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A Study of Relationship Between Color Inconstancy Level and CIELAB Color Coordinates

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ABSTRACT

*In commercial point of view, it is of great interest to find colors with high color constancy level. Color constancy as a relatively property of object's appearance could be affected by different factors. In this article, the color inconstancy index (CMCCON02) and the color coordinates were calculated for 1269 samples of Munsell at CIEL*c*hº color system to study any correlations. The corresponding color was determined under four illuminants A, TL84, and a white LED as well as an equal energy spectrum. The results showed that the variation of hue angle and chroma makes more sensible effect on the color inconstancy index CMCCON02 than the lightness. In addition, a specific proportional change in spectral reflectance curve between low and high wavelength limits makes the color to be more inconstant. Besides, the results showed that color inconstancy is depended primarily on the type of color and used illuminant pair. Prog. Color Colorants Coat. 7(2014), 165-175. © Institute for Color Science and Technology.*

1. Introduction

For quality control of colored objects in color-dependent industries, all parameters of production should be optimized in order to get high appearance quality. An important factor of great interest is color constancy [1]. Color constancy is a visual phenomenon wherein colors of objects remain relatively the same under changing illumination [2]. In other words, the perceptual ability that permits us to discount spectral variation in the ambient light and assign stable colors to objects is called color constancy [3]. For numerical evaluation of color constancy, two important color inconstancy indexes, i.e. CMCCON97 and CMCCON02 are developed [4,5].

The CMCCON97 index was proposed by Luo and Hunt in 1997 based on the chromatic adaptation transform CMCCAT97 [1] which can accurately predict the corresponding colors, i.e. two sets of tristimulus values corresponding to the same color appearance for an observer fully adapted under test and reference illuminants [6,7]. Subsequently, the chromatic adaption transform CMCCAT97 was modified and a new chromatic adaptation transform, CAT02 was introduced which is much simpler because it does not use any corrective factor for blue channel as CMCCAT97 does [8]. Chromatic adaptation models provide predictions of corresponding colors.

Thus, they can be used to predict required color

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reproductions for changes in viewing conditions [9]. Color constancy as a relatively property of object's appearance could be affected by different factors like the type of illuminant and combination of colors [8]. By identifying these factors and their control, correction possibility of color inconstancy level will be provided to get a more constant color appearance.

The aim of this work is to study the correlation between color inconstancy level and CIE color parameters, i.e. hue angle, lightness and chroma. The CMCCON02 color inconstancy index (CII) of all selected samples was calculated by replacing the different illuminants such as tungsten A, fluorescent TL84, a white LED and an equal energy spectrum instead of the illuminant D65 as the reference.

2. Experimental

A reflectance data set (400-700 nm) consisted of 1269 samples of Munsell color chart including ten different principal colors, i.e. Red, Yellow-Red, Yellow, Green-Yellow, Green, Blue-Green, Blue, Purple-Blue, Purple, and Red-Purple with an interval of 0.1 in hue, 0.05 in lightness and 0.1 in chroma was selected. The a^*b^* chromaticity diagram of 1269 samples of Munsell system is plotted in Figure 1.

The color coordinate of all samples was calculated at CIE$L^*c^*h^\circ$ system in terms of lightness (L^*), chroma (c^*) and hue angle (h°). The color inconstancy index CMCCON02 was calculated by replacing the illuminants A, TL84, white LED and equal energy spectrum by the illuminant D65. The chromaticity values (x,y) of the employed illuminants as well as their spectral power distribution (SPD) are showed in Table 1 and Figure 2, respectively.

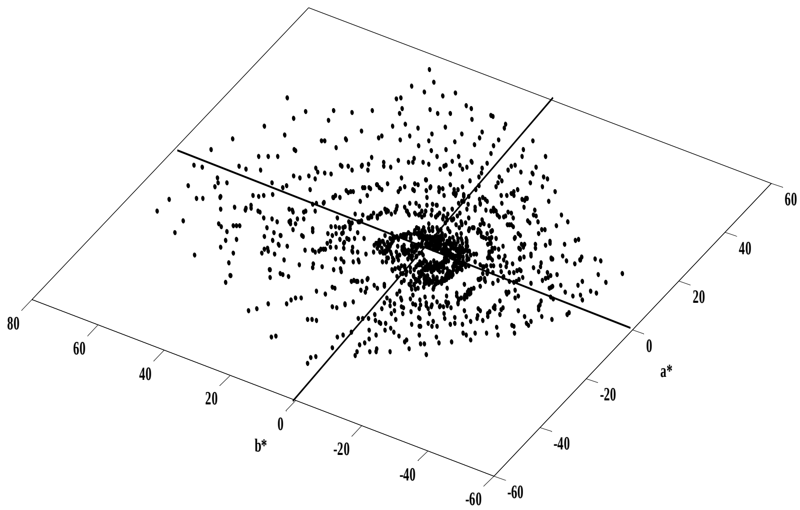


Figure 1: The a^*b^* chromaticity diagram of 1269 samples of munsell color chart.

