themselves. Finally, we try to find out the statistics of colors that correlate human impressions of the city landscape.

2. Experiment 1: Evaluation using scene slides

2.1 Methods

Subject's task in experiment 1 was to evaluate visual comfortableness and busyness of city landscapes projected on a screen one at a time with the magnitude estimation method. Score from -5 to +5 was given to the comfortableness, and 0 to 10 was given to busyness. Fifty color slides taken from large cities in Japan were prepared for the experiment. Example is shown here. Projected size is 80 cm wide and 65 cm high. The order of the slide presentation was randomized. Each slide was presented for 5 seconds. Ten subjects from the Department of Architecture, Kyoto University participated in the experiment.

2.2 Results

Mean evaluated scores of each of 50 slides are shown in Fig. 1. The upper panel gives the results of comfortableness and lower panel busyness. Error bars indicate standard deviations of 10 subjects. We can see from this figure that scores given to the slides range from low to high values. Our concern is whether the results of the subject show similar tendency. The
Table 1 summarises the correlation coefficient of the evaluated score of each of ten subjects and the mean score of all subjects for comfortableness and busyness. It shows that the evaluation made by each subject are highly correlated with the mean evaluation of all subjects except for one subject in comfortableness evaluation. In particular, evaluation for busyness shows strong correlation. It is concluded that visual impressions evaluated by each subject have similar tendency, indicating some common factors affect their evaluations.

Fig. 1 Result of experiment 1. Mean scores of all subjects plotted as the slides. The upper panel gives the results of comfortableness and the lower panel busyness.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Comfortableness</th>
<th>Busyness</th>
</tr>
</thead>
<tbody>
<tr>
<td>HY</td>
<td>0.72</td>
<td>0.93</td>
</tr>
<tr>
<td>KS</td>
<td>0.65</td>
<td>0.70</td>
</tr>
<tr>
<td>YO</td>
<td>0.68</td>
<td>0.91</td>
</tr>
<tr>
<td>YK</td>
<td>0.37</td>
<td>0.92</td>
</tr>
<tr>
<td>MS</td>
<td>0.78</td>
<td>0.94</td>
</tr>
<tr>
<td>WU</td>
<td>0.76</td>
<td>0.84</td>
</tr>
<tr>
<td>TI</td>
<td>0.72</td>
<td>0.90</td>
</tr>
<tr>
<td>YS</td>
<td>0.79</td>
<td>0.88</td>
</tr>
<tr>
<td>KY</td>
<td>0.81</td>
<td>0.90</td>
</tr>
<tr>
<td>SI</td>
<td>0.79</td>
<td>0.94</td>
</tr>
</tbody>
</table>
Fig. 2 Results of experiment 2.
Mean scores of comfortableness (left) and busyness (right) of the mosaic images.

Fig. 3 Mean scores for the scene slides (exp.1) vs mean scores for the mosaic images (exp.2).
Comfortableness (left), busyness (right)

Fig. 5 Mean scores of comfortableness(left) and busyness(right) plotted as a function of the number of color categories.
3. Experiment 2: Evaluation using color mosaic images

3.1 Methods

To examine to what extent the visual impressions are determined by colors themselves, we used color mosaic images. By using color mosaic images, the subjects could not grasp any detailed information or context of the scene while spatial structure of colors is retained. Fifteen slides were selected from those used in experiment 1 and scanned with resolution of 1280 x 1024 pixels. Then digitized images were converted into color mosaic of 40 x 32 cells. To determine a color of a particular cell, we computed distribution of colors of all pixels in that cell on three dimensional color space. The color of the mosaic cell was determined by the most densely distributed color block. Subjects could not grasp the context of the scene at the viewing distance of 150 cm.

In experiment 2, visual comfortableness and busyness of the mosaic images were evaluated using the paired comparison method. Two mosaic images were successively presented for 2 seconds on a CRT monitor separated by 1 second interval. The subjects judged which image is more comfortable or busy. The trials were done for all possible combinations of 15 mosaic images and the score of a mosaic image was determined by the times the image is judged more comfortable or busy than each other image. The same subjects as in experiment 1 participated in experiment 2.

3.2 Results

It was found the subject's could judge the comfortableness and busyness of mosaic image. The mean score of comfortableness and busyness of mosaic images are presented in Fig. 2. It is shown that scores for both comfortableness and busyness significantly changed with mosaic image. In Fig. 3, the mean score for the scene slides obtained in the experiment 1 are plotted as those for the mosaic images obtained in the experiment 2. In the left panel, the results of comfortableness are plotted. It is shown that the comfortableness evaluated for the mosaic images significantly correlated with that for the actual images. In the right panel, the results of busyness are plotted. It is clearly shown that busyness for the mosaic images closely correlated with that for the actual images.

The results indicate that color of a city landscape is the major factor that determines visual comfortableness and busyness. In particular, busyness may be determined primarily by colors themselves.
4. Correlation between visual impression and color statistics

In the analysis of the results, we investigate color statistics of the images that correlate with human visual impressions. We could not find out any basic statistics such as average, standard deviation that correlates with the subject's evaluations. Color statistics examined here are the number of color categories included in the image, and spatial distribution of colors. To analyze colors of the landscapes, all of the slide images used in experiment 1 were digitized and converted into 180 mosaic images, 80 and 64 cells. Then a color of each cell was transferred into the LAB space. All color computations were carried out based on La*b* value of the mosaic cells.

4.1 The number of color categories

First, to obtain the number of color categories, all colors in an image were classified into 11 groups on CIE C*L*h space as illustrated in Fig. 4. This classification was quite tentative, however, it worked for our current purpose. Then the number of color categories contained in the image were extracted for each of fifty images.

![Fig. 4 Method of color classification into 11 color categories.](image)

The mean score of comfortableness and busyness are plotted as a function of the number of color categories in Fig. 5. Comfortableness tends to decrease with the number of color categories and busyness significantly correlates with the number of colors.

4.2 Color gradation index

According to the subject's introspective reports in experiment 2, the images in which colors were gradually changing looked more comfortable. Then we extracted the areas where colors are gradually changing. First, we computed the color difference between horizontally adjacent cells in an image. If the color difference is larger than a certain value Ec and smaller
than Eup, the cell is marked. We defined the color gradation index as the ratio of the number of marked cells to the number of all cells. The optimal value of Ec and Eup were determined in the manner of trials and errors, and Ec was set at 2 and Eup set at 25 in this analysis.

Fig. 6 presents the relation between color gradation index and score of comfortableness. We can see from this figure that score of comfortableness tends to increase with color gradation index. The images in which colors are distributed in some good order must give comfortableness.

![Fig. 6 Mean scores of comfortableness (exp.1) plotted as a function of color gradation index.](image)

Fig. 7 Mean scores of busyness(exp.1) plotted as a function of color diversity index.

![Fig. 7 Mean scores of busyness(exp.1) plotted as a function of color diversity index.](image)
Fig. 8 Results of multiple regression (exp.1) using the color statistics obtained in this study.
Comfortableness (upper), busyness (lower)

Fig. 9 Results of multiple regression (exp.2) using the color statistics obtained in this study.
Comfortableness (upper), busyness (lower)
4.3 Color diversity index

Visual busyness may correlate with how colors are scattered over the area. We defined color diversity index\(^{[21]}\) as follows: First, all colors classified into 11 groups as in counting color categories. Next, a color mosaic was divided into 64 blocks (8 x 8 blocks), and the number of the blocks that contained each of 11 color categories was counted. Color diversity index was defined as the ratio of the total number of color blocks to the number of blocks. This index takes larger value when a color image has more color categories and colors are scattered and mixed over the area.

Fig. 7 presents the mean score of busyness plotted as a function of logarithm of the color diversity index. It shows that busyness significantly correlates with this index.

4.4 Multiple regression

Next, we carried out multiple regression to predict mean score of visual impressions using color statistics obtained so far. An upper panel of Fig. 8 gives the mean score of comfortableness plotted as the predicted comfortableness using the number of color categories and color gradation index. The results show better correlations. The lower panel gives the mean score of busyness plotted as the predicted busyness using the number of color categories and color diversity index. The results show high correlation.

Finally, we applied the same analysis to the results of experiment 2. The upper panel of Fig. 9 gives the mean score of comfortableness of mosaic images plotted as the predicted comfortableness. The lower panel gives the mean score of busyness of mosaic images plotted as the predicted busyness. The visual impressions of mosaic images are strongly correlated with the model prediction.

5. Summary

- Visual comfortableness and busyness evaluated by the subjects had consistent tendency, and therefore there must be some common characteristics of a city landscape that determine our visual impressions.

- The color must be the major factor that determines our visual impressions. In particular, busyness was determined primarily by colors themselves.
- Comfortableness may be given by color distribution in some good order like color gradation.

- Busyness highly correlated with the color diversity over an area.

Reference


METHOD OF DISPLAYING EXACT COLORED SCENES PERCEIVED BY THE AGED
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The aged people normally loose transmittance at short wavelength in their crystalline lenses and it is thought that they perceive yellower scenes compared to the young. Photographs taken through yellow filters simulating the transmittance are in some cases erroneously displayed to demonstrate their color perception. We applied the concept of the recognized visual space of illumination, RVSI, to this situation to find out the exact color perception of the aged. RVSI is the recognition for a space in terms of illumination constructed in a subject's brain. In the experiment a young subject adapted himself/herself for 5 minutes in an observing room illuminated by a yellow light. He/she then turned around to a displaying room illuminated by a white light and observed pictures through a window of 18cm high and 26cm wide. The pictures were taken beforehand for the observing room with 12 different colors of illumination. The pictures were projected on a rear screen placed just beyond the window and the subject judged which picture slide gave the same color of various objects in the observing room as he/she experienced minutes ago. The chosen picture slide was that taken with the illuminating light to include only about 40 to 80% yellowness compared to that of the observing room. This implies that the exact color perceived by the aged who observes scene under the daylight can be experienced by the young for the picture which is not taken through the colored filter to simulate the eye of the aged but through a colored filter which is more whitish than the aged if the young is observing the picture under the daylight.

KEYWORDS: aged people, elderly people, color adaptation, color constancy, color perception, recognized visual space of illumination.

1. INTRODUCTION
The concept of the recognized visual space of illumination, RVSI, is first explained as the present experiment is carried out based on the RVSI 1.3. When one enters a room, he/she can instantly understands how the room is illuminated, brightly or dimly, or whitely or a little bit yellowishly, and so on. This state is expressed as that he/she constructed the RVSI for this room in his/her brain. It is hypothesized then that he/she perceives the colors of objects in this room in relation to the RVSI. When this room is illuminated a little bit yellowishly, the color property of his/her RVSI is shifted toward yellow. At the same time the reflections from all the objects in this room also shift toward yellow. Consequently he/she perceives the colors not much different from those perceived in the room with a white illumination.

In this paper the concept of the RVSI is applied to investigate the color perception of elderly people. Elderly people normally loose the light transmittance at short wavelengths in their crystalline lenses, and it is often and erroneously practiced that a picture taken through a yellow filter equivalent to the lens transmittance is shown to demonstrate their color perception. When a young person sees this picture, he/she thinks that the picture appears very yellowish, and wonders if elderly people indeed perceive this much of yellowness in the scene.
The prediction based on the concept of the RVSI does not agree with this demonstration because of the following reason.

Suppose that a young person is observing this yellow picture in a room illuminated by a white light. He/she then constructs in his/her brain the RVSI for the white room. In other words, the color property of the RVSI is not shifted toward yellow and he/she is observing this yellow picture with his/her white RVSI. Naturally, the picture should appear very yellowish. In the case of an elderly person, his/her entire visual field is yellow and the color property of his/her RVSI is shifted toward yellow. He/she is then observing the yellow scene with his/her yellow RVSI. Because the color of the scene and the color property of the RVSI are in accordance with each other, the scene should not appear to him/her as much yellow as the young person is experiencing for the picture of the scene.

We investigate in this paper how much of yellowish picture should be displayed to a young person so that he/she perceives the exact color, as an elderly person is experiencing.

2. EXPERIMENT

The experimental arrangement is shown in Fig. 1. The left-hand space is the subject's room and is equipped with two sets of luminaires, each being composed of a white fluorescent lamp and a yellow fluorescent lamp at the ceiling. The right-hand space is the projector room. The left side of the left-hand space is called the observing room, when the space is illuminated by the left set of the ceiling light only as shown in Fig. 1a. And the right side is called the displaying room, when the space is illuminated by the right set of the ceiling light only as shown in Fig. 1b. Both rooms are decorated on the shelves and walls with artificial flowers, dolls, books, and others to simulate real rooms.

In the experiment a young subject first spent 5 minutes looking at objects in the observing room illuminated with yellow light as illustrated in Fig. 1a. This was to simulate the view of an elderly subject. The view from the subject's eye in the observing room is illustrated in Fig. 2a. The subject then turned around to the displaying room illuminated with white light as illustrated in Fig. 1b. The subject saw the objects in the displaying room and a picture through a

Fig. 1 Scheme of the experimental booth. a, subject looking at the observing room; b, subject looking at the displaying room.
window of 18cm high and 26cm wide projected from behind on to a rear screen. The positions of the right set of the ceiling light and the rear screen were arranged so that the light from the ceiling light did not fall on the rear screen. The picture projected on the rear screen was a photograph of the observing room. The view from the subject's eye in the displaying room is illustrated in Fig. 2b. The inside of the central rectangle drawn by thick line shows the picture projected, and the objects in the displaying room surround this.

It should be mentioned here that the subject used only one eye in this experiment. In this way the subject could feel as if the picture was pasted on the viewing window and could perceive it as one of the objects in the displaying room.

A series of picture slides, 12 altogether, were made beforehand for the observing room illuminated with various colors including the yellow light used for the observing phase. The colors of the pictures on the rear screen were shifted a little bit from real colors of objects in the observing room if the original slides were projected. To restore the colors for the observing room some appropriate color compensating filters and the neutral density filters were placed in front of the projector. The chromaticities of 12 different colors of the ceiling light are shown in Fig. 3. The subject could freely change the slides by pushing the button placed before him/her.

The subject's task was to decide which picture slide gave the exact impression of color as that perceived at the observing phase. Interpolation between two slides was allowed in the subject's response if necessary.

3. EXPERIMENTAL CONDITIONS

Both the observing room and the displaying room were illuminated at about 300 lx. Three different colors were employed for the illumination of each room, respectively, by changing the relative intensities of two fluorescent lamps. The colors for the observing room are denoted as O1, O2 and O3 and those for the displaying room as D1, D2 and D3 on the chromaticity diagram in Fig. 4. As seen here the colors for the observing rooms are all yellow and those for the displaying rooms are all white. They gave nine different combinations of colors of the two rooms.
For each combination of the illumination colors, a subject gave ten responses of choice of picture slide.

Five students, YM (24, female), SA (24, male), RY (23, female), KS (22, male), and YH (22, female) participated in the experiment. They had normal color vision. For all subjects but YM it was the first time to become a subject in this kind of psychophysical experiment.

Fig. 3 The chromaticities of 12 different colors of ceilings light in preparing a series of picture slides.

Fig. 4 The illumination colors for the observing room, O1, O2, O3; the displaying room, D1, D2, D3.

4. RESULTS AND DISCUSSION

The results from the subject YM for the illumination combination, O2 and D1 are shown in Fig. 5 as an example. The small filled diamonds show the chromaticities of the illumination in the observing room for the picture slides which the subject selected in the displaying room, D1 as the same color of the observing room when he/she experienced at the observing phase with the illumination O2. The ten points scatter to some extent, but all of them come between O2 and D1 and not at O2. The large open diamond shows the average of these ten determinations.
For this color combination of illumination the averaged point of each subject is plotted in Fig. 6. Different symbols are used for five subjects. There is a large variation among the subjects. The subject SA chose a very yellowish color for the displayed picture as shown by an open triangle while KS chose a color very close to white as shown by an open square. The large open circle is the average of the five subjects.

To show how much of the yellowness was required to perceive the same yellow color of the observing room, we took the ratio of the distance between the preferred picture color and the displaying color, and the distance between the observing color and the displaying color as illustrated in Fig. 7. The ratio calculated for the averages of five subjects are shown in Fig. 8 for all the color combination of illumination. Along the abscissa the three different colors of the displaying room is taken in the chromaticity x value and along the ordinate the ratio just defined is taken. Respective curves correspond to three different colors of the observing room. O1 is the most yellowish illumination, O2 is the middle, and O3 is the least yellowish illumination. It is clear that every point shows less than 100%. That is, the yellowness of the picture preferred is less than that of the original scene. No wonder if young people felt too yellowish for the picture taken through a yellow filter simulating the transmittance of the crystalline lenses of elderly people.

Fig. 5 Results from a subject YM for the illumination combination O2 and D1; 
• color of O2; ▲, D1; ○, raw data assessed by the subject YM; ◦, average of ten determinations.

Fig. 6 The averaged point of each subject for the illumination combination O2 and D1. Different symbols correspond to subjects. 
•, color of O2; ▲, D1; ○, subject YM; △, SA; +, RY; □, KS; *, YH; ◦, average of five subject.
5. CONCLUSION

It was found that the yellowness of a picture for a scene should be much less yellowish than a picture, which exactly reproduces yellowish color property of the scene, when it is observed in a room with white illumination. The amount of the yellowness in the picture is about 40 to 80% of the original scene depending on the subjects. The finding implies that the color perception by elderly people should not be so yellowish as young people are seeing on the picture taken through a yellow filter simulating the transmittance of the crystalline lenses of elderly people.

If young people want to experience the color of a scene just as elderly people are experiencing by means of a displayed picture, and if they are looking at the picture in a room with a white illumination, the amount of the yellowness should be about 40 to 80% of the original scene, provided that the pigmented crystalline lenses are the only change that takes place in elderly people though there is evidence that the change also occurs in the retina.

REFERENCES
THE COLOUR OF NATURAL LIGHT IN GRANADA (SPAIN)

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INTRODUCTION

Outdoors, the colour of the objects depends on their spectral reflectances and on natural light. This natural light (known as daylight) could be composed of light from the sun (sunlight), light scattered by the atmosphere (skylight), and any combination of these. Our daylight data presented here consist of hemispherical daylight: global spectral irradiance received on a horizontal surface from the sun and the entire sky.

Detailed knowledge of the spectral power distribution (SPD) of daylight in the visible and ultraviolet regions of the spectrum has many applications in science (atmospheric optics, meteorology, medicine, biology, etc.), technical areas (photovoltaic applications, biomass production, colour rendering and metamerism, agriculture, architecture, etc.) and industry (photography, dyes, paintings, textiles, etc.).

Daylight-measurement campaigns were conducted in different countries (U.S.A., England, Japan, India, South Africa, Australia, etc.)\textsuperscript{1-14} in the sixties to standardize, for practical purposes, the representative spectral distributions of daylight. Among these, the paper by Judd, MacAdam and Wyszecki\textsuperscript{15}, which compiled data from three different works\textsuperscript{1,2,4}, is the most referred to in the literature and was the basis for the daylight recommendations by the International Commission of Illumination (CIE).

Although daylight is basically achromatic, a great number of factors (i.e. solar elevation, altitude, atmospheric conditions, pollution, etc.) can produce variations in the spectral
composition and therefore in its colour. Given the fact that it is impossible to model all these factors, a colorimetric characterization has been performed here through experimental measurements.

Our main objective of the present work were to carried out an extensive campaign of spectral daylight measurements over the longest period of time in the literature (two complete years). For this purpose we have done it with adequate precision, frequency and spectral resolution to enable future analysis and modeling: for instance (among others) to perform our own principal-value decomposition process to obtain the mean vector and characteristic vectors.

EXPERIMENTAL MEASUREMENTS

We have used a portable and modern spectroradiometer to measure spectral daylight. Our available data for spectral curves of global irradiance on a horizontal surface come from a campaign in Granada, Spain.

Table I presents the principal characteristics of this campaign, in which measurements were taken from sunrise to sunset at intervals of 1 hour with a Licor LI-1800 spectroradiometer scanning the wavelength range between 300 and 1100 nm at 40 seconds per scan.

<table>
<thead>
<tr>
<th>Spectroradiometer</th>
<th>LI-1800 from LI-COR, Inc.</th>
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<tbody>
<tr>
<td>Type or radiation</td>
<td>Spectral global irradiance</td>
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<tr>
<td></td>
<td>(sunny) + skylight)</td>
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<td>Field of View (FOV)</td>
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<tr>
<td>Wavelength range</td>
<td>300-1100 nm</td>
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<td>Scanning time</td>
<td>40 seconds</td>
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<tr>
<td>Measurement period</td>
<td>From sunrise to sunset</td>
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<tr>
<td></td>
<td>(minimum solar elevation ~ -4°)</td>
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<tr>
<td>Measurement time intervals</td>
<td>1 measurement per hour for normal solar elevations</td>
</tr>
<tr>
<td></td>
<td>1 measurement each 10 minutes for low solar elevations</td>
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<tr>
<td>Atmospheric conditions</td>
<td>Full possible range: clear sky, scattered clouds, cloudy, hazy, overcast, misty, etc.</td>
</tr>
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</table>

Table I. Characteristics of our daylight campaign.

The set of 2600 recording cycles was taken, for two years, from the roof of the Science Faculty of the University of Granada (37°11' N, 3°35' W, altitude 680 m), situated within an urban but non-industrial area, covering all atmospheric conditions.
Figure 1 shows three different daylight SPDs measured in Granada. The first one corresponds to a clear day with a solar elevation of 69 degrees and a correlated colour temperature (CCT) of 5770 K. The second one, more reddish, was measured during the sunrise of a completely overcast day, and its CCT is 4250 K. Finally, the third corresponds to a sunrise of a partly cloudy day, with a CCT of about 24380 K.

RESULTS

Due to the latitude position of Granada the maximum solar elevation is 76 degrees over the horizon. The solar position for each measurement was calculated and the histogram for the solar elevations corresponding to the complete data set is shown in Figure 2.
The 2600 chromaticity coordinates were calculated and plotted on the CIE 1976 chromaticity diagram (Figure 3). In this figure we have included the CIE daylight locus (chosen visually) and the Planckian locus. We have also determined our Granada daylight locus, using a least square fitting:

\[ v' = -0.21199 + 5.20932 u' - 9.01087 u'^2 \]

Our measurements of daylight chromaticities provide a range unprecedented in the literature. Most of the Granada data with low correlated colour temperatures (CCTs) are located above the Planckian locus (towards the green region) and below the CIE locus, in agreement with Judd et al.\textsuperscript{15}. However, remarkable discrepancies were found between our locus and the CIE locus; for high correlated colour temperatures (values over 9000 K) the CIE locus is inadequate to represent the chromatic characteristic of daylight measured in Granada. This means that for these CCT values Granada daylight is more greenish than those adopted by the CIE.

Figure 3. CIE 1976 chromaticities of our Granada daylight measurements (open circles) overlaid with the CIE daylight locus (dashed curve), the Planckian locus (curve with open squares) and the Granada daylight locus (dotted curve). The inset shows the entire CIE 1976 diagram and Planckian locus.
The CCT histogram of the Granada daylight measurements is presented in Figure 4. Granada correlated colour temperatures range from 3758 K to 34573 K, 45% of these within the interval 5500-6000 K, and 11% between 6000 K and 6500 K. If a CCT characteristic value had to be recommended for daylight measured in Granada, a value of 5700 K would be the most suitable, whereas the CIE value is 6500 K.

CONCLUSIONS

We have measured, over a period of two years, the most extensive set of daylight spectral power distributions in the literature. This data constitutes a useful tool with many applications in different areas.

Our measured daylight provide an exceptionally broad range of natural-light chromaticities and correlated colour temperatures. The discrepancies between the CIE locus and the Granada locus are evident for high CCTs (> 9000 K) where the Granada locus is more greenish.

ACKNOWLEDGMENTS

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REFERENCES


2. The work by Budde was not published, and the details are those given by Judd *et al.*


Colour is a phenomenon so rich and complex in scope that it touches on most human activities. Architecture and art, symbolism and communication, industry and physics, psychology and sociology - virtually every field we can name is concerned with it.

Colour on architecture is the quality of architectural surroundings, historical tone of town, the important element of national culture, one of the most important components of antique and modern town surroundings formation. Architectural polychromy (from Greek poly = many, chromas = colour) - is manycolourness (not less than two colours). It is to be achieved using colour materials or painting. It has two main parameters: activity or magnitude of contrast between the elements of colour serial and degree of independence of colour space structure in relation to volume and space parameters of architectural form.

Colour on antique architecture is one of modelling elements. In the human visual experience the reflection of colour is the most directive and the most sensitive. The colour is a sign of human civilization, and represents the culture of a determinate epoch. In the ancient civilizations the likes and dislikes of colours and colour-matching presented a course of evolution and development. This was intimately relative to economy, politics, military, thought, culture, religious faith, and the custom of life and they influenced one another.

Colour on antique architecture is central to identifying all antique cultures. Ancient civilizations and nations, like cultures, tend to develop colour harmonies and combinations in distinctive palettes. Availability of pigments, colour symbolism, as well as instinctual and psychological bases, enter into and influence particular choices. Each colour group forms a chromatic cluster with historical authenticity.
Antique towns of the world were from soil, glay and sand built. Towns from glay had Mussulman, Buddhism and American Indian cultures. They have had gray-ochre and red brown colour in dependence on colour of local glay and components, that were added. Passive multicolour painting of artificial environment was the background for bright splash of pure colour.

In the first towns of Assyria and Babylon dominant in architecture towers-temples were. Known Babylon tower, tower of Navoukhodonosor in Barsyn were made from glay in the 7 century B.C. Seven its storeys had height 90 meters and reflect colour symbolism, that mean 7 planets of heaven's sphere. On Fergusson it is the series from black (that is allegory of darkness, night, disintegration and death) through dense warm tints of orange, red, yellow and green (that is property high forces and purity, the image of good and sanctity). That colouristic idea permit to melt into the sky and to become familiar with the world of good ghosts.

Having discussed the towns built from soil one could not pass the Central Asia over in silence. The town building copied the imposing living in the clouds cupolas and minarets, what were to be seen from distance of 20 or 25 km. There was designed structural stereotype of decoration. The colour emphasized the most important parts of buildings, increased their role in architectural ensemble. Mosaic from glazed ceramic of dark-blue, light-blue, white, yellow, green and black colours partly did level the real plasticity, partly create the image of relief. Small decorative painting of big planes of walls gives the expressiveness to the architectural complex of Samarkand: Registan, Shakhi-Sinda, Bibi-Hanim, Gur-Emir. Multicolour decoore express here independence and composition activity of polychromy, removes the sensation of portal weight, gives to them lacy design and vastness.

The glay as a building material durable and longlived is what about the 5 thousands km of Chinese Big Wall testify that was from glay of different regions built and took colour of << soil >>. The main theory of colour can be discussed starting in Old Chine and India. Here the theory about colour has character of philosophy having the mythological base. The source of Old Wisdom << Book of Changes >> has 64 hexagrams - compositions of 6 lines of two types: solid and dotted, were considered as the start of painting, that present variety of colour compositions in blue-yellow and black-white ranges of colours, reflect the epic of interaction of the light and the dark, << visualises >> the base of universe. In old Chine to all
elements, all seasons, lands, planets and materials their own colours were done. The system of 5 main colours is: green as outcome of blue and yellow, red, white, black and yellow.

In Old Chine the polychromy consists in architecture in form of frescos in Buddhist cave monasteries, later the wall-painting transforms in pannel, inlaid by porcelain pagodas will be outside covered with black and red varnish inlaid by bronze, mother-of pearl, the tiles will be glazed. The antique Chinese town has symbols of form and colour, that took place in philosophy and art. The image of the sky were incarnated in round temples of Sky, the image of earth were incarnated in square temples of Earth. The temples of Sky were roofed with blue tiles, and the temples of Earth - with yellow tiles, as the soil of Chine. The red brick wall of Purple Town was the symbol of perpetuity and force, and gold tiles - the Sun. The special feature of that culture is "cosmic embrace" and boundless world of colour materials.

In towns of Old Egypt the stone building is known from 5000 of B.C., rose granite was used from Assuan, onyx with black, white and red layers. But aesthetic opinion of Egyptians demands decorative treatment of surface. Stone facing was used for pyramids in Giseh. The pyramids of Keops and Kefren were faced with white stone, and the pyramid of Micerin up to half of its height was faced with black stone. On tradition of "glay period" the natural stone was covered with colour layer. The face of Big Sphinx not accidentally was painted with red pigment, it is the symbol of energy and perpetuity. Holy red colour is the mark of crown of Upper Egypt, symbol of blood, that was shed by Ossyris for Egypt prosperity. Canonization of architectural polychromy of Old Egypt is connected with religious symbolic of certain colours of nature in colouristic of Egyptian temples. This colours include blue from turquoise and cobalt, red from madder, vermilion from cinnabar, green from malachite, black from soot, various browns, yellows and dull reds from soils, and white from chalk, lime, or gypsum. This substances were washed, ground, and mixed with oils.

Palette of colours of Egyptian is not wide, but character of their use is strong canonized. Colour was pandemic in Egyptian society - buildings were polychrome, particularly inside, where frescoed hieroglyphs and organic patterns adorned walls, columns, and ceilings, and both men and women adorned their bodies, putting kohl and malachite green around their eyes and rubbing orange into their skin to heighten their faces with reddish tones. The temples and their colour symbolism can be accurately traced:
- for vertical places, bas-relief, faces of sphinx - red (symbol of perpetuity, nobleness of red race);
- for painting of floor - green (symbol of underground kingdom of God Ossyris, perpetuity of Earth and Sky);
- for painting of ceiling - dark-blue and turquoise (symbol of Sky, kingdom of Goddess Isis);
- shined white - all-spread, divine and unsmouldered.

In times of 12th dynasty in Old Egyptian architecture the ornament was created. Its design consisting from scrolls, rosettes is clear to be read out because its bright colour background, that stress the relief and space of buildings.

Colour symbolic of Old Egypt that was assimilated by countries of Asia Minor was adapted to new form of culture of Old Greece. The towns of Old Greece were pigmented, natural colour of marble, ivory, wood were considered to be not characteristic for architecture. After long denial of Greek polychromy at 1832 Gottfried Semper, then Franz Kugler and JJ Hittorff had proved that many temples have had bright colouring by encaustic-waxen dyes, that did not cover up to the crystalline structure of marble, but create the effect of deep luminescence. Encaustic, derived from the Greek word enkaustikos, from enkaiein - to burn in - refers to colorant made from pigment mixed with melted beeswax, resin, or oil as a binder and fixed with heat. In Old Greece particularly in times of Elline the town is considered as a unified << artificial image >>, the palette of what more rich is a by Egyptian. The spatial characteristics of colour are used, its forming properties, the signs of building tectonic and inner structure of material. The temples of Old Phoros from porous limestone and shell rock were plastered by lime plaster, then were painted. For it exist certain tectonic principles:

- main elements (walls, pillars, flights of steps) in colour of natural material;
- elements of upper part of building (roof, cornice, plastice of frieze and capitals of pillars) were stressed by bright colours (red, blue, ochre).

This had enriched the plasticity of temples and permit to see they from long distances. In classic Greece the tradition of inlay was continued. Polychromy has arisen as a result of combination of different rocks of stone. The frieze of Erehteion represent the solid tape of dark-violet marble with light relief of warm tint, inlayed with gilded metal and glaze.
Paraphenon was more polychromatic and besides inlay had encoustic. Pentillii marble of pillars was contrast to encoustic and inlay, gilt. The background of pediments were red, threeglief-dark-blue, horizontal elements of cornice had tapes of colour ornament.

Ancient colour aesthetic was connected with classical philosophy. It is harmony at all and relatively colouring - in particular. The harmony is connection of elements of system. Homer has called with that word the clamps what by the ships were knocked together. Pavsany has called by that word the masonry. That's why harmony as connecting origin is the main principle. The second principle the unity of opposites, contrast of the light and dark, chromatic and achromatic is, the third principle is the adaptation of colour to the possibilities of human perception.

The investigation of Roman antiquity has shown, that Romanians had certain preferences:

- gray colour of natural stone, multicolourness of expensive and precious materials;
- facing with marble, ionic and coryphs as most plastically rich;
- brightness of natural brick was stressed by light colour, Romans used to apply paint to fair faced bricks; e.g. they used deep red paint to increase the chromaticness of red brick.

Colour contrasts and gloomy magnificence create the impression of «greatness» that was characteristic to Old Rome. Roman architecture - that are strong colours (for the fictive skeleton light colours were used, for wall areas dark colours or vice versa), determination of decorative theme, imitation of expensive materials, the representations that create optical illusion. The excavations of Pompeii give exciting insights into Roman interior decoration. Pompeii was a flourishing city then, in A.D.79, an eruption of Vesuvius buried it. The layers of ash preserved it until the eighteenth century, when excavations began. The fresh colours of the wall paintings give us a unique view of painting in antiquity and provide a rare source of information.

The Romans used strong colours, such as Pompeian red, and rich ornaments and painted imitations of precious materials as well as architectural elements, using a perspective way of representation. The Pompeian red and its complementary blue-green are often used in modern palettes; Black, next to this red, has a strong decorative effect.

In Old Rome the places were decorated with «albums». One of the streets of town Pompeii Olphevre represented «albums» - all walls were white washed and ruled for red
squares where by black coal the texts of publicity was written. It was the first attempt of environmental design.

For statements can be made in a brief outline:

1. During the entire development of architecture of antique civilizations, more or less chromatic colours were an established and essential element in architectural design;

2. Colours and finishing materials of the architectural environment are closely related to human emotions. They do not only characterize the expression of a building but also mould the user's emotions very decisively.

3. An almost all antique civilization, colour use in architecture falls into two broad categories:
   a) colour used as an active element, in the form of applied finish, which is intended to enhance the appearance of a building (for example paint, pigmented whitewash, ceramics and decorative brickwork);
   b) more passive or neutral use, where colour is derived from the natural tones of the construction materials themselves stone, brick, clay or wood).
COLOUR COMPOSITIONS IN TURKISH CIVIL ARCHITECTURE
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Abstract
Color scheme of a city is a historical phenomenon. In Turkey as in the lands of the West, architecture had the status of major art. In building, the Turkish genius lay in the use of dressed and covered stone. Great Anatolia was a stone-carving center as early as the time of the Hittites, Greeks and the Achaemenids, and this tradition carried on over the succeeding centuries. In public and religious buildings, faience mosaic came into use centuries ago, and reached a crescendo at Bursa. During Seljuks period color was occasionally used within the stonework sometimes as bold patterns and at other times as modulated tones in a color balance arrangement. Multi-colored tiles were used throughout the Ottoman period.

Structural materials and their natural colors are the main factors composing the color compositions of Turkish civil architecture in each region. But they are not the only ones, since pigments and dyes are used on the surfaces too. Red and yellow ocher’s with indigo blue (all in different proportions and tones) and of course white are the dominant colors used in almost all regions. There are several examples of symbolic use of shapes and motives in Turkish architecture. This has not been valid for color, although it has been widely used on surfaces. But, in most regions, the prevalence in usage of different tones of green and blue on windows and doors is interesting. In most cases, these colors contrast with the color of other materials used on the surfaces. May be the belief of keeping the misfortune away by the “blue eye” or “blue bead” is expressed by such usage. So, blue or bluish tones stands here in order to dismiss the Evil, protect the house and members of family. This is our estimation; this may be or may not be true.
Nowadays, architectural color compositions are following the international fashions and individual tastes. Some kind of effort can be seen for interpreting and modernizing the traditional or vernacular forms, but rarely contact or interpretations of the traditional or vernacular colors are seen. The contribution of sensitive colorists is urgently necessitated.

Color In Architecture

Color scheme of a city is a historical phenomenon. It has an important role in formation of cities peculiar texture. Sometimes it is provided by the materials used in buildings or available in the environment and sometimes by the way of several paints covering surfaces.

Even if we do not want, we all experience color, use it, and have to live with it and its effects. Color in architecture has been used to emphasize the character of building, to stress its form and material, and to elucidate its divisions. By “color in architecture” we mean not only the primary hues, but also all the neutral tones from white through all grays and black. So, every building has color and what we are interested here is its use in a purely architectonic sense. One point should not be forgotten that no building, as any color, is ever seen in isolation. Every one has a context, has visual relationship with other buildings and their surroundings. And color in townscap depends upon these relationships.

Originally, color came of itself by materials which nature supplies and which experience taught man were strong and serviceable. The dwellings might be built by hard-packed mud, stones gathered nearby, trunks of trees, twigs and straw; a structure in nature's own colors. Later, man discovered how to make the materials more durable, and so, new colors began to appear like red and yellow bricks instead of the gray, sun-dried varieties. All those provided a choice of several colors, however, it was a limited one. Then, in order to protect the surfaces, man started to cover them with white lime or mix it with other natural pigments. Afterwards, we see the invention and use of enameled or glazed tile in architecture in Mesopotamia and Ancient Persia (500 BC) and its improvement (from more simple glazed tiles to ceramics and Haft-Rangi -seven colors, multicolored- tiles) and prevalence during Islamic period in the Islamic lands and Spain, and its culmination during Safavids in Iran and Ottomans in Turkey between 15th and 18th centuries.

From the moment that man started to control the color of building materials instead of ones produced by nature, a new step in architectural design had been achieved.
Color In Turkish Architecture in the Historical Process

In Turkey, as in several cultures of the World, architecture had the status of major art. Faience mosaic came into use centuries ago, and reached to its highest point at Bursa. Multi-colored tiles (seven colors) were used throughout the Ottoman period. In building, however, the Turkish genius lay in the use of dressed and covered stone. Great Anatolia was a stonecarving center as early as the time of the Hittites, Greeks and Achaemanids and this tradition carried on over the succeeding centuries.

During Byzantine period Anatolian architecture probably were too much depended on the available materials in regions. Rare examples belonging to the period have shown the usage of cut-stone, rubble, brick, timber and mud-brick in houses.

In Turkey, during the Seljuks period color was occasionally used within the stonework-sometimes as bold patterns and at other times as modulated tones in a color balance arrangement, in public buildings. But, no data is available about civil architecture belonging to the period.

The Byzantine alternate usage of stone and brick and their color combination influence early era of Ottoman period public buildings' façades (this influence on facades never has seen in plan schemes). Usually, the mosques, Medresseh's (High educational -academy- schools of sciences, medicine and of course theology), Hamams (public bath), and other public buildings were built by stones and bricks with a mortar in between (sometimes gray and sometimes colored), and they were not coated. Later, Ottomans developed their own façade arrangement with ceasing brick and using only cut-stone. The cut-stone walls became the characteristic of the public Ottoman architecture, as in Süleymaniye (Istanbul) and Selimiye (Edirne) mosques, masterpieces of chief architect Sinan.

See Fig.1 at the end part of the paper

Although, the exterior walls were left bared and have had their color compositions by the used materials, interior walls, roofs and other surfaces (almost during all periods) have been so colorful because of usage of ceramics and tiles with their rich colors. Mosaic faience, wall tiles, stuccoes (whether multi-colored or not), calligraphy's, and frescoes had important roles on coloration of interior spaces. Besides, usage of colorful glasses for windows, colorful carpets and rugs on floors, colored marbles and their colors on walls, all has participated in the color composition of the interiors.
There are no examples of civil architecture survived from the early years of the Ottomans. Houses belonging to the subsequent periods in Bursa, Edirne and Istanbul show such deep thoroughgoing developments in time. In these capitals, located in the Marmara Region, traditional house architecture developed, took root and reached to its peak during 16th century. In the rest of Anatolia, regional influences have been more effective.

See Fig. 2 at the end part of the paper

Today, in towns or neighbourhoods where still preserve their traditional townscape, the harmony of colors of natural stones, bricks, and mostly turquoise tiles, with differing ratios, on public buildings' faces with the several colors on the surfaces of houses can be seen. This color scheme is valid even in today's squatter regions (gecekondu bölgeleri).

Environmental Context

Environmental factors as climate, geography, land feature, local building materials available in the region and vegetation, with traditional house culture, are the basic factors forming the spatial character of the design characteristics of the traditional Anatolian house.

Anatolia is surrounded by seas in north, west and south. Therefore, different climatic conditions are dominant in the same season. In the Mediterranean climate summers are hot and dry and winters mild and rainy. The northern coasts are humid during summer and mild in winters. The Black Sea shores are too much affected by the mountains in the north. Precipitation has enriched the vegetation and multiplying of forestlands. Northern Anatolian Mountains in the north and Toros Mountains in the south are surrounding the Central Anatolia with its hot and dry summers, severe colds in winter and characteristic sudden heat changes. But, terrestrial climate's main characteristic effect can be seen in the Eastern Anatolia with its rough natural structure. Eastern Anatolia has very cold and snowy winters, and short and hot summers. Southeastern Anatolia with pretty hot and dry summers and showery winters has terrestrial Mediterranean climate. These climatic differences and land's features affect the formation of architecture and townscape in each region.

Timber, stone and mud-brick are the local materials used in Anatolian buildings. Usually, stones are used for basements, ground floor and walls of gardens (courtyards). Timber, in the most of the regions is used obligatory for the framework, doors, windows and framework of roofs. Stones, bricks or mud-bricks are mostly used as filling materials. The ratios between
materials determine the color composition of the building, neighbourhood and city. Also, depended on the local materials and possibilities, timber-stone or timber-mud-brick cooperation have paved the way for arise of some original architectural environment. Timber has been the main structural material in Eastern and Western Black Sea and the Marmara Regions. In the Aegean and Mediterranean Regions both timber and stone has been used due to the location of settlements. But, in the Eastern and Southeastern Anatolia Stone is the main and some times the only structural material. In Central Anatolia where both stone and timber are rarely found, mud-brick is used as the main structural material. Here again, the basement walls are built with stones and the others with mud-brick. These walls are supported vertically and horizontally by timber. Mud-brick walls should be coated with clay plaster every year and this provides some kind of homogeneous influence in the general view of cities in this region.

The natural colors of building materials belonging to each region, their ratios and relationships with each other, the differing vegetation and soil colors around, and even the color of sky that changes depended on several factors form the background of the color composition of the regions indispensably. But, human being never has being satisfied with the nature's colors and always has being used his instinct about color, his choices and preferences. Cultural background has an important role in formation of his decisions that complete the existing color palette of each region.

**Cultural Context**

Traces of ancient cultures going through 4500 years, can be seen in traditional house architecture in whole Anatolia. A cultural heritage carrying the tracks of the Turkish tents in the Central Asia, combinations with several other cultures, as Iranian traditional and vernacular, and Islamic ones. Undoubtedly, effects of the Western culture also should be taken into consideration at least since 150 years, especially in the western part of Anatolia.

*See Fig.3 at the end part of the paper*

A highly peculiar developed color-sense in Turkey derives from experience that is gained during a long time of centuries; experience of weaving carpets, kilims, textiles, making ceramics, etc. in everyday life. In most of the traditional towns women weave such handicrafts, their daily life and even their traditional clothing is full of colors and colored
materials. In some regions men also cooperate them, make ceramics or tiles in workshops. And once people start to live with color, psychologically, it's impossible not to be sensitive about it and its combinations. So, they will find a way to express this sensitivity to their life and environment. Interiors are the easiest spaces to be influenced, but some times they are not sufficient, however, in architecture the color palette is more limited. In such cases, exterior walls and surfaces are so appropriate, and in vernacular architecture there are several examples for them. Although, the availability of time, cultural, social and environmental conditions have important roles.

*See Fig. 4 at the end part of the paper*

For example, an important point is, in almost all countries that have accepted Islam as their main religion, and particularly in Anatolia, the religious and public buildings, as mosques, Hamams, Medressehes, Bazaars, etc. because of their roles in the society are built with more durable and painstaking materials. While, according to the religious rules modesty is more suitable for the house architecture, even for palaces. So, less durable materials, less ornaments, less scales, etc. are used on house facades. Therefore, in Islamic towns, houses are more modest, even if they belong to rich and wealthy people. But ornaments and other signs of wealth are shown in interiors, not reflected to the street. With their scales, forms, colors and contexts, they prepare a smooth background for religious and other public buildings.

*See Fig. 5 at the end part of the paper*

An existence of color on house facades can be seen in a short search on old miniatures, paintings, landscape pictures on Anatolian towns. But in such cases always there is some kind of interpretation. Although, no example of house architecture exist from previous times (approximately before 17th century) and even it was, since dyes and paints are the most endurable architectural elements, it is too difficult to come to an exact conclusion about color composition of townscapes. Still, the colors in old miniatures, pictures, etc. give some ideas and hints about them. Yellow and red ochers, indigo blues,... on the house facades are obviously seen. But, we are not sure about the ratios, relationships or how frequently they had used. However, today, same colors can be seen in Anatolian towns where still preserve their original texture.

In sum, the house culture refined in Anatolia is a result of social-cultural configuration of the local people. In organization of house spaces, the differences originated from such factors as;
climate, topography, production and cultural relationships with other communities are intensified with the reflection of people's faith and their life style. Even if in same climatic conditions, with same plant cover and structural materials, the faiths and believes of people and the differences in their perceptiveness of wholesness are differently reflected in architecture. Nevertheless, in separate geographies with various climatic conditions and vegetation similar architectural facades and spaces with similar color compositions can frequently found in Anatolia:

Structural Materials and Color Compositions Relations in the Anatolian Turkish Civil Architecture

Actually, there are seven geographic regions in Turkey, as Black Sea Region in North; Marmara Region in North-west; Aegean Region in West; Mediterranean Region in South; Southeastern Anatolia; Eastern Anatolia; and Central Anatolia. But, due to intersecting of geographic characteristics, there are similarities in house architectures of different parts in each region. Differences and similarities in architecture in same region and different ones cause a multiplication of kinds. So, we preferred to classify color compositions of them according to their structural materials and varieties in each, give examples from specific cities with peculiar color compositions, at the same time, representing general characteristics of their regions or specific part of them, or some times ones that defer from general view.

