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〈Research Paper〉

Comparison between the Color Properties of Whiteness Index and Yellowness Index on the CIELAB

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Abstract: The color properties of a white or nearly colorless fabric are represented by whiteness index (*WI*) or yellowness index (*YI*). These two indexes relate to a white fabric's color quality. The purpose of this study was to identify the properties of *WI* and *YI* on the CIELAB through the simulations of estimation data for a systemization of color quality control. The results indicated that the relationship between *WI* and *YI* was a negative correlation, however the coefficients of correlation function between *WI* and *YI* were depended on hue. There were two hue transition points of the rate of changes in *WI* and *YI*. These hue transition points were the reference points to divide the hue contribution to *WI* and *YI*. These points were not the point of h=0 and h=180 and asymmetric. In addition, where the colors were same distance from the white point on the CIELAB, the rate of changes in *WI* and *YI* by ΔE_w were depending on hue. Specifically, when *WI* decreased, *YI* of reddish and yellowish tinted colors decreased more than bluish tinted colors.

Keywords: *color quality, whiteness, yellowness, CIELAB, color difference, hue contribution*

1. Introduction

In our daily life, a white fabric is often used such as tablecloth, dress shirt, wedding dress, etc. Because the associated impressions of white color are related to clean and pure. Generally, a white fabric which is an untreated optical whitener has slightly tinted yellowish owing to absorption of blue wavelength of the light[1)].

Since the developments of chemical bleaching powder in 18th century and fluorescent whitening agents in 20th century, a white fabric is possible to produce a visually higher white fabric which has high reflectivity of blue wavelength of the light[2)]. Thus, the visual whiteness evaluation of white fabric is strongly depends on the spectral properties of the light[3)]. However, the treated white fabric gradually turns towards yellowish with damage owing to washing, direct rays, air pollution etc. Accordingly yellowness of the white fabric is related to deterioration of quality, and given a dirty impression[4)].

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Consequently, the quantitative measurements of both values are important indexes to represent the quality of the white fabric in textile industry. However the whiteness and yellowness evaluations for a white fabric are different in purpose and concept.

Generally, the whiteness is related to the quality of fresh white fabric, thus higher whiteness is a superior color to a white fabric. On the other hand, the yellowness is related to the white durability, thus higher yellowness is an inferior color to a white fabric.

Many previous studies have investigated about whiteness and yellowness e.g., estimation of whiteness[5)], whiteness and white cognition[6)], whiteness and tolerance[7)], prevention of yellowing[8,9)], external factor of yellowing[10,11)], etc. However, those studies were focusing on either whiteness of yellowness.

For a systemization of color quality control of white fabric, it is important to understand how the whiteness differs from yellowness in terms of a measuring concept. However the relation between whiteness and yellowness has not been considered together yet.

In respect of colorimetric, these two colorimetric values are able to calculate using based on CIE tristimulus values and indicate on chromaticity coordinates[12]. Therefore, the purpose of this study was to identify the color properties of whiteness index and yellowness index on the CIELAB through the simulations of estimation data.

2. Indexes of whiteness and yellowness

There are many declared measuring methods of whiteness and yellowness based on spectral reflectance[13]. In this study, for the comparison between the color properties of whiteness and yellowness, two standard measurement methods were chosen as following.

In textile industry, the international standard method to estimate the whiteness is according to ISO 105-J02 (Textile-tests for colour fastness- Part J02: Instrumental assessment of relative whiteness)[14]. This estimation is the CIE whiteness index (*WI*) as following equation (1);

$$WI = Y_{10} + 800(x_{n,10} - x_{10}) + 1700(y_{n,10} - y_{10}) \cdots (1)$$

where Y_{10} is the *Y*-value, χ_{10}, y_{10} are the chromaticity coordinates of the sample fabric and $\chi_{n,10}$, $y_{n,10}$ are the coordinates of the reference white (For CIE D65 standard illuminant / 10° standard observer, $\chi_{n,10}$=0.3310, $y_{n,10}$=0.3310). *WI* lies within the limits given by 40 < *WI* < (5y_{10}-280)[15]. This *WI* has the properties of hue dependence: a bluish fluorescent whitened sample has higher value than yellowish white sample[16]. *WI* is able to have more than 100 where the object has tinted bluish.