Table 1: The chromaticity coordinates of the applied illuminants D65, A, TL84 and white LED.

Illuminant	D65	A	TL84	White LED
Chromaticity x value	0.3137	0.4510	0.3855	0.3138
Chromaticity y value	0.3310	0.4061	0.3714	0.3064

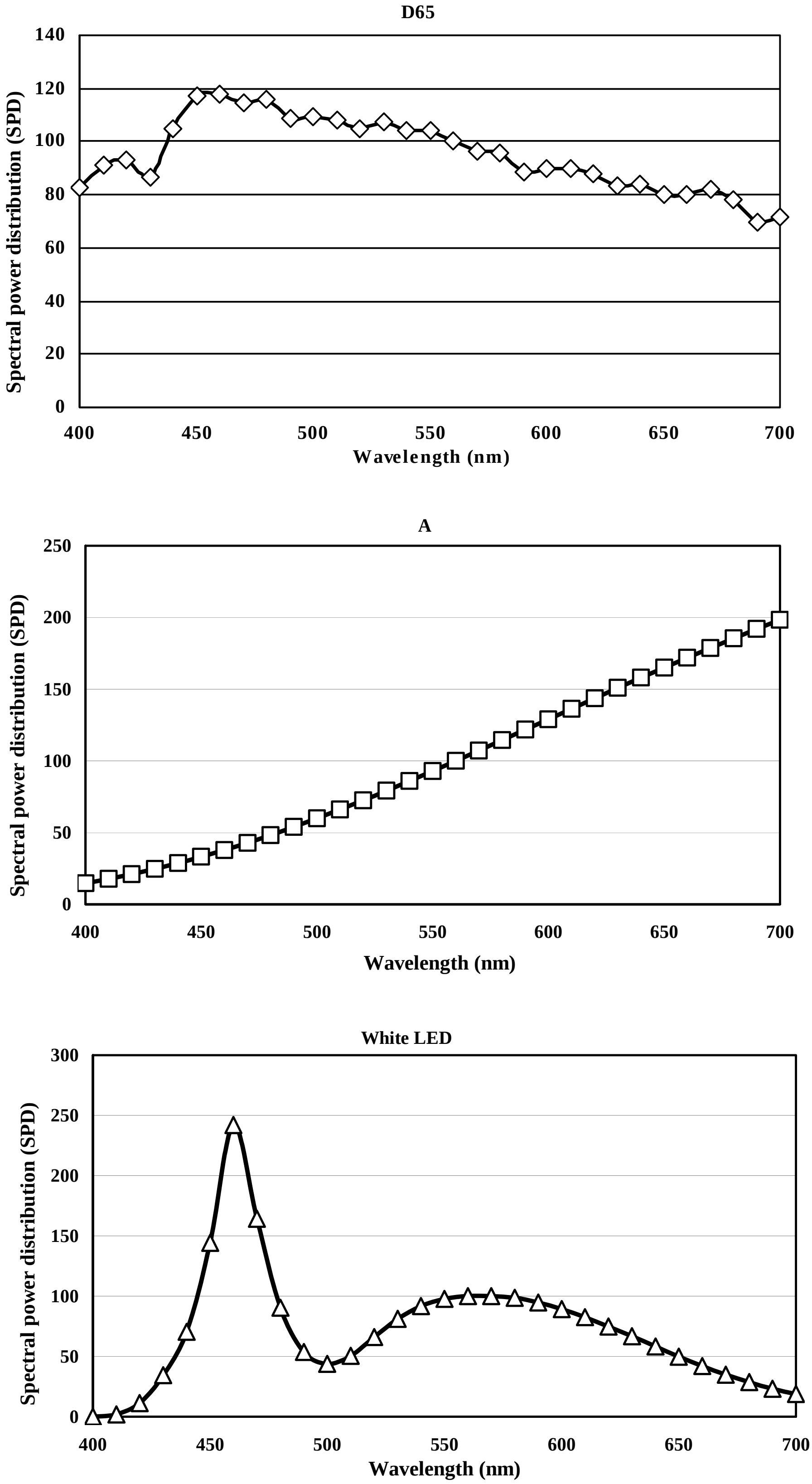


Figure 2: The spectral power distribution (SPD) of the employed illuminants D65, A, TL84 and white LED.