Half timber structure is the most widespread type with differing densities in Turkey. This structure provides a vast range of variety in texture and color composition of facades. In the most familiar type of half timber buildings ground Boor walls are made of stone, in other floor's facades spaces between timber structural elements are filled with mud brick, rubble stone or brick. Usually these walls are coated and colored. The ratios of colored parts may change. Ground floor stone walls are mostly left bare. Some times, horizontal and vertical load bearing timber beams of upper floors are left in their natural colors or painted. But some times, the owner of the house may decide to plaster and paint the whole surface in one color, or may want to ornate it with several motives, symbols, even calligraphy's. There are several examples for such houses in several cities in different parts of the country, such as, Istanbul, Kula, Bursa, Sivrihisar, Trabzon, Safranbolu, Antalya, Kütahya, ...
Color Compositions of Half-timber Structures in Some Cities:

Kula

The main source of living in Kula is agriculture, textile and carpet weaving (Original Kula carpets are so well known among carpet collectors). Most of the people weave carpets in their houses. Vivid reds (now yellows and browns) and blues with interesting landscape, vase, bird and floral patterns and yellow borders are their basic characteristics. But similar patterns and colors, drawn and painted on the interior walls, ceilings, doors, installed cupboards, shelves, especially in the "Baş Oda" (Main Room) in interiors, and on facades are genuine characteristics of the houses and town. Most of these buildings were built during 18th and 19th century. The impacts of Baroque period are so obvious in the ornament's lines and motives (besides of the traditional ones). But same is not valid for colors. All colors used in the wall paintings on facades and of ornaments in interiors are traditional ones, as red and yellow ocher, indigo blue, black, brown, green, white, etc.

See Fig. 6,7,8 at the end part of the paper

Bursa

Bursa (in Marmara Region) has a similar colorscape. But in Bursa first floor facades of houses are painted without motives and drawings as Kula. Bursa is famous with its silken textiles. Here again a kind of color-sense is obvious. Mosques, hamams, medressehs and other public buildings are mostly built of stone and brick. Their color combinations with blue tiles here and there are so impressive. According to Leman Tomsu, the houses were uncoated, because bricks, as filling material, were arranged in a decorative manner and such a careful decoration should not be plastered. Tomsu gave several details about colors ornaments in interiors but rarely wrote about colors of the exterior walls. May be color in townscape is the most architectural element that have been overlooked, because it is always around us and actually we can not imagine a world without color, as we can not imagine life without air or oxygen. We recognize it only when some thing is wrong about it. Same is valid for color. But in spite of this, her notes for colors of interiors are clues to guess the colors of exteriors, at the same time. Although, a large number of the buildings were damaged or the colors were changed, still walking in Bursa is an enjoyable experience through colorful streets.
As Maggie Quigley, describes color and asymmetry as typical characteristics of Bursa traditional house architecture. One can easily find the characteristics mentioned by Quigley in houses built in Hisar region (around citadel) during 19th century, when the Baroque influence was at its height in the Turkish provinces. The first floor facades of houses are coated with indigo blues (çivit mavisi), red ochers (as1 boyası), yellows, even blacks and greens. Originally, doors, windows and other timber architectonic elements were not painted, but recently they are in order to prevent deterioration and oldness.

See Fig. 9-16 at the end part of the paper

Sivrihisar

In some half timber buildings brick fillings are ornamentally arranged without coating or plaster. Sivrihisar (a city in western part of Central Anatolia) houses are of this kind. Basements and ground floor walls are made of stone, however, the filling material on upper floor facades is brick, originally not coated. But today some of them are coated. Some reasons as oldness, being soiled, or just a wish for change, and probably the effects of Baroque Period during last years of Ottomans may have been effective in this change on facades.

See Fig. 17 at the end part of the paper

Thus, half timber buildings can be considered as the most colorful ones. Structural material’s colors with several natural pigments in different ratios provide their colorful faces. Furthermore, half timber structures may have peculiar types of application and composition in some regions.

Rize

In Rize, a city in eastern part of Black Sea Region, timber is the main structural material. The timber framework provides several squares (10–15 cm) on the facades. Each square is filled with a colored stone in center. Pinkish, grayish, black and white stones, each surrounded by brown-gray or white mortar, framed with timber’s natural color and their view beside each other creates pretty pleasant composition in the green surrounding environment. This façade type, because of its likeliness to eye-shape, is called “Göz Dolga” that’s to say “Filled Eye”. Timber elements may be painted, but not the frames and stones.

See Fig. 18 at the end part of the paper
Trabzon

In Trabzon, however, more variety can be seen in façade arrangements. In some house facades triangles are used instead of squares, some times filled with rubble stone and plastered named "Muskah Dolgu", (Filled Triangle), some times left void, "Muska Bölme", (Triangular Division). These voids create some kind of light and shadow effect on the walls. These three façade types with their peculiar structures and color compositions are characteristic of the Eastern part of Black Sea Region.

See Fig.19 at the end part of the paper

Istanbul, Edirne, Bartın, Amasya,...

Yet, another peculiarity of half timber structure is "Yahbaskası" (Weatherboard) that surfaces of house facades are completely covered with timber planks, some painted and some not. Ones that are not painted and located near the sea shore, gradually darken to a silvery gray, because of ultraviolet light and salt ratio in the humid air. And ones that are in more inner parts turn into covered with red ochre that prevents deterioration and provides a warm and soft appearance to the building. Even in most poems and songs about Istanbul, the reddish color of ochre refers some kind of warmth in relation with home atmosphere. At the same time, other natural pigments have been used to coloration of the houses. İzebolu, Bartın, Amasya, and especially Istanbul and Edirne are cities with marvelous examples of this type of houses.

See Fig.20-30 at the end part of the paper

Color Compositions of Load bearing Masonry Structure in Some Cities:

Mardin, Urfa, Diyarbakır,...

Load bearing masonry structure is the second widespread structural system in Turkey, especially in Eastern and Southeastern Anatolia where stone is abundant. Sandstone and limestone are the most available kinds. Depending on quarry's their color range may differ from white, beige to different yellow tones and browns or grays. In Anatolia they are either used as ashlarls (cut-stone) or rubble. Stonewalls and surfaces do not require paint or plaster for protection, so they are used mostly uncovered. The color comes from the heterogeneous texture and coloration of the stone itself. In Mardin, a city in southeast of Turkey with its
original texture, all houses are made of yellow shades of cut-stone, not coated, as the other public buildings have been made. In buildings of Mardin, fine carved stone ornaments on walls create some kind of light and shadow play on them. The townscape is as if, is melted in the landscape. So any contrasting color flashes into the eye. Urfa and Bitlis in same region and Nevşehir in Central Anatolia share similar color compositions with Mardin. In Diyarbakır, however, there is a slight difference as usage of two contrasting colors for ornamentation on walls. While brownish gray stones are used as the main or background color of walls, white is selected for the ornaments.

See Fig. 31,32a&32b at the end part of the paper

Erzurum

Random rubble walling is seen in Erzurum, a city in Eastern Anatolia. Here again color comes directly from structural materials; stones, horizontal timber beams, timber windows and doors. But landscape colors are more vivid here, so the effect is different and townscape has more heterogeneous color composition other than the cities of Southeastern Anatolia with their monochrome view.

See Fig.33 at the end part of the paper

Bodrum

In Bodrum, on the Aegean shore, again stone is the main material used for house buildings. The facades are left both bare and plastered with lime. Nowadays, all houses, even reinforced concrete ones have to be plastered white, because of the municipality rules. But this time dominant white plaster on the stone or concrete surfaces loses its lyric impression, since the previous ratios between whites of the buildings and greens or blues with other colors of the surrounding nature are changed. Now, white is the dominant color in Bodrum, creating a monotonous effect in the town.

See Fig.34&35 at the end part of the paper
Konya, Göreme, Ürgüp, Van

Konya, Göreme and Ürgüp (Central Anatolia) are some cities where mud-brick is used as one of the structural materials, besides timber, rubble stone and cut-stone. But, use of mud-brick is widespread mostly in small towns or villages. Since it is not a durable material, mud-brick surfaces should be coated with clay plaster and renewed every year. The homogeneous effect that is provided by such plaster is smooth and warm. Clay plaster can be used by its natural color or painted with various colors.

See Fig. 36&37 at the end part of the paper

Conclusion

Traditional color composition in Turkish civil architecture can be estimated from miniatures and paintings or some traces (pièces) of old paints remained on the walls or under the later coats of paints.

In Turkish architecture, usually colors come from the natural colors of building materials. Different tones of natural pigments as indigo blue, yellow and red ochre are used almost in all regions on the facades with different ratios. These are not sharp but vivid tones. In other exterior architectonic elements again natural colors of the materials are originally preferred. Though, since most of the traditional and vernacular buildings and their elements are not changed for a long period, nowadays the residents have to paint them with new dying materials. Yet, usually the selected colors are not diverging ones, but harmonious with the general color scheme. Still, interference of new hues provided by today's technology could not be prevented.

An interesting thing is that, colors of interiors have been described in several written sources in detail, however, the exterior ones are not mentioned. Colors of interiors were inseparable parts of the ornaments and so might be considered as ornament itself. But in exteriors they were usually applied on wide surfaces, for protection or other reasons. So, they just were there, may be changed when they had worn out or when people get bored of them.

For color compositions in Turkish civil architecture, some kind of classification can be done, according to the regions where structural materials are composing the color composition. But, when pigments and dyes are used, approximately a homogenous view with varying proportions and tones can be observed all around Turkey.
There are several examples of symbolic use of shapes and motives in Turkish architecture. This has not been valid for color, although it has been widely used on surfaces. But, in most regions, the prevalence in usage of different tones of green and blue on windows and doors is interesting. In most cases, these colors contrast with the color of building materials. May be the belief of keeping the misfortune away by the "blue eye" or "blue bead" is expressed by such usage. So, blue or bluish tones are standing there in order to dismiss the Evil, protecting the house and 

As previously mentioned, the color compositions reflected to the architectural surfaces carry traces of several cultural factors of the community. Today we are still using color inevitably in our townscape, as well as interiors. Although, some of these are carrying on the old traditions, but mostly they are following the international fashions and individual tastes. Natural and built environments are ignored occasionally. Ordinary people are usually more sensitive about their traditional environment as can be seen in squatter regions (gece kondu bölgeleri) with their colorful environment. However, architects and urban planners are not. The contribution of sensitive colorists is urgently necessitated.

See Fig. 38-42 at the end part of the paper

Bibliography

- Sözen, M., Eruzun, C., “Anadolu’dan Ev & İnsan” (House and Man In Anatolia), Creative Yayıncılık ve Tanıtım LTD, 1992, İstanbul. (Turkish)
- Bozer, R. “Kula Evleri” (Houses of Kula), Ministry of Culture and Tourism Publications, 1988. (Turkish)
- Tomsu, L., "Bursa Evleri" (Houses of Bursa), İstanbul Teknik Üniversitesi, Mimarlık Fakültesi, İstanbul Matbaacılık, T.À.O.,1950. (Turkish)

Hokna, S. *Çomakdağ ve Kefendere'nin Renkleri*, "ADA Kentliyim" 13, March/ Apr., Yayınevî A.Ş.6 Ankara, 1998. (Turkish)


Rıfat, O., “Edirne Evleri” (Houses of Edirne), Türkiye Turing ve Otomobil Kurumu, Istanbul, 1983. (Turkish)

Koçkııerman, Ö., “Kendi Mekanının Arayışında Türk Evi” (Turkish House In Search Of Spatial Identity), Türkiye Turing ve Otomobil Kurumu, Istanbul, 1985. (Turkish & English)

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9
Fig.1. One of the entrances of the Grand Bazaar in Istanbul. (Photograph: Susan Habib, 1995) The Byzantine alternate usage of stone and brick and their color combination influence early era of Ottoman period public buildings' façades and later periods.

Fig.2. Yeşil Türbe (Green Tomb) in Bursa. Photograph: Susan Habib, 1996) One of the important factors bringing color to public buildings' faces and the townscape is glazed tile.

Fig.3. An spice-seller shop in the Grand Bazaar in Istanbul. (Photograph: Susan Habib, 1995)

Fig.4. Color is an inherent part of the Turkish traditional and vernacular life as here in Çomakdağı, a village in Western Anatolia. (Photograph: Serper Hön, from: ve Kentlerve'nin Renkleri, "ADA Kentiylim" 13, March/Apr., Yayınevi A.Ş. Ankara, 1998. –Turkish–)

Fig.5. A miniature of Erzurum by Matrakçı Nasuh, 1534, from Karpuz, H” „Türk İslam Mesken Mimarisinde Erzurum Evleri” (Erzurum Houses in Turkish Islamic Residential Architecture), Ministry of Culture and Tourism Publications, Ankara, 1988, p.169. –Turkish–

Fig.6. Beyazoğlu Evi, Beyazoğlu's House, Kula, from "Kula Evleri" (Houses of Kula), by R. Bozer, Ministry of Culture and Tourism Publications,1988. –Turkish–

Fig.7 & 8. Some details from the same house, Kula. From "Kula Evleri" (Houses of Kula), by R. Bozer, Ministry of Culture and Tourism Publications,1988. –Turkish–

Fig.9. Bursa Municipality Building that previously had been used for housing the government offices of the locality. Originally, Bursa house faces were not plastered, but probably such reasons as, climatic conditions, need of protecting the buildings and the desire for change, with the colorful culture of the native people and the Baroque impacts caused the colorful townscape of later Bursa. (Photograph: Susan Habib, 1999)
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Fig. 10

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15

Fig. 16

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DIFFERENCES IN COLOUR APPEARANCE INDOORS WITH SUN AND SKY AS SOURCES OF LIGHT IN THE NORTHERN HEMISPHERE

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1. Introduction

This paper deals with differences in colour appearance caused by variations in daylight. The study concerns the differences between coloured walls in a room lit by sunlight and skylight, one at the time. Studying colour in full-scale interiors, we have come to talk about the elasticity in colour appearance, as it in various light can shift in different ways. The aim of this project is to work out methods for describing how colours can be perceived differently due to the kind of daylight they are exposed to and compare colour appearance under different daylight conditions. Furthermore, we want to discuss different strategies concerning colour design for rooms facing north and south. I will here present the study and give some preliminary examples from a study with a yellow and a blue colour.

Keywords: colour appearance, sunlight and skylight, colour performance in interiors, visual evaluation.

2. Background

It is well-known that colour of light affects colour appearance. That is the case not only when one studies colour samples in experimental situations, but also with colours in interiors. Interiors in the northern hemisphere have a light situation that differs very much between the cardinal points. Sunlight coming in from the south is perceived as a warm...
colour of light. Light coming in from the north on the other hand is reflections from the radiant sky and therefore has a bluish colour of light. As colour appearance differs between sunlight and skylight this must be considered in work with colour plans. Though, here is a lack in knowledge, we cannot predict how a colour may appear in various lighting, and this is a design problem.

Weather a room is located to the north in a building or if it is located to the south is often clearly noticeable by differences in the light. The intensity and distribution of light as well as visual changes in colour appearance makes us perceive different locations.

How do we treat the fact that sunlight and skylight make colours appear differently? How do we treat rooms considered to have a "cold colour of light"? There are different strategies, one may try to paint them in "warm colours" to make them feel warm, i.e. they try to paint the sun into the room. Others proclaim that blue or green colours are to prefer in the "cold light" of north rooms in order to access the specific quality of these colours.

3. Problem

Natural daylight makes colour appearance shift in various ways. In return the colour design of an interior affects the experience of a room; it can affect the light characteristics and the atmosphere, and enhance or reduce the perception or the volume of the room. With this in mind it is a design problem when one cannot predict how spatial orientation and variations in daylight affect colour design within interiors. A colour in a spatial situation gives a more complex colour experience than a flat colour sample. At first it is in a larger scale, secondly it envelopes you and there are corners and luminous reflections together with the specific light distribution in the room. Then there are reflections, glare and shades that adds to the colour experience. All these colour variations affect colour vision among with surfaces different reflectance characteristics as well as textures.

In cases when one can easily compare a colour exposed in various lighting conditions the comparison makes it seem like two different colours. This may occur with rooms on both sides of a corridor and painted in the same inherent wall colour. We are well aware that this happens but the lack of knowledge about colour appearance in various light then becomes a limit and a design problem.
The aim of this project is to work out methods for describing how colours can be perceived differently due to the kind of daylight they are exposed to and compare colour appearance under different daylight conditions. Furthermore, we want to discuss different strategies concerning rooms facing north and south. In the northern hemisphere the big difference between the two cardinal points, north and south often is not specially treated, in spite of the big difference of colour appearance, light distribution and atmosphere. There are different preferences and different strategies but merely in private. I wish to see a discussion about this: how do we, with colours, treat rooms in north and south so that they differ nicely?

Can one paint the sun into a room or what would a special treatment look like?

4. Method

This study concerns monochromatically painted walls in a room. I have chosen to work with daylight from the opposite cardinal points, north and south because they differ the most as sunlight and skylight have a different spectral distribution, light intensity and light distribution. The studied wall colours are 3 yellow and 3 blue in two nuances.

Observations have been conducted both in a full-scale room and in smaller room models. There have been 2-6 observers using approximately 1 hour for each study. We used an observation form were the observers were asked to make their observations by three different methods. After adaptation to the room light, the observers where supposed to make a verbal description of the colour appearance in everyday language. Thereafter they assessed the hue and nuances of the coloured walls by a method for visual evaluation. The observers looked at the light distribution, colour appearance of shadows and shade as well as in luminous spots. They described the atmosphere of the room as an open or close impression or a warm or cold one. In order to evaluate the colours in the room, matches where made between colours in the room and colour samples placed in a colour reference box. This box has a fixed illumination witch therefore function as a standard situation. The colour reference box method is under development and is further presented by me and Monica Billger on the CIE conference here in Warsaw -99. In some situations, when there is a big difference between the illumination of the room and the standard light in the colour reference box, we have to count on a certain adaptation effect. The colour sample in the colour reference box is perceived differently as the observer adapts to various lighting conditions. This is not yet completely mapped out but it seems as if it can be controlled.
Because of the adaptation effect we have preliminary adjusted the data of the presented studies according to the results from colour reference box validations.

In this study both the identity colour and the variations were identified. The identity colour is defined as the main impression of coloured units of a room that is perceived as uniformly coloured. The colour variations are all the variations of the identity colour due to various viewing and lighting conditions such as shadows and glare. By means of this method we have a clear picture of how the colour is perceived in a specific light and we are able to compare between different situations such as various weather and rooms facing north and south.

5. Examples from the study

First I want to present the method used to assess and describe how we perceive colours within a room. This method treats the identity colour and the colour variations separately as they represent the main impression versus an impression of details. I also present two studies, a yellow and a blue colour lighted with either direct sunlight or skylight.

In this study both the identity colour and the colour variations were identified. These data were separately put in a table in such a way that one can read where changes in colour appearance took place, in hue and nuances, in the identity colour or in the colour variations or booth. With this table and by using the observation form we can make a scheme for analysing what happens in the room. Does changes in hue or nuance take place in direct light, indirect light, shade or in shadows? By that we can reach further in understanding what a colour looks like, close to the verbal descriptions, because an inherent colour range in perceived colour variety. Colour appearance differ in corners and in contrast with other colours and all this adds in the main impression. The identity colour ground on the main impression of the colour variations but it seems confusing when the verbal description of the colour appearance does not show in the identity colour. By using this method with separated identity colours and colour variations, together with the colour analysing scheme, we are able to connect these methods and the verbal description. With this and the NCS colour code we have a way to tell what a colour looks like and to understand what happens with colour appearance in differently illuminated rooms.
There are clearly visible differences in colour appearance in a room facing north and a room facing south. This seems to be the case except when it is cloudy. The first example from the study is when the room was painted in NCS S1030- R80B, a reddish blue. In the room facing north the walls appeared to be blue violet. In the room facing south, the sunlight made the wall colour appear less blackish, and more reddish violet. Yet we did choose colour samples with the same hue, and often in blackness that made the walls appear as more bluish in the north.

The second example from the study concerns NCS S1030-Y, yellow. Painted in the room facing south this colour render shades of green and brown. Changes of weather conditions showed as an elasticity in the yellow colour: first it tended towards dark orange, then it lost its redness and gained more blackness, yet again it rendered towards white and in short regained the yellow quality. The pattern of this kind of elasticity in colour appearance is not the same in skylight as in sunlight. In skylight this yellow colour more often appeared as less chromatic, either more blackish or whitish. When light intensity increased it could enhance the chromaticness, sometimes it even made the colour tend towards reddish yellow.

6. Conclusions

- In order to understand what happens when a colour interact with room and light in an interior, it seems essential with a visual evaluation concerning light, shade and shadow. This method showed that the colour variations are as important for colour appearance as the identity colour is.

- The colour reference box method is a useful aid for describing the perceived colour. Although, the adaptation effect needs to be fully studied.

- Studies concerning colour appearance in rooms seems better to be carried out in full-scale experiments. Room models can be useful but it can be difficult to evaluate colour differences in a small room model. Changes in blackness and whiteness makes a big difference for colour appearance and together with changes in chromaticness this gives an observer a different experience of a colour. On top of this, sunlight seems to make colours tend towards yellow: blue colours turns into a softer, more greenish blue, bluegreen colours turns more greenish, while yellow and orange-yellow colours often seems much more intense in sunlight. Skylight, on the other hand, often seems to make
colours tend towards blue. Skylight can increase blue colours and decrease the chromaticness in yellow colours by, as it seems, increasing blackness or whiteness. Although colour changes vary, different colours shift in various ways and occasionally the pattern is not valid. But in general there is a distinct pattern in how a colour may appear in sunlight and skylight.

References


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COLOUR AND URBAN ENVIRONMENT

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The urban environment

The city, as the physical realisation of the urban environment, constitutes the materialisation of the human habitat which has been created by man through his social practice and consolidated by the historical context; what's more, it is basically his shelter, his unavoidable reference in the process of social communication. The urban phenomenon of the last decades has shown a change in the city's image. This image has not always been successfully controlled by an urbanism expressed by codes and rules that consider neither the human aspects of urban form nor the technological advances in information and communications that influence the quality of the environment.

The city witnesses the emergence of a new space of communication and flow of information that goes beyond the boundaries and frontiers of territorial space. This can be seen in the domestic as well as in the business domains. The information and communication technologies not only facilitate this virtual elimination of territorial frontiers but also leave a transforming imprint on the urban landscape being the public spaces the places where the paradox between the local and the global, the phenomenon of globalization and the impact of computer networks take place in full measure.

When we speak of globalization, of incomprehensible simultaneity, of antipodal cities which offer the same images, attributes, customs and icons it seems as if the utopian idea of universal design were taking place, the same ideal embodied in the Bauhaus in the first decades of the century. At present, and without utopias, the supremacy of design suggests a much more varied and unbridled general trend. This tendency, which is supported by software, tries to re-formulate every graphic sign and attempts at invading the urban spaces including publicity graphics and notices as well as architecture itself.

On the other hand, the urban-mediatic phenomenon affects every city, in a direct or indirect way, and shares the reform of the public space. The city, like commercial products,
is being advertised by means of trade mark images that make up the frame of strategies of distinctness. We are trying to make the city “visible” so that it regains its meaning. In the seventies, the transformations in town planning partly destroyed the meaning of the city. Nowadays, however, visibility operations of mediatic type are being used and these would allow us to find again our own consciousness by insisting on the qualitative aspect of urban life.

The “visible” is understood as the occasional memory that originates when communicating the development of an ephemeral event. The urban interventions are managed by the media coverage which projects them as an imaginary dimension, the fiction of an organised, impressive social life and its scope.

This attitude legitimises the search for a new utopia capable of providing answers to that virtuality, to the global mimesis. This new ideal should be able to deal with public spaces so as to regain the control of the substitution of the public image for public spaces considering all the aspects involved in its construction.

The role of colour

The above mentioned encourages the consideration of the problem of colour in the definition of urban environment and the role it plays in the creation of the image of the city. We need to focus on the concept of the urban space in relation to the man that inhabits it, that is to say, a conception of the city as a system of places.

From this perspective it is possible to pose the following questions: Should colour be for the urban physiognomy or colour for the urban living space? Must colour identify a city and increase its potential for orientation and perception?

The research into the use of light and the chromatic effects on the city and its inhabitants is based on the belief that the fundamental and inherent needs of man of total comprehension, orientation and sense of place are satisfied in urban places with the substantial contribution of chromatic expression.

Colour inevitably acts in those environments as form and sign, influencing human behaviour. This allows those who make deliberate use of it to turn it into a fundamental tool of design. The expression of colour operates through its organisation, grouping or composition laws which can display a chromatic system depending on the juxtaposition of hues, the extension, the textures and the feelings of csesias: transparency, matteness, brightness, specular reflectiveness and translucency. (Caivano 1994: 351-354). The colour constitutes a real morphogenetic agent and can highlight, change or destroy the syntax
established by the components of urban form and of each one of its languages on the plane of figurative expression. (Avila - Polo 1998:112-114).

Besides, colour works as a means of comprehension and communication between man and his surroundings. The fact that it can integrate and associate different images confirms its invaluable importance as message conveyor; in fact, it is very often an intermediate step in the transformation from one perceptual channel to another as well as in synesthetic processes. The synesthetic language of colour is communication, the message that it tends to convey; in addition, the essential element of colour is the chromatic synesthesia, a sensitive entity which, when perceived as form, represents a basic suitable icon in the expression. (Sanz 1985: 59-62).

At present, the public space, and for the above mentioned reasons, tends to develop in the mediatic field of exchange of messages and the consequent construction of its image is influenced by this information and communication technologies with features of virtuality and global mimesis. If this tendency were reversed, it would be possible to revive Heidegger's concept of place, the social topology rooted in public places, in which the secular paradigm is the Greek "agora"; we would be able to bring this idea into effect by adjusting this model to the elements of the urban language so as to express its specific functions, social behaviour and meaning.

When the urban space achieves these goals, with colour as a tool to help find answers to purpose and reason, to joy and fluent social communication, the city becomes unmistakable and memorable by strengthening its identity as well as its patrimony.

The chromatic intervention

Within this conceptual framework, a chromatic intervention took place in the city of Córdoba, Argentine Republic. The municipality of this city asked the Institute of Colour of the Faculty of Architecture, Town Planning and Design of the National University of Córdoba for counselling and technical assistance in the Programme of Revaluation of Façades in the centre of the city, an area that was declared part of the Urban Patrimony in 1997. The Institute proposed a Design of Colour for Urban Exteriors, a project carried out by the Director of the Institute, author of this paper, and a team of six research architects. The bases of this work were the concepts mentioned before and the project was carried out with the permission of neighbours in more than 150 private properties, which meant 1,800 metres of façades. These façades were photographed as a whole and individually and were surveyed.
by computer; therefore, it was possible to study each of them in detail to decide, together with the owners, on colours and design.

The professional team set down the general criteria as regards the chromatic intervention and, together with the neighbours, agreed on the chromatic palette for their property. The Municipality undertook the cost of this enterprise: restoration of plaster, mouldings and ornaments and the painting of façades, joinery, fences and balconies.

By using a polychromatic system of harmonious colours in contrast it was possible to obtain an environmental colour that improved some buildings from the late last century, some testimony of religious architecture and some minor expressions of the modern age. These were incorporated to the urban context, not only by structuring their own territory with colour, but with colour highlighting some architectural elements which had certain patrimonial value but without history; they were a modest patrimony which lacked that institutional artistic prestige that is found in great monuments. The colour revived and revalued these buildings giving sense to the present time and at the same time, not only did it change the urban image or landscape but it also structured an urban place. There were changes in shops, new functions and alterations in behaviour patterns and social actions; these changes were later analysed according to a method of environmental evaluation which was developed in the Institute of Colour.

If we consider the crisis of the public space at the end of the century, which involves, at a global level, the destruction of singularity and the roots of territory, the lack of identity and sense of place, we may say that this chromatic intervention has proved effective in facing the problem. It is a joint enterprise, involving official organisms as well as citizens, where colour, as a tool of design, is capable of conveying not only a contemporary aesthetic but also the search for alternative ways; new paths to dignify identity and reinforce the idea that architecture has to be related to the environment with ideas different from universal homogeneity.

BIBLIOGRAPHY


2. AVILA, Marfa Mercedes y Marta POLO. Color Urbano, Indagaciones en ámbitos de la Ciudad de Córdoba. Iera Edición Eudecor. 53-56 Córdoba 1996.


THE NCS AS REFERENCE FOR COLOUR FILTERS IN STAGE LIGHTING

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1. INTRODUCTION

In the theatre visual aspects design (scenography, lighting, costume) the different designers generally are not accustomed to using colour order systems, and then, a problem exists because the communication between them is very difficult when they want to specify a colour.

As it is known, colour filters for stage lighting have a commercial identification number given arbitrarily from the different trademarks. Then, in most cases the communication between, for instance, a scenery designer and a stage lighting designer is very difficult. In addition, for the stage lighting designers themselves it is practically impossible to remember all commercial identification numbers of all trademarks.

2. DESCRIPTION OF THE NCS

The Natural Colour System is a simple model to describe colour and scientific knowledge is not required to use it. For this reason, the NCS is useful to be used from theatre designers. As it is remembered, the NCS is based on four primary psychophysical colours: Yellow (Y), Red (R), Blue (B), Green (G), disposed in the ends of two perpendicular axis over the chromatic circle. The Black-White axis (W-S) passes perpendicularly by the centre of the chromatic circle. In this way, the NCS solid is obtained.

3. DESCRIPTION OF THE DEVICE

Here, a simple method to do direct visual comparisons, that is to say, subjective comparisons, between stage lighting colour filters and NCS samples is shown. A same
source of light is used to light a white area with a colour filter and a NCS sample with white light, all this into a black space. The white area and the NCS sample are both put into the visual field of the observer in order to see them at the same time and to carry out the comparison. The light source used is a 3000° Kelvin lamp because generally this is the colour temperature employed in theatre.

4. RESULTS OF THE COMPARISONS

For this comparative study, NCS Second Edition Index and LEE Colour Filters (UK) was used.

The study will be completed in the future with the comparisons between NCS samples and other trade mark filters of common use in stage lighting, i.e., Rosco and GamColor (USA).

This comparative study has already started. For this reason, only initial observations are shown in the following frame:

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5. CONCLUSION

Even if this method has not scientific precision, however, its results will be useful for theatre design purposes. The author thinks that it is very important for theatre designers to begin to use colour order systems to do more easy the communication of colour ideas between them.
INSTRUMENTAL METHOD FOR ASSESSING COLOUR TONE

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I. Introduction

Colour tone systems such as Practical Color Co-ordinate System (PCCS) and ISCC-NBS Centroid Color Chart are useful to simply communicate the tone of a colour [1,2]. The iso-hue planes of the colour tone systems are divided by colour tone words such as vivid, deep and pale. But the colour tone systems do not numerically correspond to Munsell and CIELAB colour order systems, and each tone of the colour tone systems is not directly calculated from colorimetric values measured using a spectrophotometer. For example, vivid yellow, vivid red and vivid blue do not have the same lightness and chroma on the Munsell and CIELAB systems, but these colours are described as the same colour tone. Even if colour tones in the colour tone systems are the same, the coordinates of the colour tones on an iso-hue diagram such as Munsell V-C and CIELAB L* C* diagrams are different. This means the attributes of the colour tone systems are different values from lightness and chroma.

If colour tones are numerically expressed, it will be more useful to communicate them and more helpful for colour planning. Therefore, the colorimetric properties of colour emotional words were investigated [3-8], and a colour tone system calculated from Munsell values through colour measurement has already been developed [9-11]. In this paper, we would like to introduce the instrumental colour tone system. And we tried to convert it into a colour tone system based on CIELAB.
2. Necessity of colour tone assessments

The colour communication, which includes not only the communication of colours, but also colour reproduction and management, is very important for various industries. The colour tone system is the easiest tool to use for the colour communication.

On the other hand, human colour feelings are expressed through colour emotional words such as light, warm and reddish. We are communicating the colour feelings and assessments with the words. The colour tone system is also useful for expressing human colour feelings.

We have already had two useful systems for colour description. Those are Practical Color Co-ordinate System (PCCS) and ISCC-NBS Centroid Color Chart. The former was developed in Japan for colour description through colour emotional words such as vivid and deep. The later is a combination system with the colour emotional words and common colour names such as green, brown and pink.

But the two systems are not so useful for quantitative analysis and numerical expression of colour tones. In order to manage colours more quantitatively, we need to develop an instrumental colour tone system based on colorimetry.

![Figure 1: A colour tone system calculated from Munsell system](image)

3. An instrumental colour tone system calculated from Munsell values

The location of a colour tone area on Munsell and/or CIELAB spaces is changeable by hue and chroma, especially, the locations of high chroma tones such as vivid tone. The vivid tone
colour on yellow hue plane is located at high lightness area, but that on blue hue plane is located at low lightness area.

The locations of the same tone colours should be essentially fixed, even if the hues of the tone colours are different. Therefore, a colour tone system calculated from Munsell values has already been developed. In the colour tone system, colour tones are instrumentally assessed through colorimetric values measured using a spectrophotometer. Figure 1 shows that the iso-hue plane of the colour tone system is divided by colour depth and brightness values suggested as dyer’s colour values [9-12].

4. An instrumental colour tone system calculated from CIELAB values

To develop more applicable colour tone system, we need to develop another instrumental colour tone system. We thought that the colour tone system calculated from CIELAB values is the best. Because the system has the following advantages;

- Use under various viewing conditions
- Easy conversion between colour systems
- Application to Multimedia

In this study, we converted the above instrumental colour tone system calculated from Munsell values into another colour tone system calculated from CIELAB values. Figure 2 shows the iso-hue plane of the colour tone system converted. The plane is divided by colour depth and brightness values calculated from CIELAB values [13-18]. The colour depth and modified metric chroma values are calculated as follows:

\[
D = (100 - L^*) + (0.1 + \Delta h_{290} / 360) (1 - \Delta h_{290} / 360) C^* \\
B = 50 C^* / D \\
C^{**} = (1 - \Delta h_{290} / 360) C^*
\]

where, \( L^* \) : CIELAB metric lightness
\( C^* \) : CIELAB metric chroma
\( \Delta h_{290} \) : CIELAB metric hue-angle difference from h=290°
Figure 2 A colour tone system calculated from CIELAB values

Figure 3 Instrumental methods for assessing colour tones

Figure 3 shows the outline of the instrumental methods for assessing colour tones. In the case of the conversion through CIELAB system, as a colour tone area is fixed by the colour...
depth and brightness values, the computer programme of a conversion between CIELAB values and a colour tone name can easily be made through the above formulae. As a result, a colour tone can be automatically computed by a modern colour measurement system including a computer.

5. Summary

We suggested two colour tone systems calculated from Munsell and CIELAB values. With the systems, colour tones can be assessed instrumentally. The instrumental methods for assessing colour tones will be more useful to communicate the property of a colour and more helpful for colour planning. The instrumental method and the two colour tone systems will be able to bridge between colour physics and colour design fields.

But, the colour tone system calculated from CIELAB values has not been applied to the practical colour tone assessment yet. We would like to investigate whether the system is available for assessing colour tones.

References

1. K.L.Kelly, ISCC-NBS Centroid Color Chart (1958)


DIGITAL COLOR PALETTE OF NBS/ISCC COLOR SYSTEM
FOR COLOR EDUCATION ON INTERNET WWW

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1. Introduction

NBS/ISCC color system is the universal language of color. The color space is sliced into 28 hues. Within each hue, degrees of saturation and brightness are designated by modifiers such as vivid, strong, pale, and so forth. The reference colors of the standardized language, so-called centroid colors are specified as the Munsell renotation\(^{(1)}\). The color charts illustrated with 267 centroid colors are suitable for a variety of scientific and industrial uses. That is a good practical number, small enough to be easily learned but large enough to make the distinctions needed for many applications.

However color charts are inconvenient in handling and faded away some times after. On the other hand, digital colors generated by computer can be spread easily over the world via the Internet WWW. The proportions of red, green, and blue display primaries required to produce it can define a digital color. However, accurate color reproduction on different displays is not simple because different displays have different display primaries. In this study, device-independent color reproduction technique\(^{(2-3)}\) has been applied to generate digital color palettes of NBS/ISCC. The proportions of red, green, and blue primaries needed to produce colors on a display have been predicted from the measured colorimetric characteristics of each display. As a result, digital color palettes of NBS/ISCC for three different brand's CRT monitors could be developed.
2. Device-independent color reproduction technique

Object color is reflected color, where one sees the light reflected from an object under a given illuminant. This is specified by device-independent color space such as CIE x,y,Y or Munsell renotation, and so on. While, computer generated color is light source color, where one looks the light emitted from the monitor screen. This is a specified device-dependent color coordinate, \(d_r, d_g, d_b\).

If the same digital input values are applied to different display, one can see that displayed colors are different. The reason for this is that different display has different characteristics such as chromaticity coordinates and luminance functions of three primaries. Therefore digital input values to reproduce the same color on different display should be obtained considering their colorimetric characteristics as the following diagram\(^{(3)}\).

![Figure 1. Block diagram of device-independent color reproduction technique](image)

**Measurements and results**

All measurements are carried out in a dark room. Non-contact measurements were performed using a spectroradiometer CS-1000 from Minolta. The specifications of CRT monitors to test are shown in table 1. Contrast and brightness levels are adjusted differently so that three monitors have different luminance of background and white.
Red, green, and blue primary colors are displayed over the entire screen. For each phosphor, 17 levels of digital signal with the interval of 16 digits have been applied in order and the chromaticity coordinates and luminances of the light emitted from the screen has been measured.

Figure 2 shows the chromaticity coordinates of primaries for three monitors. The coordinates of each primary produced at maximum input values are similar in three monitors except for black or background. Due to the affect of background, the primaries are shaded with different color as the digital input values decreased. Monitor A shows greenish, monitor B shows cyanic, and monitor C shows purplish<sup>46</sup>.

Figure 3 shows the luminance curves fitted 17 points of primaries for three monitors. Background luminance is the lowest in monitor A, the highest in monitor B. For all three monitors, luminance curves monotonic increased with different inclination. Figure 4 shows the comparison of each primary’s inclination. For green primary, the inclinations of three monitors are almost the same, but for red and blue, the inclination of monitor A is lower than the others. This results in the difference of digital input values in three monitors for accurate color matching.

Digital palette of NBS/ISCC centroid colors is developed using device-independent color reproduction technique shown in Figure 1. Figure 5 shows the form designed by Visual Basic 5.0. Before starting the program, one selects the brand of monitor. Just click the name of hue one can see the centroid colors calibrated for selected monitor as like in Figure 6.

### Table 1. Specification of test monitors

<table>
<thead>
<tr>
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<th>B monitor</th>
<th>C monitor</th>
</tr>
</thead>
<tbody>
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<td>SAMSUNG Syncmaster 700p</td>
<td>SONY Multiscan 200sf</td>
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<td>17”</td>
<td>17”</td>
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<tr>
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</tr>
<tr>
<td>Color Temperature</td>
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<td>9300K</td>
</tr>
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</table>
Figure 2. The chromaticity coordinates of 17 points for three primaries in three monitors
(a) A monitor, (b) B monitor, (c) C monitor

Figure 3. The luminance curves fitted 17 points of primaries for three monitors
(a) A monitor, (b) B monitor, (c) C monitor

Figure 4. The comparison of each primary's inclination
(a) Red, (b) Green, (c) Blue
Conclusion

To be able to educate the NBS/ISCC color system via Internet WWW, device-independent color reproduction technique has been applied. The proportions of red, green, and blue primaries needed to produce centroid colors on a monitor have been predicted by calibrating the colorimetric characteristics of that monitor. As a result, digital color palettes of NBS/ISCC for three different brand's CRT monitors could be developed. Further research
will be performed to build up the characteristic profiles of other kind of display. This digital color palette would be very useful in various applications such as descriptions of colored object, analysis of color trend, and planning of color design, and so forth.

References

1. The NBS/ISCC Color System,


ABSTRACT

Spectrophotometric and colorimetric characteristics of reflection standards made of polytetrafluoroethylene powder and opal glass are presented. Sintered PTFE and opal glass reflection standards can be used as transfer standards or reference standards to calibration of spectrophotometers and tristimulus colorimeters.

In optical radiation metrology the reflectance and colour standards are used to calibrate and evaluate the performances of spectrophotometers and colorimeters and to transfer the reflection scale. The materials for reflectance standards must meet certain determined requirements. They should be spectrally nonselective, diffuse reflecting, nonfluorescent, opaque and stable with respect to time, radiation and environment influences. The most important requirements for reflection standards are discussed in Erb's paper. The detailed review of different materials used for reflectance standards contains CIE publication. One of these materials was polytetrafluoroethylene (PTFE), which is used now for preparation pressed or sintered reflection and colour standards.

The second important material for reflectance standards is certified opal glass CRM 406 of the Community Bureau of Reference. Physical properties of PTFE and opal glass standards are described and their spectrophotometric characteristics are given.

Polytetrafluoroethylene is white fluoropolimere resin with generalized chemical formula \([\text{CF}_2-\text{CF}_2]_n\). In spectrophotometric applications is used PTFE powder with the particle sizes...
less as 50 μm. The PTFE powder is manufactured by various firms with different trade names as Halon, Teflon, Algoflon, Spectralon and Optolon. In Optical Radiation Laboratory at the Central Office of Measures after research PTFE powder, which trade names are Algoflon F2 and Algoflon F6 were chosen finally.

The PTFE is non-inflammable, non-toxic, chemical inert, hydrophobic material with low thermal conductivity. Some physical properties of the PTFE are presented in papers4,5.

The PTFE powder may be used to preparation of pressed or sintered standards with very good reflection properties in wide spectral range. Reflection standards made of PTFE reflect optical radiation mainly in diffuse, near lambertian way. Systematical investigations of effective properties of pressed PTFE powder samples were realized in National Institute of Standards and Technology (NIST), however the pressed PTFE standards are not-resistant mechanically. Method of thermohardening of the PTFE powder samples was realized in NIST6 and presently is applied in Laboratory of Optical Radiation. PTFE powder dose is pressed to density about 1 g/cm³ and sintered in programmable electrical furnace according with special temperature procedure. Ready-to-use standards are plate-shaped with diameters of 45 mm or 60 mm and are mounted in metallic holder. PTFE powder can be easily mixed with carbon black, inorganic pigments and rare earth oxides. In this way we obtained not only white reflection standards but also grey and colour standards7. In Fig.1 is shown spectral reflectance of white standards made of PTFE powder manufactured by Montefluous-Ausimont Group (Algoflon 2) and Labsphere (Spectralon).

Since 1990 Institute for Reference Materials and Measurements of the European Commission has offered for sale the reflection standards made of certified opal glasses CRM 406. Opal glass reflection standards have form of cylinder with diameter 50 mm or 100 mm. The usefulness of opal glasses CRM 406 as reflection standards is confirmed by Erb7,8. Optical Radiation Laboratory in Warsaw also intend to use opal glass reflection standards as secondary diffuse reflection standards and as transfer standards. Six opal glass white reflectance standards were measured with Cary SE spectrophotometer. Spectral reflectance of one white opal standard in the 8/d measurement geometry is shown also in Fig.1. The results of measurements of spectral reflectance standards show that, over the wavelength range 380 nm to 780 nm, these standards have good spectral characteristics and they can be used as transfer standards or reference standards to calibration of spectrophotometers and tristimulus colorimeters.
Fig. 1 Spectral reflectance of white reflection standards in 8/d measurement geometry:

1 - PTFE (Spectralon)
2 - PTFE (Algodon F2)
3 - Opal glass CRM 406

References

2. A review of publications on properties and reflection values of material reflection standards, Publ. CIE No. 46, (1979)


8. J.C. Zwinkels, W. Erb, Comparison of absolute d(0) diffuse reflectance factor scales of the NRC and the PTB, Metrologia 34, 357-363 (1997)
EFFECT OF COLOR AND PATTERN ON SHORT-TERM MEMORY
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Introduction
The percentage of people over the age of sixty-five is expected to increase in the near future. Therefore, research should be focused on areas that enable elderly people to live self-sufficiently. As the nerve cells, especially in the frontal lobe and temporal lobe, tend to be destroyed by ageing, the human brain gradually decreases its activity and its ability to retain information¹. It is hypothesized that such undesirable phenomena would affect the short-term memory particularly². The purpose of this article is to investigate the affect of image information on the brain. Hopefully, this will enable elderly people to retain information more readily.

The effects of color and pattern on the short-term memory will be discussed. The first and the second of two stepwise task experiments of memorization-retention-recognition of the visual stimuli were studied and comparisons were made between young and elderly subjects.

The methods in the first experiment
6 colors and 6 patterns with an average size of 20 cm², thus 36 different possible combinations, were prepared. The colors were: vivid Red, vivid Yellow, vivid Green, vivid Blue, White and Black. The patterns were: Circle, Triangle, Square, Rhombus, Pentagon and Octagon.
Fig.1 and Fig.2 show the time schedule of the short-term memory task experiment and an example of stimulus used in the first experiment. The examiner placed a gray board on which 6 cards of 6 different patterns and colors were placed randomly in front of the subject for 20 seconds. The subject was then requested to memorize the colors and patterns the first task repeat 7 tasks of the 6 cards. Then the board and cards were removed for 60 seconds. Next, the examiner replaced two gray boards in front of the subject. One board had 36 cards and the other board was blank. The subject was then asked to extract the 6 cards from the board that contained 36 cards, and place them on the blank board.

Fig.1 Time schedule of the short-term memory

Fig.2 An example of stimulus used in the first experiment

The time for recognizing and picking out the 6 cards were recorded by stopwatch and video camera. The video camera was used to identify the order in which the subjects chose the cards and the stopwatch used to check the how long the subject took to complete the recognition. The subjects had a 120 seconds break between each task. Eight task examinations of visual stimuli using different combinations of 6 cards were given to each subject. After having completed the eight tasks, the subjects were asked by a questionnaire how they memorized and retained the 6 cards.