On the other hand, the method to estimate the yellowness for is according to ASTM 313-00 (Calculation Yellowness Indices from Instrumentally Measured Color Coordinates)[17]. The yellowness index (*YI*) of an opaque sample is defined as following equation (2);

$$YI = 100(1.3013X_{10} - 1.1498Z_{10})/Y_{10} \cdots\cdots\cdots\cdots (2)$$

where X_{10}, Y_{10}, and Z_{10} are the *X*-value, *Y*-value, and *Z*-value of CIE D65 standard illuminantt / 10° standard observer. *YI* has positive value to a yellowish object, but negative value to a bluish object. Therefore a negative *YI* is not estimating yellowness.

The calculated *WI* is 100, and *YI* is -0.006 where the object (perfect reflecting diffuser) has the defined tristimulus values X_{10} (94.811), Y_{10} (100), and Z_{10} (107.304) for CIE 1964 standard colorimetric observer for CIE illuminant D65.

3. The CIELAB color space

The CIELAB color space is defined lightness (*L**), hue (*a** and *b**), chroma (*C**), and hue angle (*h*) by the calculations using CIE tristimulus values. In the CIELAB color space, *L** has the value from 0 (black) to 100 (white). *a** and *b** have positive or negative values to indicate a chromatic color: positive *a**, negative *a**, positive *b**, and negative *b** point the direction of redness, greenness, yellowness and blueness respectively. Where both *a** and *b** are 0, the color is an achromatic color. And *C** is calculated by the equation (3);

$$C^{8} = (a^{*2} + b^{*2})^{1/2} \cdots\cdots\cdots\cdots (3)$$

and *h* is calculated by the equation (4);

$$h = \arctan\frac{a^{*}}{b^{*}} \text{ 12)} \cdots\cdots\cdots\cdots (4)$$

Accordingly, the perfect colorless white (white point) has the values *L**=100, *a**=0, *b**=0, and *C**=0 in theory.

4. Properties of *WI* and *YI* on the CIELAB color space

For simulations of estimation data, the CIE tristimulus values of the ninety near-white colors (nine hues: R, YR, Y, GY, G, BG, B, PB, and P by ten lightness/chroma grades) as sample colors were applied to coordinate *WI* and *YI* on the CIELAB (Figure 1). The ninety colors have used for the evaluation of whiteness and white cognition in the previous study[6]. The color samples were made up gradually tinted by the linear relationship between *L** and *C** of each hue. The relationship between *L** and *C** was a negative correlation, and the colors on the each hue direction were approximately the same *h*.

Therefore the coefficients of nine hues could estimate

Table 1. The coefficients and correlation coefficients (r^2) of the linear function between L^* and C^* of the color samples of each hue (round off the numbers to two decimal place)

Hue	R	YR	Y	GY	G	BG	B	PB	P
$\bar{h}$	25	73	92	135	175	231	263	291	345
K_{C^*}	-1.07	-1.17	-0.71	-1.10	-1.07	-0.92	-1.61	-1.85	-1.27
Const.	93.69	95.16	94.71	94.35	92.61	93.54	93.38	93.27	93.27
r^2	1.00	0.99	0.99	0.99	0.98	0.99	0.98	1.00	1.00

by a linear equation ($L^* = K_{C^*}C^* + Const.$). The regression coefficient (K_{C^*}) and intercept coefficient (*Const.*) were depended on hue as shown in Table 1.

Based on the CIE tristimulus values of the 90 color samples, the colors on the nine hue angles were able to estimate by L^*, a^*, b^*, C^*, and h values for simulations. Since C^* is indicated the distance from an achromatic color point ($a^*=0$, $b^*=0$) on the CIELAB color space, the colors range of estimation were decided within the C^* value $0 < C^* < 15$.

WI and *YI* of the nine hues were calculated by the equations (1) and (2). The results indicated that the relationship between *WI* and *YI* was a negative correlation generally. In addition, *WI* and *YI* of nine hue directions separated from $b^*=0$ (achromatic color) as shown in Figure 2 (left).