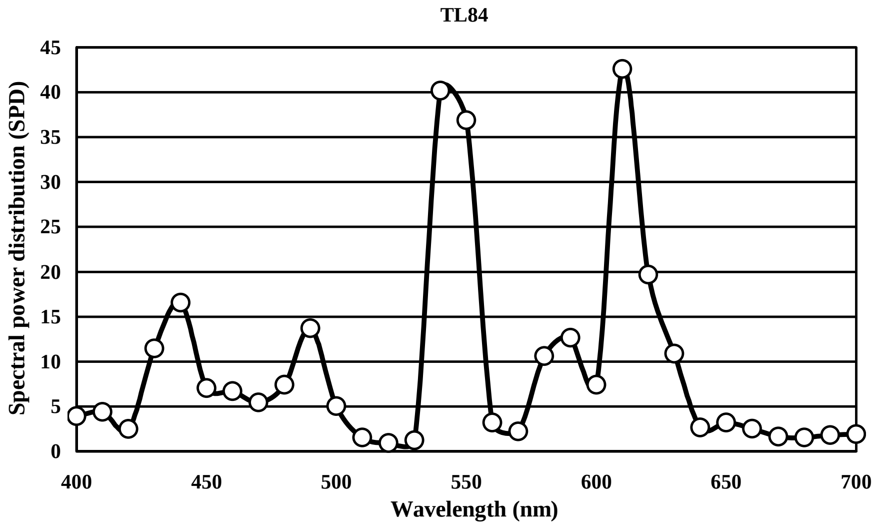


Figure 2: Continued.

Below is the step by step procedure for calculating the color inconstancy index CMCCON02[10].

- Determination of the tristimulus values of the sample under the illuminant D65 (X_r, Y_r, Z_r) and under the agreed test illuminant (X, Y, Z).
- Calculating the RGB cone responses to the sample (R,G,B) and to the reference white or the perfect reflecting diffuser under the test illuminant (R_W,G_W,B_W) and the illuminant D65 (R_{Wr},G_{Wr},B_{Wr}) according to Equation 1.

$$\left.\begin{aligned} \begin{pmatrix} R \\ G \\ B \end{pmatrix} &= M_{CAT02}\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \\ \begin{pmatrix} R_w \\ G_w \\ B_w \end{pmatrix} &= M_{CAT02}\begin{pmatrix} X_w \\ 100 \\ Z_w \end{pmatrix} \\ \begin{pmatrix} R_{wr} \\ G_{wr} \\ B_{wr} \end{pmatrix} &= M_{CAT02}\begin{pmatrix} X_{wr} \\ 100 \\ Z_{wr} \end{pmatrix} \end{aligned}\right\} \quad (1)$$

where

$$M_{CAT02} = \begin{pmatrix} 0.7328 & 0.4296 & -0.1624 \\ -0.7036 & 1.6975 & 0.0061 \\ 0.0030 & 0.0136 & 0.9834 \end{pmatrix}$$

X_{Wr}, Z_{Wr} and X_W, Z_W show the tristimulus values of the white reference under the illuminant D65 and under the test illuminant, respectively. The values of Y_W, Y_{Wr} are also adjusted to 100.

- Calculating the corresponding RGB cone responses by Equation 2.

$$\begin{aligned} R_c &= R\left(R_{wr}/R_w\right) \\ G_c &= G\left(G_{wr}/G_w\right) \\ B_c &= B\left(B_{wr}/B_w\right) \end{aligned} \quad (2)$$

- Calculating the tristimulus values of the corresponding color under the illuminant D65 by Equation 3.

$$\begin{pmatrix} X_c \\ Y_c \\ Z_c \end{pmatrix} = M_{CAT02}^{-1}\begin{pmatrix} R_c \\ G_c \\ B_c \end{pmatrix} \quad (3)$$

where

$$M_{CAT02}^{-1} = \begin{pmatrix} 1.096124 & -0.278869 & 0.182745 \\ 0.454369 & 0.473533 & 0.072098 \\ -0.009628 & -0.005698 & 1.015326 \end{pmatrix}$$

- Calculating the color difference between the tristimulus values of the corresponding color under the illuminant D65 (X_c,Y_c,Z_c) and those measured for the sample under the illuminant D65 (X_r,Y_r,Z_r) as the reference illuminant. Commonly, the color difference equation ΔE^*_{ab} is applied (Equation 4).