25 young subjects, 13 males and 12 females 21.9 years old on average, 25 healthy elderly subjects, 7 males and 18 females 61.6 years old on average, and a 60 year-old male subject (Y W) with a cerebral embolism in his right frontal lobe and temporal lobe were examined.
Results in the first experiment

Fig. 3 shows the results of the questionnaire that asked the subjects how they memorized and retained the stimuli. Most of the elderly subjects (92%) did not use any rules to help them memorize and retain the stimuli. It appeared that almost all of the elderly subjects memorized the stimuli as the visual images they saw. In the other group, the young subjects memorized the stimuli after making rules on color and/or pattern. For example, some used the capital letter of the color names or the number of corners in the pattern to help them remember.

Fig. 3 Difference in memory procedure between the young and elderly subjects

Fig. 4 shows the percentage of the correct answers. The correct answer (%) were calculated as a ratio of correct answers, both color and pattern, to the total 48 cards used in the eight tasks. Significant difference in correct answers (%) between the elderly subjects and the young subjects was discovered. The percentage of correct answer given by subject Y.W. was very close to the average scores of the healthy elderly subjects.

Fig. 4 Correct answer (%) in the first experiment

The effect of color on the correct answer (%), for the young subjects and the healthy elderly subjects, respectively are shown in Fig. 5. Although the correct answers (%) for all colors by the young subjects were much higher than among the elderly subjects, Red, and Black and Blue were memorized and recognized most easily by young subjects. Due to the low
percentage of correct answer he effect of color on color memorization and recognition among the healthy elderly subjects is not clear.

![Fig. 5 Effect of color on the short-term memory](image)

The effects of pattern on the correct answers (%) for short-term memory are presented in Fig.6. Scores for the pattern were relatively lower than the color scores. We would expect that the circle and triangle patterns would be memorized more easily than the other patterns by both generations of subjects. Significant differences between the color scores and the pattern scores were not found in the healthy elderly subjects, because, those scores were considerably low. However, circle and triangle patterns were memorized slightly more easily than the other patterns among the young subjects.

![Fig. 6 Effect of pattern on the short-term memory](image)

Fig.7 and Fig.8 respectively show the effects of the combination of color and pattern on the short-term memory with the young subject and healthy elderly subject groups. The arrows show the 95% significance level for each combination of color and pattern. From these results, it is clear that the reciprocal effects between colors and patterns should be discussed in the planning of information systems using images and signs for easy memorization, particularly by the aged.

The results of the recognition order of the six cards, recorded on video, are summarized in Table 1. Particularly in the first half, the recognition order of the six cards were nearly equal the same for color and pattern between the two subject groups.
Fig. 7 Effect of the combination of color and pattern by the young subjects.

Fig. 8 Effect of the combination of color and pattern by the elderly subjects.

Table 1 Recognition order of the six cards

<table>
<thead>
<tr>
<th></th>
<th>the first half</th>
<th>the second half</th>
</tr>
</thead>
<tbody>
<tr>
<td>color</td>
<td>pattern</td>
<td>color</td>
</tr>
<tr>
<td>young subjects</td>
<td>W·Bk·R</td>
<td>O·△·□</td>
</tr>
<tr>
<td>healthy elderly subjects</td>
<td>W·Bk·R</td>
<td>O·△·◊</td>
</tr>
</tbody>
</table>
The methods in the second experiment

The second experiment was conducted to investigate how support systems would be important for the short-term memory, particularly in the memorization process of the aged brain. The elderly subjects and the young subjects were exposed to different kinds of stimuli in the second experiment. For the elderly subjects, the same 36 cards tested in the first experiment were used with different gray boards marked in six rectangular divisions (Fig. 9-a). Two types of each of the eight stimuli named "pattern type stimuli" and "color type stimuli" were respectively examined in the eight task experiments. "Pattern type stimuli" is the eight kinds of stimuli of same patterns with different colors in corresponding division. "Color type stimuli" kept the colors constant but changed the pattern for each division.

For the young subjects, eight stimuli designed to be more difficult to memorize were used. 36 cards with combinations of six neutral tint colors on the indefinite patterns. Fig. 9-b shows the examples of stimuli used in the second experiments for the elderly subjects and the young subjects.

Results in the second experiment

With the introduction of the support system, the ratio of the subjects finding rules for memorization was increased in the elderly subjects. "Color type stimuli" was easier to memorize than "pattern type stimuli" and the score of the correct answer (%) of "color type stimuli" was also higher than the score of "pattern type stimuli". The correct answers (%) were about 20–30% higher in the second experiment than in the first experiment (Fig. 10).
The scores of the young subjects of making rule and the correct answers (%) were lower than in the first experiment. However in the second experiment, the correct answers (%) of them were still higher than the correct answers (%) in the second experiment by the elderly subjects (Fig.11). The young subjects are superior in decoding the information from visual stimuli and retaining and recognizing in the short-term memory. It also deduced from these results that the support system for memorization is important, especially for the aged. The image stimulus memorized by making rules would be impressed on the brain and resulted in good retention and good recognition.

Conclusion

From this comparison study between the elderly subjects and the young subjects, it was concluded that the visual information, especially for the aged, should be presented with support systems for easy memorization.
References


2. B. Milner, Disorders of learning and memory after temporal lobe lesions in man, Clinical Neurosurgery, 19, 421, 1972
AN EXAMPLE OF THE INFLUENCE OF THE POSITION OF THE TARGET COLOUR ON THE SENSITIVITY OF THE RECIPE COLOUR TO CONCENTRATION ERRORS

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The CMC(/:c) version of the theoretical model of the sensitivity of the recipe colour to concentration errors is briefly reviewed. The data of a few basic dyes applied to a PAN textile fabric is used to predict the sensitivities of various recipes for the sets of target colours spaced regularly in various L*C*-planes in colour space.

Then the results of a few numerical experiments are presented which illustrate the general dependence of the predicted sensitivity upon the position of the target colour in the colour space and, additionally, the differences in the predicted sensitivities of various recipes for a single target colour.

1. Review of the concept of sensitivity and numerical estimates

Let us consider the case of CMC(/:c) colour difference and the recipe  \( c = (c_1, c_2, c_3) \) consisting of the effective concentrations of three colorants.

The sensitivity (or CMC-sensitivity) of the recipe colour is defined according to the colour change \( (\Delta L*, \Delta S_2, \Delta C*, \Delta S_1, \Delta H*, \Delta S_m) \) produced by small change \( \Delta c = (\Delta c_1, \Delta c_2, \Delta c_3) \) of colorant concentrations in the recipe \( c = (c_1, c_2, c_3) \).

The directional sensitivity \( s_{\Delta c} \) of the recipe \( c \) in the direction of a nonzero vector \( \Delta c = (\Delta c_1, \Delta c_2, \Delta c_3) \) (in concentration space) is then defined by an appropriate limiting value \([3]\). Roughly, it represents the rate \( \Delta E/||\Delta c|| \) of increasing colour difference \( \Delta E \) in the direction of the small concentration change \( \Delta c \). In different directions \( \Delta c \) different rates \( \Delta E/||\Delta c|| \) occur.
Special cases of directional sensitivities in the directions \((\Delta c_1,0,0)\), \((0,\Delta c_2,0)\) and \((0,0,\Delta c_3)\) (when the concentration of only one colorant in the recipe is being changed) are the sensitivities of the recipe \(c = (c_1,c_2,c_3)\) to particular colorants:

\[
\begin{align*}
\hat{s}_1 &= 3(\Delta c_1,0,0) \\
\hat{s}_2 &= 3(0,\Delta c_2,0) \\
\hat{s}_3 &= 3(0,0,\Delta c_3)
\end{align*}
\]  

The overall sensitivity \(s_{\text{CMC}}\) of the recipe \(c = (c_1,c_2,c_3)\) is defined as the biggest directional sensitivity across all possible (nonzero) directions \(\Delta c = (\Delta c_1,\Delta c_2,\Delta c_3)\) of a move from the recipe position \(c = (c_1,c_2,c_3)\) in concentration space. Roughly, it represents the biggest possible rate \(\Delta E/\|\Delta c\|\) across all possible directions of the small concentration changes \(\Delta c\). The smallest directional sensitivity across all possible (nonzero) directions \(\Delta c = (\Delta c_1,\Delta c_2,\Delta c_3)\) of a move from the recipe position \(c = (c_1,c_2,c_3)\) in concentration space is called the overall correctability of a recipe. Roughly it represents the smallest possible rate \(\Delta E/\|\Delta c\|\) across all possible directions of the small concentration changes \(\Delta c\).

Remark. When using the appropriate recommended values for parameters \(l\), \(c\), \(S_l\), \(S_c\), \(S_h\), the above definitions of colour sensitivity and correctability apply also in the case of CIE 94 colour differences.

The numerical estimates of the colour sensitivity of a recipe have been developed also for the cases of CMC\((l,c)\) and CIE 94 colour differences [2]. They can be computed from the special matrix \(J_{\text{CMC}}B\) appearing in match prediction calculations. So the estimate for the sensitivity of a recipe to a particular colorant is the length of the corresponding column in the matrix \(J_{\text{CMC}}B\), and the estimate for the overall sensitivity of a recipe is the maximal singular value of the matrix \(J_{\text{CMC}}B\). As the computation of the singular values of a matrix is a complex procedure the following (computationally simpler) upper bound for the overall sensitivity

\[
\left( s_1^2 + s_2^2 + s_3^2 \right)^{1/2}
\]  

is sometimes used instead of the exact value \(s_{\text{CMC}}\). The lower bound for the overall correctability can also be developed and calculated.
3. Numerical experiments

The upper bounds (2) for the overall sensitivity $s_{\text{Tot}}$ of various recipes were predicted for each one from a larger set of target colours in order to investigate the dependence of the recipe colour sensitivity upon the position of the target in colour space.

The optical data of 8 basic dyes (2 yellows, 2 reds, 1 brown-red, 2 blues and 1 black) applied to textile fabric made of PAN fibres was used for match prediction. The target colours were chosen from the EUROCOLOR colour atlas, from 8 different $L^*C^*$-planes with hues 0, 125, 250, 350, 500, 650, 800 and 900 (per thousand), respectively. Targets have been spaced regularly by 10 units in $L^*$ and $C^*$ values (as depicted in the following scheme).

For each target colour sensitivities to particular colorants, the upper bound (2) and lower bound for overall sensitivity of all possible three-colorant recipes were calculated. The triplets consisting of sensitivity upper bound, sensitivity lower bound and the ratio (low bound)/(upp. bound) for the recipes (containing the same combination of a yellow, a red and a blue colorant) for targets from the green $L^*C^*$-plane of hue $h=350$ are presented in Table I.
Table I. Triplets consisting of predicted CMC-versions of upper bound (1), lower bound (of overall sensitivity) and lower bound of balance of recipes (containing the same combination of a yellow, a red and a blue colorant) for each of the green targets indicated in $L^*C^*$-plane $h=350$ (EUROCOLOR 350.xx.xx).

<table>
<thead>
<tr>
<th>$L^*$</th>
<th>CMC-value</th>
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Targets:

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</thead>
</table>

In the Tables I and II presented (for $L^*C^*$-planes of hues 350 and 650, respectively) we see that the lightest-shade recipes are the most sensitive ones (they generally have the biggest predicted (upper bound of sensitivity) and that the recipe sensitivity rapidly decreases when the target gets darker. Furthermore, the predicted (upper bound of the) overall sensitivity is almost halved when we make a 10-unit decrease along each line parallel to the $L^*$-axis. The same trend was observed also for target colours in $L^*C^*$-planes for the 6 other hues considered. As higher lightness of a target in most cases (except e.g. for very saturated yellows) implies lower colorant concentration(s) in the recipe, the above observation is somewhat in the accordance with the results of Alman’s computer simulations [4] suggesting.
Table II. Triplets consisting of predicted CMC-versions of upper bound (1), lower bound (of overall sensitivity) and lower bound of balance of recipes (containing the same combination of a yellow, a red and a blue colorant) for each of the blue targets indicated in \(L^*C^*-\)plane for \(h=650\) (EUROCOLOR 650.xx.xx)

| \(L^*=80\) | 3404 | 4812 | ... upper bound of sensitivity |
| \(L^*=70\) | 190  | 198  | ... lower bound of sensitivity |
| \(L^*=60\) | 0.06 | 0.04 | ... lower bound of balance    |
| \(L^*=50\) | 1884 | 2426 | 2572                      |
| \(L^*=60\) | 110  | 105  | 89                       |
| \(L^*=60\) | 0.06 | 0.04 | 0.03                     |
| \(L^*=60\) | 994  | 1328 | 1432                    |
| \(L^*=60\) | 63   | 62   | 51                     |
| \(L^*=60\) | 0.06 | 0.05 | 0.04                  |
| \(L^*=50\) | 507  | 768  | 822 | 885 |
| \(L^*=50\) | 37   | 38   | 30 | 21 |
| \(L^*=50\) | 0.07 | 0.05 | 0.04 | 0.02 |
| \(L^*=40\) | 272  | 414  | 444 | 516 |
| \(L^*=40\) | 21   | 22   | 17 | 12 |
| \(L^*=40\) | 0.08 | 0.05 | 0.04 | 0.02 |
| \(L^*=30\) | 141  | 211  | 16 | 11 |
| \(L^*=30\) | 12   | 13   | 0.09 | 0.06 |
| \(L^*=30\) | \(C^*=0\) | \(C^*=10\) | \(C^*=20\) | \(C^*=30\) |

that weighing errors are very important at low concentration, whereas the strength errors are more important in middle range concentrations and that both are less important at high concentrations.

Contrary to the great variation of the predicted (upper bound of the) overall sensitivity with changing lightness \(L^*\), the (upper bound of) the overall sensitivity of recipes varies much less when the chroma \(C^*\) of the target is increased at the constant lightness level \(L^*\). When the target is moved radially from the grey axis the recipe colour sensitivity moderately decreases in most directions, it can be almost halved at the border of gamut (see Table I). This feature is in accordance with the observations that, generally, neutral shade recipes are more sensitive than others [5]. In our experiment but, in some of such radial directions (e.g. hue 650 of 1000)
Table III. Triplets consisting of predicted CMC-versions of upper bound (1), lower bound (of overall sensitivity) and lower bound of balance of recipes (containing the same combination of a yellow, a red and a blue colorant) for each of the target colours indicated in the plane of constant lightness $L^*=50$ (EUROCOLOR xxx.50.xx).

The recipe sensitivity can also moderately increase (see Table II). These last statements are illustrated also by Table III presenting the same data as Tables I and II but this time the targets are placed in the plane of constant lightness $L^*=50$. 
Remark. Interestingly, the CIELAB version of the recipe sensitivity (upper bound) is (in our particular case) moderately increasing in all 8 considered radial directions of increasing chroma \(C^*\) at the constant lightness level \(L^*\).

In addition, the upper bounds (2) for the sensitivity of the first 10 least metameric recipes per target were considered. These exhibited the same general trends as observed in the cases of recipes consisting of a single 3-colorant combination treated above. To illustrate this, the triplets consisted of the maximal (above), average (bold face in the middle) and minimal (beneath) of the mentioned 10 sensitivity upper bounds for targets in \(L^*C^*-\)plane with hue 350 are presented in Table IV.

Table IV. Predicted upper bounds (1) for CMC-version of overall sensitivities of the first 10 least metameric recipes for each of the green targets indicated in \(L^*C^*-\)plane \(h=350\) (EUROCOLOR 350.xx.xx). The asterisk following (some) numbers in the table means that the average upper bound has been obtained from less than 10 values (at least from 4).

| \(L^*=80\) | 4701 | 3115 | 2486 | 2148 | ... max. |
| \(L^*=70\) | 3862 | 2009 | 1447 | 1139* | \(\ldots\) aver. |
| \(L^*=60\) | 2590 | 1043 | 720  | 571  | \(\ldots\) min. |
| \(L^*=50\) | 2660 | 1737 | 1390 | 1249 | 1150 | 1140 |
| \(L^*=40\) | 2091 | 1181 | 916  | 706  | 584* | 564* |
| \(L^*=30\) | 1211 | 556  | 415  | 309  | 261  | 236  |
| \(L^*=20\) | 1436 | 915  | 762  | 698  | 693  | 704  | 754  |
| \(L^*=10\) | 1117 | 696  | 458  | 396  | 383  | 346* | 434* |
| \(L^*=0\)  | 645  | 396  | 226  | 171  | 149  | 140  | 182  |

| \(L^*=350\) | 747  | 570  | 438  | 405  | 404  |
| \(L^*=30\)  | 575  | 346  | 261  | 227  | 247* |
| \(L^*=20\)  | 330  | 178  | 128  | 93   | 83   |
| \(L^*=10\)  | 406  | 318  |      |      |      |
| \(L^*=0\)   | 311  | 232  | 179  | 127  |      |
| \(L^*=30\)  | 215  | 176  |      |      |      |
| \(L^*=20\)  | 163  | 102  |      |      |      |
| \(L^*=10\)  | 93   | 52   |      |      |      |

Targets: 350.xx.xx green

| \(C^*=0\) | \(C^*=10\) | \(C^*=20\) | \(C^*=30\) | \(C^*=40\) | \(C^*=50\) | \(C^*=60\) |
| \(--\) | \(--\) | \(--\) | \(--\) | \(--\) | \(--\) | \(--\) |
In Table IV it can be seen that for some targets the sensitivity bound of the most sensitive among 10 recipes treated is up to 5-times higher than the sensitivity bound of the least sensitive one. The question arises whether such a distinct difference in predicted sensitivity to concentration errors also results in a significant difference in the repeatability of the (two) recipes considered. In future research this crucial question should be investigated.

Conclusions

An inspection of the results of the presented particular coloration method shows that the sensitivity of the recipe colour to the concentration errors is the highest for the lightest target colours and it rapidly decreases (almost geometrically) when the lightness \( L^* \) of the target colour gets lower.

On the other hand, the variation of sensitivity is much smaller when we increase the chroma \( C^* \) of the target at the constant lightness level \( L^* \): when the target is moved radially away from the grey axis the recipe's colour sensitivity moderately decreases in most directions and it can be almost halve at the border of of the gamut. Exceptionally, in some such radial directions (e.g. hue 650 of 1000) the recipe's sensitivity can also moderately increase.

Acknowledgment

This research was supported by the Ministry of Science and Technology of the Republic of Slovenia.

References

1. B. Sluban, Quantifying the sensitivity/robustness of a predicted colour match, Die Farbe 39, 247-252 (1993)
AN EXAMPLE OF THE INFLUENCE OF THE POSITION OF THE TARGET COLOUR ON THE REPEATABILITY OF THE RECIPE COLOUR

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E-mail: boris.sluban@uni-mb.si

Abstract

This article describes an experiment involving the laboratory dyeing of PAN fabric using basic dyes. A few recipes were chosen for each one of a small number of target colours in the colour space. A number of repeat dyeings of these recipes were carried out. The repeatability of the recipe colour in the produced groups of samples was considered and mutually compared in regard to the position of the target in the colour space.

Introduction

In the paper [1] a theoretical model [2], [3] has been applied to predict the sensitivity of the recipe colour to concentration errors in the case of the dyeing of PAN fabric with a chosen set of basic dyes.

The analyses of sensitivity predictions (according to the CMC(2:1) colour difference formula) for a larger set of target colours showed the following two trends:

- the recipe’s (colour) sensitivity to concentration errors is the highest for the lightest target colours and it rapidly decreases (almost geometrically) when the lightness \( L^* \) of the target decreases
- much less variation is observed when the chroma \( C^* \) of the target is increased at constant lightness level \( L^* \) : when the target is moved radially from the grey axis the recipe colour sensitivity moderately decreases in most directions and it can be almost halved at the border of the gamut. Exceptionally in some of such radial directions (eg. hue 650 of 1000) the recipe sensitivity can also moderately increase.
The results of a few laboratory experiments in which the mentioned two trends have been checked are briefly presented and discussed.

Experiments

Three target colours Grey 60, Grey 70 and 350.70.30 were chosen from the EUROCOLOR colour atlas. Their positions in the colour space are located in the L*C*-plane for hue=350 (green) as indicated:

<table>
<thead>
<tr>
<th>L*=70</th>
<th>Grey 70</th>
<th>350.70.30</th>
</tr>
</thead>
<tbody>
<tr>
<td>L*=60</td>
<td>Grey 60</td>
<td>C*=0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C*=10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C*=20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C*=30</td>
</tr>
</tbody>
</table>

A few three-colorant combinations were chosen to predict recipes for the above three targets. Test dyeings were prepared and recipes corrected until the colour difference ΔE CMC(2:1) against the target became less than 1.

The following two colorant combinations.

Yellow, Red, Blue (in diagrams Y...R...B...) and

Yellow, Blue, Amber (in diagrams Y...B...J...) produced matches to all three above targets.

For our research we used a substrate made of PAN fibres. The commercial name for this type of substrate is Malon. To make sure the substrate, i.e. samples, were completely clean, we washed the material and rinsed it thoroughly. Maxilon dyes were mixed with water to form homogeneus paste.

For our experimental work graduated pipettes were used, each dye having the same pipette. The concentration of the bulk solution was adjusted by measuring the solute with a measuring cylinder. All weighings of dyes and auxiliary chemicals were carried out on an analytical balance with an accuracy of ± 0.0002 g. Cloth weights were always adjusted to the
value required to an accuracy of 0.05g. pH values were balanced using a pH meter, separately in each experimental tube. Dyeing apparatus Labomat AG (W. Mathis) was used. After the dye process was finished, the samples were rinsed thoroughly with warm and cold water. The ironing procedure for the PAN samples was then carried out using the dry heat treatment composite specimen in the heating device for 90 s at 100°C.

All reflectance measurements on the samples were carried out on a Texflash DC 3881 (Datacolor) spectrophotometer. Each sample was measured five times at different points.

In the experiment:

20 dyeing sessions were carried out, each time 6 recipes were dyed:

two recipes (combinations YRB and YBJ) for each of the 3 targets

The scattering of the colour positions of the samples in all six 20-member groups was calculated using the CMC(2:1) colour difference formula.

In Table I the data of the 3 recipes containing the colorant combination of YRB and data about the scattering of 3 groups of samples are presented. Table I is followed by the diagrams, which illustrate the scattering graphically. The same order of presentation is then used for the recipes and samples containing the colorant combination YBJ (Table II and subsequent diagrams).

Samples with colour positions exceeding the CMC(2:1)-distance of 2 standard deviations from the group average were treated as outliers and were excluded from further calculations. In the diagrams the outliers are circumscribed.
Table I: The data of 3 recipes (all consisted of the same colorant combination with basic dyes Maxilon [Ciba Geigy] ) matching the three targets colours from the EC Colour Atlas and the data of the observed scattering of the colour positions of the groups of samples according to these 3 recipes.

<table>
<thead>
<tr>
<th>Combination YRB</th>
<th>EC GREY 60</th>
<th>EC GREY 70</th>
<th>EC 350.70.30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration (%)</td>
<td>0.0781</td>
<td>0.0299</td>
<td>0.2156</td>
</tr>
<tr>
<td>Maxilon Yellow 5GL dye</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concentration (%)</td>
<td>0.0250</td>
<td>0.0112</td>
<td>0.0061</td>
</tr>
<tr>
<td>Maxilon Red GRL dye</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concentration (%)</td>
<td>0.0562</td>
<td>0.0265</td>
<td>0.0348</td>
</tr>
<tr>
<td>Maxilon Blue GRL dye</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_1$</td>
<td>342</td>
<td>673</td>
<td>63</td>
</tr>
<tr>
<td>$S_2$</td>
<td>845</td>
<td>1597</td>
<td>846</td>
</tr>
<tr>
<td>$S_3$</td>
<td>395</td>
<td>738</td>
<td>293</td>
</tr>
<tr>
<td>Sensitivity upper bound</td>
<td>994</td>
<td>1884</td>
<td>898</td>
</tr>
<tr>
<td>Sensitivity lower bound</td>
<td>63</td>
<td>110</td>
<td>31</td>
</tr>
<tr>
<td>standard deviation $L^*$ scaled</td>
<td>0.244</td>
<td>0.229</td>
<td>0.203</td>
</tr>
<tr>
<td>standard deviation $a^<em>$ or $C^</em>$ scaled</td>
<td>0.766</td>
<td>0.528</td>
<td>0.427</td>
</tr>
<tr>
<td>standard deviation $b^<em>$ or $dH^</em>$ scaled</td>
<td>0.534</td>
<td>1.134</td>
<td>0.317</td>
</tr>
<tr>
<td>RMS ΔE CMC</td>
<td>0.965</td>
<td>1.272</td>
<td>0.569</td>
</tr>
</tbody>
</table>

1. Y – Maxilon Yellow 5GL 300%
2. R – Maxilon Red GRL 180%
3. B – Maxilon Blue GRL 300%
An Example of the Influence of the Position of the Target Colour on...
Table II: The data of 3 recipes (all consisted of the same colorant combination with basic dyes Maxilon [Ciba Geigy]) matching the three targets colours from the EC Colour Atlas and the data of the observed scattering of the colour positions of the groups of samples according to these 3 recipes.

<table>
<thead>
<tr>
<th>Combination YBJ ²</th>
<th>EC GREY 60</th>
<th>EC GREY 70</th>
<th>EC 350.70.30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxilon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow 5GL dye</td>
<td>0.0256</td>
<td>0.0091</td>
<td>0.1878</td>
</tr>
<tr>
<td>Maxilon</td>
<td>0.0556</td>
<td>0.0264</td>
<td>0.0359</td>
</tr>
<tr>
<td>Blue GRL dye</td>
<td>0.0357</td>
<td>0.0158</td>
<td>0.0091</td>
</tr>
<tr>
<td>Red 2GL-N dye</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_1$</td>
<td>420</td>
<td>786</td>
<td>66</td>
</tr>
<tr>
<td>$S_2$</td>
<td>368</td>
<td>699</td>
<td>286</td>
</tr>
<tr>
<td>$S_3$</td>
<td>324</td>
<td>601</td>
<td>400</td>
</tr>
<tr>
<td>sensitivity upper bound</td>
<td>645</td>
<td>1211</td>
<td>496</td>
</tr>
<tr>
<td>sensitivity lower bound</td>
<td>69</td>
<td>119</td>
<td>36</td>
</tr>
<tr>
<td>Standard deviation L* scaled</td>
<td>0.273</td>
<td>0.318</td>
<td>0.269</td>
</tr>
<tr>
<td>Standard deviation a* or C* scaled</td>
<td>0.647</td>
<td>0.789</td>
<td>0.352</td>
</tr>
<tr>
<td>Standard deviation b* or dH* scaled</td>
<td>0.284</td>
<td>0.648</td>
<td>0.355</td>
</tr>
<tr>
<td>RMS $\Delta E$ CMC</td>
<td>0.758</td>
<td>1.070</td>
<td>0.568</td>
</tr>
</tbody>
</table>

2

Y – Maxilon Yellow 5GL 300%
B – Maxilon Blue GRL 300%
J – Maxilon Red 2GL-N 200%
Slaban B., Šauperliš O.: An Example of the Influence of the Position of the Target Colour on...
Discussion

For recipes containing a colorant combination of YRB:

The 10 unit increase in lightness $L^*$ from target Grey 60 to Grey 70 caused an increase in the predicted sensitivity upper bound of the recipe from (the value) 994 to 1884 (for about 90%)

The resulting standard deviation (CMC(2:1) metrics) of the corresponding group of samples increased to about 30% from 0.96 to 1.27 unit of CMC(2:1) colour difference

<table>
<thead>
<tr>
<th>YRB</th>
<th>Sensit. upp. Bound</th>
<th>Std. dev. ($\Delta E_{CMC}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey 70</td>
<td>1884</td>
<td>1.27</td>
</tr>
<tr>
<td>Grey 60</td>
<td>994</td>
<td>0.96</td>
</tr>
</tbody>
</table>

The 30 unit increase in chroma $C^*$ from target Grey 70 to green 350.70.30 caused a decrease in the predicted sensitivity upper bound of the recipe from (the value) 1884 to 898 by (for more than 50%)

The resulting standard deviation (CMC(2:1) metrics) of the corresponding group of samples decreased by about 55% from 1.27 to 0.57 unit of CMC(2:1) colour difference

<table>
<thead>
<tr>
<th>YRB</th>
<th>Grey 70</th>
<th>350.70.30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensit. upp. bound</td>
<td>1884</td>
<td>898</td>
</tr>
<tr>
<td>Std. Dev. ($\Delta E_{CMC}$)</td>
<td>1.27</td>
<td>0.57</td>
</tr>
</tbody>
</table>
For recipes containing colorant combination YBJ:

The 10 unit increase in lightness \( L^* \) from target Grey 60 to Grey 70 caused an increase in the predicted sensitivity upper bound of the recipe from (the value) 645 to 1211 (by about 90%).

The resulting standard deviation (CMC(2:1) metrics) of the corresponding group of samples increased by about 45%
from 0.75 to 1.07 unit of CMC(2:1) colour difference

<table>
<thead>
<tr>
<th>YBJ</th>
<th>Sensit. upp. bound</th>
<th>Std. dev. (( \Delta E_{\text{CMC}} ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey 70</td>
<td>1211</td>
<td>1.07</td>
</tr>
<tr>
<td>Grey 60</td>
<td>645</td>
<td>0.75</td>
</tr>
</tbody>
</table>

The 30 unit increase in chroma \( C^* \) from target Grey 70 to green 350.70.30 caused a decrease in the predicted sensitivity upper bound of the recipe from (the value) 1211 to 496 (for about 60%).

The resulting standard deviation (CMC(2:1) metrics) of the corresponding group of samples decreased by about 50%
from 1.07 to 0.57 unit of CMC(2:1) colour difference

<table>
<thead>
<tr>
<th>YBJ</th>
<th>Grey 70</th>
<th>350.70.30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensit. Upp. bound</td>
<td>1211</td>
<td>496</td>
</tr>
<tr>
<td>Std. Dev. (( \Delta E_{\text{CMC}} ))</td>
<td>1.07</td>
<td>0.57</td>
</tr>
</tbody>
</table>
Conclusion

In the small number of experiments presented the changes in the scattering of colour in various groups of samples follow the directions of changes in the predicted sensitivity values when the target colour is moved either along the grey axis (only the lightness \( L^* \) is changed) or along the particular chroma line (only the chroma \( C^* \) is changed). Both changes are (of course) not simply proportional. Further experiments need to be conducted in order to clarify the dependence of the repeatability of the recipe colour in regard to the position of the target colour.

Acknowledgement

This research was supported by the Ministry of Science and Technology of the Republic of Slovenia.

References:

1. An example of the influence of the position of the target colour on the sensitivity of the recipe colour to concentration errors, AIC Midterm Meeting ’99, Warsaw


COLOR SPACE MODEL OF THE TOOTH CROWN

T. Katayama, Y. Ichimura, Y. Otake
Meikai University School of Dentistry

Abstract

The purpose of this study was to compare a previously prepared color chart of Japanese coronal tooth structure with a theoretical color space model. In a foregoing study a color test chart comprised of color tabs representing coronal tooth color was prepared with reported ranges of Hue 8.75YR-2.5Y, Value 6.0-8.0, Chroma 1.0-4.0. The original color tabs (63) were examined by spectrophotometer (PR-650 Photo Research) and analyzed reflectance data of the measurements. The results were: ranges offL*= 61.2-83.0, a*=1.1-7.7, b*=5.0-29.0. Color difference (ΔL*ab) between the original color samples and theoretical color space value is smaller than the discrimination threshold (1.3-1.4). The original color samples described a color space that is well defined demonstrating good agreement between the theoretical and the visual perception of Japanese tooth color.

The full text has not been received by editor
ENVIRONMENTAL COLOR SCHEMES FOR TOWNSITE OF INCHON INTERNATIONAL AIRPORT

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Seoul National University, College of Art and Design, Korea

Abstract
Complying with the rapidly increasing air transportation in the Asian region, the Inchon International Airport, which has been under construction for several years, is expected to be a new operational base for cultural and economic activities in Korea. This project of national support, is scheduled to be completed by 2002. (...) The purpose of this research is to establish the environmental color identity for the townsite of the Inchon International Airport as a core for the region and a new gateway to Korea. It will provide effective guidelines for the practical color application as well as the sound basis for the site's pro-environmentality. Designing the image identity of the townsite in terms of aesthetics and communication has significance in determining a local identity. This area should realize certain cultural traits of Korea, since it is the first and last focal point of foreigners experiencing our national image.

As the main subject of investigation, the townsite of Inchon International Airport is constituted with several functional zones of private residence, apartment houses, city life facilities, commerce, etc. According to the function of each zone, dominant colors and accent colors were decided to reinforce their own characteristics and identification. The townsite has 8 districts and 14 subdivided zones. This study tried to realize the traditional value and conformity as well as the variety in unity.

First of all, many landscape factors were closely investigated in deciding the symbolic color for the airport. With the milieu factors, the color of 'Chungja (Celadon porcelain of Chosun dynasty of Korea)' was analyzed and adopted as the most appropriate one to represent the color sensibility of Korean people in general. With the main color as Chungja, 13 colors used in making conventional Danchang (Colorful patterns usually applied to the eaves and interiors of Korean traditional architecture) were adopted in developing the supplementary colors.

Since the townsite is under construction on a existing island near reclaimed ground, the diffused reflection from the surrounding sea was the most critical consideration. A thin color layer perceived in the atmosphere by the diffused reflection may engender visual pollution. Avoiding the ambient abhorrence, the contrast of brightness was emphasized instead of enhancing the contrast of chroma.

Due to the distinctive climatic differences of the 4 seasons, the light source in terms of seasonal factors affects the color and environmental perception profoundly. Especially the combination effect of the deflection and reflection of the surroundings makes the things worse. Considering the conspicuous seasonal factors and milieu factors as a shoreward airport, neutral colors were recommended generally, with variations of color for the townsite to create an environmental harmony.

The full text has not been received by editor
APPLICATION OF TRISTIMULUS COLORIMETRY IN ANALYSIS OF SOME TRANSITION METAL IONS AND THEIR MIXTURE.

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The influence of the concentration of the metal ions Ni²⁺, Co³⁺, Cr⁶⁺ solutions on the coordinates of CIE and CIELAB colorimetric systems was analyzed. The colour changes between samples of a mixture containing various quantities of the metal ions was calculated from ΔEₐ values.

Colour is an important property of a chemical substance; it makes possible identification of compounds in qualitative analysis, characterises dyes and pigments (used for different applications), and also enables studies of chromotropic phenomena as electrochromism, thermochromism, solvatochromism and piezochromism.

Theoretical problems connected with nature of colour have been studied very extensively, especially in the case of organic dyes [1,2]. In the case of inorganic compounds much less attention has been devoted to studies of colour as connected with electronic spectra of these compounds. The transition metal compounds are coloured in most cases, irrespective of their phase [3,4]. This is due to partly filled d-subshells in these metals, which lead to their chromophoric properties caused by d-d, and to various charge transfer transitions. Locations, intensity and shape of absorption bands in the electronic spectra determine the colour of these metals. The differences in the position of the bands as well as their intensity induce the colour changes.

A physical description of the character of the light reaching the eye combined with the measured additivity of colour mixtures provide the basis for the numerical parameters (chromaticity coordinates). From the chemical point of view the search for relationships between the chromatic parameters of a substance with the variation of its property is the one of greatest interest [5-9].

The purpose of the present paper is:
- an evaluation of the colour of the metal ions Ni²⁺, Co³⁺, Cr⁶⁺ aqueous solutions and their two component mixtures,
- study of the influence of the concentration of solutions on the coordinates of the CIE and CIELAB systems.

Colorimetric investigation have been carried out for the following compounds: cobalt(II) chloride \(\text{CoCl}_2\), nickel(II) chloride \(\text{NiCl}_2\), chromium(III) sulphate \(\text{Cr}_2(\text{SO}_4)_3\) in aqueous solutions. The colour calculation have been performed on the basis of electronic spectra in the range 380-780nm for light source D65 and path length of \(d=1\) cm.

The electronic spectra of investigated ions differ from each other in the position of the component bands, their intensity and shape. The spectrum parameters are dependent upon the electronic configuration of the central ion, crystal field strength, its symmetry, and the solvent nature. The absorption spectra of the investigated ions are shown in Fig.1.

![Absorption spectra](image)

**Fig.1. Absorption spectra of aqueous solutions: a) NiCl\(_2\), b) \text{Cr}_2(\text{SO}_4)_3, c) \text{CoCl}_2.**

The spectra are characterised by bands arising from the energy of \(d-d\) electronic transitions within the configuration \(d^1\) (Cr\(^{3+}\)), \(d^7\) (Co\(^{3+}\)) and \(d^8\) (Ni\(^{3+}\)) under \(O_h\) symmetry [10]. Cr\(_2(\text{H}_2\text{O})_6^{3+}\) aqua ions occurring in blue \(\text{Cr}_2(\text{SO}_4)_3\) solutions display the bands at 575 nm and 407 nm. The aqueous solutions of cobalt(II) chloride display pink colour. The asymmetric band is well seen near 500 nm in Co\(_2(\text{H}_2\text{O})_6^{3+}\) ions. Nickel(II) chloride occurs as a green coloured heksaaqua ion Ni\(_2(\text{H}_2\text{O})_6^{3+}\). The bands at 724 nm and 400 nm are observed in the
absorption spectrum.

The change in concentration of the above ions is due to the change of intensity of bands and causes the change of the chromaticity coefficient values.

Colorimetric analysis was performed using CIE 1931 (x,y,Y) and CIELAB 1976 (L*,a*,b*) systems. The chromaticity coordinates for the investigated solutions are summarised in Table 1-3.

Table 1. Variation of the coordinates of CIE and CIELAB systems with the concentration of cobalt (II) chloride.

<table>
<thead>
<tr>
<th>c, mol/dm³</th>
<th>x</th>
<th>y</th>
<th>Y</th>
<th>a*</th>
<th>b*</th>
<th>L*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>0.3401</td>
<td>0.3198</td>
<td>79.89</td>
<td>17.71</td>
<td>1.47</td>
<td>91.64</td>
</tr>
<tr>
<td>0.07</td>
<td>0.3512</td>
<td>0.3174</td>
<td>73.18</td>
<td>23.42</td>
<td>2.50</td>
<td>88.53</td>
</tr>
<tr>
<td>0.09</td>
<td>0.3620</td>
<td>0.3150</td>
<td>67.62</td>
<td>28.69</td>
<td>3.49</td>
<td>85.81</td>
</tr>
<tr>
<td>0.10</td>
<td>0.3677</td>
<td>0.3140</td>
<td>64.47</td>
<td>31.09</td>
<td>4.10</td>
<td>84.21</td>
</tr>
<tr>
<td>0.125</td>
<td>0.3805</td>
<td>0.3124</td>
<td>59.70</td>
<td>36.28</td>
<td>5.67</td>
<td>81.68</td>
</tr>
<tr>
<td>0.15</td>
<td>0.3925</td>
<td>0.3105</td>
<td>53.98</td>
<td>40.60</td>
<td>6.88</td>
<td>78.45</td>
</tr>
<tr>
<td>0.20</td>
<td>0.4146</td>
<td>0.3074</td>
<td>46.35</td>
<td>47.87</td>
<td>9.30</td>
<td>73.77</td>
</tr>
<tr>
<td>0.25</td>
<td>0.4352</td>
<td>0.3064</td>
<td>40.38</td>
<td>52.96</td>
<td>12.07</td>
<td>69.74</td>
</tr>
<tr>
<td>0.30</td>
<td>0.4534</td>
<td>0.3058</td>
<td>35.01</td>
<td>56.04</td>
<td>14.63</td>
<td>65.75</td>
</tr>
<tr>
<td>0.40</td>
<td>0.4837</td>
<td>0.3096</td>
<td>28.35</td>
<td>59.17</td>
<td>19.76</td>
<td>60.20</td>
</tr>
<tr>
<td>0.50</td>
<td>0.5071</td>
<td>0.3106</td>
<td>23.76</td>
<td>61.21</td>
<td>23.05</td>
<td>55.85</td>
</tr>
</tbody>
</table>

Table 2. Variation of the coordinates of CIE and CIELAB systems with the concentration of nickel(II) chloride.

<table>
<thead>
<tr>
<th>c, mol/dm³</th>
<th>x</th>
<th>y</th>
<th>Y</th>
<th>a*</th>
<th>b*</th>
<th>L*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>0.3073</td>
<td>0.3360</td>
<td>97.63</td>
<td>-6.35</td>
<td>1.68</td>
<td>99.07</td>
</tr>
<tr>
<td>0.07</td>
<td>0.3053</td>
<td>0.3389</td>
<td>97.79</td>
<td>-8.76</td>
<td>2.41</td>
<td>98.74</td>
</tr>
<tr>
<td>0.09</td>
<td>0.3034</td>
<td>0.3419</td>
<td>94.74</td>
<td>-11.11</td>
<td>3.17</td>
<td>97.93</td>
</tr>
<tr>
<td>0.10</td>
<td>0.3027</td>
<td>0.3432</td>
<td>92.69</td>
<td>-12.02</td>
<td>3.48</td>
<td>97.1</td>
</tr>
<tr>
<td>0.125</td>
<td>0.3001</td>
<td>0.3467</td>
<td>90.90</td>
<td>-14.86</td>
<td>4.25</td>
<td>96.37</td>
</tr>
<tr>
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<td>0.2980</td>
<td>0.3502</td>
<td>89.47</td>
<td>-17.44</td>
<td>5.11</td>
<td>95.77</td>
</tr>
<tr>
<td>0.20</td>
<td>0.2934</td>
<td>0.3563</td>
<td>87.60</td>
<td>-22.93</td>
<td>6.39</td>
<td>94.99</td>
</tr>
<tr>
<td>0.25</td>
<td>0.2890</td>
<td>0.3623</td>
<td>85.10</td>
<td>-26.87</td>
<td>7.64</td>
<td>93.93</td>
</tr>
<tr>
<td>0.30</td>
<td>0.2849</td>
<td>0.3684</td>
<td>82.44</td>
<td>-31.13</td>
<td>8.89</td>
<td>92.77</td>
</tr>
<tr>
<td>0.40</td>
<td>0.2769</td>
<td>0.3789</td>
<td>77.36</td>
<td>-38.48</td>
<td>10.76</td>
<td>90.49</td>
</tr>
<tr>
<td>0.50</td>
<td>0.2697</td>
<td>0.3891</td>
<td>73.60</td>
<td>-45.08</td>
<td>12.57</td>
<td>88.73</td>
</tr>
</tbody>
</table>
Table 3. Variation with the concentration of chromium (III) sulphate of the CIE and CIELAB coordinates.

<table>
<thead>
<tr>
<th>$c$, mol/dm$^3$</th>
<th>x</th>
<th>y</th>
<th>$Y$</th>
<th>$a^*$</th>
<th>$b^*$</th>
<th>$L^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>0.2968</td>
<td>0.3152</td>
<td>61.15</td>
<td>-1.33</td>
<td>-7.09</td>
<td>82.46</td>
</tr>
<tr>
<td>0.02</td>
<td>0.2810</td>
<td>0.2996</td>
<td>39.63</td>
<td>-1.63</td>
<td>-12.85</td>
<td>69.20</td>
</tr>
<tr>
<td>0.03</td>
<td>0.2661</td>
<td>0.2838</td>
<td>26.51</td>
<td>-1.46</td>
<td>-17.16</td>
<td>58.52</td>
</tr>
<tr>
<td>0.04</td>
<td>0.2537</td>
<td>0.2699</td>
<td>18.34</td>
<td>-1.08</td>
<td>-19.84</td>
<td>49.90</td>
</tr>
<tr>
<td>0.05</td>
<td>0.2427</td>
<td>0.2567</td>
<td>13.08</td>
<td>-0.45</td>
<td>-21.77</td>
<td>42.89</td>
</tr>
<tr>
<td>0.07</td>
<td>0.2266</td>
<td>0.2332</td>
<td>6.86</td>
<td>1.50</td>
<td>-23.43</td>
<td>31.50</td>
</tr>
<tr>
<td>0.09</td>
<td>0.2200</td>
<td>0.2192</td>
<td>4.12</td>
<td>3.15</td>
<td>-22.74</td>
<td>24.06</td>
</tr>
<tr>
<td>0.10</td>
<td>0.2190</td>
<td>0.2130</td>
<td>3.10</td>
<td>4.15</td>
<td>-21.86</td>
<td>20.45</td>
</tr>
<tr>
<td>0.125</td>
<td>0.2229</td>
<td>0.2039</td>
<td>1.88</td>
<td>6.34</td>
<td>-19.79</td>
<td>14.86</td>
</tr>
<tr>
<td>0.15</td>
<td>0.2345</td>
<td>0.1997</td>
<td>1.18</td>
<td>8.31</td>
<td>-17.04</td>
<td>10.41</td>
</tr>
</tbody>
</table>

The change in concentration gives rise to a non-linear variation of chromaticity coordinates. This is closely related to the dichromatic behaviour, which occurs in vast majority of all coloured systems depending upon the experimental conditions [11]. The largest changes were observed for the luminosity values $Y$; it diminishes with increasing concentration of the object. The colour points corresponding to above coordinates on the CIELAB plane are presented in Fig.2.

Fig.2. Position of colour points on the CIELAB plane of solutions:
- a) NiCl$_2$
- b) CoCl$_2$
- c) Cr$_2$(SO$_4$)$_3$. 
Table 3. Variation with the concentration of chromium (III) sulphate of the CIE and CIELAB coordinates.

<table>
<thead>
<tr>
<th>c, mol/dm³</th>
<th>x</th>
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<td>0.01</td>
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</tr>
<tr>
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</tr>
<tr>
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<tr>
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<td>0.2229</td>
<td>0.2039</td>
<td>1.88</td>
<td>6.34</td>
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<td>14.86</td>
</tr>
<tr>
<td>0.15</td>
<td>0.2345</td>
<td>0.1997</td>
<td>1.18</td>
<td>8.31</td>
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</tr>
</tbody>
</table>

The change in concentration gives rise to a non-linear variation of chromaticity coordinates. This is closely related to the dichromatic behaviour, which occurs in vast majority of all coloured systems depending upon the experimental conditions [11]. The largest changes were observed for the luminosity values Y; it diminishes with increasing concentration of the object. The colour points corresponding to above coordinates on the CIELAB plane are presented in Fig.2.