$$\Delta E^*_{ab} = \sqrt{(L^*_c - L^*_r)^2 + (a^*_c - a^*_r)^2 + (b^*_c - b^*_r)^2} \qquad (4)$$

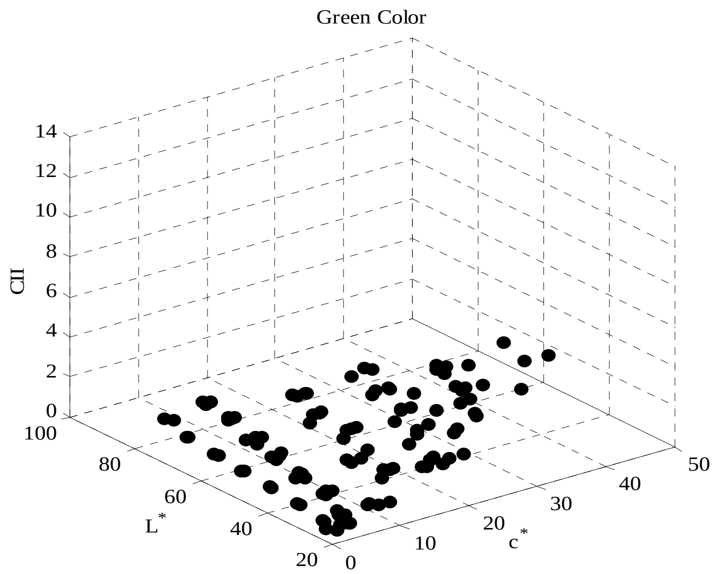
where L^*, a^* and b^* are the tristimulus values or the color parameters at the CIELAB color system. The ΔE^*_{ab} value obtained from Eq. 4 shows CMCCON02 color inconstancy index (CII).

3. Results and discussion

Figure 3 shows the color inconstancy index variations for the Green samples versus L^* and c^* under different illuminant pairs, i.e. D65-equal energy spectrum, D65-A, D65-white LED and D65-T84.

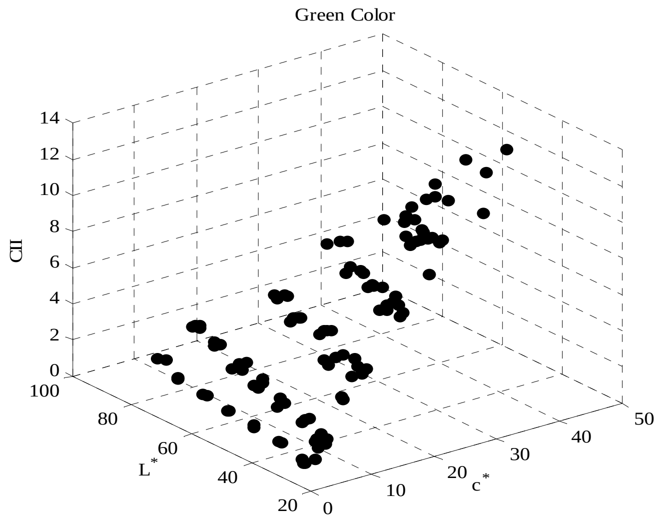
For all the cases, it can be seen that the value of color inconstancy index increases by chroma. Unlike c^*, no significant relationship is observed between color inconstancy index and lightness. In other words, color constancy should not be influenced by lightness parameter.

To give the reasons for such behaviors, two different groups of samples were selected. The first group consisted of samples with varying lightness. They include 2.5G 3/2, 2.5G 4/2, 2.5G 5/2, 2.5G 6/2, 2.5G 7/2, 2.5G 8/2 and 2.5G 9/2. The second group with the chroma as variable was consisted of the Munsell codes 2.5G 7/2, 2.5G 7/4, 2.5G 7/6, 2.5G 7/8 and 2.5G 7/10. The reflectance spectra and their normalized forms for the first group are plotted in Figure 4.