Fig.2. Position of colour points on the CIELAB plane of solutions:
a) NiCl₂, b) CoCl₂, c) Cr₂(SO₄)₃.
In the case of NiCl₂ solutions the increase in Ni²⁺ ion concentration results in the increasing purity of colour, but the hue angle remains practically unchanged in the investigated concentration range. $\Delta E_{ab}$ is function of concentration:

$$\Delta E_{ab} = 1.102 + 127.6c - 66.599 c^2 \quad (R^2 = 0.9989)$$

The study of the relationship between the parameters of colour and concentration of ions was carried also for their two component mixtures (Co²⁺ - Ni²⁺ and Co²⁺ - Cr³⁺).

It was found that for various concentration of cobalt and nickel ions in the mixture the band positions can be related to the band positions in simple metal ions. However, when using various ratios of components changes in the intensity distributions of absorption bands were apparent (Fig.4a). For various concentrations of Co²⁺ and Cr³⁺ ions in the mixture, the band positions showed deviations from band positions of individual components (Fig. 4b).

![Fig.4. Absorption spectra of aqueous solutions:](image)

- a) mixture of Co²⁺ and Ni²⁺ (for $c$ of Ni²⁺ ions = constant)
- b) mixture of Co²⁺ and Cr³⁺ (for $c$ of Cr³⁺ ions = constant)

The colour change between samples of a mixture containing various quantitative of the metal ions are calculated from colour difference values of two component mixtures. For quantitative evaluation of $\Delta E_{ab}$, differences $\Delta a^*$, $\Delta b^*$, $\Delta L^*$ were calculated from characteristic colour parameters of two component mixtures and the values of the solution.
containing constant metal ion concentration as the reference sample. Table 4 presents the $\Delta E_{ab}$ values as a function of the cobalt ion concentrations obtained for three series of the samples where the concentration of Ni$^{2+}$ ions is constant.

Table 4. Colour difference $\Delta E_{ab}$ of the mixture of CoCl$_2$ and NiCl$_2$ solutions for A, B, C series of samples where the concentration of Ni$^{2+}$ is constant. (A = 0.05, B = 0.1, C = 0.125 mol/dm$^3$)

<table>
<thead>
<tr>
<th>Concentration of Co$^{2+}$ ions, mol/dm$^3$</th>
<th>Colour difference $\Delta E_{ab}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>0.05</td>
<td>20.63</td>
</tr>
<tr>
<td>0.07</td>
<td>27.59</td>
</tr>
<tr>
<td>0.09</td>
<td>33.25</td>
</tr>
<tr>
<td>0.10</td>
<td>35.78</td>
</tr>
<tr>
<td>0.125</td>
<td>41.93</td>
</tr>
<tr>
<td>0.15</td>
<td>47.26</td>
</tr>
<tr>
<td>0.20</td>
<td>55.89</td>
</tr>
<tr>
<td>0.25</td>
<td>62.63</td>
</tr>
<tr>
<td>0.30</td>
<td>68.49</td>
</tr>
<tr>
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<tr>
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<td>76.13</td>
</tr>
<tr>
<td>0.45</td>
<td>78.72</td>
</tr>
<tr>
<td>0.50</td>
<td>81.47</td>
</tr>
</tbody>
</table>

It can be seen that if samples contain an identical quantity of Co$^{2+}$ ions the $\Delta E_{ab}$ values are practically the same.

If the concentration of Co$^{2+}$ in two component mixtures is variable, the correlation equation has the form:

$$\Delta E_{ab} = 9.381 + 298.5c - 306.9c^2$$

Such a correlation has also been observed for aqueous solution of Co$^{2+}$ ions. (eq. 4). These good correlations demonstrate that the colour difference can be applied to the quantitative analysis of coloured substances. The function $\Delta E_{ab} = f(c)$ is practically the same irrespective of the composition of the mixture.

References:
ANALYSIS OF FASHION COLOR AND COLOR IMAGES

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1. Purpose of the study

Image is an important aspect of communication in modern society, and its importance has increased as an emotional factor in the fashion industry.

The design elements of fashion products are color, texture, and shape. Among these factors, color is the first to be noticed and it is the most important tool to transmit the message visually. Color is the most effective factor in determining which goods get chosen first and can also increase a product's value.

Fashion color information is generally divided into 3 categories: fashion forecasting, market, and consumer color information. In order to create a system compiling and utilizing color information, it is first necessary to collect and classify the data from each category to construct a database for color design. (Fig 1)
The purposes of this study are as follows:

1) To analyze the characteristics of the fashion color.
2) To classify the fashion color images.
3) To develop the color database system for fashion design.

2. Method of the study

For this research, the fashion color and color image data were collected and analyzed based on the structure of fashion image formative factors. Features of fashion colors were analyzed from the themes and the names of colors forecasted in 12 fashion trend books (Carlin, Premiere Vision, NellyRodi, Trend Union Promostyle, Design Intelligence, ICA, Expofil, Moda In, Samsung, Interfashion Planning) from 1990 to 1999. Finally, 2758 fashion colors, 150 visual images, 313 themes and 1136 color names were analyzed in this study.

The questionnaires consist of showing 75 color prints selected from 150 visual images and also 54 color adjectives selected from 313 themes in fashion forecasting books. Total 305 copies were used for survey from 20 to 50 years old students and the specialists in the fashion clothing companies. These questionnaires showed each color image with 54 adjectives with the results analyzed via Factor Analysis and MDS (Multi Dimensional Scale).

Based on the Web, the fashion color database was developed using

Fig 2: Selection of the fashion trend color data
Access and Visual Basic. The database consists of the visual image and the linguistic image. In order to group the practical use of the fashion color database, the image map, the color pallet and the color combination were showed.

3. Analysis of the Fashion Color and Color Images

For effective communication in design field, it is necessary to systematize the colors based on both hue and tone. It is also effective to consider both visual and linguistic images. The results of this study are as follows:

1) The dominant fashion trend color distribution were especially in R(19.8%), YR(15.7%), PB(13.6%), Y(13.2%), and d(19.8%), g(15.7%), sf(12.4) were also prominent tones (Fig 3, Fig 4). The result is like to the inclination of Korean fashion color characteristics.

![Fig 3: Hue distribution of the fashion trend color](image1)

![Fig 4: Tone distribution of the fashion trend color](image2)

2) This study shows that the 5 main factors of fashion images are 'bright', 'romantic', 'feminine', 'intense', and 'modern' from factor anaylsis. The relative positions of 54 color adjectives make clear form MDS. The axes of the color image scale are 'bright-dark' and 'vigorous-calm' from factor analysis and MDS result. 54 color adjectives and 5 main factors are placed on the fashion color image adjective space (Fig 5). The characteristic of the fashion color image is not extreme nor indistinct.
Fig 5: Fashion Color image adjective space
3) The structure of fashion color database is composed into image and color division. In order to find out each information effectively, the searching conditions were included each categories. The image was classified into 5 factors and each factor has 54 adjectives against color information. Color divided into hue with 40 kinds of hues and tone with 12 tones. From the final chosen color, users are able to get information about COS code of each color, hue, tone, color predicted information (year, season, related theme and the name of color) and the market information (year, season, item)

Fig 7: Development of the fashion color database
The predicted information were 2330 colors which were converted to COS(Color system) in the 12 fashion trend books from 1990 to 1999 and the market information are 2238 used colors collecting from 109 brands from the domestic fabric companies from 1993 to 1997. For practical application of database, Web database form was applied for user friendly and the system extension is available through the sustainable update of database and common uses of data.

4. Conclusion

The developed color and image database of this study is useful not only for the methods of design through linguistic and visual images, but also for the process of color planning by using specific color information and various visual images. The color image planning tool of this study has been compiled into internet accessible database. User can not only access this system to forecast fashion color information (mainly for the Korean fashion market) but they can also add their own information to update the database.

Reference
FIBRE-OPTIC COLOUR SENSING
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Keywords: colorimetry, colour sensing, optical fibres

Abstract
This paper presents construction of a simple fibre-optic colour sensor designed for recognition of objects from a set comprising an „a priori“ defined, limited number of colours. Hereby, colour recognition is understood as distinguishing among coloured objects and not as a colour measurements, because it is not conditioned to any standardisation. The device operation is therefore close to machine colour vision but not to colour measurement. The construction was assumed to be simple and low-cost, therefore using standard, cheap optoelectronic elements. Colour sensing is based on the diffusive reflectivity of the examined surfaces measured in several separate spectral channels. Number and positions of channels depend on predetermined set of colours. The channels are fed by selected LED's sequentially in TDMA-mode. Collected serially analogue signals are converted onto digital data enabling some processing variants. The constructed device was tested and results of examination are also given.

I. Introduction
Although colour has been used as indicator of various processes and reactions since very long time, recent progress in sensing methods and techniques extended essentially potential applications of colorimetry. Many new indicators and sensing surfaces were developed, as number of elastomers or liquid crystals, which colour is influenced by a diversity of parameters and agents ought to be controlled. They spread possibility of use colorimetric
methods from conventional applications in analytical chemistry over a new areas, for measuring and sensing temperature, mechanical stress, current, electric and magnetic fields, pH-degree, composition of fluids and gases in chromatographic examination, presence of selected ions and/or substances, and even blood parameters as oxygen content and OB-level. Colorimetric sensing is advantageous because it is simple and in many cases can be non-invasive. Moreover, some additional advantages is to be drawn out by combining plenty of new colorimetric sensors with optical fibres technique. Such a combination offers miniaturisation, improved operational feasibility and local (point-to-point) measurements. Fibre-optic colorimetry enables construction of low-cost devices with intrinsic balanced light source, less interfering monitored environment, immune to undesired ambient influences and distortions. In this work an attempt was made to build a simple, chip and reliable device by using general-purpose optoelectronic elements.

II. Construction of the sensor

Our colour sensor is designed to distinguish colours of non light-emitting, non transparent, light scattering objects and is based on diffusive reflectivity of the examined surfaces measured in 3 separate spectral channels + the reference one (IR, 900 nm) + receiving one. However, number and positions of channels can be changed depending on predetermined set of colours. On general consumer market there are at least 4 narrow-band LED’s emitting in the visible region. This LED’s generating light at maximum wavelength 625 nm (R), 590 nm (Y), 565 nm (G), and 430 nm (B) with half-band width 20 ± 50nm can be used as a light sources in colorimetric channels. We have built our sensor in two variants with RGB - and RGY - channels to test the capability of colour resolution.

The channels are fed by selected LED’s sequentially in time-division driving mode. The TDMA-mode for the sensor is chosen to avoid the use of spectral filters for channel separation, which cause apparent optical losses and are expensive. The light is guided by big-core, multimode optical fibres of PCS-type (200/450 µm, clad-polymer). These simple fibres allow to easy bring in much amount of light. Topographic view of the device is shown on Fig.1. It consists of three functional parts of the sensor - the fibre-optic head, the electrooptical converter, the TDMA driver, and the external part to the sensor - the processor unit.
The sensing object is enlightened by sequentially pulsating LED's (250μs pulses) and reflected light of corresponding wavelength is synchronously collected in one common receiving channel. Then this optical signals are converted onto electrical pulses, led to separate spectral channels by means of standard logic (4-channel lock-in), compared with the reference IR reflected from the same place of the object, and stored in a buffer for parallel reading. Further the data can be carried to a processor unit (PC) to transform a set of electrical signals in all spectral channels onto easy-to-read communicate. Visualisation of sensing results depends on the preferences, equipment and requirements of the user. The output signal of the sensor can directly control an automated production process, but human-directed communication requires reprocessing the sensor signal. Since the sensor output is a three-element (or more) vector, it is inconvenient to perceive and evaluate the final result of measurement. Two following ways of output signal processing we recommend to make it convenient for visualisation:

- to digitalise colorimetric signals and send the data to standard PLC terminal for further processing and visualisation. It is, of course, a cost-lifting solution, but in any control system the terminal usually already exist and is supplied also with another monitored data (e.g. with a network of various sensors), so each particular sensor, as an information source, takes only a small part of terminal capability. We have decided for this way by applying standard Windows NT environment to install a simple visualisation software. The colorimetric results can be displayed graphically, as a word communicate (see Fig.2.), or as a set of the signal levels in each chromatic channel,
- the alternate way is to adapt neuronal methods, which, generally taking, assign a multi-value input to one-value output, so fitting, in final effect, some function ( „Colour” = C) joining a set of arguments from the signals domain with numerical value for the output. This output can be shown on any conventional display; however this function C can good work only with small number of colours for recognising, because it is generally not univalent. The neurone network was already successfully applied for another sensors [1,2]. It seems to be promising because it can be re-learned to adapt the system to various samples examined and in its optical version can became significantly cheaper then PL.C.

III. Laboratory test results of the sensor

We have tested two variants of the sensor with RGB and RGY channels for reliability of colour discrimination among the sample colours in various conditions (head distance, ambient light, speed of reading, e.t.c.). The colour test comprised of 16 colours including black and white. The capability of colour recognition of RGB-variant is illustrated by viewgraph on Fig.3. It can be easy still increased by adding the 4th spectral channel to the sensor ( to RGBY) if necessary. For the test colours used, we have not noticed any wrong reading by the sensor in several series of 50 trials.
Tab.1. Technical data of the colour sensor

<table>
<thead>
<tr>
<th>operation mode</th>
<th>TDMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>sensor head</td>
<td>fibre-optic; 5 single PCS fibres 200/450μm</td>
</tr>
<tr>
<td>number of spectral channels</td>
<td>3+1 (chromatic + reference), can be extended to 4+1</td>
</tr>
<tr>
<td>channel HBW</td>
<td>20 ± 30 nm</td>
</tr>
<tr>
<td>light source</td>
<td>LED’s (intrinsic)</td>
</tr>
<tr>
<td>measurement error of electronic part</td>
<td>± 10%</td>
</tr>
<tr>
<td>results representation</td>
<td>optional: graphical, word communicate, or channel signal values on PLC-terminal</td>
</tr>
<tr>
<td>reliability</td>
<td>depending on predetermined set of colours</td>
</tr>
</tbody>
</table>

Fig.3. Colour test for RGB-variant of the sensor

IV. Conclusions

At present there is an increasing demand of a simple, low-cost sensors for monitoring a number of physical parameters. The presented colour sensor can work in conditions
frequently met in practice, as in dye and textile industry or food processing, were the colours for control are well defined and limited. However, after some modifications the device can be potentially applied for sensing another parameters beside colours. By adding adapters with adequate converting surfaces (indicators) it can control or measure temperature, mechanical stress, pH-degree, e.t.c.

V. References


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COLOUR MEASUREMENT AND VISUAL COMMUNICATION

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Colour is part of the symbol, not only in traditional cultural facts: also in logos, and more recently in machinery and instruments, walls and roofs of corporative buildings, their arquigrafics and designs. In or over all the materials. Under all light sources. By reflection and by transparency. Brilliant, or dull. Smooth or textured. Indoors and outdoors. In the Arctic, the Kalahari, or the Amazon, in a car workshop or a fluorine factory, while there is a man that perceive it.

Technologies goes creating resistant synthetic materials, but the adequate pigments may add the metamerism as a problem to solve.

The traditional solutions no longer reach: it is excellent to count with the sample of the colour and its tolerances toward the black, white, red, green, yellow and blue, as a guide.

But: What a metamerism grade we will accept when reproducing, in a fabric or ceramics, a colour created with graphic inks or artist’s paints? What about to communicate these tolerances 1600 Km away, requiring the formula for that colour before the next 48 hours? When the surface is less brilliant?

The eye is and it will be the last umpire.

But colour measurement is becoming essential in quickly sharing information about colour between professionals from different disciplines.

The colour sensation does not permit to intuitively associate it to a number, and it is difficult to separate it from other appearance characteristics. Sometimes, it can make unclear the meanings of the CIEL*a*b*, XYZ or any other coordinates numbers.

So, it is necessary to spread the scopes and fundamentals of the measurement of colour and it tolerances, its limitations and peculiarities, as the non-uniformity of the colour spaces.
Colour is one of the most important resources of the visual communication.

Even though the colour-form relationship is indissoluble, the tonal referring is more primary and powerful, perhaps by being the fundamental element outside of what is human in the visual communication. Everything else, the form, the cultural instances and the semantic knowledge are of importance for the visual communication, but are impossible without light and normal human eye in normal brain. Therefore, colour measurement will be an indispensable tool so that the necessary tonal parameters achieve effectiveness for the proposed visual messages, either in the measurement of originals, referring, or in its quality control.

ARTISTIC PAINTINGS RESTORING

Within the current line variants of I restore and artistic paintings conservation the measurement of the colour is converted into an indispensable all for the rapidity and precision in the areas coverage shortages.

In those variants we distinguished the variant "trateggio" (intertwined linear vertical, generally employed for existing works in museums and galleries, so much for the trestle painting, as the mural paintings). The areas measurement that are presumed equivalent in the work, will make possible to determine the location in L, a, b. or in x, y, z of the same, and the possible 3 or 4 tones that will constitute the intertwined of the "trateggio".

In the other varying more used by request of particular, consists of covering the zone with a stroke and equivalent colour to the supposed original, after re-establishing previously the "plaste" lacking. The measurement of the colour, will make possible with the use of the corresponding software through the application of the pigments suggested by the same, be approached optimum tone to cover the lacking.

In this case, also it will be avoided a metameric pronounced.

GUARANTEEING A GOOD VISUAL COMMUNICATION

ARQUITECTONICAL DESIGN

In the architectural design the election of the colour can emerge for foreign as well as for the environmental colour. In either case, the colour can have to do with the in itself same architectural material, or with those of protection and finishis (paintings, coatings, etc.)
Also in either case, this election will be held to the colour of the environment or context; to the relationship colour - function - meaning; to the subjectivity of the user or client.

As influences the measurement of the colour the election process of the same.

The example is taken on a building for odontologic consulting in their stage of finalisation.

1° to establish the promedial measurement of the environment, in case that do not exist large differentiated areas. In case that yes exist, they are determined these, most the measurement promedial.

2° measured the colour of the coating of the socle to put.

3° to establish response or possible answers to the unknown " foreign wall", considering: colour of 1 and 2, connotation of the colour (existing and possible), relationship colour - function, pleasures of the user, measurement of the solutions to 3.

4° search of the existing colour in the market, within margin of identity tolerance.

5° in case that is not found already produced, to adjust the pigments to one similar, or to produce it, taking into account the resulting of the respective measurements, since make possible that to reproduce in I study the existing reality, and their possible solutions in laboratory.

Notes:

To measure the market colour to control his quality in postproduction, and of that manner be assured the departure.

GUARANTEEING A GOOD VISUAL COMUNICATION

PLASTICS ARTS

The importance of the measurement of the colour in the plastics arts, resides in the emission quality control of the pictorial product for artistic use.

The plastic work of Libero Badii, so much sculptural as pictorial, is identified by that in your chromatic palette employs fundamentally white, black, yellow, red and blue cobalt, cerulean and very little overseas as colours.

If in the chain of paintings production artistic did not exist the quality control by measurement of the final product, for example the blue identified between Libero Badii's
cobalt and cerulean, that the artist employs in his stage of the "dolls", or of the "sacrifice" would lose his presence and identity. Where the luminosity effect and ethereal solidity of its blue, inherent to the good use of the material, support and own harmonization of the artist, would be seen altered by the modification of the dyes. On the other hand it is certain that the author would not have let go by that defect and would try to reconstructing with its trade, he, or the colours that dial their identity. Of have happened this, would have resulted in a dangerous adjustment on account of the nature pigments of the personnel products. Their metamerics, and their possibilities of perdurabilided, before the need of the improvised adjustment, that might have been necessary made by negligence in the quality control of the adjustment of the proposed factory colour.

From there that the colour measurement in the quality control of the product, guarantees the make-up persisting and

A GOOD VISUAL COMMUNICATION

VISUAL COMMUNICATION DESIGN

In the visual communication design, the problem of the chromatic identity is bound directly to the brands identity, signs, marketing colour, institutional identity and of product, that it is moved to the papers, arquigrafics, wall-posters, vehicles painting, labelled and tagged of products, and to the variants of impression techniques, and reproduction by different means, either graphic or of massive communication and to the lighting by refraction or transparency of the same.

If we take as example the brand of the GAC, in her is fundamental, in addition to observing the relevant formal structure in their reproduction, the identifiable presence of the yellow, magenta and cyan. That is to say, that within the possible tolerance margins, for the colour, will be made present the perceptual identity threshold of the same, and the relativity variables by irradiation of the neighbouring zones, in the event of very fine areas in the typography. The measurement of the colour contributes to the fact that said logotype is found within the perceptual identity margins, upon adjusting original, and impression and reproduction tests,

GUARANTEEING A GOOD VISUAL COMUNICATION
PRODUCTS DESIGN

In the area of the products design, where marketing is essential, the good adjustment of the colour in the visual communication, either by the proper characteristics of the material, or by colouring, is almost indispensable.

Colour deviations of a same product in it final issue, are, in a first place, signs of poor quality and in second place, the departure toward new significants that are not the own: those selected in the market research and in the decision of the design. Its probable consequences are a failure or lowering of consumption levels.

Just there the importance of the colour measurement in the analysis instances of the model for his reproduction, and in the successive quality controls, including those of packaging, will result in the marketing efficiency marketing, GUARANTEEING A GOOD VISUAL COMUNICATION

INDUSTRIAL COLOR MEASUREMENT

In the painting, ink and textile industries, the measurement of the colour has become common practice in quality control; the same is made for the pigments and colorants that constituted them and determined its tone.

Fundamentally, it is pursued an adequate adjustment of the colour tested in conditions of typical use for the product. In the system CIEL*a*b* - the most used - are measured the differences ΔL*, Δa* and Δb* of each sample with respect to a established standard. When each one of the differences is within an adequate tolerance, the product is released to the market.

Using spectrophotometers, the measurement allows an easy adjustment of Tinting Strength, important property in paints for artists and tints, materials that typically are used mixing various colours mutually and therefore demand not only a good colour: but also it capacity to dye other colour must be maintained constant in consecutive batcher.

It use allows to select alternative pigments or colorant, evaluating by means of the spectral curves the degree of metamerism that the replacement would produce.
rainbow colours are associated with the wavelengths of the tight. Many arrangements, based on classifications of colour samples, and including the purples, were developed. The best known is the Munsell system, based on steps of equal visual perception. It introduces the coordinates Hue, Value and Chroma.

1931 - the CIE adopted the experimental definition of the Standard Observer: all the spectrum colours were matched by combining three well-controlled primary lights, red, green and blue, by a certain number of observers. The average relative amounts of each primary for each spectrum colour, were called tristimulus values.

As the obtained tristimulus values showed negative numbers, a mathematical transformation was made, being the virtual new primaries called X, Y and Z and x, y and z its tristimulus values.

By transforming tristimulus in chromaticity coordinates, it is possible to plot the CIE chromaticity diagram. Purples can have its x, y values. It can be added the third colour dimension (luminance) to the diagram, obtaining the CIE colour space.

By convenient mathematical transformations, the CIE colour space is transformed in the CIEL*a*b colour space. Here, coordinates represents opponent colours (at negative and positive sides). When transforming the orthogonal coordinates in its cylindrical equivalents, we obtain the description of colour in terms of CIEL*C*h*, analogous in significance to Munsell's Value, Chroma and Hue.
JUDD AWARD CITATION

Paula J. Alessi

He has been an inspiring mentor to all in the color science community. He has been an educator to 15 Ph.D, 11 M. Sc, a few B. Sc and many industrialists in the area of color. He was founding Editor-in-Chief of the world's leading color journal, Color Research and Application. He has held many leadership positions with the AIC member organization as the Inter-Society Color Council (ISCC). As a matter of fact, he was the program chair of the AIC 2nd Quadrennial Congress, Color '77 held in Troy, New York and hosted by the Inter-Society Color Council.

It is with great pleasure that the AIC bestow its highest honor, the 1999 AIC Deane B. Judd Award to Dr. Fred W. Billmeyer, Jr. at this AIC Interim Meeting in Warsaw, Poland. The AIC Deane B. Judd Award was established in 1975 to recognize work of international importance in the fields of color perception, color measurement, or color technology. Dr. Billmeyer will join such previous recipients as Dorothy Nickerson, W. David Wright, Gunter Wyszecki, Manfred Richter, David MacAdam, Leo M. Hurvich and Dorothea Jameson, Robert W. G. Hunt, Tarow Indow, Hans Vos and Pieter Walraven, Yoshinobu Nayatani, Heinz Terstiege, Anders Hård, Gunnar Tonnquist, and Lars Sivik.

Dr. Billmeyer received his Bachelor of Science in chemistry from the California Institute of Technology in 1941 and his Ph.D. in physical chemistry from Cornell University in 1945. From 1945 to 1964, he worked for E.I. du Pont de Nemours & Company. In 1956, Du Pont purchased two General Electric Hardy Spectrophotometers. One of these was located in Dr. Billmeyer's Experimental Station Laboratory in Wilmington, Delaware. In 1960 and 1961, on loan from Du Pont to the Massachusetts Institute of Technology, he established and taught courses in polymer science as Visiting Professor in Chemical Engineering.

Although he started out his work in polymer science, his work in color escalated. First he devised a graphical method of calculating CIE color coordinates from Hunter colorimeter readings. He devised color order systems for, and applied color difference measurements to, transparent plastics. He carried out pioneering research on computer color matchings, and
began publishing a distinguished series of articles on color measurement that continues today. Altogether he has published some 275 technical papers on color and polymer science. The value of these papers is made evident by how extensively they are referenced in the literature.

In 1964, he resigned from DuPont to join Rensselaer Polytechnic Institute (RPI) as Professor of Analytical Chemistry, and soon established a course on color because he had become convinced of the importance of color technology in industry. Within the chemistry department, he established The Rensselaer Color Measurement Laboratory, which was the principal center of color science activity in the United States for twenty years. Here he supervised courses leading to degrees in chemistry with a specialization in color science. Fifteen Doctor of Philosophy, eleven Master of Science and a few Bachelor of Science degrees were awarded. Today these graduates have moved into industry and academia to form a major part of the leadership in color technology.

In The Rensselaer Color Measurement Laboratory, he also directed the work of visiting scientists and postdoctoral research in color. The Laboratory contained traditional as well as the latest in color instrumentation. Dr. Billmeyer also established a series of highly successful continuing education courses on color that were held at the Laboratory during the summers. Over the twenty years, the courses introduced modern color theory and measurement practices to roughly a thousand individuals from industry and at the same time put his students in touch with the practical problems in the business world. The courses included the basic Principles of Color Technology, Advances in Color Technology, and (with the assistance of Max Saltzman) Color Technology for Management.


As his retirement approached in the early 1980’s, it became clear that Rensselaer could not provide the necessary support to continue the program. So Dr. Billmeyer, as Trustee and Secretary to the Munsell Color Foundation, worked with Richard S. Hunter to found the Munsell Color Science Laboratory at the Rochester Institute of Technology in 1982.

Dr. Billmeyer has been a major figure in the Inter-Society Color Council since the early 1960 s. In 1964, he was elected a director. In 1966, he was elected Vice President and, in
1968, he became President of the Council. In 1970, he was elected to the time consuming job of Secretary and remained in that office until 1982. For 12 years, he maintained the ISCC records, corresponded with prospective members, and managed the myriad of details that are necessary in the administration of a national organization. Currently, the work he did as Secretary is divided among several people.

In 1978, the ISCC presented him with the Macbeth Award for recent outstanding accomplishments in the field of color. In 1983 he was awarded the first Nickerson Service Award for his outstanding service to the Council through the years. He has been made an Honorary Member of the Council in further recognition of those years of service. In 1993, I, as President of ISCC and a former student had the honor of presenting Dr. Billmeyer with the most prestigious ISCC Godlove Award.

Dr. Billmeyer was instrumental in enticing John Wiley & Sons to publish a journal on color. He served as Editor-in-Chief of that journal, Color Research and Application, for eleven years, from its founding in 1976 through 1986. He has continued as Founding Editor to assist Mr. Rolf Kuehni and now his former student, Dr. Ellen Carter, who have followed him as Editor-in-Chief. Fred Billmeyer always contributed an extra measure of time and attention to ensure that the journal represents the best in scholarship and has, at the same time, strived to encourage articles from all color fields and from all over the world. Dr. Billmeyer's active participation through the years in international organizations connected with color was important in making the contacts necessary to create a truly international journal. His work for the Commission Internationale de L'Eclairage (CIE) included studies on calculation of tristimulus values from 1981 through 1984 and on fluorescent measurement from 1975 to 1983, culminating in the publication of CIE Technical Report No. 76 in 1988. In recognition of his many contributions, he has been made a Life Member of the U.S. National Committee of the CIE.

He has also been very active in the International Color Association (AIC). Perhaps the most notable contribution he made to AIC was to host the AIC 1977 Congress at The Rensselaer Color Measurement Laboratory in Troy, NY. Among other contributions to the AIC, he prepared the Technical Report "Survey of Color Order Systems" in 1985. This was updated to 1986 and, through the generosity of Mr. Faber Birren, made more widely available as the "AIC Annotated Bibliography on Color Order Systems."
Dr. Billmeyer has also made a significant contribution to color through his participation in the American Society for Testing and Materials (ASTM). He joined ASTM in 1971 and is currently serving on Committees D-01 on Paint and Related Materials, D-20 on Plastics E-12 on Appearance, and E-12 on Road and Paving Materials. His knowledge and experience led to an appointment to the important ASTM Standing Committee on Terminology.

Within each of these committees, he has taken an active part in the subcommittees that do the work necessary to develop national consensus standards. He is active in many of E-12’s subcommittees and his input to each is significant. But his most significant contribution has been in the area of terminology. He has been instrumental in revising the important Standard Practice E-284, Terminology of Appearance. This year, ASTM recognized Dr. Billmeyer for his contribution in the area of terminology standardization by bestowing upon him the coveted Reihart Award. ASTM has also recognized his outstanding contributions by presenting him with its Award of Merit, making him a Fellow of the Society.

Dr. Billmeyer is a member of the Phi Kappa Phi and Sigma Xi honor societies. In addition to ASTM, he has been made a Fellow of the American Association for the Advancement of Science, the Optical Society of America, the American Physical Society, and the Society of Plastics Engineers. He is a 50-year member of the American Chemical Society and has served on its delegation to the ISCC. He is a member of the New York Society for Coatings Technology and the Federation for the Societies for Coating Technology, which awarded him the important Armin J. Bruning Award in 1977. He is a former Director and Secretary-Treasurer of the Council for Optical Radiation Measurement. He has been a member of the American Association of Textile Chemists and Colorists and of the Society of Dyers and Colourists of Great Britain. He also was a member of the Colour Group of Great Britain. He has actively encouraged the formation of color societies in other countries.

As you can see, his list of contributions to the field of color is endless and has been felt by all, be it individuals or industries, in some way, shape or form around the world. I am personally grateful to him for sparking my interest in color, which has now blossomed into a successful career. Dr. Billmeyer’s legacy is found every day in his former students and I’m all those whom he has touched by his interest in all aspects of color. I was proud to bestow upon him the Godlove Award as President of ISCC. Now, as AIC Vice President, I am even more honored to bestow the AIC’s most coveted Deane B. Judd Award on the most deserving and inspirational color scientist I have ever met, Dr. Fred W. Billmeyer, Jr.
ADVANCES IN COLOR TECHNOLOGY
The 1999 AIC Judd Award Lecture
Fred W. Billmeyer, Jr.

Wynwood' Commons; Apartment 218
1786 Union Street, Niskayuna, New York 12309, USA

Introduction

Shortly after the author joined the professorial staff at Rensselaer Polytechnic Institute after an industrial career in color science and polymer science, he and Adjunct Professor Max Saltzman initiated a series of continuing-education courses in color technology. For the first several years Billmeyer taught a course designated Principles of Color Technology, using the Billmeyer and Saltzman book of that name as text. Professor Saltzman soon began teaching a companion course titled Color Technology for Management.

The success of these courses, and the encouragement of their participants, suggested that a more advanced course, discussing the latest advances in the field, would be well received. In planning this course, called Advances in Color Technology, Prof. Saltzman and I felt that the participants should be required to have an advanced level of knowledge of color technology. We attempted to organize the course so that it assumed that the principles were well understood and the material could be presented starting at an advanced level. This was only partly successful, as many potential participants were convinced that the necessary basics could be assimilated essentially at once after attendance at the beginning-level Principles course. However, most of those taking the Advances course felt that the concept was successful.

During the years that Advances was taught, and in some respects even today, there was no textbook at the desired advanced level. Instead, a course book was put together from reprints, preprints, and original notes. One such course book, for the year 1981, containing 400 pages, forms the basis for this manuscript. The course book content varied significantly
from year to year, but the same major topics were usually found. The first of these had to do with color measurement.

At the time this course was given, the emphasis in color measurement was on instrumental, not visual, measurement. The first topic for discussion dealt with the performance of then existing instruments. The first entry in the course book was a manuscript preprint of what became a chapter in the book, Golden Jubilee of Colour in the CIE, by Billmeyer and Henry Hemmendinger, titled "Instrumentation for Color Measurement and Its Performance." The term MCDM, mean color difference from the mean of a set of measurements (here, color differences), was introduced. Data were presented for short-term repeatability and long-term accuracy and the authors concluded that for the first time the results indicated that reliance on instrumental color measurements could be superior to the use of retained material standards. A second paper in the course book, a reprint of "Statistical Study of Color-Measurement Instrumentation", by Robert Marcus and Billmeyer, warned that such measurements are not likely to be normally distributed, and the usual statistical treatments may not apply.

It was clear that careful attention had to be paid to instrument calibration to obtain the results just described. A reprint of the paper "A Standards Program for Color Control," by Hugh Fairman, next addressed this problem. It placed emphasis on the selection of material standards. There followed two reprints dealing with the use of standards. They were "A Review of Wavelength Calibration Methods for Visible-Range Photoelectric Spectrophotometers," by David Alman and Billmeyer, and excerpts from a reprint of "Accurate Measurement of and Corrections for Nonlinearities in Radiometers," by C. L. Sanders.

The final section of this topic dealt with errors arising from geometric aspects of measurement. First, a reprint of a paper on

"Generalized Integrating Sphere Theory" by David Goebel dealt with integrating-sphere errors in a general way. Then a reprint of "Integrating Sphere Errors in the Colorimetry of Fluorescent Materials," by Alman and Billmeyer, applied this theory to a case of importance in a specific measurement problem of interest to the color community. Finally, a reprint of "The Gloss Trap in Diffuse Reflectance Measurements," by Wolfgang Budde, addressed errors at the bottom end of the photometric scale.
Although the author's interest in terminology had not yet developed to the extent seen later, the first series of papers in the course book under that title gave promise of later specialization. The first manuscript in addition introduced a new type of entry, Notes. These were unpublished comments on subjects not covered in the literature at the time in question. Here the Notes were titled "Geometric Aspects of Radiometry Related to Materials Properties." They were meant to supply just enough background in radiometry so that the following reprints could be read and understood easily. These were excerpts from CIE Publication 38, "Radiometric and Photometric Properties of Materials and Their Measurement"; "Colour Terminology," by R. W. G. Hunt; and a pair of trivial Letters to the Editor.

The final entry was again of a type not seen before: "Lecture Experiment-The Variables of Perceived Color." These notes accompanied a light projection experiment in which lightness and brightness were considered separately, and the variable fluorescence described by Ralph M. Evans was produced under a variety of conditions. As the notes pointed out, the phenomena cannot be reproduced on the printed page.


Colorimetric calculations were next considered. Much of the course book material for this section has been superceded, as noted in the following narrative. Today readers should look on this material as a historical essay, but not as current practice.

Perhaps the most basic calculation in this field is that leading to tristimulus values. In a series of short articles E. I. Stearns provided the groundwork for these calculations, not yet adopted by the CIE but forming the basis for ASTM Standard Practice E 308 for Computing the Colors of Objects by Using the CIE System.
In its latest revisions this standard provides the currently recommended calculation procedures. The preprints in the course book, all by E. I. Stearns, are "A New Look at the Calculation of Tristimulus Values," Calculation of Tristimulus Weights by Integration" (with R. E. Stearns as coauthor), and "The Determination of Weights for Use in Calculating Tristimulus Values."

Metamerism was next introduced, in a section opening with a discussion of the phenomenon and its various definitions in the reprint "What is Metamerism" by Allan Rodrigues and Ralph Besnoy. This is still a useful article. It is followed by three short articles addressing specific aspects of metamerism: "Observer Metamerism," by Billmeyer and Saltzman; "Special Metamerism Index: Change of Illuminant," the then and still current CIE recommendation; and "Notes on Indices of Metamerism," by Billmeyer. The latter reviewed the status of special indices of metamerism for change in illuminant and change in observer, and proposed consideration of a general index that would depend only on spectral differences suitably weighted. Published many years later, these notes have not led to useful indices.

The final item in this group is a preprint of what became CIE Publication 51, "A Method for Assessing the Quality of Daylight Simulators for Colorimetry." This is still the preferred practice.

A single reprint by Charles Jerome next covered "Color Rendering Indices of Light Sources." It is now superceded by a continuing series of modifications to the CIE procedure, but no definitive publications have resulted to replace the 1965 article included here.

A reprint of "Whiteness: Photometric Specification and Colorimetric Evaluation," by Ernst Ganz provided good background material, but was soon superceded by a proposed CIE whiteness formula described in the preprint "CIE Proposal for Study of Whiteness Formulae." The present CIE formula differs only slightly from that proposed here.

Finally, the reprint "Calculation of the Spectral Radiance Factors of Luminescent Samples," by Billmeyer and Tak-fu (Patrick) Chong provides an article still considered one of the primary references in the field of fluorescence measurement.

The next section began with a reprint of a 1967 article "Colorant Identification" by Saltzman and A. M. Keay. It provides a historical review of the development of the solution
spectrophotometry technique for the identification of organic pigments. At the time of this advanced course, the technique had been developed by Billmeyer, Saltzman, and Romesh Kumar. A series of articles have described it, and a preprint of the first of these appeared next in the course book: "Identification of Organic Pigments in Artists' Materials by Solution Spectrophotometry," with the above authorship.

Finally in this section is the reprint titled "The Color Index" by Emil Wich. Again the material is outdated but more recent articles are only now beginning to appear.

By 1981 the Advances course had been modified to include a section on advanced experiments in The Rensselaer Color Measurement Laboratory. As material serving as background for several advanced experiments had by now been covered, it was logical to present the experiment details at this point in the course book. Brief descriptions are given here.

I. Integrating-Sphere Errors

This experiment evaluated the error inherent in single-beam integrating sphere geometry. A simple photometer was constructed based on a Hunterlab D-25 single-beam sphere instrument. A series of neutral gray papers served as samples. Sphere efficiency and sphere error were evaluated. With a second set of chromatic samples, the chromatic sphere error was evaluated.

II. Spectrogoniophotometry

In this experiment, several samples known to have colors sensitive to changes in measurement geometry were provided. They were measured on a Leres Trilac spectrophotometer for several different combinations of illumination and viewing angles. Both spectral curves and chromaticities were available as instrument output. These results were compared to visual assessments of the samples.
III. Performance and Diagnostic Testing of Color-Measuring Instruments

Two sets of standard samples, NBS SRM 2101-2105 glass filters and the BCRA ceramic tiles, calibrated by the NBS and the Hemmendinger Color Laboratory, respectively, were measured on a Zeiss DMC-25 sphere spectrophotometer. The photometric and wavelength scales as measured were compared to the standard values. Short-term stability of the instrument and uniformity of the samples were tested.

IV. Pigment Identification Using Solution Spectrophotometry

The technique described in a preprint noted above was tested using prepared mixtures of two organic colorants with different solubility characteristics. The General Electric Recording Spectrophotometer was used with the log absorbance cam.

Resuming the lecture portion of the Advances course, color spaces and color differences were next considered. A sole item on standard conditions for visual observations summarized an ISCC project committee report, which led to the drafting of ASTM Standard Practice D 1729, then titled "Visual Examination of Small Color Differences." The standard still exists with this numerical designation, though the title has been changed in the course of continuing revisions.

This course was given just at the peak of activity on new color-difference formulas; no less than eight reprints and preprints on this subject were placed in the course book. They are (reprints except as noted): Supplement 2 to CIE Publication 15, Colorimetry, "Recommendations on Uniform Color Spaces, Color-Difference Equations, Psychometric Color Terms"; "The CIE 1976 Color-Difference Formulae," by Alan Robertson; Preprint, "Advances in Color-Difference Formulas," by Rolf Kuehni; "A Study in Black: The CIELAB and CIELUV L* Function for Very Low Values of Y," by Ake Stenius; "CIELAB Hue-Angle Anomalies at Low Tristimulus Ratios," by K. McLaren; "Guidelines for Coordinated Research on Colour Difference Evaluation," unsigned but by Alan Robertson; "Color Difference Terminology," by William Longley.

The following four reprints made up a section on uniform color spaces: Excerpts from "Cube-Root Color Spaces and Chromatic Adaptation," by Klaus Richter; "Uniform Color Scales," by David MacAdam; excerpts from "OSA Uniform Color Scale Samples; A Unique
Set,” by Dorothy Nickerson: and “On the Geometry of the OSA Uniform Color Scales Committee Space,” by Billmeyer.


Concluding Remarks

Of course there have been many advances in color technology since this course was designed, and I shall make no effort to list them all. As examples, I note the development of several new color-difference equations, including CMC and CIE 94, and of several new color-order systems, including the Natural Colour System and the Colorcurve System. Many new books have appeared or are in preparation, and the journal Color Research and Application, now in its 24th volume, continues to dominate that field.

The courses described could not have been offered without the support of the Continuing Studies program at Rensselaer and of my colleagues Adjunct Professors Max Saltzman and (briefly) L. Willard Richards. Special thanks is due to the following students who assisted in the presentations of lecture and the laboratory sessions, or were coauthors of many of the items in the course book: Drs. Richard Abrams, David Alman, Ellen Carter, Tak-fu (Patrick) Chong, Romesh Kumar, and Robert Marcus; Mr. Patrick Chassaigne and Mr. Jean Dubois. Finally, in my unavoidable absence I give special thanks for her capable handling of arrangements for this manuscript and its presentation to Ms. Paula Alessi; and for the oral presentation so capably presented, to Mr. Calvin McCamy.
The series of short courses on Advances in Color Technology terminated with the retirement of Billmeyer and the closing of The Rensselaer Color Measurement Laboratory in 1984. No similar replacement has come to my attention.
COLORIMETRY, DESIGNERS and XENOPHOBIA

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PRELIMINARIES

If the title of this paper sounds provocative, it is not my intention to stir up conflict; I prefer the role of peacemaker to that of warmonger. However I do want to attract attention so that I can focus that attention on a situation which I think is an obstacle to progress in the art and science of colour.

Before I introduce the main argument of this paper there are some questions I would like to put so that I can refer to the questions and possible answers later on. When this paper was presented at the conference in Warsaw, people wrote down their answers to the questions on slips of paper which were distributed at the beginning. When the questions had been answered, people put the slips of paper in an envelope which was circulated during the remainder of the presentation and collected at the end. A record of the answers and some tentative comments are included in a postscript. If you were not in Warsaw, please record your answers to the questions before reading on.

A. What colour would you choose for a new motor car?

Imagine that you are visiting a large international motor show where the holder of the lucky entry ticket will win a new car. It turns out that you are the winner and you are told that you can have the car in any colour you like. What colour would you choose?
Please write down your chosen colour: .................................................................

B. How can two things be the same colour?

Fig 1 represents a sheet of white card (marked A) on which there are two small squares (marked B.) The small squares have been cut from the same sheet of uniformly printed paper which is a kind of mustard yellow colour.

Are the two small squares the same colour?

Please record your opinion by underlining YES or NO.

Fig 2 is similar to fig 1. The small squares (both marked B) have been cut from the same sheet of mustard yellow paper as those in fig 1, but one square is surrounded by a vivid yellow (C) and the other by a deep violet (D). The phenomenon of simultaneous contrast affects the appearance of the two small squares; they no longer look the same.

Are the two small squares the same colour?

Please record your opinion by underlining YES or NO.

Fig 3 is similar to fig 2. One small square is surrounded by vivid yellow and the other by deep violet. One small square (B) has been cut from the same mustard yellow paper as those in figs 1 and 2. The other small square (E) has been cut from another sheet of uniformly printed paper which is a darker brown. The phenomenon of simultaneous contrast affects the appearance of the two small squares; although they were cut from different sheets of paper, in this situation they both look the same.

Are the two small squares the same colour?

Please record your opinion by underlining YES or NO.

Fig 4 represents concentric discs fitted to a motor. The larger disc has been cut from the same mustard yellow paper as the small squares marked B in figs 1, 2, and 3. The smaller disc has been made up from three separate discs which have slits in them. The slits allow the discs to be overlapped so that we see a single disc divided into segments. The three small
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discs have been cut from papers coloured red, green and blue (F, G and H). When the motor is switched on the discs spin very fast. The separate colours of the smaller overlapping discs blend so that we see a single colour. Now the colours of the larger and smaller discs look the same.

When the discs are spinning are they the same colour?
Please record your opinion by underlining YES or NO.

INTRODUCTION

At this point I need to provide some definitions. I will be using the words 'foreigner', 'xenophobia', and 'tribe' with particular meanings.

Foreigners: A foreigner has been defined as 'a person not belonging to a particular place or group' (Thompson 1995). It is the second half of that definition that I have in mind here. That means that for me, anyone who is not a designer is a 'foreigner'.