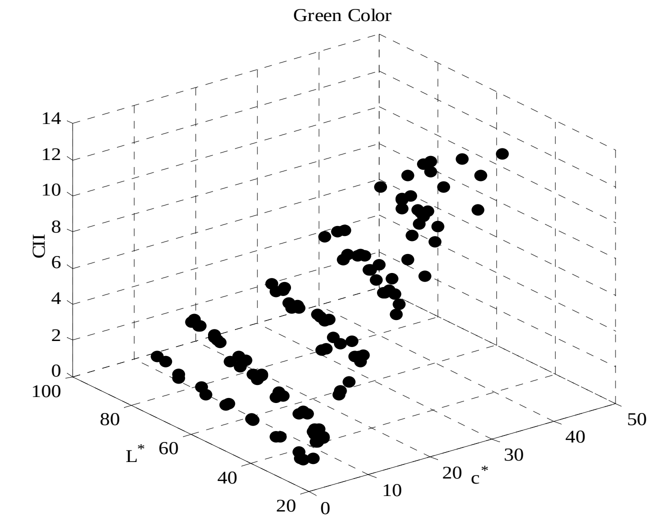


(a)

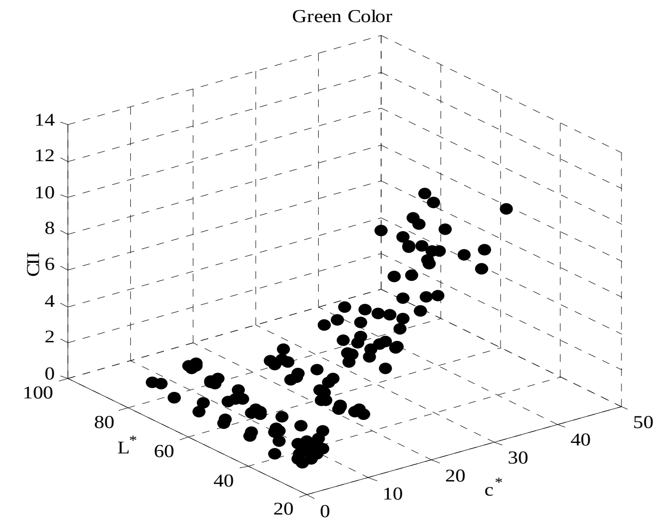
Figure 3: Color inconstancy index vs. L^* and c^*; (a) equal energy spectrum, (b) illuminant A, (c) white LED, and (d) illuminant TL84.



(b)



(c)



(d)

Figure 3: Continued.