Xenophobia: Xenophobia is really too strong a word. It has been defined as meaning 'a fear or hatred of foreigners' (Delbridge 1990). For the purposes of this paper I mean something rather less extreme. I mean the ambivalent feelings that people from one group can have for those of another - feelings, attitudes and values that can get in the way of fruitful cooperation.

Tribes: People who share the same concerns with respect to colour could be said to belong to the same colour tribe. That makes me a member of the colour design tribe.

In my work, but especially through my involvement with the AIC, I have met people from many other colour tribes. In many situations a concern for colour brings people from one tribe into contact with those from another. Often they find themselves working together with a common goal, each contributing a particular expertise. My experience is that there is a kind of xenophobia operating between the tribes. They have different values and speak different languages. This can lead to misunderstanding and frustration. One or another or all involved in a common project can end up disappointed with the outcome. To turn this situation around it is necessary to deal with the xenophobia.
TWO CULTURES

There is nothing new in the observation that people from different disciplines might find it difficult to communicate effectively. The most famous expression of this concern came in C.P. Snow's lecture The Two Cultures delivered to a Cambridge audience in 1959 (Snow 1964). Snow was unusual in that he was a scientist by training who became better known as a writer. He himself was equally at ease with other scientists and with other writers. But he noticed that scientists of his acquaintance had virtually nothing to say to the writers and vice versa. There was, he said, "Between the two a gulf of mutual incomprehension - sometimes (particularly among the young) hostility and dislike, but most of all lack of understanding" (Snow 1964, p. 4). This is what I am calling xenophobia.

Susan Sontag (1966) argued that it was not a case of a conflict between two cultures, but rather the birth pains of a new single culture. Thirty three years later that vision has faded, but I like it nevertheless. Snow himself (p. 16) saw how things ought to be: "The clashing point of two subjects, two disciplines, two cultures - of two galaxies, so far as that goes - ought to produce creative chances". He went on to show how such creative chances were being denied by the education system which was driving a wedge between the arts and sciences. He urged as a solution radical educational reform.

Several years ago I suggested that colour would be an ideal topic for linking educational disciplines (Green-Armytage 1981). And it is the multidisciplinary nature of colour that is, for me, one of the chief attractions of an organisation like the AIC. The AIC is a meeting place for Snow's two cultures and for all the subcultures or tribes that can be identified within each main group. There may still be some lingering xenophobia within the AIC, but my main concern is with the xenophobia that exists outside in the 'real world' of industry and commerce.

RECIPES AND RESULTS

To illustrate how the various colour tribes interact I will use some examples, beginning with the range of colours for a new motor car. Now I need to make a distinction between what members of different tribes might understand as 'colour'.

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Physical colour and visual colour

For many of those involved with colours for a new car, colour would mean paint. They would be concerned with the availability, suitability, and durability of pigments and the processes of mixing, matching and application. Others would be concerned with the appearance of the car; for them colour would be what they see. They would be concerned with colour preference and the economics of offering a choice. The terms I have adopted for the distinction are 'physical colour' for colour meaning paint, ink etc., and 'visual colour' for colour meaning what we see.

Having made that distinction I want to draw a parallel between colour and cooking. Paints and the processes of mixing, matching and application can be equated with the ingredients and method of a recipe. The appearance of the finished car can be equated with the taste of the dish of food. For those working in the paint shop and the kitchen the focus is on the recipes. For those in the showroom and the dining room the focus is on the results. People preoccupied with recipes are likely to be thinking in terms of physical colour; those preoccupied with results are likely to be thinking in terms of visual colour.

Perhaps your own preoccupations were revealed by the way you answered the questions I asked at the beginning about how things can be the same colour.

There was no problem with the first example. The small squares cut from the same uniformly printed paper could be described as being the same physical colour. Since they were presented against a uniform background in the same light they would also have looked the same and so been the same visual colour.

In the second and third examples the phenomenon of simultaneous contrast came into play. In the second example the physical colours were the same, but the visual colours were different. In the third example the situation was reversed - same visual colours but different physical colours.

The fourth example was an illustration of metamerism and the principle of colorimetry as first demonstrated by James Clerk Maxwell (Sherman 1981). You may or may not consider a metameric pair to be 'the same colour'.

Field of Operational Relationships

Fig 5 (next page) represents in diagrammatic form what I am calling provisionally a 'field of operational relationships'. This is an attempt to show how various things relate which all
have a bearing on the colours for a new car. The two main points of focus are the recipes and the results. Contributions are made by instruments, systems, research data, and by various people. Here we can find various colour tribes represented and we can recognise different value systems at work. We can also imagine different motives and different rewards for the participants: joy of ownership, desire for a good investment, financial gain, prestige, job satisfaction etc.

The *customer* wants a large range of desirable colours to choose from and is not prepared to wait too long for delivery.

The *dealer* and *manufacturer* want to sell cars, but the size of the showroom and the economics of manufacture limit the range of colours that they can afford to offer. So the colours must be chosen with great care.

The *market researcher* and *colour forecaster* analyse sales figures, customer psychology, and prevailing fashion trends to predict likely colour preferences for the future.

The *designer* in this model, informed by market research and colour forecasting, is the one who makes the initial decisions about colour choice. Assuming that the manufacturer has set clear parameters, the designer’s recommendations would normally be adopted. Up to this point the main focus of all concerned is with the *results*, what the car looks like. But the designer also needs to know something about *recipes*, what colours and finishes are possible.

Much of what is possible now is due to the contributions of *colour science*: improved *raw materials* - more durable pigments, metallic and pearlescent finishes; *systems* and

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Fig 5
instruments which make possible extreme precision in paint formulation and colour matching. While all this is aimed at better results, the focus of attention is on the recipes.

For those who work in the paint shop, especially, it is the recipes that matter. It is not the painters' role to have an opinion about the choice of colours. Their task is to deliver the cars in the colours required. From their point of view it is simplest if they are just given a recipe. If they are required to match a colour sample they would use the sophisticated technology available to work out the recipes themselves, and they would judge their success by the accuracy of the match.

VALUES IN CONFLICT

What counts as a 'good' colour depends on what tribe you belong to and whether you are more concerned with recipes or results. There can be situations where good visual colours are not good physical colours. The following case study is about painting a house.

The Blue House

This house, overlooking the Indian Ocean west of Perth, became famous when the owner, David Bianchi, had it painted an intense blue (Green-Armytage et al. 1996). For Bianchi and the people who sent him fan mail this was a good colour. For many of the local residents who complained to the local council it was a bad colour. For the local newspaper and television station the dispute was news, so for them it was a good colour. For the paint manufacturer and painting contractor it was a bad colour. And for the painters who did the work it was a very bad colour.

The intense colours that Bianchi wanted for his house - blue outside, and blue, green, yellow, orange, red and purple inside - were not available in standard house paints. His vision could best be realised with Solver scenic paint, a water based flat acrylic paint developed for such specialist uses as scene painting and sign writing. Outside the paint would not be expected to withstand long exposure to the sun or to the wind blowing off the sea. Inside the house the paint surface marks easily and the marks cannot be wiped off. For his house Bianchi had chosen what for him were good visual colours, but they were not good physical colours.

The painting contractor, Richard Gipson (1996, pers. comm.) protested and notified the paint manufacturer. Neither wanted to have their reputations jeopardised by a paint job that
would quickly deteriorate. As for the painters, prolonged exposure at close quarters to large areas of intense colour, especially red, gave them headaches. Bianchi was sympathetic but insistent, and his solution to the expected deterioration was very simple: a fresh coat of paint.

COMMUNICATION BREAKDOWN

Members of the different colour tribes can find it difficult to see beyond their own value systems. For Richard Gipson durability of the paint finish was more important than any aesthetic vision and he painted the Blue House under protest.

The Blue House is an extreme case, but it can serve as an example of the kind of breakdown that occurs. Such breakdowns are, perhaps, more common between designers and printers.

A designer who asks for an 'impossible colour' might be regarded by the printer as ignorant.

A printer who tells a designer that colours in the artwork can't be matched might be regarded by the designer as incompetent. Mutual misunderstanding can lead to mistrust and xenophobia. That process needs to be reversed (Green-Armytage 1989a).

MENUS and RECIPE BOOKS

One way to deal with the problem of impossible colours is to offer an alternative, a ready-to-specify range of possible colours from which the designer can choose. Such a range can be presented in two forms: what I will call 'menus' and 'recipe books'.

Menus, typically provided by the manufacturers of house paints, present colour samples (i.e. colour results - visual colours) which are identified by proprietary names or numbers. The designer can select and specify colours knowing that the recipes have already been worked out and that the colours are all possible and 'good' as physical colours.

Dulux Colour Solutions

Typical menus are those produced by Dulux Australia (1997) for their Colour Solutions range. These menus are available at no cost and are intended primarily for people who plan to do their own painting and decorating. The choice is limited. On the current menu for interiors there is a choice of 96 colours. The colours are organised in groups to help people develop successful colour schemes. Menus like this have a limited life; as fashions change, new menus, with different colour selections, are produced.
**Dulux Master Palette**

The Dulux Master Palette is intended for professional designers and architects (Dulux Australia 1997). There are more than 6,000 colours in the range. The complete range is comprehensive and is presented in a colour atlas. From the colours in the atlas, 1,600 have been selected for a more portable fandeck. Colour samples are also available in tear-off swatches, and larger samples of individual colours can be ordered. Peter McGinley, Manager of Colour Services for Dulux Australia, has explained the reasons behind his company’s choice of the Master Palette (1993, pers. comm.). Dulux know their customers. Designers just want a very large and comprehensive range of colours. They want inexpensive colour samples to play with, stick down, and give away. For architectural applications they particularly want a large choice in the range of paler colours. And they want to be confident that the visual colours in the atlas or fandeck will all be good physical colours. Judged by these criteria the Master Palette is a good menu.

**Recipe books**, typically provided for use in the printing industry, present colour samples (results) together with the recipes for matching the colours. The recipes specify how much of each of a standard set of inks (or ‘ingredients’) the printer needs to mix together to match the colours shown. Recipe books as used in the printing industry are of two kinds: those for ‘process colours’ and those for ‘spot colours’. Process colours are produced in the process of printing by superimposing varying densities of the four transparent ‘process inks’ - cyan, magenta, yellow, and black. Spot colours are pre-mixed from a larger number of different inks. Pre-mixing makes for more exact colour reproduction of single colours, and the larger number of different inks used in the recipes extends the gamut of colours that can be produced.

**Harald Kueppers Color Atlas**

Harald Kueppers has produced a colour atlas (1982) which illustrates over 5,500 visual colours together with the recipes for their reproduction by the four process inks. The range is comprehensive and illustrates clearly the limits of what is possible.

**Pantone Matching System**

I have a love-hate relationship with the Pantone Matching System (Green-Armytage 1989a, 1989b). I am grateful for the large range of Pantone papers and have used them extensively, but I am baffled by the choice of colours in the range. The choice is limited. There is a kind
of order, but there are areas of colour space that are very well served and other areas where there are significant gaps - no colours at all. It does not seem likely that the colours needed to fill these gaps would fall into the impossible category. I have found this frustrating in my own work, but my main concern is that designers have allowed themselves to be imprisoned by the Pantone range and I get depressed when my colleagues accept its limitations without complaint as the 'industry standard'.

VALUES AND STANDARDS

It may be safe to work with menus and recipe books like these, but where the colour choice is limited that does not seem to me to be the best route to innovative design. Standards like these can work against innovation, but there are other kinds of standards which can achieve the opposite. Standards can make new things possible. However it should be born in mind that standards come with values attached.

Colour order systems

Colour order systems are a case in point. There are many instances of new knowledge generated through their use. I have also witnessed lively debates between the tribes about the merits of rival systems. Usually it is simply a case of different values being best served by different systems. There is no such thing as one 'best' system for everybody. My own values are best served by the Natural Colour system (NCS), but like all colour order systems, the NCS comes with hidden values which I would reject if I could. As it is, I can't have it both ways. I value the system partly because I can carry a model around in my head. That model helps me think about colours, but, by its very structure, it also controls the way I think.

Some twenty years ago I was discussing a colour circle with Western Australian artist David Gregson (1978, pers. comm.). I could see that it was bothering him. Eventually he was able to put his concern into words: yellow was at the top of the circle which gave it a kind of unmerited status. For Gregson any kind of artificial and permanent colour hierarchy was anathema.

Norms and normality

Norms are not quite the same thing as standards. Some might think of normality as meaning the same thing as that which is natural, but Georges Canguilhem has argued that normality, like standards, is a social construct. "No structure is normal in itself" (Canguilhem in
Delaporte 1994, p. 54). If this is so there can be no such thing as a truly 'natural' colour order system, only systems that reflect the values of particular groups.

Note: Without denying the general thrust of Canguilhem's argument a case might now be made for claiming that there is, after all, a 'natural' colour system. C.L. Hardin (1997) has reported results of recent research in support of that idea.

If there is conflict between those who promote one system over others, that is to be expected. I might claim to value several different systems, and I do, but a claim to value them equally couldn't make sense. The norms of one system would be cancelled out by those of another if both were equally valued. Canguilhem suggests that acceptance of more than one norm only makes sense if it is accompanied by some kind of rank order.

Different systems reflect the different values of the different colour tribes. I am not arguing for valuing all systems equally, but I am calling for acknowledgement of other values. This is to make way for Snow's 'creative chances' that might come from open-minded cooperation between members of different tribes.

**Industrial standards**

I still find it miraculous that I can present a colour sample in a paint shop and walk out a few minutes later with a can of paint that will match my sample. This is just one of the miracles that depend on the international standards established by the CIE.

I wish things were so easy in the world of computerised graphic design and printing. It is not that there is a shortage of miracles. If anything there are too many miracles, too many independent devices - scanners, processors, monitors, imagesetters, printers. What you see on the computer screen may, at best, be only an approximation of what you will get in the print.

At AIC Color 97 in Kyoto, Roy Berns (1997) and Michael Stokes (1997) both spoke about the problems of colour management. I understood that the key to it all was seen to be the establishment of a new international standard - a standard colour appearance model.

**CONSTRUCTIVE DIALOGUE**

I hope progress has been made with the colour appearance model and that the new standard will soon come to our rescue. My colleague Milton Andrews (1999, pers. comm.) tells me
that local printers are beginning to relinquish responsibility for their work. They get their instructions in a computer file and so have little control over the outcome. This is having the effect of turning designers into technicians as full responsibility for the outcome falls back on them. They are having to learn new languages and become open to other values.

**Colour science for designers**

Designers are beginning to pick up the language of colour science, out of necessity, and much as one might learn another language from living in another country. They might benefit from a good textbook like the one written with them in mind by George Agoston (1987), but, as Tibor Kalman has wryly observed, "designers don't read" (1991, p. 50). So they must learn on the job, often from the mistakes.

**Design for colour scientists**

No doubt those working on the problems of standardising a colour appearance model are guided by the values of their own colour tribe. I hope they are also open to other values and maintain a dialogue with other tribes - the prospective users, designers and print technicians.

**COMMON LANGUAGE**

There are certain key concepts that I think designers and colour scientists should share. The best way to establish these would be through dialogue. A good place to start would be with the dimensions of appearance and related terminology. Terms that need sorting out include hue, value, lightness, brightness, nuance, chroma, chromaticness, colourfulness, fluorence, saturation, darkness.

Perhaps it is naive to hope that there will ever be an international standard to eliminate the confusion over terminology, or that people would then change their language habits and use the terms with their new 'official' meanings.

An alternative might be a kind of all-language phrase book. I might then be able to look up a word like hue and find out that one group uses it to mean 'dominant wavelength' while for another group it means 'relative resemblance to two elementary colours'. Then I could look up elementary colours and so on. I could also look up an expression that I heard an artist use that still baffles me. She was having difficulty with a painting and said she would have to 'take that colour back'.
Meanwhile communication of a kind is still possible. We do have a common language: the jargon-free speech of everday and ordinary people.

Hailing

When I asked you at the beginning what colour you would like for a new car I wonder what you wrote down. CIE xyY chromaticity co-ordinates? Something like 5R 5/14 or 1080 Y90R? A proprietary name like Windsor Red or a national standard like Waratah? My guess is you just wrote something like 'red' or 'metallic dark blue'. By the way I set up the question I put you in the position of customer, an 'ordinary person' who had won a prize at a motor show. According to Louis Althusser's use of the word, I 'hailed' you as a customer.

John Fiske (1990, p. 175) has explained Althusser's point that hailing is one of the most insidious aspects of ideology. If you responded to my question you effectively accepted the role I assigned to you, you participated in your "social, and therefore ideological, construction" as a capitalist subject. However it is not my intention here to demonstrate the principles of Marxism.

My point is that you responded in the language of an ordinary person because I addressed you - hailed you - as an ordinary person. If I had addressed you as a colour scientist or a marketing expert you might indeed have used chromaticity co-ordinates or a proprietary name.

Since all colour tribes understand everyday language it might help to use it more often. It might also help if we can find a way to make everyday language more precise, and that is a project in which I am currently engaged.

MEANS AND ENDS

I would like to finish with more questions.

Canguilhem draws a distinction between utility and value. He suggests that a concern with utility focuses attention on means in such a way that we lose sight of the ends. But "means only exist in relation to ends" (Canguilhem in Delaporte 1994, p. 380) and by accepting certain means we unconsciously accept the ends and, therefore, the values that the ends imply.
So I think we need to go back to the future as it were. If certain means are perfected, what ends will be achieved and who will benefit? What values will be served? What are the objectives of colour science? of colour design? and whose objectives are they?

CONCLUSION

I don't think those questions can be answered within a single colour tribe. The case of the motor car showed how intricately the values of the different tribes are bound up with each other. But it can help to focus on the ends, and at the end of that particular process is the person who buys the car, the customer, and the customer's values.

The same can be said of graphic design. The client who pays the designer and printer wants to communicate a particular message to a particular audience. Graphic communication is a business with an insatiable appetite for new ideas. Menus and recipe books may not be the best places to look. Designers, printers and colour scientists can only do so much on their own. To achieve the creative chances they must work together.

Mutual respect, acknowledgement of each others' values, shared concepts, and, as far as possible, a common language can bring an end to xenophobia and that can open the way to a more stimulating, satisfying, and meaningful colour environment.

POSTSCRIPT

Following the Warsaw conference I reviewed people's answers to the questions I had posed at the beginning of my presentation.

This exercise was more a game than serious research, but I think such games can be worth playing. Sometimes they can lead to unexpected insights, and they can also show what directions a more carefully constructed research project might follow. Ian Hacking (1983, p 154) has argued in favour of conducting experiments simply out of curiosity. Apparently the physicist George Darwin used to recommend that one should, from time to time, carry out "... a completely crazy experiment, like blowing the trumpet to the tulips every morning for a month".

What follows are the raw data and some preliminary observations.
Participants

The list of participants at the conference has 89 names. I received answers from 60. Not all those on the list would have attended my presentation and, perhaps, some of those who did attend chose not to answer my questions. According to the list there were participants from 23 different countries. The largest numbers were from Japan (16), Korea (12), Poland (8), Argentina (8), U.S.A. (7), Spain (6), and Turkey (5). There were three each from Germany and Sweden, two each from the Czech Republic, France, Hong Kong, Italy, Russia, Slovenia, and South Africa, and one each from Australia, Bulgaria, Canada, Hungary, the Netherlands, Singapore, and the United Kingdom. Judging by the affiliations of the participants it would seem that each of C.P. Snow’s two cultures were well represented, with the scientists in the majority. For every two who might have been loosely categorised as ‘designers’ there were roughly three ‘scientists’.

Colours for a new car

In the case of people’s colour choices for a new car I was testing a specific hypothesis. And I believe I can claim to have made my point. The hypothesis was that, if I addressed people (hailed them)

<table>
<thead>
<tr>
<th>COLOURS</th>
<th>WARSAW 60 conference participants</th>
<th>AUSTRALIA 61 design students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>Metallic red</td>
<td></td>
<td></td>
</tr>
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<td>Reddish wine colour</td>
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<td></td>
</tr>
<tr>
<td>Deep/dark red</td>
<td>1</td>
<td>3</td>
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<tr>
<td>Metallic dark red</td>
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<td></td>
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<td>Dark pearly red</td>
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</tr>
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</tr>
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<tr>
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</tr>
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<td>8505 (?)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Rainbow car</td>
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</table>

Table 1
as 'ordinary people', they would respond in the language of ordinary people. This turned out to be the case in spite of the fact that those attending the conference were certainly not 'ordinary people' with respect to colour. Many were well versed in colour science and very familiar with the use of chromaticity co-ordinates and spectrophotometric curves for the precise specification of colours. Others were architects or designers who were probably familiar with the use of colour order systems and their notations as another means of specifying colours with a high degree of precision. But there was little precision in the answers they wrote down. The majority just used an unqualified general term like 'red', 'blue', or 'green'.

People's choices are set out in table 1. The colours are arranged roughly in hue sequence from reds, via blues and greens to yellows, followed by whites, greys, and blacks. Gold follows yellow, and pearl and silver are between white and grey. General preferences seem to follow a similar kind of order if in-between colours like purple and blue-green are excluded.

It was interesting to compare the choices of the Warsaw conference participants with the choices made by a group of 61 of my first year design students, so I have put the two sets of figures side by side. At the beginning of their course my students were 'ordinary people'. I had different reasons for asking them to choose car colours: I wanted to raise issues of the role of colours in marketing. I also asked my students to give reasons for their choices, and an interesting distinction emerged in their answers. The most frequently given reasons were either that the colours were personal favourites or that the colours were "stylish" or "classy". Amongst other reasons: six chose colours because they were "good colours for a car" and four chose colours that were "easy to see".

How two things can be the same colour

There was a bigger question behind my questions about whether or not two squares or two concentric discs were the 'same colour'. The bigger question was: What is colour?

I think it can be helpful to think of colour as something with a multiple identity. In the paper I made a distinction between what I called 'physical colour' and 'visual colour'. I am now reconsidering the merits of those terms. Perhaps I would have done better to have used Gunnar Tonnquist's (1989) distinction between 'colour stimulus', 'colour percept' and 'colour valence'. My 'physical colour' roughly equates with Tonnquist's 'colour stimulus', and my
'visual colour' with his 'colour percept'. 'Colour valence' is a useful addition and can be understood as a bridge between stimulus and percept:

"In colorimetry, the spectral power distribution of the stimulus is measured with physical methods. Human colour vision is simulated by an evaluation, based on psychophysical colour-matching experiments made once for all. Using the mean values as the CIE standard observer ... reduces colorimetry to physical measurements and mathematical calculations, resulting in the colour valence of the stimulus, expressed as its tristimulus values and chromaticity coordinates". (Tonnquist 1989, pp 162-3)

'Colour valence', therefore, is "the capacity of a stimulus to evoke a colour percept".

The four situations illustrated in figs 1 - 4 can be grouped in three ways: those where the colour stimulus is the same, those where the colour percept is the same, and those where the colour valence is the same.

For the first three situations I used two sheets of card. One sheet had two square windows cut in it. It was uniformly white on one side; on the other side two pieces of Pantone paper were stuck down so that the sheet was half yellow and half violet, each window being surrounded by a different colour. The other sheet of card had pieces of Pantone paper stuck on each side. That is what people saw through the windows when I held up the two sheets of card one close behind the other. That is how the two small squares were produced for people to judge. On one side of that second sheet there was a single piece of mustard yellow paper which appeared behind both windows. On the other side were two pieces of paper, a mustard yellow piece to appear behind one window (on the yellow side) and a darker brown piece to appear behind the other window (on the violet side).

I am fairly sure I revealed what was behind the windows in the order I intended.

For the situations illustrated in figs 1 and 2 I believe everyone knew before they made their judgements that there was a single piece of paper behind both windows. Since Pantone paper is uniformly printed, the two squares were shown to be the same 'colour stimulus'.

For the situation in fig 3 I tried a conjuror's sleight of hand and showed the mustard yellow surrounded by yellow and the darker brown surrounded by violet and asked people to judge before revealing that there were different pieces of paper behind the windows.
To my great dismay I was not able to demonstrate the situation illustrated in fig 4. My motor was working when I tested it in my hotel room the night before, and it works now that I am back in Australia. For reasons unknown it would not work in the lecture room. I could only hold up the two discs, explain what was supposed to happen, and ask people to trust me that the match would be a good one.

Hindsight: This might have been to my advantage. Although the match is indeed a good one, it is not quite perfect. But the circumstances are as exacting as they can be with no separation between the inner disc and the outer ring. Since I could expect people to be familiar with the spinning disc technique and to know that such a perfect match is indeed possible, I could expect them to trust me. If I ever do these demonstrations and ask these questions again I will introduce a ring of neutral grey to separate the central disc and outer ring. With that separation the very slight difference in colour would not be discernible.

So what is required for two things to be the 'same colour'?

For the situations in figs 1 and 2 the colour stimulus was the same. For the situations if figs 1, 3, and 4 I believe most people would have agreed that the colours looked the same, so the colour percepts would have been the same. And if Maxwell's spinning discs are acknowledged as representing the principles of colorimetry I could claim that for the situations in figs 1, 2 and 4 the colour valences were the same.

People's answers are set out in table 2. Rather than simply record the number of people who answered 'yes' or 'no' to each question I have also indicated how many gave what pattern of yes/no responses.

I had anticipated that a significant number would have judged the squares in the fig 2 situation to be the same colour. They were the same colour stimulus and had the same colour valence. The overwhelming 'no' response suggests that, even among those whose main concern is with colorimetry, colours are not the same unless they look the same. The colour percepts must be the same. And in that situation the phenomenon of simultaneous contrast ensured that they did not look the same.
Replies to the question:

Are the two small squares the same colour?

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TOTALS: 55 3

When the discs are spinning, are they the same colour?

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<table>
<thead>
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<tbody>
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<td>2</td>
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<table>
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</thead>
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</tbody>
</table>

TOTALS: 34 25

Table 2

Given that response I might have expected an equally strong 'yes' response for the situation in fig 3. While the 'yes' responses do exceed the 'no' responses, the comparatively large number of the latter could be taken as an indication that I was not as successful as I might have been in counteracting the affect of simultaneous contrast. In spite of my best efforts, perhaps the colours did not look the same. That interpretation is supported by the 13 who said 'no' to the situation in fig 3 but 'yes' to the situation they imagined for the spinning discs of fig 4. However that interpretation is challenged by the nine who said the opposite - 'yes' for fig 3, but 'no' for fig 4.

I would like to conclude with a serious request for feedback - comments on the paper itself and any other ideas on how the responses to my questions might be interpreted.
REFERENCES


Dulux Australia, 199?, The Master Palette, Dulux Australia, Clayton, Victoria.


Green-Armytage, P. 1989a, Printers and Designers should be Friends. Invited paper, Lithographic Institute of Australia, 10th Biennial Convention, Fremantle, Western Australia.


Hardin, C. L. 1997, 'Basic Color Terms and Basic Color Categories', in Colour and Psychology, ed. L. Sivik, Scandinavian Colour Institute, Stockholm.


THE COLOR DESIGN IN THE EXPERIMENTAL CHROMATIC MEASUREMENTS FOR ENVIRONMENTAL SYSTEMS FOR CHILDREN

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This research refers to a project for a "Playground of Colors" that can be implemented in Genoa (Italy).

Hence the creation of environmental systems for children based on a pedagogic approach in between scientific culture and colour expression. In addition to the original shape-design, with its own symbolic/environmental references, colours will give life to emotional and evocative scenarios also following chromatic-dynamic and chromatic-psychological principles. The pedagogical objective is achieved through the use of color, for a joyful and stimulating balance, for "lighting up" children's senses and imagination.

In order to support my research with a strong scientific background, I have carefully studied the historical as well contemporary literature on color (by authors like Pfeiffer, Itten, Helmholtz: "Physiological Optics") up to the excellent work by Shigenobu Kobayashi (Nippon Color & Design Research Inst.) as well as studies on photography.

It is thus a "creative" processing of color measurements linked to feelings and to the evocative meaning from different perceptions of environments.

- "The Sea Space": formal waves accompanied by dynamic tone-rich notes from blue to turquoise, which accompany the emotion raised by the environment;

- "The Geometry Space": rational constructions with different planes with primary and secondary colors, as a function of the orthogonal and "rational" arrangement of the environment;
• "The Island of Colours" and "The Maze": these areas are built with discreet shapes-colors with symbolic-chromatic shapes (red circle etc.): all routes must be remembered by their color. The surface sizes match the various color forces in order to maximize the resulting effect and, at the same time, give a correct and harmonious presentation to children.

In this research work, color-design, besides its space-environmental function, also offers a new cultural and pedagogic experience: color is intended to stimulate vital perceptions, but also as a color to be loved.

By applying science and creativity in full awareness, the aim is also to create for children while offering suggestions to grown-ups.

In-depth Analysis:

- The Playground of Colours is the first project of this type
- Characterisation of colour-design in the project:

Shapes in colour design become chromatic measurements as part of space development for environmental systems for children (to be considered from a pedagogic point of view)

Measurement = selected colour perception aiming at creating "harmonious assemblies" even in their overall distribution.

Aims: learning; intelligent and creative involvement of colour

- This strict functionality, although somehow reducing improvisation and causality, aims at giving children a rich and sophisticated experience, since colours are considered not only as an intelligent but also as a creative and involving form of learning.

- The colour shapes designed in these environmental systems for children are clearly expressed and give a specific spacial rhythm through different expressions. Their role is to characterise different sections, thus becoming routes or colour shapes to be "walked across" and therefore becoming measurements of the body.

On the other hand, colours clearly self-quantify themselves in their own expressive form.

This, being an empirical research work, is likely to generate greater intuitions and creativity in designed solutions.
Actually, all "ingredients" are in perfect synergy: colour design, pedagogy, creativity, emotion, play, fascination. In other words, a soft context to create these environmental systems.

These modular spaces are specially designed to be freely interpreted by children - where, I stress this point again, colour is offered as an intelligent form of learning, which is also creative and involving.

...Hence, colours become a "Child colour" when - this is actually an apparently simple name I have invented after this complex experimental work -, ...when colour is matched with pedagogy, art, creativity, play, fantasy and imagination...

Therefore, this "Child Colour" finds all its possibilities of expression in the "Playground of Colours".

If we analyse the project, what has been stated above can be verified on a formal level. Owing to the essential type of children's perception, the colours scale is the essential one, because it is the one which bests suits learning.

This project is based on previous extensive educational work by Silvia Rizzo on visual art, design, art education and pedagogy presented at the following international events:

1983 - "Creation et Pédagogie à partir du matériau terre", Atelier des Enfants, C.Pompidou, Paris,
1984 - "Silvia Rizzo: An Italian Painter between History and Contemporaneity", Italian Cultural Institute, New York,
1985 - "The Creative Experience", New York University, Dept. of Art and Education, New York,
1987 - "Communicating Creatively through Color", Stanford University, California,
1987 - "Kognitives Farberlebnis zwischen Kreativität und Projekt" (1st Prize for Didactics), Internationaler Farb-Design Preis, Stuttgart, Germany
1988 - "Color signals in the city and pedagogical experiences", Colour Dynamics 88, Budapest,
1991 - "Discovery of Color through Play", Boston Children's Museum, Boston,
1993 - "Color and Environmental System for Children", Colour 93, Budapest,
1994 - Presentation of the project "Museum of European Children, Citizens of the World", Atlanta, USA,
1997 - AIC Color 97, Kyoto Exhibition in Poster Session of the "Soft Energy of Color" (Art Education), Chairwoman at the Oral Session "Environmental Color Design".
1998 - ACTFL International Conference, Chicago.
Cover of the project "Playground of Colours"

A detail of project

Child colour: Colour Sculpture by Silvia Rizzo

Child colour: "Colour Games" by Silvia Rizzo at the Children's Museum in Boston

Studies on "Child Colour", "Telephone", "Clock" designed by Alessandro Picasso, a former student of Silvia Rizzo
COLORS OF THE FOUR ELEMENTS IN RELATION TO THE ECOLOGY

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1. Introduction

Increased awareness of environmental problems has recently created a new social issue known as the ecology. The concept of ecology was initially derived from the apprehension of destroying the mutual relations of harmonious equilibrium shared by individuals and nature, or eventually, of man and nature.

In the field of design, the concept known as the Green Design signifies the study of design in relations to environmental issues. Through the usage of colors which symbolize the ecology, the green design emphasizes the importance of environmental preservation throughout our society and inaugurates various design-related social activities with the intent of establishing a nature-friendly society.

This study focuses on the method of communicating the nature-friendly ecological message through the use of visual colors.

The natural environmental elements closely related to ecology have been defined into the four elements of water, fire, air, and earth.

Figure 1. Flow chart of the research

From the ancient times, the four elements have always been associated with colors. Therefore, this paper endeavors to understand the characteristics of colors of four elements in three different aspects; first the paper observes the four elements and related...
colors in history of art according to each period leading up to the 18th century; second, the paper examines paintings to observe the colors of the four elements used in the paintings as the colors reflect subjective usage of colors based on reality and memory of natural factors; and third, the paper considers the proposed colors of the four elements in the fashion industry where the premise of the four elements emerges as an important theme in relations to ecology. In addition, the study proposes specific color palettes for transmitting the image of the four elements.

2. Theory of the Four Elements

Nature's basic constituents of water, fire, air, and earth are the four elements, which possess the distinctive feature of undergoing perpetual change, and they provide an important manifestation on the human perception of nature's image. The origin of the four elements can be traced back to the element which symbolizes the creation of the universe.

As Table 1 shows, from the time of Thales to Stephanus of Alexandria, the theory of elements offered symbolic insights in enriching the material imagination of all cultures.

In 5 B.C., by classifying different materials into four elements, Empedocles offered the theory of the four elements, a concept we are most familiar with today. He used the four elements to explain the relations of uniformity and versatility and considered the four elements as the means of existence suitable for different material rather than as a part of nature. That is, the earth was viewed as solid and dry, water as liquid and cold, and air as vapor and gas. Meanwhile, fire, as the hardest element to catch, was considered to be a flowing, ethereal element changing to moving particles as it flickered in light and warmth.

In 6th century, Stephanus introduced the concept of 'intermediate body' to explain the organic integration of cosmic elements and like Platon, offered the principle of interdependent genesis. That is, fire is hot and dry therefore, impregnates the heat into the atmosphere and results in the dryness of the earth whereas since water is cold and humid, it impregnates humidity into the air and causes coldness of the earth. The earth in turn is cold and dry, therefore, impregnates the coldness of water and dryness of fire whereas the humidity and heat of air impregnates the heat of fire and humidity of water. The logic behind this innovative concept resulted in integrating the relations of the four elements into
the classified combination of metaphysics, physics, and chemistry, thus providing the basis for schematization.

In the 20th century, the theory of elements is found in the work of Bachelard which shows the diverse materialistic imaginations in relations to the natural elements of fire, water, air, earth.

Table 1. Theory of elements according to each period

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<tr>
<th>Era</th>
<th>Author</th>
<th>Theories of elements</th>
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<tr>
<td>7 B.C.</td>
<td>Thales of Miletus</td>
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<td>6 B.C.</td>
<td>Heraclite</td>
<td>Sea: Dry of humid atmosphere.</td>
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<td>5 B.C.</td>
<td>Empedocles</td>
<td>Water: Liquid, cold</td>
</tr>
<tr>
<td>Greece</td>
<td>'Elements of the Universe.'</td>
<td>Air: Evaporation, Gasification</td>
</tr>
<tr>
<td>5 B.C.</td>
<td>Philolaus Pythagorean</td>
<td>Aquatic icosahedron</td>
</tr>
<tr>
<td>Greece.</td>
<td></td>
<td>Aerial octahedron</td>
</tr>
<tr>
<td>6 A.D.</td>
<td>Stephanus of Alexandria</td>
<td>Water: Humid, cold</td>
</tr>
<tr>
<td>Alchemy</td>
<td></td>
<td>Air: Warm, humid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fire: Warm, dry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Earth: Cold, dry</td>
</tr>
</tbody>
</table>

3. Colors of the Four Elements

1) The colors of the four elements in art history

The theory of the four elements has drawn much interest from the ancient times of Pliny to Goethe. The changing relations of colors and elements as stated in art history materials can be summarized as the following.

As Table 2 shows, in 5 B.C. in Greece, Empedocles explained the harmony of the four elements by referring to the analogy of the mixture of colors used by painters. Democritus, in his writing ‘On Colors’, associated air, earth, and water to the color white and fire to yellow.
As Table 2 shows, until 1-2 B.C., nobody was able to scientifically link colors to the four elements. The belief of Democritus that the element itself does not possess any color (color is the secondary feature of an object) remained dominant until the Middle Ages. The only person who succeeded in associating the different colors to each element appeared after 2 B.C. An Athenian astrologer named Antiochos associated earth to black, air to red, water to white and fire to yellow.

In the 15th century, in his thesis on paintings, Alberti linked the elements to colors. His association varied from previous theories in view of the fact that he did not consider black and white to be basic colors. Instead, Alberti associated red to fire, blue to air, green to water, and ash color to earth.

Meanwhile, Leonardo da Vinci defined the four colors that exist between black and white as the four colors of the elements. The association made by Leonardo da Vinci is almost identical to the one made by Alberti except for the fact that, da Vinci defined yellow to be the color representing the earth.

Table 2. Colors associated with the four elements according to each period

<table>
<thead>
<tr>
<th>Era</th>
<th>Author</th>
<th>Colors associated with four elements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Air</td>
</tr>
<tr>
<td>5 B.C</td>
<td>Empedocles</td>
<td>black</td>
</tr>
<tr>
<td></td>
<td>Democritus</td>
<td>white</td>
</tr>
<tr>
<td>4 B.C.</td>
<td>Aristotle</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Peripatetic</td>
<td></td>
</tr>
<tr>
<td>2nd century</td>
<td>Antiochos</td>
<td>red</td>
</tr>
<tr>
<td></td>
<td>Theon of Smyrna</td>
<td>blue</td>
</tr>
<tr>
<td>12th century</td>
<td>Urso de Salerno</td>
<td>blue</td>
</tr>
<tr>
<td>13th century</td>
<td>Pseudo-Dionysius</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thomas of Cantimpre</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pope Innocent III</td>
<td></td>
</tr>
<tr>
<td>14th century</td>
<td>Bartolo of Sassoferrato</td>
<td></td>
</tr>
<tr>
<td>15th century</td>
<td>Alberti</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Leonardo da Vinci</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rosex</td>
<td></td>
</tr>
<tr>
<td>18th century</td>
<td>Goethe</td>
<td></td>
</tr>
</tbody>
</table>
2) The colors of the four elements expressed in paintings

The colors of natural elements based on our memory differ slightly when we compare them to the actual colors of the objects. However, the most specific colors of the four elements can be found in paintings. In order to observe the characteristics of natural colors of the four elements revived in paintings, the 35 paintings of famous artists after the 17th century including Rembrandt, Goya, Cezanne, Renoir, Monet, Chagall, Kandinsky, Miro, Edouard Pignon, Rene Magritte, Natalia Nesterova, and Guy-Rachel Grataloup have been analyzed according to the colors of the four elements used in their paintings. As a result, in 11 paintings, water was depicted by using 35 different colors; in 7 paintings, fire was depicted in 17 different colors; in 14 paintings air was depicted in 39 different colors; and in 4 paintings earth was expressed in 12 different colors.

As shown in Figure 2, water was mostly expressed in the color ranges of blue and green. Only in the paintings of Kandinsky and Rembrandt was the water depicted in colors of purple and orange. Fire was expressed in red, orange, yellow, and purple and air in the color range of yellow, green, and blue. Red, orange, and yellow were used to express earth and plants were depicted with green. Therefore, fire and earth were depicted in warm colors whereas water and air were depicted in cold colors.

By comparing the colors of the elements as shown in the Figure 3, the color range used to express water and air was broader than that which was used to express fire and earth, proving that water and air is expressed in versatile ways using various colors. Water was depicted by using darker colors whereas air was expressed in lighter colors. Meanwhile bright and vivid colors were mostly used to express fire and darker and soft colors were used to express earth. Although it is common in paintings to select color usage based on individual, subjective interpretation, the study proved that the colors used to express each natural element can be classified into a specific range of colors. Furthermore, by observing the colors used after the Middle Ages to express the four elements of nature, the study confirms that water can be associated with green, air with blue, fire with red and earth with yellow.
Figure 2. Hues of the four elements expressed in paintings

Figure 3. Tones of the four elements expressed in paintings
3) Colors of the four elements in the fashion industry

In order to understand the colors of the four elements used in the fashion industry, recent fashion magazines were scrutinized and as the result, conducted research on the theme related to the four elements and proposed colors as shown in the '88-'89 L’année de mode, '97 View on color, and '95-'98 Textile view. Since in the fashion industry, the colors were presented in various images associated with the four elements, the analysis of the images were made by grouping them according to their similarities. As Figure 4 shows, water was expressed in all colors except for red and the colors of green and blue were used most frequently to represent water. Fire was particularly represented in warm colors such as red, however, colors in the range of green and blue were not used to represent the theme of fire. The subjects associated with air were mainly depicted in blue purple, and often, warm colors were also used. Earth was mainly represented with orange and colors such as green and purple were never used to express the theme of earth. As Figure 5 illustrates, the color distribution of the four elements shows a certain disparity. Water was represented by using the broadest color range although soft colors were not used to represent water. Air was depicted in soft colors, fire in dark and vivid colors, and earth in dark and dull colors. Therefore, in the fashion industry, colors of the four elements can be represented in different color ranges and the various images related to the four elements can be represented by the versatility of different colors.
Figure 4. Hues of the four elements in the fashion industry

Figure 5. Tones of the four elements in the fashion industry
4. Conclusion

Under the hypothesis that the environmental concept in relations to ecology can be expressed in the four elements representing nature, this paper focused on uncovering the distinctive characteristics of the colors related to the four elements, which can be used effectively to convey the nature-friendly message. As a result, the paper confirmed that from the ancient times to the middle ages, nature has always been an object of great interest and played an important role in establishing philosophical and esthetical classification of values.

The four elements of nature are represented in multifarious color schemes, and in particular, the symbolic representation developed from the middle ages of associating red with fire, yellow with earth, green with water, and blue with air has established the norm for color representation of the four elements. It is within this color spectrum that images of colors and natural elements are transmitted to humans. The four colors of red, yellow, green, and blue is also associated with the basic colors in the standardized color classification which is based on man’s instinctive color perception. Furthermore, the images transmitted by color ranges correspond to the material images projected by the four elements; air is soft blue, water is cool green, earth is hard yellow, and fire is warm red.

![Diagram showing the four elements of nature and their properties](image-url)

Figure 7. Development of the concepts the four elements
REFERENCE

- Young in Kim, Recherche sur une méthode de communication par la couleur dans la création vestimentaire – Pour une couleur écologique liée aux quatre éléments, Université de Paris 1 Panthéon-Sorbonne, Doctorat en arts et sciences de l'art, 1998
- John Gage, Colour and Culture, London, Thames and Hudson, 1993
THE CHARACTERISTIC OF KOREAN SAIKDONG COLORS USING NATURAL DYEING

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379-33 Nasan-ri Subuk-myen Damyang-gun Chonnam 517-910 KOREA
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e-mail: nanoh@hanmail.net

Preface
The "Green Round" movement has been headed toward recovering the polluted earth. Public awareness for this has been established by environmentalists and conservationists. For example, in the textile industry, only natural dyes were used until W. H. Perkin made artificial dyes in 1856. But, with the development of science, the advanced artificial dyes have made a remarkable contribution to the textile industry. Its advantages are simple dyeing process, unlimited use of textiles, excellent color representation and resistance to fading. These dyes were produced in great amounts and it brought a great improvement in quality and quantity. But too much waste water from textile factories destroy the environment. This has proved that some dyes are harmful to man.¹

Natural dyes are still used in undeveloped countries more than in advanced countries. These days, awareness about natural dyes is increasing all over the world. Natural coloring looks elegant and is moth-proof and antibiotic. It does not contaminate water, and it is not harmful to human skin. But it's sometimes said that its color representation is understated and its resistance to fading is a little low.

Difficulties are in mass production, management and storage of dyeing materials and the delicate production process, so studies by public and private research organizations are in progress. Recently, an emotional aspect of colors has been noticed. The simple arrangement of colors that represents the traditional folk scheme were chosen as a subject of the study. The color arrangement represents the feeling that colors imply. It is rooted in the national
consciousness of Koreans. Each nation has its unique color. It is often arranged according to the climate of its country and it sometimes represents its national character.

This study is focused on Saikdong textile. They were used for clothes of the royal family, wedding dresses of the civil and the gentry, children's clothes for national holidays and shamans' clothes. The purpose of this study is to judge if the represented colors of Saikdong using natural dyes can be used for modern textiles. The method of the study is that red, blue and yellow colors are extracted from various kinds of dyeing materials. They are applied to cotton, ramie cloth and silk to estimate and compare colors that look differently according to materials used using spectrophotometer. This is to establish the Korean image with aesthetic character and develop new natural dyeing materials.

Aesthetic Character of Saikdong Colored Stripes

This study is focused on Saikdong colors. It is a trial of recovering Korean traditional beauty to find the aesthetic value of Saikdong colors. The aesthetic character of Saikdong are divided into internal and external factors. Art and beauty are loving fellows that bring joys and pleasures to people. They help people to enjoy their clothes. The pleasant aesthetic culture is enjoyed only by humans. It is said the German poet, Goethe, had an excellent talent in the study of colors. He said in his book, 'The Theory of Colors' that original colors are mainly used by the primitive and neutral ones by people who live in a advanced culture.

Korea has beautiful scenery and four distinct seasons. When they use colors in daily life, they usually select Korean-style colors. It is deep-rooted habit inherited from ancestors.