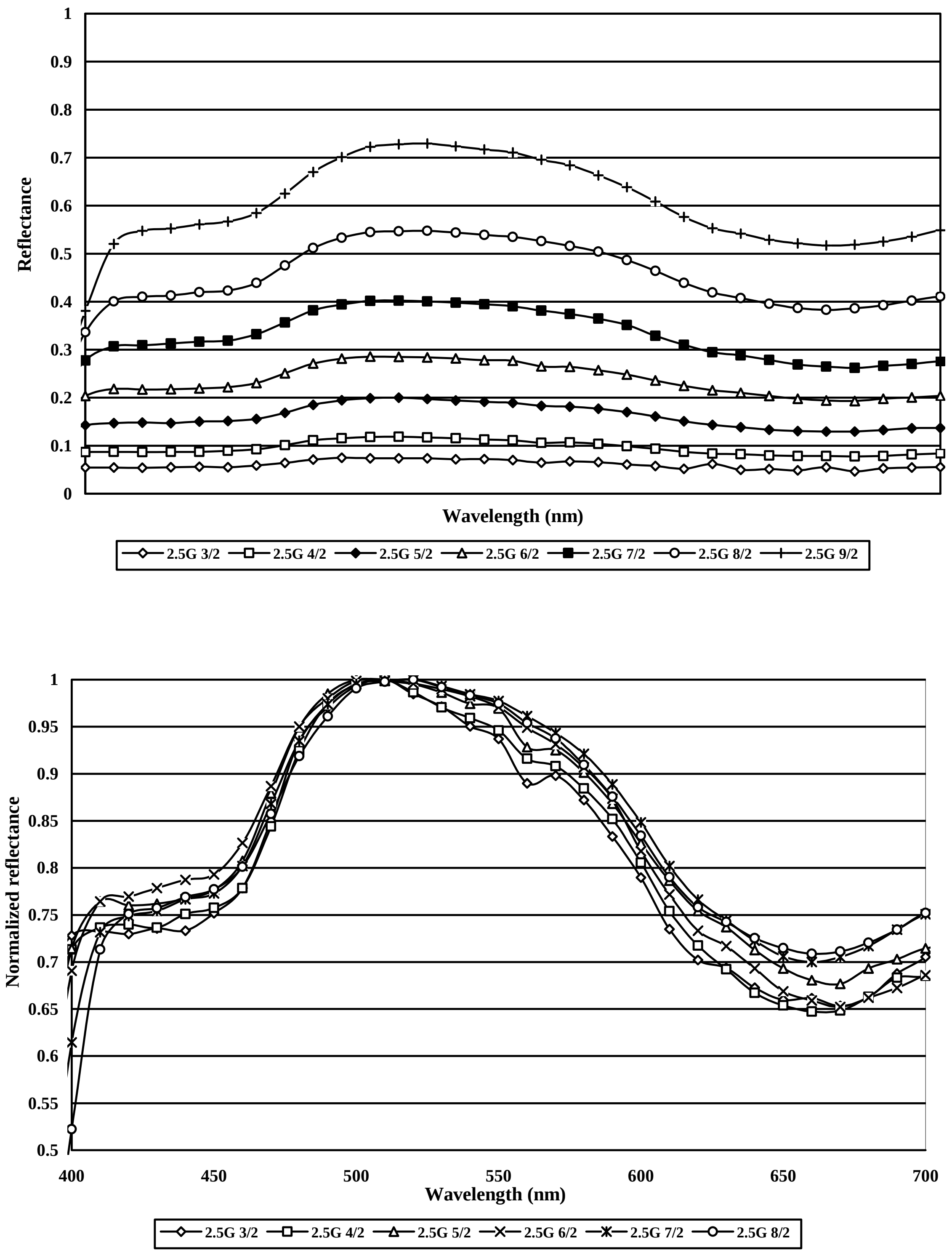


Figure 4: The reflectance spectra and the normalized forms for the samples 2.5G 3/2 – 9/2.

It can be seen that the similarity of the reflectance spectra is retained when the lightness increases. This is confirmed by the normalized forms for the reflectance spectra. In other words, as the Figure 3 showed, the color constancy of these samples will show no significant change by increasing the lightness.

In Figure 5, the reflectance spectra and their normalized forms for the second group are plotted. Figure 5 shows that by increasing the chroma, the shape of the reflectance spectra clearly changes (also see the scattering of the normalized forms). It seems that a specific proportional change in reflectance spectrum occurs between the low and high wavelength limits at the visible range by increasing the color content of the sample. Most likely, the color appearance of the sample with higher chroma will be affected by the spectral power distribution of the illuminant.

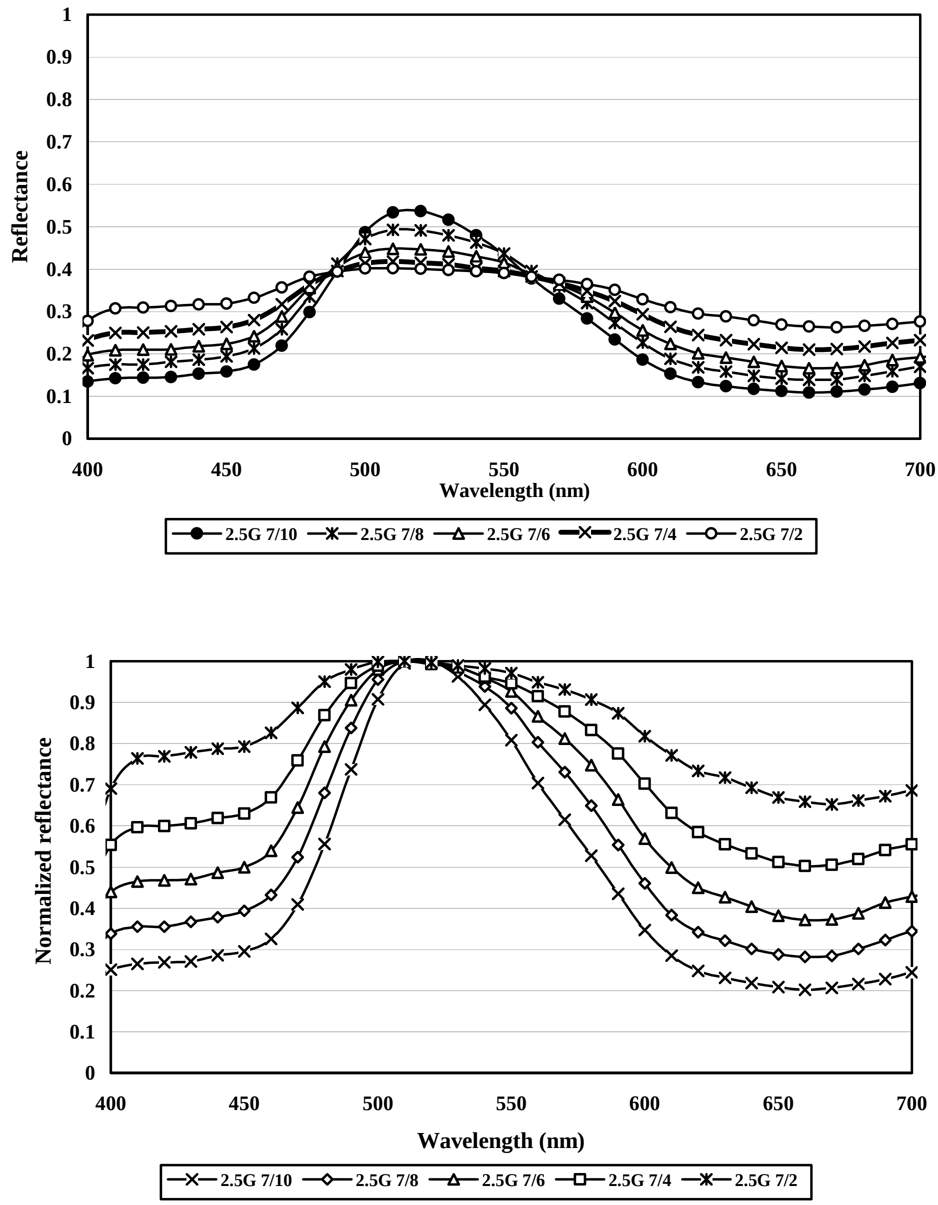


Figure 5: The reflectance spectra and the normalized form for the samples 2.5G 7/2 – 7/10.