1. Philosophical Background.

In the middle of nineteenth century, pragmatism was introduced in Korea. The central consciousness of Koreans who were first in contact with the scientific world in the age of enlightenment is based on the dual principle of the negative and positive, and the Five Elements Theory. They have a close connection with colors. This principle has been established based on the ideology of the universe. It suggests the origin of the universe is Yin and Yang. In the Five Elements Theory, Su, which means water and consists of one heaven and six lands is located in the north. Wha which means fire and consists of one heaven and two lands is in the south. Kum which means gold and consists of three heavens
and eight lands is in the west. To which means earth and consists of five heavens and ten lands is in the center. Tongbang (eastern direction) represents Mok which means trees, blue and the left. It is said that it located in the springtime of life. Kum represents four directions, white and the right. Wha represents the south, red, the upper section and a hot summer. Su represents the north, black, the lower section and a black winter. This theory considers the universe as five elements, Kum, Mok, Su, Wha and To. It has a complete system of various phenomena of the universe such as changes, disasters, human businesses and fortune. So blue, white, red, black and yellow are regarded as the five colors of the universe and are called the five emotional colors.

The colors above belong to Yang. Another five secondary colors that are placed in the east, the west, the south, the north and the center belong to Yin. The secondary color of blue and yellow is green. That of blue and white is light-blue. Light red is regarded as a secondary color of red and white. Sulfuric yellow is a secondary color of black and yellow, and purple is a secondary color of black and red. The ten colors above are considered the basic colors of Yin and Yang. It is inferred that Saikdong are related to the Yin and Yang principle, and the Five Elements Theory in that stripes in a Saikdong colored pattern mainly consist of red, blue, yellow and white that are the main colors of the theory. In natural dyes, blue, red and yellow should be arranged in order so that the desired colors are shown. It is a natural law according to the two theories.

- The five element theory -

<table>
<thead>
<tr>
<th>five elements</th>
<th>color</th>
<th>directions</th>
<th>season</th>
<th>emotion</th>
<th>viscera</th>
<th>sense</th>
<th>virtue</th>
<th>taste</th>
</tr>
</thead>
<tbody>
<tr>
<td>wood</td>
<td>blue</td>
<td>east</td>
<td>spring</td>
<td>delight</td>
<td>liver</td>
<td>eye</td>
<td>benevolence</td>
<td>sour</td>
</tr>
<tr>
<td>fire</td>
<td>red</td>
<td>south</td>
<td>summer</td>
<td>anger</td>
<td>heart</td>
<td>tongue</td>
<td>politeness</td>
<td>bitter</td>
</tr>
<tr>
<td>earth</td>
<td>yellow</td>
<td>main</td>
<td>all season</td>
<td>desire</td>
<td>spleen</td>
<td>body</td>
<td>fidelity</td>
<td>sweet</td>
</tr>
<tr>
<td>metal</td>
<td>white</td>
<td>west</td>
<td>fall</td>
<td>enjoyment</td>
<td>lung</td>
<td>nose</td>
<td>justice</td>
<td>plain</td>
</tr>
<tr>
<td>water</td>
<td>black</td>
<td>north</td>
<td>winter</td>
<td>decline</td>
<td>kidney</td>
<td>ear</td>
<td>wisdom</td>
<td>salty</td>
</tr>
</tbody>
</table>
Also the combination and arrangement of Saikdong are made according to the concepts of the incompatibility and the compatibility of the Yin and Yang principle and the Five Elements Theory. A compatible arrangement of colors has the meaning that the universe is cooperated and harmonized for pleasure and happiness, so it is used for making clothes of holidays and wedding dresses. Also it's used as a media to visualize a shamans' enchantments. For the clothes of children, it means innocence and a presented will to protect them from disaster. The desire toward beautiful colors like those of the rainbow, is regarded as common to the oriental and the western. In Korea, the rainbow is thought of as a sacred path for angels and is seen to represent the joy of childhood.

2. External Character

In Saikdong, the colors used and the width of stripes have great meaning. For clothes of national holidays, seven or eight colors at a minimum and sixteen or seventeen at a maximum are used. Colors with low chroma are arranged in a row and those with high chroma arranged in a row. They have a repetitive pattern. Most stripes have a regular width, less than 2 centimeters. For shamans' clothes, six or seven colors are used. Variation in chroma and width of stripes are rather irregular. For wedding dresses, six or seven colors are used. Bright colors are mainly shown and the width of stripes are confined to less than 7 centimeters. Colors have their own rhythm and are combined as a unit. The whole unit can be repetitive and identical colors can be repeated in one unit. But the rhythm of colors are irregular and unlimited. From the core of the pattern, an unsymmetrical balance is made on both sides. Results of research show that main colors used for Saikdong are yellowish red (12%), yellow (10%), red (10%), purplish blue (10%), purple (9%), green (7%) and white (7%) in order. It's inferred that warm colors are main. Purplish red through greenish yellow account for 54 percent of Saikdong colors. In cold colors, purplish blue. Deep blue (15%), purple (9%) and green(7%) are used at a low rate.

Dyeing Experiment

1. Fabrics: Cotton, ramie cloth, and silk were chosen as experimental materials. They were rinsed after arrangement and dried in the shade. Each fabrics (30×100m) were used.
### Specification of Fabrics

<table>
<thead>
<tr>
<th>Specification</th>
<th>Cotton</th>
<th>Ramie</th>
<th>Silk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber Content</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Weave</td>
<td>Plain</td>
<td>Plain</td>
<td>Plain</td>
</tr>
<tr>
<td>Density (warp x filling/5cm)</td>
<td>150 x 106</td>
<td>101 x 81</td>
<td>230 x 138</td>
</tr>
<tr>
<td>Weight (g/m²)</td>
<td>102.75</td>
<td>88.5</td>
<td>182.5</td>
</tr>
<tr>
<td>Whiteness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L*</td>
<td>83.78</td>
<td>76.80</td>
<td>80.71</td>
</tr>
<tr>
<td>a*</td>
<td>0.47</td>
<td>-0.26</td>
<td>3.69</td>
</tr>
<tr>
<td>b*</td>
<td>0.13</td>
<td>2.39</td>
<td>-5.48</td>
</tr>
</tbody>
</table>

### 2. Dyeing Materials

- **Indigo**

  There are a great number of indigos in the world. The botanical name of the indigo that grows in Korea, is *Persicaria Tinctoria H Gross.* It originates from India and China. It is mainly grown in Korea, Japan and China. It grows in high temperatures and humid areas. Its stalk is reddish-purple and is forty through sixty centimeters tall. Its leaves are long and oval-shaped, have no hair and are smooth. The leaf contains indican (C₄H₇O₆N) and when it is combined with oxygen in the air, it produces indigo. But it is insoluble and it requires a delicate process. Insoluble indigo is reduced to white indigo and when it is alkaline, it is dissolved. These alkaline dyes have an affinity to fiber. After dyeing, the fiber reproduces insoluble dyes when it is in contact with air. These dyes are classified as the vat dyes of modern artificial dyes.

- **Amur Cork Tree**

  This tree produces the most vivid yellow dyes. It is a deciduous and latifolious tree. Its scientific name is *Phellodendron Amurense Rupr.* It grows everywhere in Korea except in Chonnam province in the southern part of Korea. It is ten meters tall and it has thick and spreading branches. Its cortex is light gray, it has v-shaped cork and its inside skin is yellow. The inside skin is used as a peptic. In ancient China, yellow was regarded as the best color. Yellow dyes are made from the amur cork tree. Record shows that paper made in China and
Japan was dyed using it. It might also have been used for making yellow paper in Korea. It is produced when its cortex is removed from amur cork trees. A coloring agent of it is berberin. This is a only basic dyestuff. The residue is drawn after the cortex is broken to pieces and it is immersed in warm water. It's not influenced by alkali and acids. So it requires no mordant. When it is used with deep blue dyes, it produces a vivid green.xv

Goldthread

Goldthread is a member of berberidaceae family. Its scientific name is Coptis Japonica. It grows in Kyun-gi, Kang-won, Whang-hae, Pyoung-buk, Ham-nam and Ham-buk in Korea. It's known that it has been used since the period of the Three Kingdoms. It has no stalk and its leaves spread out from the root with no hair. The leaves are like those of chrysanthemums. Its flower is purplish red and blooms in April and May. Its root tastes bitter and it is used as dyes after it is dried a little. Its stalk is removed and smoked. Its coloring agent is also berberin and it produces yellow color. The acid is added to the fluid drawn from boiled it. And then without a mordant, vivid yellow dyes are produced. Alum works as a fixative for yellow color. When chroma is used, dyes are a little reddish. Iron prevents dyes from being shaded. Lime makes greenish-brown dyes.xvi It is a good dye but hard to get. It has been mainly used as medicine. It's moth-proof and used for making children's clothes.

Turemeric

Turemeric is in the ginger family. Its scientific name is Curcuma Longa L. Its flowers are light-yellow during fall. Its root is long and oval. Yellow dyes are made from powdered root. Asia is its home. It grows in Chon-ju, Korea, India, China, Taiwan, Peru and Jamaica. It's used in food coloring and spice. It contains curcumin and yellow coloring elements. This matter is insoluble in cold water and ether, but it is soluble in alcohol and acetic acid. Sometimes some elements are soluble in hot water. Also, it's used as medicine after it is boiled. Curcumin test paper can be produced. Acid works for clear dyes. Alkali works for red dyes. Iron is used for brown dyes. Lime makes amber color.xvii
© Gardenia

It's an indedidious bush spices which originate in China. Its scientific name is Gardenic Jasminodies. Its stalk is 150 to 180cm tall. Its leaves are evergreen, broad, long, oval and shiny. Its flowers bloom in June and July and give off a strong fragrance. They are 6cm in diameter. It has six petals. First, they are white and then become yellow. It grows in China, Japan, and the southern part of Korea, Che-ju Island in particular. Its fruits are used as dyes and they have pointed edges. They are hexagonal and gathered in September. They have a lot of orange-yellow coloring matter. Yellow color drawn from fruits of Gardenia contain plenty of crocin. It tastes bitter. It works for orange color. Its color is not influenced by any mordants. When iron is used as a mordant, light-yellow is made. When it is applied to cotton, reddish orange color is generated. Gardenia dyes are moth-proof. So They are useful for underwears for children and used for graveclothes and for protected.xviii

© Safflower

This flower has a lot of different names in Korea. Its scientific name is Carthamus Tinctorious Linne.xix It's an annual plant. Its stalk is 1m tall and its flowers bloom in July and August. It looks like thistles. It is reddish yellow and has only one flower per branch and a stalk. It is 2.5cm through 4cm in diameter and 2.5cm tall. It has a unique fragrance. It originates from the mountains of Afghanistan, Ethiopia and is grown in China and Tibet. In Korea, most of flowers used as dyes are imported. Flowers contain soluble safflower yellow, C24H30O15 and insoluble red coloring matter, cartharmin, C21H22O11. Safflower yellow is made only if the petals touch water. It works well for silk. For clear red, coloring matter should be removed. Red coloring matter is solved in alkali and deposited in acid. It is used as red dyes, and materials for cosmetic and Chinese medicine.

© Red Wood

Its scientific name is Caesalpinia Sappan Linne. Red Wood comes from the bean family and a evergreen bush. It's 5m high. Its leaves are small, long and oval. In spring, butterfly-shaped flowers bloom and they are purple-red. Its trunk is elastic and made as bows. The red-yellow part of the core contains brasiline coloring matter. Yellow dyes are made from the root. Chopped root is imported for medicine. It's recorded that during the Shilla Dynasty dyes
were exported to Japan (Three Countries Chronicle). According to Japanese ancient document, Japan imported products from Korea during the Shilla Dynasty period. The gentry of Japan imported about 120 kinds of products including coloring matters and pigments. Four kinds of coloring matter and nine kinds of pigments were purchased from delegates of the Shilla kingdom. It can be inferred that dyes imported from the southern countries were exported to Japan.

3. Dyeing Method.

© Amur Cork Tree, Gardenic, Turemric and Goldthread: First, boil 3000 ml of water and 30×100 cm per material and then sieve them. Put experimental fabric into the dyes at the temperature of about 80°C. Draw coloring elements for 2 days, then take them out of the water, dye, wash and dry.

© Indigo: Indigo used in this study was grown in the about 302.5 m² field and gathered in August. 700 of indigo is enough to dye 810 m of ramie cloth, and 540 m of cotton and silk. Dyeing is repeated three times. The indigo was put in a jar and water was poured. After the indigo was taken out of the water, lime was added and stirred. A part of the water was removed and coloring deposit was gathered. Alkaline solution was added to it and then stirred. The rising of coloring matter was induced. The cloth was put in dyes and pressed with fingers. And afterwards it was dried three times, dry-up was completed. and was rinsed. The depth of color depends on the times of dyeing.

© Safflower: 3000 ml of water and 500 g of Safflower, and each 30×100 cm fabrics are combined. Immerse Safflower in water for a week, which removes yellow coloring elements, draws red coloring elements, add lyre, juice of fruits of schisandra chinensis and vinegar and then dye the cloth two times in the water at 80°C. Rinse, wash and dry.

© Red Wood: Each 30×100 cm fabrics is immersed in 3000 ml of water, 500 g of Red Wood. After that, 25 g of alum is dissolved as a mordant in 2000 ml of water. Immerse Red Wood in water for a week. Add ash juice to it.
Analysis of colors

To analyze colors after dyeing, a color spectrometer was used. Three analyses are made at the given point of the experimented cloth. And another three analyses are made at another point. Then arithmetical mean is drawn. The result is changed to Hunter's $L^*a^*b^*$, HV/C by Munsell's method and marked on the appropriate coordinates. In table 1, the results of this study are classified according to the fabrics. In table 2, classification is made according to the dyes to analyze how differently three natures of color show according to materials used. In table 3, the Korean traditional standard color of Saikdong xx

Table 1

<table>
<thead>
<tr>
<th>Fabrics</th>
<th>Dyeing materials</th>
<th>Hunter</th>
<th>Munsell</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$L^*$</td>
<td>$a^*$</td>
</tr>
<tr>
<td>Amur cork tree</td>
<td>78.64</td>
<td>-4.50</td>
<td>33.12</td>
</tr>
<tr>
<td>Goldthread</td>
<td>78.70</td>
<td>4.47</td>
<td>38.11</td>
</tr>
<tr>
<td>Turmeric</td>
<td>81.78</td>
<td>4.48</td>
<td>68.14</td>
</tr>
<tr>
<td>Gardenia</td>
<td>83.99</td>
<td>3.10</td>
<td>60.11</td>
</tr>
<tr>
<td>Safflower</td>
<td>66.66</td>
<td>44.21</td>
<td>-3.29</td>
</tr>
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<td>Red wood</td>
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<td>33.95</td>
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Table 3

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Conclusion

The primary dyes of this study are blue, red and yellow. Neutral colors are produced at mixing the colors above. So they are not involved in this experiment. Under even identical conditions, different dyeing methods shows on different materials.

Silk has an excellent dyeing result, because it has a high brightness. Depth of colors in ramie cloth is different according to the density of the texture. Color of cotton is darker than that of ramie cloth because it is textured densely. In dyes of Safflower, silk, animal fiber has a totally different result. The yellow of Turmeric is the most vivid. Different materials show different results even though identical dyes are used. Yellow color of cotton is greenish. In Red wood, different colors are shown according to the number of dyeing and materials used. Several problems are suggested in practical use of traditional and natural dyes. The scientific system is not yet established enough to draw results from data gathered. The result depends on experiences largely and is greatly influenced by the environment and weather. For this, the development and growth of dyes should be proceeded to supply consistent result for mass production and industrialization. Also, consistent dyeing environment should be provided. Standards of amount of water, materials, dyes, mordants, sampled colors of different times of dyeing should be established. Mordants should also be improved. The design of Korean traditional Saikdong should be modernized to be suitable for modern taste. The development of natural and soft dyes prevents the environment from being polluted and helps the promotion of health. Through further development, they can be used for various purposes such as modern dresses, bedclothes, and accessories.

1) S.V. Kulkani etc., Textile Dyeing Operation, Noyes Publication, (1986)


3) Yong-duk Ha, Korean Traditional Color and Psychology of Color, Seoul; MyungJi Publisher, p.29 (1997)

4) Yong-Duk Ha, Ibid, pp.31-32 (1997)


vii) key-sook Guem, The Beauty of Korean Traditional Costume, Seoul; Youl HwaDang Publisher, p.79, (1994)


xi) Chang-Buk Lee, Illustrated floral of Korea, , Hwang Mun Publisher, p.310 (1993)


xiv) Kong-Joo Kim etc, Chemisty of Dyes; Seoul, HyungSul Publisher, pp.118-119,178-179 (1988)


xvii) Yang-Sup Lee, Ibid, p.15 (1981.2)


xx) Yean-Ok Oh, A Study of Dyeing from Safflower, Graduate School of konkuk Univ. p.37 (1988)


COLOR EMOTIONAL ASSESSMENTS WITH THREE INDEPENDENT MEDIA
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1. Introduction
The psychological effects of color schemes were examined through three independent media. The aim of the study is to examine and evaluate at least semi-quantitatively the psychological effects from the visual assessment of the color schemes designed for the doors at a school. A set of eighteen semantic differential scales was used to rate the human impression from four color schemes through the three independent media. A total of 310 Japanese assessed the color schemes visually against the semantic differential scales such as warm-cool, light-dark and dynamic-passive. The previous studies roughly indicated that the psychological effects depend on several factors of colors, bipolar, subjects, media and so on [1-7].

In the present study, the characteristics of visual assessments were mainly discussed, in order to evaluate the psychological effects from the color schemes more quantitatively. The histogram pattern was employed to analyze the visual results.

2. Experiments
This experimental method excluding color preference assessments have been shown in the previous paper [1]. In order to inform the outline of this experiment, it was briefly written as below.
2-1. Color samples

The four door colors through the three independent media were red, blue, pale green and light grey. Real room doors, monitors and color chips were used as three independent media. The door colors were assessed from the both of inside and outside of rooms. Table 1 shows the details of color samples and viewing conditions.

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<td>Sample</td>
<td>Surrounding color Inside</td>
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<tr>
<td>4-gray</td>
<td>3.0-3.5</td>
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</table>

Table 1: Environment of this experiment

2-2. Subjects

A total of 310 Japanese, 161 males and 149 females, participated in this study. Their ages ranged from 19 to 50s, with 76% of the subjects falling less than 24 years. The mean age of the subjects was 22.1 years. The numbers of the subjects for assessing through the three media were also added into Table 1.

2-3. Assessments

The subjects visually assessed the colors against the eighteen semantic differential scales such as warm-cool, light-dark and dynamic-passive. Each scale was defined in terms of a pair of polar modifiers divided into 7 steps. The semantic scales and examples of visual results against blue were shown in Figures 1 and 2, respectively.
3. Results

3-1. Histogram patterns of visual assessment

In order to analyze the characteristics of visual assessments, they were summarised as histograms. It was found that most of histograms do not have normal distribution. Therefore, the histograms were categorised into four groups shown in Figure 3, and those were named as Neutral, One-sided, Random and Biased patterns.
One-sided: The histograms of this group have one-sided shape. One-sided patterns were also categorised 3 more levels according to the degree of one-sided pattern. Those are One-sided level 1, 2 and 3.

Biased: The histograms of this group have a peak at each side of the semantic differential scale.

Random: The histograms of this group have a random shape.

Neutral: The histograms of this group have the shapes of normal distribution. The patterns, where the visual assessments were made most frequently to 'neither', were also included in this pattern group.

Figure 3. Four histogram patterns of visual assessments

According to this categorization, all four hundred thirty two histogram patterns were classified. The frequency in each pattern groups against four colors was shown in Figure 4. When a histogram was not clearly categorised into the above groups, the histogram was added into others-group. Figure 4 shows that colors strongly affected visual assessment.
3-2. One-Sided pattern

Figure 5 shows the case fallen in One-sided patterns. In the case of assessments against red, One-sided pattern is appeared more frequently.

3-3. Biased pattern

Figure 6 shows the case of Biased patterns. According to this figure, this pattern can be seen frequently in blue, especially for "dynamic-passive" pair. The stronger influence of the relationship between color schemes and SD word pair can be seen than the difference in media.

In Japan, it is generally said that the human impression of blues and purples is "calm". Therefore, the color of purple may give a "calm" impression. However, actually, there are two groups assessing quite "dynamic" and quite "passive".
3-4. Random pattern

Figure 7 includes the case of Random patterns. We can find this pattern frequently in light grey, especially on SD word pairs which relate to the personal taste, such as "like-dislike" or "strange-friendly".

3-5. Natural pattern

Figure 8 shows the case of Neutral patterns. By the conventional analysis using averaging, the first impression will tell that the expected answer in Biased or Random patterns is...
"Neither". However, as shown in this figure, there were few people who gave that answer actually.

![Figure 7 Random pattern assessments](image)

![Figure 8 Neutral pattern assessments](image)

4. Conclusions

The characteristics of visual assessments were analyzed with pattern categorising. The results were summarised as follows:
1. The results of visual assessments were categorised into four groups on histogram pattern. Those pattern groups were named as Neutral, One-sided, Random and Biased-patterns.

2. With most semantic differential scales, the psychological effects from color schemes were clearly distinguished among the four color schemes. However, in some cases the semantic differential scales yielded no appreciable difference in the psychological effects.

3. In the case of the visual assessments against some semantic differential scales, observers’ assessments were clearly divided into two extremes yielding Biased-pattern. The frequency of the Biased-pattern is the highest on the assessments for blue door.

With the histogram analysis, we found out human impressions of color schemes, which we missed by conventional analysis. As we had only limited number of data in this study, we are going to carry out further experiments on other color schemes. From now on, we would like to search more for human impressions of colors in our daily life.

5. References


THE SUITABLE COLOR PALETTE ON CRT FOR INDIVIDUAL HUMAN COLOR VISION SENSITIVITY

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I. INTRODUCTION

Firstly, water colors and oil paints have long been used as the painting materials in color studies and color sensitivity exercises. Water colors and oil paints are good painting materials to mix on a palette for creations.

Yet, as these painting materials are object colors, and thus show completely different properties from light-source color, color harmony theories developed for them can only be applied to light-source colors with difficulty. Particularly, the concepts on Hue, Value and Chroma, as learned with object colors, raise problems when applying them to colors on a CRT display screen. PC displays can illustrate more than sixteen million colors.

Electric colors in computer arts and on the Internet World Wide Web are made up of three basic colors. These are primary colors of light: orange-red, green, and violet-blue. Since the release of Netscape and other World Wide Web browsers, we have been able to control the numerous colors using HTML.

Artists have often mixed the colors on water color or oil color palettes. These paints are object colors and they are quite different from light-source colors.

When we used red, green and blue light-source colors on CRT, there were significant variations in color matches made by individuals whose color vision is classified as normal.

So, in order to research into how people see light-source colors, we asked student and instructors of art to select colors on an electronic palette. The result can be seen on CIE-xy color spaces.
2. EXPERIMENT

We conducted two experiments. First was the experiment in which 34 subjects selected their own DIGITAL COLOR PALETTE. The Second experiment was painting pictures on CRT using the DIGITAL COLOR PALETTE.

2-1 Our first experiment was made to determine the appropriate colors for the DIGITAL COLOR PALETTE. The subject group of the experiments consisted of 34 young instructors and students enrolled at the Tokyo National University of Fine Arts and Music and in the Art and Design Faculty at the Hosen Gakuen Junior College.

The sizes of the colors stimulation and the colors in the surrounding stimuli are principal issues when selecting a color. The selected color was created at the center of the field shown here in Figure 1.

Since the purpose of the experiment was to find out the kinds of colors typically chosen when viewing and creating images on the World Wide Web, the distance between the subject and the screen was not specified, but distances of fifty to seventy cm were more or less observed. The Minolta luminance and colorimeter, CS-1000, was used to take measurements. The color stimuli of luminance and chromaticity displayed at the center of the CRT display were measured.

In the experiment for selecting the DIGITAL COLOR PALETTE, the subjects selected colors to draw their own painting. Color names were devised using Basic Color Terms. And the color names that are frequently used in art work were also added. The following colors include:

Pink, Red, Maroon, Orange, Brown, Beige, Yellow, Yellowish Green, Olive, Emerald, Green, Viridian, Cyan, Bluish Green, Turquoise, Pale Blue, Blue, Indigo, Lavender, Blue Purple, Violet, Purple, Magenta, and Reddish purple

In addition the subjects were allowed to omit colors that they could not visualize as well as colors they do not usually use. They were also allowed to create separately colors not included in the list that they usually do use.
2-2 Second experiment

The subject group of the second experiment only consisted of 9 young women aged between 18 and 20 who were students in the Art and Design Faculty at the Hosen Gakuen Junior College.

Using the picture model in Figure 2, of the red, yellow and green peppers, and the red, reddish purple, purple and bluish purple flowers. The students paint the line drawing for coloring as in Figure 3 on CRT using their own DIGITAL COLOR PALETTE from the first experiment. Before this each of the peppers and flowers in the model in Figure 2 was measured using the Minolta colorimeter, CM-503i. Table 1 shows the results of the chromaticity x, y, and the reflectance Y.

Each of 9 subjects, line drawing for coloring on CRT in Figure 3 was measured by the Minolta luminance and colorimeter, CS-1000.

3. CONCLUSION

The results of our first Experiment are shown here in Figure 4 and 5.

The 34 subjects fell into three distinct groups determined by the level of red or green light in their color palette. We categorized these groups as the Zigzag type, the Spiral type and the Circle type. When the subjects selected Yellow controlling the level of RGB on CRT, the Yellow colors of 5 of them had higher red luminance than green luminance. (Zigzag type)

7 subjects selected Yellow with higher green than red. (Spiral type)

And then the choices of remaining, 22 subjects were almost the same level of red and green luminance. (Circle type)

Fig. 4 shows 10 color choices:
Red, Orange, Yellow, Yellowish Green, Green, Bluish Green, Blue, Blue Purple, Purple, and Reddish purple of these color choices are the three types on CIE-xy color spaces.

Fig. 5 demonstrates the same data as in Fig. 4 with luminance added in at the Z axis.

When yellow was chosen the Zigzag type had higher red luminance than green, meanings that the chosen colors usually possessed high red luminance.
Accordingly, the dominant wavelengths of Yellowish Green when chosen, came closer to those of yellow. So again, the luminance of green was lower than red. We found that the level of each luminance made a zigzag line from Blue through Purple to Red. This was due to the high level of luminance on Reddish purple and Purple.

The Circle type was standard as it accounted for 64 percent of the selections. 10 colors were chosen in good balance on CIE-xy space. The Yellows were the highest luminance and the Blues were the lowest, the reds and the Bluish Greens were the same low level of luminance, and the Oranges and the Greens were the same high level. We found that the 10 colors arranged themselves into almost a circle or a ring.

The Spiral type was distinctive. Opposite to the Zigzag type, the 10 chosen colors held high green luminance. As the Bluish Greens and the Greens had higher luminance than the Oranges and the Reds, the 10 colors arranged themselves into almost a spiral. The dominant wavelengths of the chosen Yellowish Green closely approached those of Green. In a few cases, we found that the dominant wavelengths of Yellowish Green possessed even shorter dominant wavelengths than those of Green. In the spiral type, the luminances of the Yellowish Greens were higher than those of Greens.

Consequently, the differences between Greens and Yellowish Greens came down to the luminance rather than the dominant wavelengths.

And then in some spiral types, there were no choices in the reddish purple area. Although this example in Fig. 4 selected Reddish purple, selection was generally in the purple or blue Purple area.

The Second Experiment was basically double check in the first experiment. In a word, the colors selected from their own DIGITAL COLOR PALETTE can be matched off against those of the picture model. We counpaired how to the subjects selected painted color had, for example, high luminance of red or green against the red pepper or the green pepper. The results of our Second Experiment are shown in Figure 6.

In 9 subjects, 2 subjects were Spiral type, 1 subject was Zigzag type, and 5 subjects were Circle type, the remaining 1 subject was not clear and did not correspond to any types.

Figure 6 shows luminance in these three types of line drawing for coloring on CRT.

Although the luminance of green peppers was higher than that of the red pepper in table 1, the subjects of Zigzag types selected higher luminance of red digital color on the red pepper
than green digital color on the green pepper. And the Spiral type selected higher luminance of green than red.

4. PERSPECTIVES

Because color matching between different media currently does not always correspond, the kinds of electronic palettes for art education proposed in this study are regarded by some experts as too early for implementation. Yet, the rapid increase, in the number of colors that can be expressed on computer displays, as well as in their resolution, together with revolutionary improvements in personal computers in recent years, can not be ignored.

A totally new type of art material, in the form of electronic colors, is now about to be introduced to elementary and middle school art classes. The results of these studies and DIGITAL COLOR PALETTE are made available to the public, through our Home Page on the Internet.(http://www.fa.geidai.ac.jp/~ichihara/index-e.html/)

Our text on color sensitivity education is for instructors of art education at all levels, including primary and secondary educational institutions.

In Addition, a plan to gather opinions, on designs for an easy-to-use DIGITAL COLOR PALETTE, using the interactive communication of the Internet, is on the drawing board and will be developed over the coming months.

References


Fig. 1 Field used in Palette Experiments

Fig. 2 The picture model of peppers and flowers

Fig. 3 The line drawing for coloring on CRT of Fig. 2
Fig. 4 CIE-xy color spaces of the 10 color choices in the three types

Fig. 5 Luminance at Z axis of the 10 color choices in the three types

Table 1 The pepper and flower model's chromaticity x, y and their reflectance Y
Fig. 6 Luminance in the Zigzag type, Circle type and Spiral type of the line drawing for coloring on CRT.
Introduction

The paper presents some generalities on semiotics and the lightness design approach in an interior. In the paper’s approach the lightness design is the most important and the first step in the color design, in succession another steps are the hue and saturation design. These another steps are not considered here. Semiotics, as a discipline that is at the basis of human cognitive system, provides the adequate epistemological framework for all aspects of a design. Furthermore, the paper presents conception of the lightness pattern in an interior based on the natural environment stimuli. The fifteen verbally described situations in natural environment and the semantic differential measures are used to confirm this conception.

Some phenomena of the lightness

Apparently the perceived object colors are lighter, other darker, the lightest color being white, the darkest black. It is also apparent that the lightness is something very important and is rather difficult to define phenomenologically. Figs. 1, 2, 3, 4 and 5 show complicated relationships between phenomenon of the lightness of a perceived object and the composition, background, form and distribution.

Fig. 1. The lightness of a pattern can change the composition
Fig. 2 We see two arrows, one on a white background, the other on a black.

The two arrows are not perceived as equal in lightness in spite of the fact that both, together with the gray frame, are printed with the same dot screen. The surrounding lightness influences the stimulus - perception relationship of the gray arrows. This effect is called Contrast Induction Phenomenon.

Fig. 3 The lightness can even be influenced by form.

The two gray triangles are not perceived as equally light in spite of the fact that they printed with the same dot screen. Since they are both surrounded by white and black in the same way, this cannot be a result of Contrast Induction Phenomenon. It depends on the fact that one of the triangles destroys, or at least disturbs, the black cross, whilst the other does not. The disturbing triangle is perceived as lighter. This is known as Wertheimer's Cross.
Fig. 4 The darkness opens itself. Symbol for the light.

Optimistic atmosphere (after Petersen). The first condition required to make this possible is that the darkness is perceived as a figure with a hole in it through which can be seen the light background behind the figure. A second condition seems to be that the visual perception shall give rise to an image of motion which is directed through the opening in the dark figure.

Fig. 5 The darkness assembles

Symbol for pressing darkness. Pessimistic atmosphere (after Petersen). If the darkness is perceived as a background seen through a hole in the light figure, something threatening is experienced where fear and sorrow both exist. Siting at night in a lighted room and looking out into the provides the same experience, and one is happy to remain in the room instead of having to walk out into the dark night.
Generalities on the lightness in an interior and semiotics

Human perception of the lightness in an interior is an active, information-seeking process which involves many mechanisms in the eye and the brain, some conscious others unconscious. We directed our voluntary attention to the patterns of the lightness which provide information we need to perform our conscious activities, like office work. Some patterns are the objects of involuntary attention and its relate directly and logically to the essence of human beings as biological organisms to their security, sustenance and stimulation. In this sense, the lightness in designers practice are becoming recognized as part of a visual language that can assist the designer in implementing impressions such as the spaciousness, orientation, equilibrium, relaxation, privacy and pleasantness. If we consider the lightness as a sign or symbol, we are including all the aspects, because they are not the previously defined things, but the consequences of various factors and of the context in which they are taken as such. Signs and symbols, as classification, are not clear and distinct from one another; rather they interact and distinct from one another; rather they interact and overlap, demonstrating considerable similarity in both use and character. Nevertheless, there are differences. Signs can be understood by animals as well as humans; symbols cannot. Signs signal; they are specific to a task or circumstance. Symbols are broader in meaning, less concrete. Both are surrogates. In case of representational pictorial signs or symbols they may appear convincingly like the originals they stand in for and can be understood without explanation. As abstract shapes, with no physical resemblance to the information they represent, signs or symbols possess meaning solely through social agreement.

The patterns of the lightness in an interior

At the moment there is the suggestion that the patterns of the lightness provide a number of signs which people use to interpret space and these signs are at least partly independent of an interior that is being experienced. Fig.6 and table 1 give some review of the patterns of the lightness in an interior. Commonly, the accepted pattern of the lightness in an interior is 1, 2 and 3 (fig.6).
The simple patterns of the lightness in an five surface interior are presented and evaluated in table 1. The phenomenological analysis leads to the impressions of spaciousness, orientation and equilibrium. The spaciousness are evaluated by categories of the closeness and the openness. The orientations are evaluated by categories of the disorientation, the orientation of closeness (c) and the orientation of openness (o). The equilibrium is evaluated by categories of the stability and the unstableness.

Tab. 1 The patterns of the lightness in an five surfaces interior.

<table>
<thead>
<tr>
<th>Item</th>
<th>floor</th>
<th>left wall</th>
<th>front wall</th>
<th>right wall</th>
<th>ceiling</th>
<th>the impression of spaciousness, orientation and equilibrium</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>dark</td>
<td>dark</td>
<td>dark</td>
<td>dark</td>
<td>dark</td>
<td>closeness disorientation stability</td>
</tr>
<tr>
<td>2</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td>openness disorientation unstableness</td>
</tr>
<tr>
<td>3</td>
<td>dark</td>
<td>light</td>
<td>dark</td>
<td>dark</td>
<td>light</td>
<td>closeness orientation (c) stability</td>
</tr>
<tr>
<td>4</td>
<td>dark</td>
<td>light</td>
<td>dark</td>
<td>dark</td>
<td>light</td>
<td>openness orientation (c) stability</td>
</tr>
<tr>
<td>5</td>
<td>dark</td>
<td>light</td>
<td>dark</td>
<td>light</td>
<td>dark</td>
<td>closeness orientation (c) unstableness</td>
</tr>
<tr>
<td>6</td>
<td>light</td>
<td>dark</td>
<td>light</td>
<td>light</td>
<td>dark</td>
<td>openness orientation (c) unstableness</td>
</tr>
<tr>
<td>7</td>
<td>dark</td>
<td>dark</td>
<td>dark</td>
<td>dark</td>
<td>light</td>
<td>closeness orientation (o) stability</td>
</tr>
<tr>
<td>8</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td>dark</td>
<td>light</td>
<td>openness orientation (o) stability</td>
</tr>
<tr>
<td>9</td>
<td>dark</td>
<td>light</td>
<td>light</td>
<td>dark</td>
<td>light</td>
<td>closeness orientation (o) stability</td>
</tr>
<tr>
<td>10</td>
<td>light</td>
<td>light</td>
<td>dark</td>
<td>light</td>
<td>dark</td>
<td>openness orientation (o) unstableness</td>
</tr>
</tbody>
</table>
Some of these patterns can be identified in nature. This concept is based on the theory that an experience of the patterns is, in part, the experience of recognizing communicative patterns conditioning by nature. Hence, it is important to recognize the natural signs coming from different zones of an natural environment. There has been an increasing concern with the effects of the natural environments on emotional responses of the persons within it. Available literature of environmental psychology provides evidence that there are environmental stimuli which are linked to behavioral responses by the emotional responses of pleasure and arousal. By considering the impact of the set of verbally described situation in natural environment on these emotional responses, effects of diverse visual stimulus components can be readily compared. The fifteen verbally described situations in natural environments and semantic differential measures are used to confirm this conception.

In the experiment 96 students served as subjects. Each of them was presented with random order of the 15 verbally described situations in natural environments (Appendix A) and was asked to describe how he would feel in each one by using semantic differential measures (Appendix B). The result has been represented graphically in fig.1. It leads to following observations:
(1) The findings are positive in the pedestrian situations, negative in the visual performance situations and positive or negative in the relaxation situations.

(2) The most positive emotional responses are in situation 3. This situation corresponds to the rhythm of the lightness in the pedestrian situations.

This study has shown that exist the phenomenological reason for seeking the nature-oriented approach to the patterns of lightness in an interior. Further studies based on the more representative situations will help to better recognize the patterns of lightness in an interior and their links with the emotional responses.

Fig. 7 The emotional response scale.

The changes of the emotional responses on the verbally described situations: pleasure (continuous line) and arousal (dash line) involved with the different situations in the natural environment: 1-5 pedestrian traffic, 6-10 visual performance and 11-15 relaxation after visual performance.
Appendix A

The set of verbally described situations in natural environment. The two consecutive numbers preceding the description of each situation refer to weighed mean values of elicited pleasure and arousal, respectively.

1. ( +2.4, +0.7 )
   You are going in natural open plane. There is the extensive sight of sky and land in front of you.

2. ( +1.8, +1.7 )
   You are making for nearby bright opening in the brushwood.

3. ( +2.7, +2.0 )
   You are going where the bright glade is visible through tree-trunks.

4. ( +1.3, +0.6 )
   You are making for the appearing outlines of branches against a background of the sky.

5. ( +0.7, +1.1 )
   You are going to the nearby brushwood.

6. ( -0.3, -0.3 )
   You are concentrating on detailed parts of composed object. And you are being at the place where you have the natural sight of sky and land.

7. ( -0.4, 0.0 )
   You are looking at something what is composed of detailed elements. Nearby, there is the bright opening in the perimeter zone of land.

8. ( -0.7, -0.8 )
   You are straining eyes with looking at the small elements of an object. Nearby, the three-trunks are outlined against a background of the glade.

9. ( -0.5, -0.1 )
   You are straining eyes with looking at an object composed of the detailed parts. You are staying at a place where the branches are outlined in the sky background.

10. ( -0.7, -0.8 )
    You are tired of looking at the something what consist of the small elements. You are staying at a brushwood.

11. ( +1.4, -1.0 )
    Your tired eyes needs a rest. You are looking at the extensive sight of sky and land.

12. ( +1.0, -0.2 )
    Your overworked eyes are looking for the restful places. You are seeing the bright opening in brushwood.

13. ( +1.2, 0.0 )
    Your strained eyes are looking for restful places. Nearby, you are looking at the tree-trunks which are outlined on the glade background.

14. ( +0.8, -0.5 )
    Your tired eyes are looking ahead to rest. The outlined branches in the sky background are in front of you.

15. ( +0.5, -0.6 )
    Your strained eyes are taking away from the work. The brushwood is in front of you.
Appendix B

Semantic differential measures of emotional state in a particular situation.

Instructions to subjects are as follows:

Take about two minutes to really get into the mood of the described situation; then rate your feelings in the situation with the adjective pairs below. Some of the pairs might seem unusual, but you will probably feel more one way than the other. So, for each pair, put a check mark (example: ----:---:----) close to the adjective which you believe to describe your feelings better. The more appropriate that adjective seems, the closer you put your check mark to it.

<table>
<thead>
<tr>
<th>Pleasure</th>
<th>Unhappy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Happy</td>
<td>Annoyed</td>
</tr>
<tr>
<td>Pleased</td>
<td>Unsatisfied</td>
</tr>
<tr>
<td>Satisfied</td>
<td>Melancholic</td>
</tr>
<tr>
<td>Contented</td>
<td>Despairing</td>
</tr>
<tr>
<td>Hopeful</td>
<td>Bored</td>
</tr>
<tr>
<td>Relaxed</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Arousal</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Stimulated</td>
<td>Relaxed</td>
</tr>
<tr>
<td>Excited</td>
<td>Clam</td>
</tr>
<tr>
<td>Frenzied</td>
<td>Sluggish</td>
</tr>
<tr>
<td>Jittery</td>
<td>Dull</td>
</tr>
<tr>
<td>Wide-awake</td>
<td>Sleepy</td>
</tr>
<tr>
<td>Aroused</td>
<td>Unaroused</td>
</tr>
</tbody>
</table>

A numerical scale of +4 to -4 is used for each dimension (e.g., +4 is assigned for extremely happy and -4 for extremely unhappy). Subjects responses are averaged across the six dimensions of each of the two factors.

Literature


RESEARCH ON THE COMBINATIONS OF COLOURS IN DATA PROCESSING

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This paper presents a method of analysis of colour images in order to extract from them the most relevant coloured information.

The goal is to obtain, in the future, an automatic classification of these images, as coloured groups.

PICTORIAL ANALYSIS ON COMPUTER:

Museology currently does not have a truly operational system of colour classification of the works of art, such as paintings.

Actually the analysis is carried out starting from isolated colours and not as a whole. However this is contrary to the properties of visual perception, which functions in a synthetic and total way.

The goal is thus to define an operational mode which sticks more closely to the performances of human perception.

In fact the problem comes to finding an interface between the colour information extracted from analysis and the perceptive space of the virtual colour groups.

PICTORIAL ANALYSIS:

So it is a question of extracting as much information from a painting, characterizing it as well as possible. But on the other hand, it will be necessary to avoid too much data, which would become impossible to handle. In particular it will be advisable to leave aside the...
formal and figurative aspect, so as to focus primarily on the colours. However any colour is conceived only inside the limits of forms. It thus rests with to us to choose the most neutral and least constraining possible forms.

One could try, at first, crossing the image with a band. But then various problems arise of how should this band be oriented. A horizontal, vertical or oblique statement will not give the same result. Does this line have to be straight, or admit zigzags? Do we have to be satisfied with one line or several?

One could, also make note of the most remarkable specific colours of the painting and then establish a range between them. But this method appears very strongly tarnished with subjectivity and does not solve the problem of quantity. A colour applied over a small surface or a large one will not produce the same effect.

To solve these difficulties and avoid as much as possible the subjectivity of the observer, we propose to analyse the image by reducing it to elementary squares. Various data-processing programs make it possible to transform the image into a mosaic of squares increasingly limited in number, until there remains nothing but one single square, representing the entropic colour of the painting, that is the final mixture of all the colours which make it up.

The squaring can be optimized between two extremes:

- To have much information, to be faithful to the image. But then the disadvantage is that the data is cumbersome and difficult to manage.

- Or to have little information, but then the model is likely to be too poor.

It would thus seem that good optimization is at approximately 1,000 cells on the same pixel, that is to say approximately 33 X 33 cells. This is completely manageable by today's computers.

This method teaches us many things about the structure of the images and lets us understand better what constitutes the original chromatic structure of a painting.

**THE PERCEPTIVE SPACE OF COLOUR GROUPS:**

We need not be concerned with the forms resulting from the squaring, the composition, etc...

We need refer only to certain criteria giving an immediate correspondence with previously indexed colour groups.
The computer will thus have to operate calculations starting from the squaring of the image, according to successive criteria. These various components can be estimated on scales graduated in percentage.

Let us take these criteria by order of importance:

1- SATURATION:

Saturation brings the fundamental distinction between what is very coloured, what is coloured a little and what is not at all. This estimate of saturation will have to be total. It can be reproduced on this scale:

<table>
<thead>
<tr>
<th>NIL</th>
<th>SLIGHT</th>
<th>MEDIUM</th>
<th>STRONG</th>
<th>MAXIMUM SATURATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100%</td>
</tr>
</tbody>
</table>

Three main categories are raised here:

- CHROMATICS: of maximum saturation, comprising only pure hues.
- VALUES: of null saturation, comprising only neutrals: black, gray, white.
- MIX: of average saturation, comprising at the same time hues and values.

2 - POLYCHROMY:

This distinction is based on the number of hues and their quality.

It follows and details the preceding categories.

In the case of absolute values, these criteria are not to be taken into account. But the case is not very frequent.

Contrasts of hues define the criterion of polychromy.

One finds here:

<table>
<thead>
<tr>
<th>MONOCHROME</th>
<th>BICHROME</th>
<th>ANTAGONIST</th>
<th>TRICHRONE</th>
<th>QUADRICHROME</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100%</td>
</tr>
</tbody>
</table>
One will thus determine the number of hues present in a painting.

The scale thus starts with the monochrome and ends on the quadrichrome or presence of the four basic hues. There is no use in further increasing the number of the hues, for that would necessarily be reduced to polychromy. In fact this criterion of polychromy precedes that of hues in the tree structure.

3 - DOMINANT HUE:

This criterion has primarily to do with the overall dominant of the image.

One can distinguish:

<table>
<thead>
<tr>
<th>YELLOW</th>
<th>RED</th>
<th>BLUE</th>
<th>GREEN</th>
<th>YELLOW</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100%</td>
</tr>
</tbody>
</table>

The scale is, in fact, circular. That is why there is yellow at the two extremities. We could also include the intermediate colours: orange - purple - turquoise - chartreuse. It should also be noted that the criterion of dominant hue disappears in the antagonists and the quadrichromes, where the hues balance each other.

4 - DOMINANT CLEARNESS:

The neutrals can moderate these last categories.

The following dominant ones will thus be found there:

<table>
<thead>
<tr>
<th>BLACK</th>
<th>DARK</th>
<th>MEDIUM</th>
<th>CLEAR</th>
<th>WHITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100%</td>
</tr>
</tbody>
</table>

This criterion of clearness is relative to the ordinary pigment (white generally accounts for 80 percent).
5- MIX CONTRAST :

The three contrasts:

- Hues contrast (polychromy)
- Clearness contrast
- Saturation contrast

lead to a total contrast and the resulting contrast will then be optimized.

At the opposite, if there is absence of contrast in these three criteria, there will then be fusion in a uniform colour:

<table>
<thead>
<tr>
<th>FUSION</th>
<th>SLIGHT</th>
<th>MEDIUM</th>
<th>STRONG</th>
<th>MAXI CONTRAST</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100%</td>
</tr>
</tbody>
</table>

Contrast and fusion are in opposition. A more or less advanced fusion leads to the category of nuances. A fusion pushed to its extreme consequences leads to a plain entropic colour.

6- CLEARNESS CONTRASTS :

In the same set of average clearness, the average clearness can result from a contrasting balance between to dark tones and clear tones.

Thus an estimate on the following scale will be established:

<table>
<thead>
<tr>
<th>NIL</th>
<th>SLIGHT</th>
<th>MEDIUM</th>
<th>STRONG</th>
<th>MAXIMUM CLEARNESS CONTRAST</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100%</td>
</tr>
</tbody>
</table>

In general the greater the number of hues, the weaker the role of the values and conversely. Thus the monochromes can comprise important contrasts in clearness, whereas the polychrome will be more unified in the field of clearness.
7 - SATURATION CONTRASTS:

In the case of average saturation, associating colours and neutrals, there could be contrast between the saturation of the colours and the desaturation of the neutrals. But it can also be the case that colours and neutrals are mixed and in this case there will be little or no saturation contrast.

<table>
<thead>
<tr>
<th>NIL</th>
<th>SLIGHT</th>
<th>MEDIUM</th>
<th>STRONG</th>
<th>MAXIMUM SATURATION CONTRAST</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100%</td>
</tr>
</tbody>
</table>

8 - NUANCES:

The nuances constitute a separate category, included in fact in the category of average saturations with weak contrasts.

The nuanced sets are defined as colour groups revolving on small spheres, at short distance from an entropic point of colour. This is why we return to the diagram of the hues and contrasts of hues to define them.

In addition to desaturation, the difference will come from the fact that the contrasts of hues, clearness and saturation are taken into account simultaneously.

9 - PATTERNS:

This is about the way in which fusion takes place, it can be:

<table>
<thead>
<tr>
<th>REPEATED</th>
<th>EQUALIZED</th>
<th>DEGRADED</th>
<th>INTERLACED</th>
<th>AT RANDOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100%</td>
</tr>
</tbody>
</table>

Uniform repetition generates the clearest and strongest structure.

The random one represents here the optimum disorder, through which it is no longer possible to detect a structural intent. The random case leads to an interesting paradox: its variations are infinite, but for our visual perception, they are all reduced to a single impression: that of
disorder. Thus the space of colour groups, which we could believe to be infinite, is closed upon itself.

**TREE STRUCTURE:**

Taking into account these various scales:

- Saturation
- Polychromy
- Hues
- Clearness
- Mix Contrast
- Clearness contrast
- Saturation contrast
- Nuances
- Patterns

We can draw a tree structure, where we locate in only one point the chromatic criteria of the image under study.

Thus the position of the total statement will find its place in the space of the colour groups. This space of the colour groups can thus be described like a tree structure or a progression, starting from the main sets, illustrated in the shape of large planets and moving towards increasingly tenuous satellite variations.

Thus we obtain increasingly fine families, which are used as a basis for our classification. One could then not only catalogue paintings according to their dominant features, but further pursue the analysis of their chromatic structures and make comparisons between paintings of various periods.

Representation on a planetary mode was adopted, owing to the fact that it makes it possible to describe a multidimensional space, according to a definite hierarchy.
One could add still more criteria, such as matter, transparency, reflection, etc... But the total representation of such a space is relatively unimportant. Reference to our scales of appreciation is sufficient.

The systematic application of this method should allow an automated classification of the works of art: painting, fabrics, design, architecture, etc... It will also provide us with an experimental verification of this colour group theory and will make it possible to see whether it comprises errors or insufficiencies.

Similarly the expert software is still to be developed.

Thus there is still much work to be done before all the problems can be completely solved. But we hope to have shown a way towards this resolution.

BIBLIOGRAPHY:

1981 - “Rôle des permutations colorées dans l'image numérique et analogique”: A.I.C. Color 81 - Berlin
- "Les ensembles colorés, une nouvelle approche de la couleur": Information Couleur n° 15

1982 - "Le Planets-Colour-System": Dynamic Colour Symposium publication A.I.C. - Budapest
- "La sémio-informatique" ou le traitement d'images sur ordinateur, selon le modèle de la perception visuelle Revue Telecom n° 50

1983 - "Planètes-Couleur-Système": Catalogue exposition E.N.S.A.D. - Paris

1983 - "Jouez la Couleur": Information Couleur n° 20 - C.F.C. Paris (les locaux scolaires: fut très demandé)
- "Das Planeten-Farb-System": Farbe und Raum 5/1983 Berlin Ost
- "Colour Chart Measures in Planets-Colour-System" Far Grapport A.I.C. - Kungalv Suède

1984 - "A frog's eye view": Color Education A.I. C. - Salamanca Espagne

1985 - "Cosmologie de la couleur"
- "Typologie des Ensembles Colorés": Mondial Couleur A.I.C. - Monte-Carlo

1986 - "Application des Ensembles Colorés à la pédagogie":
   Colloque "La couleur à l'Ecole, la couleur et l'Ecole"
   C.F.C. et Ministère de l'Education C.E.S.T.A. – Paris

1987 - Réédition: "Des couleurs pour nos Ecoles" du C.F.C. par le Ministère de l'Education
   – Paris

- "Color Approximation by relative groups": Symposium "Colour Appearance"
  Volume 15 - Annapolis U.S.A.

1988 - "Les mécanismes de la nature par les ensembles colorés". Dans: La couleur et la
   nature dans la ville, Académie Nationale des Arts de la rue, Editions du Moniteur
   Paris

1989 - "Planetary System": The Color Compendium by Hope and Walch - Van Nostrand
   Reinhold Book - New-York

1993 - "Basic colour groups sequence": Colour 93 A.I.C Technical University of Budapest

1994 - "The Planetary Colour System, methodology and applications" Aspect of Colour,
   AIC Helsinki Finlande

1997 - "Description of the Planetary Colour System" Kyoto Japon A.I.C.

1998 - "Les combinaisons de couleurs" dans "ACE COLOR 98" Villefranche-Sur-mer
TREE STRUCTURE

**Polychromy Scale and Dominant Hues:**

- **Monochrome**
  - Yellow
  - Red
  - Blue
  - Green

- **Bichrome**
  - \( Y + R \)
  - \( R + B \)
  - \( B + G \)
  - \( G + Y \)

- **Antagonist**
  - \( G + R \)
  - \( Y + B \)

- **Trichrome**
  - \( Y + R + B \)
  - \( R + B + G \)
  - \( B + G + Y \)
  - \( G + Y + R \)

- **Quadrichrome**
  - \( Y + R + B + G \)

**Mix (Colours and Values):**

- **Monochromes**
- **etc...**

- **Clearness:**
  - **Yellow**
  - **Red**
  - **Blue**
  - **Green**
  - **Clear**
  - **Medium**
  - **Darker**
  - **Random**

- **Saturation Contrast**
- **Uniform Clearness Contrast**

**Nuances:**

- **White**
- **Black and White**
- **Grey**
- **Black**
REMARKS ON THE USING COLOUR IN COMPUTER VISION

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Abstract:
This paper addresses the problem of using colour in computer vision from the first to the last stage. Different colour spaces used in computer vision are compared. Significance of colour spaces for colour image segmentation on example of region growing method is presented. The application of highlights in object counting task is proposed.

Computer vision process interprets one or more images taken from a real scene. For a long time, in computer vision systems were mostly used grey-level images. Reasons for this situation were: hardware costs (colour camera, special framegrabber etc.) and the lack of proper algorithms. Nowadays the interest in colour computer vision is growing. Surveys of colour in computer vision are found in [1,2,3] and the first handbook that covers the important developments in colour image processing is published [4].

Colour image acquisition should be preceded by such adjustment of camera and framegrabber parameters in order to make system work in dynamic range and to avoid such negative effects as a clipping, blooming or colour imbalance. This stage, named colorimetric calibration, is very important because not all acquisition errors can be corrected during later stages. Colour image acquisition is less straightforward than monochrome acquisition. The choice of camera (three CCD chip versus single CCD chip) and lighting is very important.
1. In search of ideal colour space

Different colour spaces used in computer vision systems, their transformations and first of all the reasons for using colour spaces other than basic RGB are presented. Spaces used in computer vision are derived from human visual system models (e.g. RGB, opponent colour space, IHS etc.), adopted from technical domains (e.g. colorimetry: XYZ, television: YUV etc.) or developed specially for image processing (e.g. Ohla space, Kodak space etc.). These colour spaces can be evaluated using following important criteria: linearity of transformation, stability of calculations and perceptual uniformity (Table 1).

Table 1: Properties of transformations between RGB and other colour spaces

<table>
<thead>
<tr>
<th>No.</th>
<th>Colour space</th>
<th>Linearity of transformation</th>
<th>Stability of calculations</th>
<th>Perceptual uniformity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>rgb</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>2.</td>
<td>XYZ</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>3.</td>
<td>xyz</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>4.</td>
<td>YUV</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>5.</td>
<td>YIQ</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>6.</td>
<td>YCbCr</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>7.</td>
<td>Opponent</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>8.</td>
<td>Ohla</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>9.</td>
<td>IHS</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>10.</td>
<td>CIELAB</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>11.</td>
<td>CIELUV</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>12.</td>
<td>Munsell</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>13.</td>
<td>PhotoYCC</td>
<td>no</td>
<td>yes</td>
<td>no</td>
</tr>
</tbody>
</table>

In practice there does not exist an ideal colour space (produced by linear transformation, stable and perceptually uniform) for all stages of computer vision process. The decision on which colour space to use depends on given task. Optimal decision can be very hard to find. However, knowledge about colour space properties makes the proper choice easier.
2. Colour image segmentation: an example

Relative good developed is the use of colour in low-level vision tasks with many image segmentation methods adapted for colour. A good example is here the region growing method [5]. The general purpose of the colour image segmentation is to arrive at results insensitive to shadows, changes in lighting intensity and surface reflection properties (e.g. highlights). Region growing is a bottom-up segmentation technique that can use different criteria for measurement of region homogeneity. The idea of region growing is one of the most fundamental concepts used in image segmentation techniques. Individual pixels (sometimes called seeds) are merged if their attributes (grey level, colour or texture etc.) are similar enough. Colour similarity can be established by computing the value of a homogeneity criterion. Each tested pixel is compared to its immediate neighbouring regions. If a homogeneity criterion is fulfilled then the tested pixel belongs to region and all attributes of region are updated. If a homogeneity criterion is not fulfilled then the tested pixel with a new label starts as a new region. The process of growing is continued until all pixels in image merge in regions as homogeneous as possible. Proposed method does not use special regions or pixels (seeds) to start the segmentation process. A simple raster scan of the colour pixels is employed: from left to right and from top to bottom.

In most cases colour similarity is used as homogeneity criterion for colour images. The homogeneity criteria with some tuning parameters control the formation of regions into which image is segmented. Below different homogeneity criteria based on IHS and YUV colour spaces are presented:

- intensity-based criterion (I-criterion):
  \[
  |I - \overline{I}| \leq k\sigma
  \]
  (1)

- criterion defined on the HS-plane (HS\(_1\)-criterion):
  \[
  \sqrt{S^2 + \overline{S}^2 - 2S\overline{S}\cos(H - \overline{H})} \leq d_1
  \]
  (2)

- criterion defined on the HS-plane (HS\(_2\)-criterion):
  \[
  |H - \overline{H}| \leq d_2, \quad |S - \overline{S}| \leq d_3
  \]
  (3)

• criterion defined in the IHS space (IHS-criterion):

\[ \sqrt{(I - I')^2 + S^2 + S' - 2SS \cos(H - H')} \leq d_s \]  

(4)

• criterion defined on the UV-plane (UV-criterion):

\[ \sqrt{(U - U')^2 + (V - V')^2} \leq d_s \]  

(5)

• criterion defined in the YUV space (YUV-criterion):

\[ \sqrt{(Y - Y')^2 + (U - U')^2 + (V - V')^2} \leq d_s \]  

(6)

where Y, U, V are current values of colour components of tested pixel and \( \overline{Y}, \overline{U}, \overline{V} \) are mean values relate to a region. Tuning parameters (k, σ, d1, d2, d1, d2, d3, and d6) which determine the segmentation results have to be set by the user of program. Mean values and standard deviation relates to a region whereas current values relate to tested pixel. In formulae (2) and (4) we are taking into account the cylindrical character of HS components (H is an angle, S is a distance). The main difference between HS1 and HS2 consist in used distance function (metric). The HS1-criterion is much more computationally expensive than HS2-criterion. The IHS-criterion merges all IHS colour components.

The proposed algorithm was tested for a number of different images. Below we present some experimental results of segmentation as a map of region boundaries. Black lines on a white background are used to show the separated regions.

![Fig. 1. Segmentation results: (a) original colour image, (b) region boundary map for the HS-criterion, (c) region boundary map for the UV-criterion.](image-url)
We have proposed the region growing algorithm working in different colour spaces. In general, the criteria based on IHS space generated better results than the criteria based on YUV space. In some number of cases UV-criterion introduces shadow regions (Fig.1).

3. Highlights in colour images

Highlights are the characteristic bright spots occurring on the surfaces of individual objects. On the contrary, in computer vision highlights are very often treated as an obstacle in image segmentation as well as in high-level vision (stereovision, motion analysis etc.). During segmentation process the highlights are considered as separate regions with high lightness. Highlight generation on the surface of object depend on object position with respect to camera. This means that in case of moving objects or in active vision system the highlights occur on the surface of object in one image and do not occur in another image. Significant part of machine vision algorithms works only with images without highlights i.e. all objects in the scene should be matte (Lambertain). To avoid specular reflections, the special illuminatores with e.g. uniform diffuse illumination, are produced. Moreover, at present polarisation methods are used to remove highlights from grey level and colour images. By changing orientation of polarising filter more images of the scene can be acquired and the analysis for scene with highlights can be simplified.

However, highlights are also rich sources of information about objects that can be useful. In many works authors presented possibility of using highlights in grey level images for characterisation of shape, size, and location as well as orientation of objects. Highlights, detected in the colour image, can be also used for estimation of illumination colour. Here a new idea of object counting based on highlights counting on surfaces of objects is presented [6]. Object counting is composed of four following stages: extraction of highlights in colour image by thresholding of selected IHS components, morphological consolidation of extracted highlight regions and region counting (labelling) in binary image. Object counting takes into consideration the number of used light sources, because in case of more than one lighting source multiple highlights per object are observed.

The proposed method was tested for a number of different, real world images. Input images were acquired directly from 1-CCD colour camera without preprocessing. Best results were achieved for optically inhomogeneous (e.g. plastic) chromatic objects in dark background. Typical lighting system based on two fluorescent tubes (5400 K) was used. The method
seems promising for practical applications. Fig. 2 shows 3 monochromatic copies (Fig.2 a, d, g, ) of such colour images. Scene presented in Fig.2a was illuminated by white light from left side and next scene (Fig.2d) was illuminated from both sides. Therefore, the background of image is lighter and double number of highlights is visible. The scene in Fig.2g was illuminated from left side. Linear shape of highlights is a result of the shape of lighting sources (fluorescent tubes).

![Image](image-url)

**Fig.2.** Detection of highlights in colour images: (a), (d), (g), intensity copies of colour images, (b), (e), (h), results of $S$- and $I$-thresholding of colour images, (c), (f), (i), binary images after threefold dilation.

Following the colour space transformation thresholding of IHS components is realised, which is most crucial stage of the object counting. In case of using the white light in the scene, the thresholding of $S$ and $I$ components should be applied. The advantage here is simplicity and fastness. By setting the saturation thresholds to $S_{\text{min}}=0$ and $S_{\text{max}}=0.3$ and the
intensity thresholds to $I_{\text{min}}=150$ and $I_{\text{max}}=255$ we separate the highlights from tested images. As a result, pixels with S- and I values in above-mentioned intervals will be white in binary image and other pixels will be black. Fig.2b, e, h, present results of such thresholding.

A few small regions represent sometimes single highlight in binary image. Therefore, a simple morphological operation (threelfold dilation with $3 \times 3$ structuring element) is useful for consolidation of regions. Results of morphological consolidation are shown in Fig.2c, f, i. The shape and size of morphological mask can be matched with the shape of highlights. Object counting in binary image is not a complex problem. This is typical task of region labelling with algorithms described in many image processing handbooks. In case of few lighting sources (Fig.2f - two fluorescent lamps) the result of counting should be divided by number of sources.

The method seems promising for practical applications. However, further research work is required for other lighting sources e.g. coloured illumination, other colour of backgrounds and objects with more complicated surfaces.

4. Conclusions

Some colour image processing can be generalised from greyscale techniques using separate application to the colour or chrominance or luminance components. However, in the opinion of many researchers in the field, the future lies with vector methods.

Research on the mechanism of colour constancy still arouses great interest in computer vision community. There is very important because colour, as natural recognition cue can be used in object recognition, for single- and multicoloured objects.

Some researchers [7] present the colour image processing systems as “imaging colorimetry” systems and emphasised their advantages over traditional colorimetry systems. Traditional colorimeters can not be used for fast monitoring of complex objects: multicoloured, textured, non-flat etc. Many existing industrial applications encourage engineers to use “imaging colorimetry” systems.

Literature


DIGITAL COLOR EDUCATION
WITH COMPUTER ASSISTED INSTRUCTION (CAI)

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Abstract

As digital forms of communication become more and more important to all our lives, designers find themselves doing more of their design works not only with computers but also online. This radical change of working environment requires designers of understanding the values of digital color and applying it to the design process. This paper investigates characteristics of digital color and develops a Computer Assisted Instruction (CAI) program in order to teach digital color theory and its applications to industrial design students. Through a field research, the importances of learning digital color in the design curriculum were emphasized from designers in the professional design areas. The case study showed the possibilities and potentials of CAI for an individual learning environment as well as supplementary aide for learning in digital color education.

Background of the Study

In the Information Age, the medium is not only delivering a content, but also creating it. The importance of understanding media has been emphasized from Marshall McLuhan and his famous doctrine, ‘The Medium is the Message’. He said that “unawareness of the specific modalities of the senses is a great disadvantage, especially when one encounters artistic extensions and amplifications of the various senses” (Sanderson 1989, p. 125) If we use the digital media in the classroom and other areas, his doctrine should be considered as the bases of using media effectively and efficiently.
Traditionally, designers have used water-based plastic colors, color papers and color swatch books in the design process. The current development of digital technology, however, has influenced the usage of media from those analog things to digital. The effectiveness of using digital technology in the design process has been realized not only from the economic aspects but also to the generation of creative ideas and the quality of final products. The purpose of this paper is to identify the importance of using digital color in the design process, and to explore effective instructional methods for teaching digital color theories and its applications in design education. The objectives of this study are:

- To identify the importance of using digital color in the design professional fields, and the needs of digital color education.
- To investigate characteristics of digital color, which can be the basis of the diverse contents and methods for digital color instruction.
- To develop a Computer Assisted Instruction program for digital color education.

The Usage of Digital Color in the Design Fields

To find out how designers are involved in technological changes, a preliminary survey was conducted asking designers in several areas about the ways in which they are using digital color in their design processes. In 1998, thirty-eight designers from product design and multi-media design companies in Korea responded to the questionnaire. From this survey, they confirmed many of new changes in the working environment: designers are doing a large proportion of their works with computers, and they are increasingly using the Internet and other software for a multitude of purposes. Multimedia designers used the computer to

![Figure 1. The answers from multimedia designers (left) and product designers (right) regarded to the computer as an important tool in their work.](image)
complete 100% of their work, while product designers used the computer for approximately 87% of their work. As explained in Figure 1, 100% of the multimedia designers and 93% of the product designers regarded the computer as an important tool in their work.

A computer is now regarded as the first important medium for the designer. As might be expected, this increasing use of electronic communication carries a number of benefits as well as some serious challenges for designers. In spite of their increasing dependence of computers in their design work, designers have relatively little knowledge of digital color theories. When asked about the needs of digital color theory education, 85% of survey participants recommended providing digital color lessons in the design curriculum.

Unfortunately, most color courses offered in the design institutions are still using traditional, analogue medium, and are not addressing computer technology. These findings suggest that the effectiveness of design education, especially in a course of ‘Color Theories and Practices’ needs to be carefully and critically reviewed. The question is where to place digital color theories in the design curriculum. Elements of digital color theories can be included in both ‘Computer Graphics’ courses and traditional color theory courses.

In addition to this, there is a disparity between industry requirements and what design institutes are providing. This missing link between the academic world and the world of industry cannot be reunited unless design curricula are updated and developed based on the needs of design industries.

**The Goal of Digital Color Education**

Color is defined as that “part of perception that is carried to us from our surroundings by differences in the wavelengths of light, is perceived by the end, and is interpreted by the brain” (Nassau, p.3). Digital color can be defined as computer-generated color and its diverse applications on the display and in the color press. The color on the display is generated by the additive mixture of three primaries, which is totally different from the subtractive mixture in the printing process. As far as digital color covers these two mixtures, digital color education encompasses diverse issues such as science, technology, philosophy, psychology, and art. These issues are part of the larger question concerning how digital color technologies can change the ways designers see the world, and how we relate to the world.
around us. Digital color education is now able to synthesize the dichotomy between Newton and Goethe.

The goal of digital color education is to provide students the power to liberate creative thinking and energies in all spheres of human senses through the acquisition of computer skills. On the basis of this paradigm, the digital color education consists of three domains of knowledge. The first domain of knowledge is the acquisition of computer technology such as color representation and management system. The main themes and its elements of understanding basics of computer-generated color can be categorized as follows.

- **Concept of Digital Color**: color representation (resolution and memory), additive color mixing, subtractive color mixing for hard copies.

- **Language of Digital Color**: color models (RGB, CMYK, HSB, HLS, CIE L*a*b*), device-dependent color, device-independent color, color matching systems.

- **Management of Digital Color**: digital palette, calibration, color management systems

The second domain of knowledge deals with a holistic and heuristic issue: the understanding of multiple sources of input images and multiple types of output devices and media. Because most of digital color systems are device-dependent, clear understandings about functions of each hardware and software programs are very important to manage different color systems within a holistic view of using digital color. Since a designer's ability to generate innovative ideas can be dependent on his/her familiarity with the technology he/she is using, it is important that students are well versed in imaging process, electro scanning, printing process, and color reproduction.

The third domain of knowledge in digital color education is to create patterns or sequences of harmony and beauty. Compared to traditional media, computer technology allows designers expand the scope of designs from two- and three-dimensions, to four-dimensions. The fourth-dimension is related to the temporal structure of design elements and principles. Along with the technical understanding and applications, which are the first and second domains of knowledge in this paper, digital color education should also include experiments of exploring new visual language by harmonizing two- to four-dimensions. This creative
design problem solving process and its outputs are the themes of the third domain of knowledge in digital color education.

Case Study: Development of Computer Assisted Instruction

On the basis of literature review of color theories and learning theories from the area of educational technology, the researcher selected Computer Assisted Instruction (CAI) as an instructional method for teaching digital color education. CAI is referred to which computer systems delivers instruction directly to students and allows them to interact with lessons programmed into the system. CAI makes use of several techniques to support learning including tutorial, drill-and-practice, presentation, demonstration, game, simulation, problem-solving methods.

The underlying motivation for selecting CAI as a tool in digital color education is to use the same media for the instruction that will be used in the design problem-solving process. From Skinner's reinforcement to Gagne's conditioned learning, behavioral and cognitive learning theories have emphasized the importance of using symbolic elements for the learning event. The newly developed CAI program in this paper has the same semantic representation of digital color, which is simultaneously and consecutively implied as objects of instruction as well as methods of delivering the contents. The effectiveness of using CAI in digital color education is enhanced by the interactive nature of the program and the fact that it is self-paced.

In order to identify the effectiveness and possibilities for the digital color education, a CAI program was developed and used as a supplementary instruction for the freshmen of the Industrial Design Department, KAIST in 1998. The course, named 'Color Theories and Practices', provided students the holistic understandings of color through hands-on experiments with traditional analog medium. As a supplementary instruction, a newly developed CAI program taught the concepts and language of digital color. Figure 2 and 3 shows the title and an instructional scene of the program. This CAI program combined the

1. The course of 'Color Theories and Practices' was taught by the researcher, and the supplementary instruction was guided by a graduate student, Hyun-Jin Kim. The timing of providing CAI was carefully considered in relation to the student's understanding levels of color studies.
first domain of knowledge in digital color and third domain of design creations. It consists of two levels of lessons: tutorial and drill-and-practice.

![Title of the program](image1.png) ![Image of CAI program](image2.png)

**Figure 2. Title of the program**  **Figure 3. Image of CAI program**

**Analysis of the Effectiveness of CAI**

The potential uses of computers in design education go far beyond the provision of direct instruction. Besides delivering better instructions directly or indirectly, computers can assist educators to improve the quality of instruction by analyzing the elements of the learning event systematically. The case study of implementing CAI for digital color education showed the possibilities of improving the quality of color education, and the potentials of developing new design language with digital color. The case of 'simultaneous contrast' and 'consecutive contrast' is a good example of where CAI proved to be helpful in color studies. The phenomena caused by both contrasts are regarded as difficult subject matters to teach in the traditional lecture format and with analog media. Using animation afforded by the computer, the causes and effects of both contrasts can be easily displayed in relation to each other. The student can then develop interactive design ideas on the basis of understanding two phenomena.

The real-time exercise showed how the computer adds a new dimension to both the design language itself and to the way in which color theory can be taught. Figure 4 explains an example of students' work, which creates a basic color palette from the original image and develops harmonious patterns with design principles. All of images were animated to discover the new applications of temporal structure in digital color theories.
Conclusion

The new digital color paradigm requires new domains of knowledge in color theory studies. This paper investigates the importance of learning digital color theories and its applications in the design problem-solving process. As a case study, a computer assisted instruction program was developed to address this new domain of knowledge and to assist in the development of designs with this new visual language. The CAI program included the characteristics of computer as a medium, and it influenced to the development of spatial and temporal structure of digital color design education. While this case study didn’t cover all of the areas of knowledge which need to be addressed in a digital color design curriculum, it did show that CAI can be an effective method for teaching digital color theory. Further studies would be required to develop in-depth digital color theory lessons and help uncover the creativity aspects of digital design education.
In summary, the old media are in transition to a different technological, social, and cultural environment. The implications of this new media in the design process are that new domains of knowledge need to be taught and that new methods in teaching them need to be established in order to enhance the quality of education. The diverse issues of digital color related to the design process are not separable with the characteristics of media itself. The meanings and values of media technology should be investigated to enhance the quality and effectiveness of design education. The media is not truly a tool, but a part of contents in digital color education.

References

REPRODUCTION OF OBJECT COLORS ON CRT MONITOR SCREEN
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Abstract

The digital input values $d_r, d_g, d_b$ needed to produce object colors on CRT monitor can be predicted from the each channel's luminance functions $f(d_r), f(d_g), f(d_b)$ independently if monitor's performance matches the following assumptions. In this study, assumptions of phosphor constancy and channel dependence could be held by adjusting the monitor's setup using it's nested "brightness" and "contrast" controls. However, in practice this control is limited, so measured spectrum for background light has been subtracted from all measurements. Second order polynomial model is used to obtain the luminance functions of each channel. As a result, Macbeth ColorChecker chart specified by CIE chromaticity coordinates and luminance based on CIE illuminant C could be reproduced accurately on CRT monitor.

1. Introduction

Vision researchers are often using color CRT monitor, driven by a set of digital red, green, and blue signals, to produce object color. The digital RGB signals necessary to produce any object color can be predicted from the relation between the digital input values of the monitor and the CIE XYZ tristimulus values of the displayed colors\(^1\text{–}^2\). Because of the large number of colors that may be displayed on the monitor, direct measurement of this relation is not possible\(^3\). Generally, a linear relationship has been used under some assumptions about the monitor condition. These assumptions are white balanced, gamma corrected, phosphor constancy, channel independence, spatial uniformity, temporal stability, etc. However these assumptions are not true for most of the monitors\(^4\). Violations of these assumptions limit the accuracy of the reproduction of object color on the monitor screen.
In this study, monitor assumptions could be satisfied by adjusting the monitor's set up using it's "brightness" and "contrast" level. However, in practice this control is limited, so measured spectrum for background light should be subtracted from all measurements. For each primary, 16 color patches have been displayed at the center of screen in order and measured the radiometric data using spectroradiometer. Second order polynomial model is used to obtain the luminance functions of each channel. As a result, Macbeth ColorChecker chart has been reproduced and evaluated their accuracy.

2. Theory

CRT monitor is driven by digital red, green and blue signals \((d_r, d_g, d_b)\). If a monitor satisfies the gun independence which is no interaction between the electron guns, the tristimulus values \(X_c, Y_c, Z_c\) of a reproduced color is the sum of the three stimuli of phosphor corresponding each signal. However, there is background light emitted by the CRT when all signals are zero, then for color C

\[
X_c = X_r + X_g + X_b + X_0
\]

\[
Y_c = Y_r + Y_g + Y_b + Y_0
\]

\[
Z_c = Z_r + Z_g + Z_b + Z_0
\]

Where the right side of the equations are the sum of tristimulus values of pure phosphor for three signals and background light.

In the case of given chromaticity coordinates and luminance \((x, y, Y)\) of three phosphors, corresponding \((X, Y, Z)\) can be recovered by:

\[
X = \frac{x}{y}, \quad Y = Y, \quad Z = \frac{(1 - x - y)Y}{y}
\]

By substituting Eq. (2) into Eq. (1), Eq. (1) can be rewritten as a matrix equation:

\[
\begin{pmatrix}
X_c \\
Y_c \\
Z_c
\end{pmatrix} =
\begin{pmatrix}
x_r & x_g & x_b \\
y_r & y_g & y_b \\
1 & 1 & 1
\end{pmatrix}
\begin{pmatrix}
x_r \\
y_r \\
z_r
\end{pmatrix}
\begin{pmatrix}
y_r \\
y_g \\
y_b
\end{pmatrix}
\begin{pmatrix}
X_0 \\
Y_0 \\
Z_0
\end{pmatrix}
\]

\[
-----------------------------(3)
\]
where transformation matrix is particular to three phosphor’s chromaticity coordinates.

The goal is to obtain the necessary digital signals \(d_r, d_g, d_b\) to produce an object color specified with chromaticity coordinates \(x_c, y_c\) and luminance \(Y_c\). Rearranging Eq. (3) so as to solve for the phosphor luminances:

\[
\begin{pmatrix}
X_R - X_0 \\
X_G - Y_0 \\
X_B - Z_0
\end{pmatrix}
= \begin{pmatrix}
x_R & x_G & x_B \\
y_R & y_G & y_B \\
z_R & z_G & z_B
\end{pmatrix}^{-1}
\begin{pmatrix}
X_c \\
y_c \\
z_c
\end{pmatrix}
\]

The digital signals \(d_r, d_g, d_b\) corresponding to \(Y_R, Y_G, Y_B\) can be determined using the luminance functions \(f(d_r), f(d_g), f(d_b)\) fitted with the subsequent luminance measurements. These digital signals are linearly quantized to video voltages and fed to the guns to produce the specified object color on the monitor screen.

3. Measurement

All measurements are carried out in a dark room. Equipment arrangement is as shown in Figure 1. Non-contact measurements were performed using a spectroradiometer CS-1000 from Minolta. The acceptance angle of CS-1000 is 1° and the measurement area on screen is \(h\) over 20 of diameter when CS-1000 is aligned at a distance of 3h (h: the vertical height of screen). The instrument optical axis should be the normal angle to the surface of the monitor. It is specified to have a wavelength accuracy of ±0.3 nm and a spectral bandwidth is 5 nm. The minimum value that could be measured was of the order of 0.01 cd. The accuracy of CS-1000 is ±2% in luminance (for CIE illuminant A).

The monitor to test is Sony 17” controlled by Matrox MGA Mystique card (1024x768, 8-bit DACs). Contrast and brightness levels are adjusted to an optimum state. The “brightness” has been reduced until the measured luminance for background signal (0,0,0) is just 0. However, in practice this control is limited, so measured background spectrum has been subtracted from all measurements. And the “contrast” has been raised so that a white signal (255,255,255) produces the appropriate level of intensity.

Seung-ok. P., Hong-suk K., Youn-woo J.: Reproduction of Object Colors on CRT Monitor Screen
Red, green, and blue primary colors are displayed over the entire screen. For each phosphor, 17 levels of digital signal with the interval of 16 digits have been applied in order and the spectrum of colored light emitted from the screen has been measured.

4. Results and Discussions

Figure 2 shows the measured spectra for 17 levels of digital signal of red, green, and blue phosphor. The chromaticity coordinates of each phosphor could be obtained from these spectra subtracting spectrum of background light. The chromaticity coordinates of each phosphor is constant independent of the level of digital signal as shown in Figure 3. Table 1 shows the resulted chromaticity coordinates for red, green, and blue phosphor. The transformation matrix can be determined from Table 1.
Figure 3. The chromaticity coordinates of three phosphors independent of the level of digital signal

Table 1. Chromaticity coordinates for red, green, and blue phosphor

<table>
<thead>
<tr>
<th></th>
<th>Red</th>
<th>Green</th>
<th>Blue</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>0.6177</td>
<td>0.2812</td>
<td>0.1512</td>
</tr>
<tr>
<td>y</td>
<td>0.3395</td>
<td>0.6017</td>
<td>0.0624</td>
</tr>
</tbody>
</table>

The luminance curves can be obtained from the 17 spectra as shown in Figure 4. Figure 4 shows the nonlinear relationship between digital signals and luminances for all phosphors, however this relationship is monotonic increasing. Green phosphor, at any given digital signal emits substantially more luminance than the red phosphor, which in turn emits more luminance than the blue phosphor. For neutral colors driven with the same $d_x, d_y, d_z$ signals, the inclination of the curve is the same as that of red, green and blue phosphor. At any level, luminance of neutral is consistent to the sum of red, green and blue luminance. This shows there is no interaction between the channels. Second order polynomial model is used to obtain a good fit of the digital signal to luminance relationship $f(R), f(G), f(B)$. Two-sliced fit yields the best fit for lower digital signals. Macbeth ColorCheker's 24 color chips are chosen as an object color set. For each color, The chromaticity coordinates and luminance under illuminant C can be calculated from their reflectance spectrum. The tristimulus values $X, Y, Z$ for each color can be obtained by Eq. (2).
The luminances $Y_R, Y_G, Y_B$ needed to produce a desired color given $X, Y, Z$ can be determined substituting transform matrix in Eq. (3). With these, the digital signals $d_R, d_G, d_B$ can be predicted using the fitting functions $f(R), f(G), f(B)$. The voltage corresponding to these signals are fed to the CRT, and monitor color is produced on the screen. Displayed chromaticity coordinates are measured and compared with the calculated values from the reflectance spectrum. Figure 5 show the comparison of measured and calculated values. The chromaticity coordinates are shown in Figure 5(a) and the luminances are shown in Figure 5(b). These results are the average color difference $\Delta E'_{ab}$ of 1.5.

![Figure 4. The nonlinear relationship between digital signals and luminances](image)

![Figure 5(a). Measured and Calculated Chromaticity Coordinates](image)
5. Conclusions

Reproduction of object colors on the CRT monitor is performed. CRT monitor’s “Brightness” and “Contrast” levels are adjusted to an optimum state where nearly satisfies the monitor assumptions. By subtracting the minute amount of background light, the chromaticity coordinates of red, green and blue phosphors can be obtained to determine the transform matrix. With the measured relations between the digital input values and the produced luminance for three primaries, Macbeth ColorChecker’s 24 color chips can be produced on the monitor within average $\Delta E^*$ of 1.5. This technique need not limited to use with the CRT monitor. Once the color coordinates of the display’s primaries and the digital signals-luminance relationship are measured, this technique can be applied to any kind of display. However the accuracy depends on the satisfaction of monitor assumptions.

References


ANALYSYS OF VISUAL PROCESSING OF CHROMATIC CONTRAST AT ISOLUMINANCE

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ABSTRACT

On the basis of signal theory, we analyze the different efficiency of the red-green and tritan channels (or chromatic signals) of human color vision. The experimental results for 5,774 color stimuli confirm a lower chromatic contrast for S variations that could cause differing efficiency of chromatic-opponent signals in certain visual tasks. This information should be taken into account in areas (color-vision models, optical signal processing, pattern recognition) which use or apply chromatic information based on human chromatic perception.

INTRODUCTION

Chromatic codification of information is continually more commonplace and important, and therefore different disciplines dwell on this aspect, such as: optical processing [1-2], optical recognition of objects [3] and color-vision models [4-7]. Color is a fundamental perceptive aspect of human vision and vital in many tasks (e.g., discrimination, identification, recognition), and thus many models or algorithms take color into account. Most of the systems which work with color include 3 signals or channels-- one achromatic which transports the information on luminance (black-white or light-dark) and two on chromatic aspects (red-green and yellow-blue or tritan). This form of processing coincides basically with the first stages in the processing of human vision; that is, color-vision two-step models [4-5] propose that one pathway processes the luminance or achromatic signal while two other pathways process the chromatic-opponent information. According to Boynton's color-vision model [4], these three pathways are an achromatic channel (L+M), a red-green...
channel (L-2M) and a yellow-blue or tritan one (L+M-S). These channels are obtained as a combination of the L, M and S response of the photoreceptors sensitive to long, medium and short wavelengths, respectively.

Traditionally, most of the work on image processing has dealt with the luminance signal, without considering chromatic aspects despite their being present at the scene. In recent years, optical pattern-recognition studies based on visual models have been introduced [2-3]. Until now, the incorporation of the chromatic signals has not implied their comparison, nor have weights been established for the different signals, although it should be taken into account that the chromatic information makes more sense when signals are compared in tasks with reference to the human observer. Within this framework, the luminance and chromatic signals are found not to have equal efficiency for the observer. It is widely known that luminance variations are more efficient for an observer than are chromatic ones in tasks such as stimulus discrimination, spatial vision, temporal aspects and movement [8-9]. This is one of the reasons for which, until recently, work on image processing was done only with the luminance signal. These psychophysical data on the black-white signal are corroborated by the analysis of the ideal observer, based on the signal theory, which confirms that chromatic information at the level of the photopigments is minor compared to intensity information [10].

The incorporation of the chromatic information introduces two chromatic signals, but one question that emerges from the study of chromatic-information processing is whether the visual system processes the red-green and the yellow-blue signals with the same efficiency at isoluminance. A partial response to this question is provided by certain data obtained from some psychophysical data of the visual system:

---Chromatic discrimination. When discrimination thresholds are determined at isoluminance (L+M is constant in Boynton’s model), some authors [11] have detected that nearly all the chromatic discrimination ellipses are oriented along the S-cone-variation axis (poorer discrimination along this axis), that the size of the ellipses increases with the excitation level of the S cone, and that at low and moderate levels of S-cone excitation the threshold in the yellow-blue mechanism appears to be independent of the degree of red-green excitation. Yeh et al. [12] reported that the discrimination steps along the S-cone axis increase more than the steps along the M/L-cone axis as luminance and field size decreased. It can be concluded that, within
a wide range of experimental conditions, the discrimination based on S-cones is worse than that based on M-L-cones (red-green).

-- Spatial Vision. There is evidence for the differences in spatial sensitivity between the chromatic-opponent signals [9-13]. Webster and De Valois [13] found a higher contrast sensitivity for the red-green variations. Most of these researchers [9-13] concur that, with regard to high frequencies, the cutoff frequency is higher for red-green variations than for the S variations.

-- Visual reaction times. Baker and Mollon [14] found that at equal luminance, response time increases when there are variations in the S-cone signal. These reaction times are longer than those for variations in the L/M ratio. Comparable results were reported by other authors [15] -- that is, the L-2M signal is reportedly faster than the S signal.

-- Stereopsis. Several studies have reported the contribution of chromaticity to stereoscopic perception, on introducing chromaticity variations at isoluminance in random-dot stereograms (RDS) [16-18]. When the disparity range (maximum displacement of the small square of the RDS) is determined, results reveal, for observers who perceive stereopsis via tritan directions, a gradation in the disparity range, with the disparity range for stereograms generated by red-green variations being greater than for stereograms generated in tritan directions [18].

Although this behavioral difference is confirmed in some visual tasks, it would be useful to introduce some type of quantitative analysis which could evaluate or predict this difference. For this, we used the chromatic contrast derived from the ideal-observer analysis proposed by Geisler, which has provided good predictions for other aspects of vision [19]. This ideal-observer analysis (chromatic contrast) includes information about the different spectral sensitivities, proportions of cones, and optical transmittance of the eye, and is based on signals theory.

The aim of the present work was to evaluate the chromatic contrast brought about by equal-luminance stimuli according to variations over the red-green directions and of the tritan directions derived from the Boynton's two-step scheme [4]. The finding of any differences--in our case higher chromatic contrast for red-green variations--would signify that the qualitative differences in the behavior of chromatic signals would have been predicted by the ideal-observer analysis. In this case, we should find a certain correlation between the psychophysical phenomena described above and the chromatic information derived from the chromatic-contrast analysis which should be incorporated in the visual models and image-processing.
models that take into account chromatic aspects. Finally, we must say that our analysis (as in the experiments described above) will be carried out at isoluminance--i.e. maintaining the luminance constant--since, if we seek to compare the chromatic signals, we must maintain luminance constant to avoid masking our analysis with variations in the luminance signal. We must indicate that at isoluminance (L+M=constant), variations in the yellow-blue channel [4] (L+M-S) are due to variations in the S values.

METHOD

Color stimuli

We determined the chromatic-contrast for pairs of stimuli (presented in a CRT-color monitor) distributed along red-green (S constant, L-2M varying) and tritan (S varying, L-2M constant) directions at isoluminance (L+M constant) according to Boynton's color-vision model [4] (Fig. 1).

In Boynton's color-vision model, the values L, M and S are easily determined from the absorption spectra of the photopigments, as well as from the spectral radiance of the stimuli, and are related numerically to the chromaticity coordinates and luminance coordinates related to the CIE-1931 diagram (x, y, Y) [4]. When we used color stimuli located on lines originating at point (x=0.175, y=0.0), we obtained stimuli with the same L-2M excitation level and a variable level for S (Fig. 1). Similarly, when the stimuli were located on lines passing through point (x=1.0, y=0.0), we got stimuli with the same S excitation level and a variable L-2M excitation level (Fig. 1).

Two different sets of color stimuli were used in our analysis. First, color stimuli were obtained from a colorimetrically calibrated color monitor connected to an 8-bit graphic card. We should bear in mind that many color experiments are performed with color monitors. We took stimuli for two luminance levels, 12 and 30 cd/m$^2$ (100 stimuli for each luminance level). We accepted color stimuli with a luminance tolerance of 2% with respect to isoluminance. For chromaticity coordinates, we accepted a tolerance of ±0.05 for x and y chromaticity coordinates. We measured the chromaticity and luminance using a SpectraScan PR-704 PhotoResearch spectroradiometer.
Secondly, although color monitors are frequently used in color-vision experiments, the stimuli are obtained as a combination of the three monitor phosphores, limiting the possibilities of obtaining different combinations of stimuli. To generalize the results as much as possible, we also used a large sampling of color stimuli hand painted [20] using 24 basic acrylic colors (for artists), providing a total of 5,574 different samples that covered all the different hues. The spectral reflectance of each sample was measured with a Hunterlab UltraScan™ spectrophotometer. In our analysis, we considered the stimuli which are obtained when the reflectances are illuminated by the D65 illuminant. We allowed the same tolerances for luminance and chromaticity coordinates as in the case of the stimuli generated by the color monitor.

Ideal-observer analysis

To evaluate the chromatic contrast, we used the ideal-observer proposed by Geisler, which, as mentioned above, provides good predictions in studying other visual tasks [19]. The formula used for the chromatic contrast corresponding to a pair of stimuli was:

$$C_a = \frac{\kappa \ln I_1 p_L c_L d_L + m p_M c_M d_M + s p_S c_S d_S}{(l p_L d_L + m p_M d_M + s p_S d_S)^{1/3}} \tag{1}$$

where $p_L = 0.65$, $p_M = 0.33$ and $p_S = 0.02$ are the proportions of the L, M and S cones in the foveal area of the retina; $l$, $m$ and $s$ are the sums of the numbers of photons absorbed in the L, M and S...
cones by the stimuli to be used in calculating the contrast; and \( c_i, c_m, c_s, d_i, d_m \) and \( d_s \) are determined by the expressions:

\[
    c_i = \frac{\text{abs} (\Delta i)}{i}, \quad d_i = \ln\left(\frac{1 + c_i}{1 - c_i}\right), \quad i = l, m, s.
\]  

where \( \Delta l, \Delta m, \Delta s \) represent the differences in absorption values of the 3 types of cones produced by the two stimuli to be used in calculating the contrast; \( n \) is the total number of cones under one stimulus element. These absorption values were determined from the spectral radiance of the stimuli, the average transmittance function of the eye and the absorption spectra of photopigments [21-22].

We shall normalize the chromatic contrast to the highest value of those obtained for the set of stimulus pairs tested, and therefore it is not necessary to take the \( n \) value into account. In any case, the results obtained differ only in a constant, which does not affect the analysis of our results on whether or not the chromatic contrast for red-green or tritan pairs of stimuli differ significantly.

**RESULTS AND DISCUSSION**

The results (see Table I) of the average chromatic contrast for color stimuli obtained with the color monitor were: 0.48 for stimuli distributed along red-green directions and 0.22 for S directions \( (C_e \) was computed for every possible pair in these directions and then averaged) The differences were statistically significant (with 95% confidence level) and red-green chromatic contrast was approximately twice (a ratio of 2.18:1) the S chromatic contrast. We found that red-green variations caused a higher chromatic contrast than did S variations.