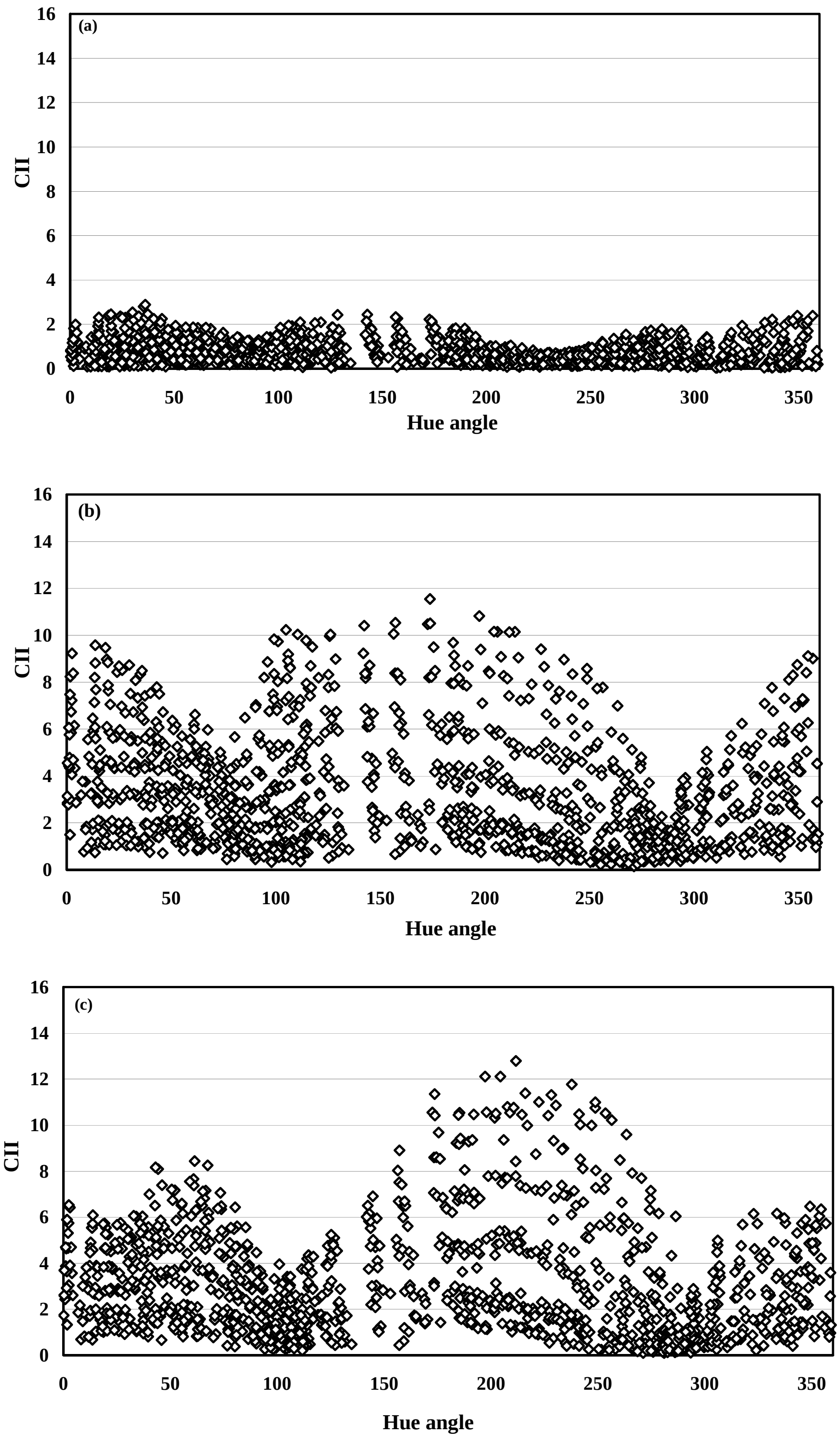


Figure 6: Color inconstancy index vs. hue angle; (a) equal energy spectrum, (b) illuminant A, (c) white LED and (d) illuminant TL84.

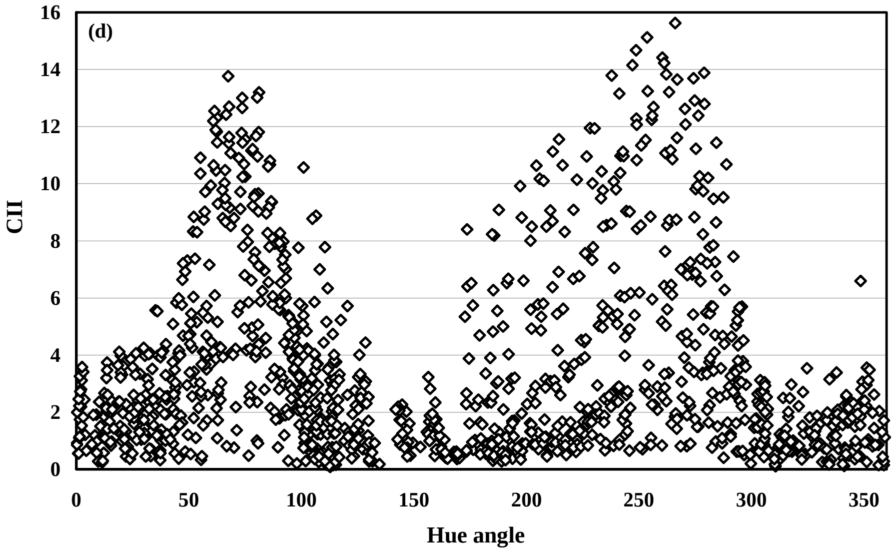


Figure 6: Continued.

Accordingly, the color constancy of these samples decreases. Calculations with the other colors showed qualitatively the similar results.

In Figure 6, the values of color inconstancy index versus the hue angle are plotted for different illuminant pairs. The illuminant with equal energy spectrum is employed as the reference illumination.

In other words, the color inconstancy index calculated for the illuminant pair of D65 and the equal energy spectrum changes within a limited range which can be negligible. Moreover, Figure 6 shows that the level of color inconstancy varies noticeably by the hue angle parameter under all the employed illuminant pair. However, the acquired correlation does not show any definite trend. As a result, the colors with the highest change in the reflectance spectrum like Red, Blue and Green may be the most inconstant samples. Besides, it seems that the highest inconstancy level is occurred between D65 and TL84. It is obvious that by increasing the spectral dissimilarity level of the illuminant pair, the color constancy decreases (as seen between D65- A and D65-TL84). Lower color inconstancy index is obtained for the illuminant pair of D65-white LED in comparison with A and TL84.

It can be concluded that the color inconstancy is primarily determined by the color itself and the illuminant pair is of the second importance. Therefore, the change of color inconstancy could be controlled by altering the used colorants or the lightening conditions. However, some colors with certain characteristic curve shapes are always color inconstant.

4. Conclusions

The main results are as follows:

A relatively significant relationship between color inconstancy level and the hue angle and the chroma was observed, whereas lightness seems not to follow a definite pattern. Unlike hue angle and chroma, the lightness is an achromatic stimulus. Color inconstancy index CMCCON02 is a color parameter, so its changes are independent of lightness level variations.

The most pronounced color inconstancy was provided by the colors that show a specific proportional change in reflectance spectrum between the low and high wavelength limits of the visible range like Red and Blue shades. In other words, the color inconstancy may depend on the shape of reflectance curve.

Color inconstancy index was affected by the level of spectral dissimilarity of the used illuminant pair.

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