Although we found differences between the two signals, this analysis is even biased against red-green variations. In this analysis, we compared pairs of a small Euclidean distance in the CIE-1931 chromaticity diagram with pairs of larger Euclidean distances and vice versa. It should be borne in mind that we averaged stimulus pairs with small differences in spectral radiance (with the same primaries, stimuli with similar spectral radiance have similar chromaticity coordinates) the chromatic contrast would be low and therefore the red-green and S differences might remain hidden (or would not be seen clearly). If we compare only the pairs of stimuli in red-green and S directions with a large Euclidean distance, the differences probably might be greater. Therefore, we determined the same average, but for pairs of stimuli with large
Euclidean distances (the four pairs with a larger Euclidean distance for each red-green and tritan line), obtaining the following results: 0.81 for red-green and 0.33 for tritan (a ratio of 2.45:1). This result not only confirms the previous tendency but enhances it.

Table I. Values of average chromatic contrast \( (C_s) \) for the red-green and yellow-blue chromatic signals calculated for color-monitor stimuli and hand-made samples. The ratio of the chromatic contrast between the two signals is also included.

<table>
<thead>
<tr>
<th>Chromatic contrast</th>
<th>( C_s ) (red-green)</th>
<th>( C_s ) (yellow-blue)</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color-monitor stimuli</td>
<td>0.48</td>
<td>0.21</td>
<td>2.18:1</td>
</tr>
<tr>
<td>hand-made samples</td>
<td>0.66</td>
<td>0.30</td>
<td>2.20:1</td>
</tr>
</tbody>
</table>

Our results show that ideal-observer analysis finds differences between the chromatic signals at isoluminance and it confirms their different efficiency, which could explain the differences detected in some psychophysical aspects of the visual system, just as the ideal-observer analysis detected the differences between chromatic and luminance information, as we indicated above [10].

The results for the 5,574 hand-made samples (Table I) were as follows: 0.66 for red-green variations and 0.30 for pairs of stimuli distributed along S directions (a ratio of 2.2:1). We confirmed the results obtained with color-monitor stimuli but they are generalized to a larger collection of stimuli: the chromatic-contrast is approximately twice for red-green variations than for S variations. From the point of view of colorimetry, the analysis of the results could be somewhat more detailed, although those results do not alter the trends observed. Thus, with the stimuli generated on the CRT color monitor, if we take into account the luminance level, the ratio of the chromatic contrast between the red-green and S variations is 2.16:1 and 2.20:1 for the levels of 12 cd/m² and 30 cd/m², respectively. In addition, an analysis was made by zones in the CIE-1931 diagram, since the 5574 hand-made samples were divided into 5 hue groups [20]: red, yellow, green, blue and purple. The ratios of maximum contrast were found when the red-green groups and the red-blue groups (2.31:1 and 2.27:1, respectively) were compared.

The results show that the ideal-observer analysis can predict some of the differences between the chromatic signals at isoluminance and may explain the different behavior for different aspects of the visual system. According to the ideal-observer analysis, a lower chromatic contrast implies a lower chromatic information, and therefore, perhaps less information is processed for the different visual tasks. In addition, these differences between the chromatic-
opponent signals for some psychophysical tasks could be connected with some anatomical differences in the color pathways found in the primate retina [23-24]: the red-green opponent signal is transmitted by one type of ganglion cell, the midget cell, while S-cone excitatory signals are conveyed by a type of non-midget ganglion cell, the small bistratified one [23].

In summary, the ideal observer would detect a lower chromatic contrast for tritan variations, which could cause less efficiency for these variations than along red-green directions in some visual tasks. This information should be considered for the different algorithms and models that take into account chromatic information, so long as their use is applied to or is made to simulate the human visual system, since chromatic signals (traditionally treated equally) do not show the same information, either in terms of psychophysical tasks or in chromatic processing.

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REFERENCES

SUGGESTIONS ON THE FACADE COLOUR ARRANGEMENTS

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ABSTRACT

The architectural characteristics and colours of building facades are the major factors that effect the general appearance of cities. When cities are examined in various perspectives, the first impressions are obtained through geometrical forms and building colours. Therefore, the colour arrangements of buildings should reflect the features of the region and buildings. In mass housing, there are many buildings. The colour arrangements should be appropriate for the specifications of both "the single building" and "all of the buildings". Therefore, the colour arrangements design of mass housing is more complex than single building. Colour design of mass housings may be done in three stage. Firstly, the specifications of environment and settlement (topography of land, position and form of buildings etc.) should be examined. Secondly, a general colour arrangement should be chosen for the mass housings according to the specifications that were determined in the first stage. Thirdly, a suitable colour arrangement should be designed for each building.

The aims of this paper are to mention elements of colour contrast, colour arrangements and colour design stages of mass housing, and to explain colour arrangements of "Bizimkent Mass Housing" in Istanbul as an example.
INTRODUCTION

The architectural features of the building envelope play important roles in creating a special character that belongs to the settlement. To make an effective and attractive environment, buildings have to be in harmony within each other and their surroundings. Building facade colour is an inseparable part of architecture and one of the elements to create meaningful, expressive, discernible architectural environments. By using the power and effect of colour, emphasising the building, giving particular identity and even camouflaging some constructional mistakes can be possible. Colour composition of the facade should be designed having appropriate qualities both in building scale; for showing its originality, and in the settlement scale; according to the natural, architectural and colour features of the settlement region.

It is obvious that, for colour arrangement design of mass housing, more extensive and detailed studies are necessary compared to one building arrangement, because there are more than one building. In this study, the elements of colour contrast, contrast limits and basic contrast arrangements have been briefly mentioned and also basic principles, design stages and facade colours of "Bizimkent Mass Housing - Istanbul" have been explained as an example of the facade colour composition studies for mass housing.

1. CONTRAST AND CONTRAST QUANTITIES

The perception of any object or surface within the visual field, depends on the differences of light that comes the eye from various parts of the visual field. If there are no changes in the quantity or quality of light and if this case does not change in time, it is impossible to have visual perception. Therefore, the creation of a certain effect, evoking emotion or rendering specific ideas on the observer, can be attained by using contrasts in the visual field.

The term "contrast" is used to distinguish certain elements in lighting and colour. There are three contrast elements in the visual sensoius stimulus-light; dominant wavelength, luminance and excitation purity. The sensory impressions corresponding to these are, hue, brightness and chromaticness and according to the Munsell Color System they correspond to hue, value and chroma. Contrast quantity limits can be calculated by using equations that are given below for the elements of the Munsell Color System. These equations have been derived from basic
contrast equation \((C=|L_1-L_2|/L_1)\), in which maximum contrast quantity is 1, minimum contrast quantity is 0.

For the elements of the Munsell Color System, examples of contrast quantities have been calculated and presented below:

- **Maximum contrast** (the greatest quantity of contrast is ‘1’) can be created by using together:
  - for hue; complementary hues which have 50 hue step difference between each other (for instance, 5R(5) and 5BG(55); 5Y (25) and 5PB (75); etc.).
  - for value; black (0) and white (10).
  - for chroma; gray (0) and maximum chroma of that hue.

- **Minimum contrast** (the smallest quantity of contrast is ‘0’ ) can be provided by using together;
  - for hue; same hues (for instance, 5R (3) and 5R (5); 5Y (25) and 5Y (25); etc.).
  - for value; same values (for instance, black (0) and black (0); 5 and 5; 8 and 8; etc.).
  - for chroma; same chromas (for instance, 2 and 2; 7 and 7; 12 and 12; etc.).

- The contrast quantities which are in between the two limits (1 - 0) and that decrease can be shown as;
  - for hues; lessening of the complementary hue ratio (for instance, contrast is 0.8 between 5R (5) and 5G (45); contrast is 0.4 between 5R (5) and 5Y (25); etc.).
  - for values; convergence of values of hues (for instance, contrast is 0.7 between 2 and 9; contrast is 0.4 between 4 and 8; etc.).
  - for chroma; convergence of chromas of hues (if maximum chroma is 20 for any hue, contrast will equal to 0.4 between 2 and 12 or 0.2 between 2 and 6; etc.)
2. BASIC COLOUR ARRANGEMENTS AND MASS HOUSING

2.1. BASIC COLOUR ARRANGEMENTS

Creating a certain effect or a specific aesthetic message on the observers, depends on the existence of one or two of the hue, value or chroma contrasts in the visual field. And also, different effects and meanings can be made according to the numbers, types, quantities and distributions of the contrasts. The effect of the visual field that has three contrasts is natural, usual and unremarkable, as in the nature. These are called "natural contrasts or triple contrasts". In the natural contrast arrangements, every three colour element (hue, value and chroma) change randomly and there are big contrast quantities among them. Therefore, to create an aesthetic image, natural contrasts should not be used in a colour composition. For two dimensional surfaces-plans, colour contrast arrangements that have an artistic message can be collected in two main groups, according to contrast limits of the colour elements that take place next to each other, as follows:

a. Simple Contrast Arrangements

In this composition, contrast quantities of only one colour element changes; because of this, there is only one contrast. The effects of the simple contrast arrangements are opposite from the natural and accustomed. To create a strong visual effect, two limit situations that have maximum contrast quantities should be determined for changing element (for example hues, 5 and 55). One of the determined limit situations (55) should be used with similar colours (similar hues; 50, 55, 60) that have little contrast. In other words, a colour group that has little contrasts should be designed. The second of the determined limit situations (5) should be left alone. By this way, within many little contrast, the other changing colour element that has bigger contrast is emphasised. There are three types of simple contrast arrangements:

• Arrangement of Hue Contrast (hues change, values and chromas are constant). For example; 5-6/6, 50-6/6, 55-6/6, 60-6/6, quantity of hue contrast is 1 between 5 and 55; or 55-6/6, 5-6/6, 10-6/6, 15-6/6, quantity of hue contrast is 1 between 55 and 5.

• Arrangement of Value Contrast (values change, hues and chromas are constant). For example; 65-2/4, 65-7/4, 65-8/4, 65-9/4, quantity of value contrast is 0.7 between 2 and 9, or 65-9/4, 65-2/4, 65-3/4, 65-4/4 quantity of value contrast is 0.7 between 9 and 2.
Session VII: Applications of Colorimetry

- Arrangement of Chroma Contrast (chromas change, hues and values are constant). For example; 85-5/2, 85-5/10, 85-5/12, 85-5/14, quantity of chroma contrast is 0.86 between 2 and 14; 85-5/12, 85-5/2, 85-5/4; 85-5/5, quantity of chroma contrast is 0.86 between 14 and 2.

a.a. Similar Colour Arrangements to Simple Contrast Arrangements

In these arrangements, all colour elements change. But, two of three colour elements (hue, value, chroma) are less changed than third colour element. In other words, two of three colour elements have little contrast quantities and third one has bigger contrast quantity. This type is called “similar colour arrangements to simple contrast arrangements”. They can be shown as below:

- Similar to Arrangement of Hue Contrast (hues change, values and/or chromas have small changes). For example; 5-6/5, 50-5/6, 55-5/6, 60-5/7 or 5-5/6, 55-5/6, 60-7/6.
- Similar to Arrangement of Chroma Contrast (chromas change, hues and/or values have small changes). For example; 95-5/2, 90-5/10, 85-5/12, 80-5/14 or 85-5/12, 85-4/2, 85-6/4; 80-5/5.

b. Binary Contrast Arrangements

In binary contrast arrangements, contrast limits of only two colour elements change; therefore, they have two type of contrasts. Their effects are far from the natural and accustomed, but they are less impressive, powerful than the simple colour arrangements. There are three types of binary contrast arrangements. In these arrangements, if contrast quantity of one of the changing elements is chosen greater than the others, the effect of the arrangement would be strengthened.

- Arrangement of Same Hues (hue is constant, values and chromas are variable). For example; 20-2/3, 20-3/5, 20-5/4, 15-5/5 or 20-5/2, 20-4/4, 20-3/5, 20-6/12.
- Arrangement of Same Values (value is constant, hues and chromas are variable). For example; 30-5/6, 35-5/5, 40-5/7, 85-5/6 or 30-5/12, 38-5/6, 43-5/3, 50-5/5.
- Arrangement of Same Chromas (chroma is constant, hues and values are variable). For example, 5-4/7, 50-5/7, 85-6/7, 60-6/7 or 5-4/7, 10-5/7, 15-8/7, 20-5/7.
b.b. Similar to Binary Contrast Arrangements

In such arrangements, all colour elements change. But, one of three colour elements (hue, value, chroma) are less changed than other two. These types are called “similar colour arrangements to binary contrast arrangements”. They can be shown as below:

- Similar to Arrangement of Same Hues (hues have small change, values and chromas change). For example; 17-2/3, 20-3/5, 23-5/4, 26-9/5 or 17-5/2, 20-4/4, 23-3/5, 26-6/12.
- Similar to Arrangement of Same Values (values have small change, hues and chromas changes). For example; 30-8/6, 35-4/5, 40-6/7, 85-5/6 or 30-5/12, 38-4/6, 45-5/3, 52-6/5.
- Similar to Arrangement of Same Chroma (chromas have small change, hues and values changes). For example; 5-4/7, 50-5/6, 55-6/7, 60-5/8 or 5-4/7, 12-3/8, 20-9/6, 100-5/7.

2.2. COLOUR DESIGN FOR MASS HOUSING

In order to successfully use the arrangements mentioned and to achieve strong and impressive results, the colour contrast element chosen -emphasised- should cover a smaller area than the others. And as known, warm, light and saturate colours always attract the attention of people. In other words, if hue effect is aimed, the emphasised hue in the visual field must be selected in the warmers, in order to create stronger impressions. Similarly, for value effect, lighter colours; for saturated effect, higher chromas must be used to achieve effective appearance.

While colouring a building facade, basic colour arrangements for two dimensional surfaces which have been given in chapter 2 may be used. But, there are a lot of buildings in the mass housings and it is necessary to arrange the colour of all buildings in detail. Because of this, the colour arrangement process of mass housing has different stages than colour arrangement of single building. Three stages are recommended in such a colour design. In the first stage of design, designer should examine the specifications of mass housing. The examination criteria are as follows:

- environmental conditions (water, forest, open land, settlement district etc.),
- land topography and regional climatic conditions,
- site plan, geometrical form and position of buildings, architectural style,
- instruction system, materials and etc.
Secondly, in the settlement scale, basic principles of the colour arrangement should be determined according to the specifications of the first stage; and all buildings should be considered as a whole. In the third stage, which is the building scale, a specific colour composition should be created considering form, dimension, building materials, architectural features and etc. for each building. Also, shadowed (dark) and illuminated (light) areas produce on the building surfaces due to the architectural features of the facade and the sun movement. It must be noted that, these natural contrast between the dark and the light areas influence the colour composition of the building exterior.

3. THE COLOUR ARRANGEMENTS OF BIZIMKENT MASS HOUSING

3.1. SETTLEMENT FEATURES

Bizimkent Mass Housing is placed at the new dwelling zone with other mass housings in Büyükçekmece town of Istanbul. The land shape is rectangular and dimensions are 350 m x 950 m. The level difference is 15 m in the longitudinal section of land. There are 3948 apartments, 53 blocks in the settlement. The specifications of the blocks are given below:
• 18 blocks are 16 stories and the block plan is square (S type),
• 33 blocks are 9 stories and the block plan is L (L type),
• 2 blocks are 9 stories and the block plan is rectangular (R type).

The higher blocks that have 16 stories are placed in the middle axis and lower blocks that have 9 stories are placed on the edge of the land. In other words, the lower blocks surround the higher blocks. The positions of the blocks in the land is shown in Figure 1; characteristics of blocks are given in Table 1.

Table 1: Characteristics of Blocks

<table>
<thead>
<tr>
<th>Position</th>
<th>Number</th>
<th>Type</th>
<th>Form</th>
<th>Dimension (m)</th>
<th>Story</th>
<th>Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>middle</td>
<td>18</td>
<td>S</td>
<td>Square</td>
<td>26×30</td>
<td>16</td>
<td>48.50</td>
</tr>
<tr>
<td>edge</td>
<td>33</td>
<td>L</td>
<td>L</td>
<td>33×50; 39×80</td>
<td>9</td>
<td>27.50</td>
</tr>
<tr>
<td>edge</td>
<td>2</td>
<td>R</td>
<td>Rectangular</td>
<td>42×17</td>
<td>9</td>
<td>27.50</td>
</tr>
</tbody>
</table>
3.2. DESIGN STAGES OF COLOUR ARRANGEMENT

Design stages of colour arrangement for Bizimkent Mass Housing can be explained as below:

Stage 1: Determination of Specifications
The settlement has been examined according to the criteria mentioned in section 2 and the determined basic specifications are as follows:

- The settlement should have attractive features and should be separated easily from the other mass housings.
- Massive appearance should be lessened. In other words, different blocks should be distinguished from each other and some of them should be emphasised by using colour.
- An inner court effect should be created in the open spaces among the blocks. Blind-alley, long street and wall impressions which are caused by plans, long facades and position of L types, should be reduced.
- The building facades are made of concrete and precast elements. Therefore, colour arrangement should strengthen the architectural features and it should be in harmony with the facade construction system and materials.

Stage 2: Settlement Scale
Using the basic specifications determined in the first stage, the mass housing has been taken as a whole, and the hue contrast arrangement has been designed in the settlement scale. It was suitable to use this arrangement on the large concrete surfaces that have priority in perception. In establishing hue contrast arrangement, following process was used:

- Blocks were divided into two main part considering plans and positions. 6 basic groups for high blocks (S type) and 6 basic groups for low blocks (L and R type) were determined (see, Figure 1). Warm hues were chosen for high blocks (S types) which are placed in the middle axis. Cool hues were chosen for low blocks (L and R types) which are placed on the edge, surrounding S types which are less in number. Thus, maximum contrast quantities are obtained from the point of view of hue contrast, between the high and low blocks.
- 6 warm hues from pink to yellow which have little hue contrasts were chosen for S block groups. And, similarly, 6 cool hues from green to purple which have little hue contrasts
were chosen for L block groups. By this way, a series of hue specific to each block group that does not lead to confusion was created.

- While applying the determined hues on the blocks, bigger hue contrast quantity has been selected for the high and low blocks which close to each other. Munsell Color System symbols of determined colours for the block groups in the settlement scale are given in Table 2.

### Table 2: Basic Hues and Contrast Quantities for Block Groups

<table>
<thead>
<tr>
<th>Group/Block numbers</th>
<th>Hue (Warm)</th>
<th>Group/Block numbers</th>
<th>Hue (Cool)</th>
<th>Hue Contrast quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1 \times 2$</td>
<td>100 (10 RP)</td>
<td>$L 1 \times 6$</td>
<td>42.5 (2.5 G)</td>
<td>0.85</td>
</tr>
<tr>
<td>$2 \times 4$</td>
<td>7.5 (7.5 R)</td>
<td>$L 2 \times 8$</td>
<td>52.5 (2.5 BG)</td>
<td>0.80</td>
</tr>
<tr>
<td>$3 \times 4$</td>
<td>12.5 (2.5 YR)</td>
<td>$L 3 \times 8$</td>
<td>62.5 (2.5 B)</td>
<td>1.00</td>
</tr>
<tr>
<td>$4 \times 2$</td>
<td>17.5 (7.5 YR)</td>
<td>$L 4 \times 4$</td>
<td>70 (10 B)</td>
<td>0.95</td>
</tr>
<tr>
<td>$5 \times 4$</td>
<td>22.5 (2.5 Y)</td>
<td>$L 5 \times 5$</td>
<td>77.5 (7.5 PB)</td>
<td>0.90</td>
</tr>
<tr>
<td>$6 \times 2$</td>
<td>27.5 (7.5 Y)</td>
<td>$L 6 \times 4$</td>
<td>85 (5 P)</td>
<td>0.85</td>
</tr>
</tbody>
</table>

**Stage 3: Building Scale**

In building scale generally, Similar Colour Arrangement to Same Chromas Arrangement has been applied, and hue contrasts have been emphasised in the building scale of Bizimkent Mass Housing. While the arrangement was selected, position, form, plan type, architectural features of facade and areas of building elements have been considered. Complementary hues of the concrete large surfaces were used on the precast small surfaces and meanwhile, the contrast quantities of chromas were changed a little. In other words, greater quantity in the hue contrasts, middle quantity in the value contrasts, least quantity in the chroma contrasts is obtained. The features of applied colour arrangements are briefly summarised below:

- **S types**: Warm hues were used on the concrete large surfaces and cool hues were used on the precast small surfaces of S blocks. By this way, to emphasise the height of the blocks, vertical strips (cool and middle value) were created. Higher chromas of warm hues has been used on the jamb linings, blind boxes and etc. that cover small areas on the facade. Munsell Color System symbols and contrast quantities of determined colours for S types are given in Table 3.
Table 3: Munsell Color System Symbols for the Colours of S Type Block Groups

<table>
<thead>
<tr>
<th>S</th>
<th>S 2</th>
<th>S 3</th>
<th>S 4</th>
<th>S 5</th>
<th>S 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 - 9 / 2</td>
<td>7.5 - 9 / 2</td>
<td>12.5 - 9 / 2</td>
<td>17.5 - 9 / 2</td>
<td>22.5 - 9 / 2</td>
<td>27.5 - 9 / 2</td>
</tr>
<tr>
<td>100 - 5 / 4</td>
<td>7.5 - 5.5 / 4</td>
<td>12.5 - 5.5 / 4</td>
<td>17.5 - 5.5 / 4</td>
<td>22.5 - 5.5 / 4</td>
<td>27.5 - 5 / 4</td>
</tr>
<tr>
<td>100 - 9.5 / 2</td>
<td>7.5 - 9.5 / 2</td>
<td>12.5 - 9.5 / 2</td>
<td>17.5 - 9.5 / 2</td>
<td>22.5 - 9.5 / 2</td>
<td>27.5 - 9.5 / 2</td>
</tr>
<tr>
<td>42.5 - 4 / 3.5</td>
<td>52.5 - 5 / 4</td>
<td>62.5 - 4.5 / 4</td>
<td>70 - 4.5 / 4</td>
<td>77.5 - 4 / 4</td>
<td>85 - 4 / 4</td>
</tr>
</tbody>
</table>

- L types: In general, cool hues were used on the concrete large surfaces and warm hues were used on the precast small surfaces of L blocks. But, the arm length of some L types is approximately 80 m and they are followed by each other due to the position of these blocks, so an unwanted long and high wall effect is produced. Therefore, to lessen the wall effect, to create a motion and to give high building impression, a lower value of the main hue is used on the vertical precast elements. And also, to emphasise block entrance, to reduce massive appearance, warmer hues were used on surfaces of the entrance zone. In the corners block (connection of the arms) of L types, warm hues were applied on the large surfaces and cool hues were applied on the small surfaces. Thus, arms of the L type has been separated from each other, and the inner court effect has been strengthened for these groups. Munsell Color System symbols and contrast quantities of determined colours for L types are given in Table 4.

Table 4: Munsell Color System Symbols for the Colours of L Type Block Groups

<table>
<thead>
<tr>
<th>L 1</th>
<th>L 2</th>
<th>L 3</th>
<th>L 4</th>
<th>L 5</th>
<th>L 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>42.5 - 9 / 2</td>
<td>52.5 - 9 / 2</td>
<td>62.5 - 9 / 2</td>
<td>70 - 9 / 2</td>
<td>77.5 - 9 / 2</td>
<td>85 - 9 / 2</td>
</tr>
<tr>
<td>42.5 - 4 / 3.5</td>
<td>52.5 - 5 / 4</td>
<td>62.5 - 4.5 / 4</td>
<td>70 - 4.5 / 4</td>
<td>77.5 - 4 / 4</td>
<td>85 - 4 / 4</td>
</tr>
<tr>
<td>42.5 - 9.5 / 2</td>
<td>52.5 - 9.5 / 2</td>
<td>62.5 - 9.5 / 2</td>
<td>70 - 9.5 / 2</td>
<td>77.5 - 9.5 / 2</td>
<td>85 - 9.5 / 2</td>
</tr>
<tr>
<td>100 - 9 / 2</td>
<td>7.5 - 9 / 2</td>
<td>12.5 - 9 / 2</td>
<td>17.5 - 9 / 2</td>
<td>22.5 - 9 / 2</td>
<td>27.5 - 9 / 2</td>
</tr>
<tr>
<td>-10 / 0</td>
<td>-10 / 0</td>
<td>-10 / 0</td>
<td>-10 / 0</td>
<td>-10 / 0</td>
<td>-10 / 0</td>
</tr>
</tbody>
</table>
CONCLUSION

The facade colours have high importance creating an effective and meaningful appearance of a settlement and/or city. Facade colours should be attractive and should stimuli aesthetic impressions. The settlement can be perceived as a whole and it can be separated quickly from others. Therefore, the basic colour arrangements mentioned and design stages given in this study should be considered during colour selection. And also, colour compositions should be a part of the architecture and should emphasise architectural specifications. For these reasons, ideally, the architectural form of a facade should be determined by considering the applicable colour arrangements.

Facade colour designs of mass housing should investigate both in settlement scale and in building scale. If colour studies are made for only building scale, it can result in various negative -undesirable- appearances. Furthermore, while colour arrangements are planned, habitants and even visitors should consider. Habitants should be able to understand general colour composition and should not feel irritated. And also, occupants and especially visitors should be able to easily see and perceive the position and the entrance of the block. Briefly, for the colour arrangement design of the mass housing, extensive and detailed studies are necessary.

REFERENCES:


• Lancaster, M., Colourspace, Academy Editions, Maryland, 1996.


THE APPLICATION OF COLORIMETRY IN INDUSTRY AND DESIGN
IN FRONT OF 21 TH CENTURY

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Let us look back at the past: just to perceive the present situation as it really is, and to see how far we have moved ahead! Viewed in a historical plane, the development of color science, the experience on the issues of colors and the attempts for their analysis have started already in remote ancient times which is testified by the marks of the Altamir frescoes, and we should not forget the achievements of the Greek philosophers and thinkers, the novel knowledge accumulated during the last centuries, and the contributions of many outstanding persons, just to mention a few of them: Leonardo da Vinci, Goethe, Newton, Oswald, Hering and a myriad of celebrities, living and working until and during the 20th century.

What has really happened? Maybe, the most impressive development has occurred in parallel in the two of the principal fields of color science and practice: the problems of visual analysis of color and those of the instrumental (digital) assessment and reproduction of those colors that are essential for the development of industry.

In is beyond any doubt that much more than any individual and significant contributions made by different states, the two international organizations: CIE and AIC are most outstanding in this respect scientists and experts from different count. Already in 1931, CIE was able to unite the efforts of scientists and experts from various professions and disciplines within its Vision and Color Division, and it was then that it began to issue its primary documents with recommendations to the CIE member countries, however presently most new CIE documents become a standard for all countries in the world, and are recognized by the International Standardization Organization (ISO). The CIE congresses are held every 4
years and every time new documents are issued and the previous ones are updated and implemented in the activities and practice of instrumental and visual analysis throughout the world; the specialized thesaurus is enriched by definitions of all terms in the sphere of light and color, etc. The International Color Association (AIC) founded later on, held its first Congress in 1965, and demonstrated before professionals in the sphere of color that it had some more specific tasks and objectives, and its activities united scientists and experts in the sphere of visual problems and color analysis, such as architects, designers, artists, etc. The growth of AIC made a significant contribution by applying new educational methods, as well as in the sphere of criticism and analysis of the different color systems, e.g. those of CIE, Mynsel, DIN, NCS, etc. In the 1960ies and 1970ies, many scientists and experts in individual countries had even the general feeling that there might be some competition and even conflict between CIE and AIC, however this could be overcome particularly during the 1980ies and the 1990ies. A process of moving over of experts from one and into the other interdisciplinary profiles of both CIE and AIC became apparent by some most active contributions: presidents and chairpersons of working committees and groups moved over to leading jobs from AIC to CIE and vice versa. In other words, these international organizations were mutually supporting teach other and nowadays they have imparted a new and strong momentum to the development of visual and instrumental color related methods and applications. This is evidenced by the last AIC Congress held in Kyoto, Japan, in 1997, by the Interim Meeting in Warsaw, Poland, in June 1999, as well as by the last CIE congress held also in June 1999 in Warsaw.

The number of national color groups in the world is on the rise. Such is for instance our COLOR GROUP BULGARIA and their total number in AIC has recently exceeded 30 formal members and 8 observers. Their active participation can be illustrated by the following example: during late September and in October this year, the time of our International Color Conference BULCOLOR'99, a number of AIC member countries will hold their annual conferences or other national-level events. In the AIC Bulletin, the growth and increased activity in the majority of branches within the AIC member counties are illustrated.

What was the other factor that contributed to this tremendous development during the recent years? It is beyond doubt that the development of the important spheres of color analysis for the industrial environment: of instrument-building and computer technology had a great impact. The times of the first color analysts, such as Preterma in the 1970ies are already gone.
We can now see on the market, and we want to use compare color samples and objects with the help of tiny "pocket" format instruments that are able to resolve accurately enough our color-related problems. Some companies have offered last year some mini-instruments that can replace e.g. visual means like color maps and catalogues or a great number of systematic color samples offered by most companies, like the ones of MINOLTA, providing the accurate code number of the NCS visual color system. The ever more improving accuracy of color scanners and printers will apparently bring about the implementation of color analysis methods also in some new spheres of the environment and the industry.

What more can we expect in this field? By way of example, the adoption of a new universal ISO visual assessment standard, the development of ever more cheaper instruments enabling color assessment of very small areas, e.g. microns! This is still another chance for a "revolution" and for the use of color in the sphere of medicine!

The present statement does not claim to be thorough, however its objective is to draw attention to the great significance of this vast interdisciplinary sphere: color science and its application.
VIDEO-COLORIMETRY
- MEASUREMENT OF CIE 1931 XYZ BY DIGITAL CAMERA -

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ABSTRACT

A new colorimetry technique by a digital camera is developed and named "Video-Colorimetry". To eliminate the difference in products, the digital camera is colorimetrically calibrated using a spectra-colorimeter, a xenon lamp, and color samples. The calibrated results are described as a series of regression functions. In the actual video-colorimetry, the colorimetric calibration functions transfer the RGB signals on a digital color image into the absolute values of the CIE 1931 tristimulus values XYZ pixel by pixel. The XYZ values of each pixel are transferred into the absolute luminance Y, color coordinates xy, correlated color temperature, etc. The validation by the spectra-colorimeter shows reasonable accuracy of the video colorimetry.

1. INTRODUCTION

To evaluate the color in the interior or exterior of buildings, the spatial distribution of color in a visual field should be measured colorimetrically. Though a conventional telescopic colorimeter could measure the color of a field point by point, it might take a long time to finish a scanning and the obtained distribution could be too coarse to analyze the spatial distribution of color.

For the application of colorimetry in research and practice of architecture, the author has developed the video-colorimetry systems using color CCD video cameras. The first system was composed of a CCD color video camera and a video capture board with a desktop computer\(^1\).\(^2\). It was colorimetrically calibrated with a tri-filtered colorimeter. The RGB values of each pixel on a color video image were converted into the absolute values of CIE 1931 color coordinates \((x,y)\). The color coordinates were transferred into the correlated color temperature (CCT) for the measurement of the CCT distribution of the sky to estimate the cloud cover.
The second system was composed of a precision color CCD camera and interface board with a desktop computer\(^3\). The system was colorimetrically calibrated with a spectra-colorimeter. The RGB values of each pixel on a color video image were converted into the absolute values of CIE 1931 color coordinates \((x,y)\) for the colorimetry of building interiors and exteriors.

This paper describes the third system in which the colorimetric calibration technique is applied to a digital camera\(^4\). The latest colorimetry system measures the absolute values of CIE 1931 tristimulus values \(XYZ\) of each pixel on captured images. The \(XYZ\) values are converted into the absolute luminance \(Y\), color coordinates \((x,y)\), and correlated color temperature (CCT).

2. METHODOLOGY

2.1 Basic formula

The CIE 1931 tristimulus values \(X, Y, Z\) and \(R, G, B\) are related by the following equations,

\[
\begin{align*}
X &= 2.7689 R + 1.7517 G + 1.1302 B \\
Y &= 1.0000 R + 4.5907 G + 0.0601 B \\
Z &= 0.0000 R + 0.0563 G + 5.5943 B
\end{align*}
\]

where the value \(Y\) is identical with the luminance, which has the unit of candela per square meters [cd/m\(^2\)].

The National Television System Committee (NTSC) in USA recommended the color television standards in 1953. Countries as USA, CANADA, Japan, and Mexico adopted this standard. Many other countries have chosen different system as SECAM or PAL. The transformation equations from the normalized RGB video signals \(R_v, G_v, B_v\) of the NTSC system to the normalized CIE 1931 tristimulus values \(X_n, Y_n, Z_n\) for the illuminant \(C\) are expressed as,

\[
\begin{align*}
X_n &= 0.6067 R_v + 0.1736 G_v + 0.2001 B_v \\
Y_n &= 0.2998 R_v + 0.5868 G_v + 0.1144 B_v \\
Z_n &= 0.0000 R_v + 0.0661 G_v + 1.1150 B_v
\end{align*}
\]

The transformation equations for the illuminant \(D_{65}\) are given as follows\(^5\),

\[
\begin{align*}
X_n &= 0.5880 R_v + 0.1789 G_v + 0.1828 B_v \\
Y_n &= 0.2998 R_v + 0.6036 G_v + 0.1043 B_v \\
Z_n &= 0.0000 R_v + 0.0679 G_v + 1.0201 B_v
\end{align*}
\]
The parameters in the transformation equations were decided by the colors of CRT phosphors available when the NTSC system was proposed a half century ago. Recent TV systems tend to adopt the new standards by the Society of Motion Picture and Television Engineers (SMPTE) and European Broadcasting Union (EBU) which propose closer colors to modern phosphors. In this paper, the NTSC equations (3) for the illuminant D65 is adopted through the preliminary calibration with the digital camera to compare the formulae including the NTSC (C), NTSC (D65), SMPTE(C), EBU, and HDTV standards.

The NTSC formulae are so popular that a lot of image analysis software and hardware have utilized them to convert RGB images to device independent CIE XYZ images. However, simple applications of these formulae provide no more than relative values of CIE XYZ, though the absolute XYZ values are essential to the applications of colorimetry in research and practice of architecture. On the other hand, the new method described in this paper converts the RGB values of each pixel on a color image into the absolute values of CIE XYZ by the colorimetric calibration of the digital camera.

2.2 The Inverse Matrix Colorimetric Calibration

The purpose of the colorimetric calibration is to obtain the calibration functions that convert the normalized values of RGB signals captured by a digital camera into the absolute values of CIE 1931 tristimulus values XYZ which might be measured by a spectra-colorimeter as the reference.

In the colorimetric calibration of the former studies by the author123, captured video values \( R_v, G_v, B_v \) are transferred into the normalized CIE 1931 tristimulus values \( X_v, Y_v, Z_v \) by the NTSC formula (2) or (3) at first. Then the regression analyses were applied between the normalized values \( X_v, Y_v, Z_v \) and the absolute values \( X, Y, Z \) measured by the reference spectra-colorimeter. This straightforward calibration was accurate but not efficient in collecting sample data. If any of the captured video values \( R_v, G_v, B_v \) beyond the range of digitization, all the normalized values \( X_v, Y_v, Z_v \) must be discarded. This problem occurred frequently for the color chips of high chromatisity (e.g. red, green, blue, etc.).

In this paper, a new technique, "the Inverse Matrix Colorimetric Calibration" is introduced as follows.

2.2(a) Normalized values of RGB signals
A digital camera captures the video images of color samples illuminated by a reference lamp at various illuminance levels. The settings of exposure (e.g. shutter speed, f-stop of the lens, gain control of the CCD, etc.) and white balance (e.g. daylight, incandescent lamp, fluorescent lamp, etc.) must be recorded for each video image. The normalized values of RGB signals \( R_v, G_v, B_v \) of each color sample on captured video images are read numerically by image analysis software.

2.2(b) Absolute values of CIE XYZ and the reference RGB signal values

A reference spectra-colorimeter measured the absolute values of CIE 1931 tristimulus values \( X_s, Y_s, Z_s \) of each color sample at the same conditions of illumination as the video images. The inverse functions of equations (3) convert the absolute values of \( X_s, Y_s, Z_s \) into the reference RGB signal values \( R_{vs}, G_{vs}, B_{vs} \) as follows.

\[
R_{vs} = 1.971 X_s - 0.549 Y_s - 0.297 Z_s \\
G_{vs} = 0.954 X_s + 1.936 Y_s + 0.027 Z_s \\
B_{vs} = 0.064 X_s - 0.129 Y_s + 0.982 Z_s
\]  

2.2(c) Regression functions

The regression analysis between the \( R_{vs}, G_{vs}, B_{vs} \) and \( R_v, G_v, B_v \) decides the set of regression functions \( F_r, F_g, F_b \).

\[
R_{vs} = F_r(R_v, E, W) \\
G_{vs} = F_g(G_v, E, W) \\
B_{vs} = F_b(B_v, E, W)
\]

where \( E \) and \( W \) are the parameters of exposure and white balance controls of the digital camera. Though most digital cameras have the functions of automatic controls, the video-colorimetry described here requires a digital camera that has repeatable manual controls of white balance and exposure.

2.3 Video colorimetry in practice

In the actual video colorimetry, the digital camera captures the video images of objects. The image analysis software read normalized RGB signal values \( R_v, G_v, B_v \) first, then convert them to the reference RGB signal values \( R_{vs}, G_{vs}, B_{vs} \) by the regression functions (5), and finally obtains the absolute values of CIE 1931 tristimulus values \( X, Y, Z \) by the transformation equations (3).
The values $X$, $Y$, $Z$ of each pixel are transferred into the color coordinates $(x,y)$ and the correlated color temperature $T$ as follows.

\begin{align}
    x &= X / (X + Y + Z) \\
    y &= Y / (X + Y + Z) \\
    T &= 1437 n^2 + 3601 n^2 - 6861 n + 5514.31
\end{align}

where, $n = (x - 0.3320) / (y - 0.1858)$

### 3. COLORIMETRIC CALIBRATION AS A CASE STUDY

#### 3.1 Instruments

The digital still camera (Nikon, E2n) used for the case study is capable of capturing a 24bit color images of 1280 by 1000 pixels through a conventional still camera lens (e.g. Nikon, AF Zoom Nikkor 35-70/2.8D). Each of the RGB signals of a pixel is expressed by an 8-bit integer between 0 and 255. The installed special optics reduce a whole circle image by the fisheye lens (Nikon, Fisheye 8mm F2.8S, Figure 1) to fit the 2/3 inch CCD array.
The white balance is manually set to 'CLOUDY' position, which corresponds to 6500K in CCT according to the user's manual\(^\text{19}\). The shutter speed, and f-stop are also manually controlled and unified to the exposure value \(E_v\) as a parameter of the brightness.

\[
E_v = \log_2(F^2/T)
\]  

where, \(F\) is the f-stop value of the iris, \(T\) is the shutter speed [sec]. The images are stored in a PC card. The RGB values of images are read and processed by an image analysis software (NIH Image, http://rsb.info.nih.gov/nih-image/) on a note-type PC (Apple, PowerBook 1400c).

The colorimetric reference for the calibration is a spectra-colorimeter (Photo research, PR650, Figure 2). The 24 chips of color samples (Macbeth, Color checker, Figure 3) are illuminated by a Xenon lamp (Ushio, UXL-500D) in a dark room. The illuminance values on the color samples are changed from 353 lx to 4867 lx by controlling the distance to the lamp.
3.2 Regression functions

Figure 4 shows the scatter diagrams of the \( Rv_v - R_v \), \( Gv_v - G_v \), and \( Bv_v - B_v \). The regression analysis resulted in the following equations (9), and the parameters shown in Table 1. In most cases, the correlative coefficients \( R_r \), \( R_g \), and \( R_b \) beyond 0.9. The regression functions are also drawn in Figure 4.

\[
R_v = a_0(E_v) + a_1(E_v)^*R_v + a_2(E_v)^*R_v^2
\]
\[
G_v = a_0(E_v) + a_1(E_v)^*G_v + a_2(E_v)^*G_v^2
\]
\[
B_v = a_0(E_v) + a_1(E_v)^*B_v + a_2(E_v)^*B_v
\]

Table 1. Parameters for the regression functions

| \( E_v \) | \( a_0(E_v) \) | \( a_1(E_v) \) | \( a_2(E_v) \) | \( R_r \) | \( a_0(E_v) \) | \( a_1(E_v) \) | \( a_2(E_v) \) | \( R_g \) | \( a_0(E_v) \) | \( a_1(E_v) \) | \( a_2(E_v) \) | \( R_b \) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8.5 | 1.65e+0 | -1.17e+1 | 4.38e+1 | 0.959 | 1.21e+0 | -6.45e+0 | 3.57e+1 | 0.844 | 1.13e+0 | 1.62e+1 | 2.83e+1 | 0.873 |
| 9.5 | 1.90e+0 | -6.82e+0 | 6.75e+1 | 0.952 | -4.96e-1 | 2.59e+0 | 5.77e+1 | 0.888 | 2.90e+1 | 1.05e+2 | 4.94e+1 | 0.931 |
| 10.5 | 3.65e+0 | -2.23e+1 | 1.43e+2 | 0.965 | -4.12e+0 | 2.98e+1 | 9.12e+1 | 0.912 | 1.67e+0 | 9.35e+0 | 1.13e+2 | 0.942 |
| 11.5 | 9.06e+0 | -3.70e+1 | 2.83e+2 | 0.944 | 9.06e-2 | 1.70e+1 | 2.12e+2 | 0.946 | 2.92e+1 | 1.17e+2 | 2.42e+2 | 0.963 |
| 12.5 | 6.07e+0 | -4.98e+0 | 4.93e+2 | 0.991 | 4.11e+0 | 6.60e+0 | 5.19e+2 | 0.970 | 6.85e+0 | -7.21e+0 | 5.47e+2 | 0.993 |
| 13.5 | 7.44e+0 | -2.06e+1 | 8.74e+2 | 0.994 | 8.79e-2 | 2.73e+1 | 9.97e+2 | 0.982 | 1.34e+1 | -3.85e+0 | 1.06e+3 | 0.995 |
| 14.5 | 1.93e+1 | 1.98e+1 | 1.92e+3 | 0.996 | 9.84e+0 | 1.30e+2 | 1.92e+3 | 0.988 | 1.54e+1 | 9.97e+0 | 2.15e+3 | 0.995 |
| 15.5 | 2.26e+1 | 1.85e+2 | 3.53e+3 | 0.993 | 8.90e+0 | 4.56e+2 | 3.33e+3 | 0.987 | 8.08e+0 | 2.51e+2 | 3.71e+3 | 0.995 |

The following equations obtain the absolute values of CIE 1931 tristimulus values \( X \), \( Y \), \( Z \) pixel by pixel. The equations (6) and (7) transfer the values \( X \), \( Y \), \( Z \) of each pixel into the color coordinates \( (x,y) \) and the correlated color temperature \( T \). The regression functions and parameters are described as a macro program for the image analysis software.

\[
X = 0.5880 \, R_{ev} - 0.1789 \, G_{ev} - 0.1828 \, B_{ev} \\
Y = 0.2998 \, R_{ev} + 0.6036 \, G_{ev} + 0.1043 \, B_{ev} \\
Z = 0.0000 \, R_{ev} + 0.0679 \, G_{ev} + 1.0201 \, B_{ev}
\]

4. APPLICATION

The video-colorimetry technique was applied to measure the luminance and the color coordinates on the interior and exterior of the university hall at Fukuyama University (Figure 5), as well as the luminance and correlated color temperature of the sky (Figure 6). The color images captured by the digital camera are transferred to the PC. The macro program on the image analysis software read the R, G, B values pixel by pixel, and convert into the absolute values of the CIE 1931 XYZ, the color coordinates, and the correlated color temperature.
For the validation, the spectra-colorimeter measures the XYZ values at the same time. Figure 7 and Figure 8 show the comparison of the CIE XYZ values and the color coordinates measured by the video-colorimeter and the spectra-colorimeter on the interior and exterior of the university hall. Though the video-colorimetry slightly overestimates, the errors are small enough for the application to evaluate the colors of buildings.
Figure 7  Comparison of CIEXYZ values measured by the video-colorimeter and the spectra-colorimeter

Figure 8  Color coordinates measured by the video-colorimeter and the spectra-colorimeter
5. CONCLUSION

A new colorimetry technique is developed. The system is simply composed of a digital camera, a note-type PC, and a macro program on image analysis software. The digital camera is calibrated with a spectra-colorimeter. At the actual colorimetry, the color image of the scene captured by the digital camera is transferred to the PC. The macro program converts the RGB values on color images into the absolute values of CIE 1931 XYZ pixel by pixel. The XYZ values are also transferred to the color coordinates and the correlated color temperature.

Finally, the author names this new colorimetry technique as "Video-Colorimetry".

Acknowledgment

The image processing is performed using the NIH Image program written by Wayne Rasband at the U.S. N.I.H.

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>X, Y, Z</td>
<td>Absolute values of the CIE 1931 tristimulus values XYZ.</td>
</tr>
<tr>
<td>R, G, B</td>
<td>Absolute values of the CIE 1931 tristimulus values RGB.</td>
</tr>
<tr>
<td>x, y</td>
<td>Color coordinates</td>
</tr>
<tr>
<td>T</td>
<td>Correlated color temperature</td>
</tr>
<tr>
<td>Xn, Yn, Zn</td>
<td>Normalized values of the CIE XYZ.</td>
</tr>
<tr>
<td>Rv, Gv, Bv</td>
<td>Normalized values of the video signals RGB.</td>
</tr>
<tr>
<td>Xs, Ys, Zs</td>
<td>Absolute values of the CIE XYZ measured by the reference spectra-colorimeter</td>
</tr>
<tr>
<td>Rvs, Gvs, Bvs</td>
<td>Reference values of the video signals RGB as the inverse functions of Xs, Ys, Zs</td>
</tr>
</tbody>
</table>
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