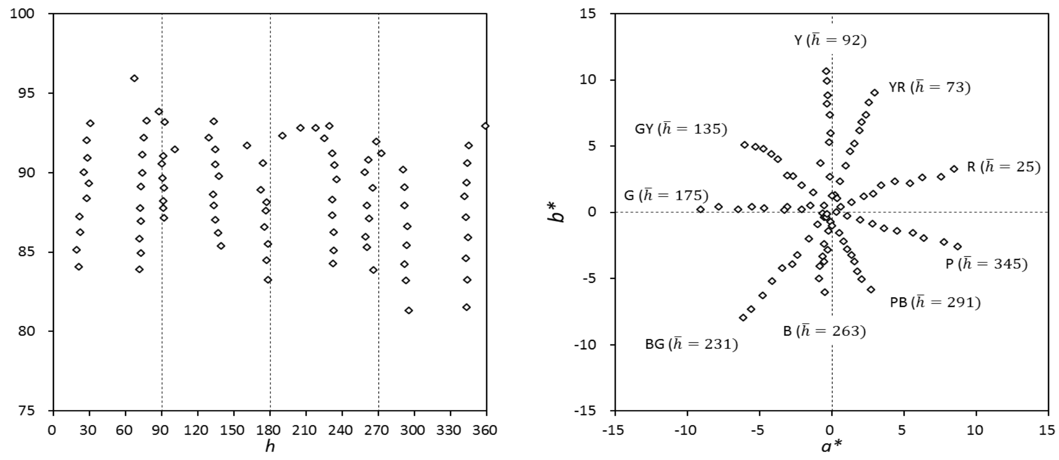

Figure 1. The 90 color samples in the CIELAB color space.

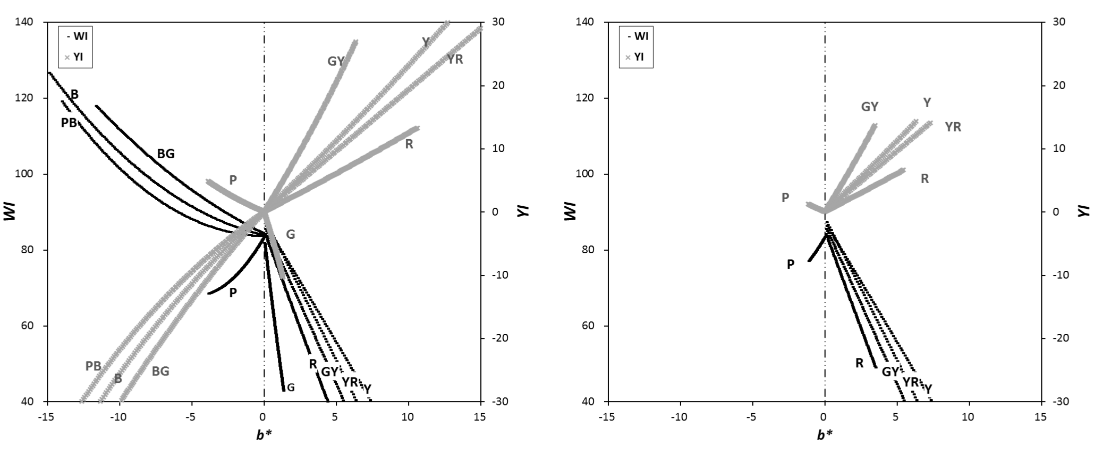

Figure 2. *WI* and *YI* against of b^* (blueness (-) - yellowness (+)): for all colors on the nine hues (left) and for only the colors within the *WI* limits and the positive *YI* (right).

There were two main hue groups: R-YR-Y-GY group and BG-B-PB group roughly; those two groups were opposite directions each other. G and P colors were positioned the middle of the two hue groups.

When the absolute value of b^* was increasing, *WI* of the R-YR-Y-GY group, G and P was decreased but *WI* of the BG-B-PB group was increased. On the other hand, when the absolute value of b^* was increasing, *YI* of the R-YR-Y-GY group and P was increased but *YI* of the BG-B-PB group and G was decreased. The R-YR-Y-GY group was the colors belong to yellowish or reddish, and the BG-B-PB group was the colors belong to bluish or reddish.

Accordingly, these results were suggested that *WI* and *YI* were influenced based on the amount of yellowness-blueness: b^*.

WI and *YI* were compared with ΔE_w since the *WI* and *YI* are the indexes of a white object. ΔE_w was the color difference from the white point (L^*=100, C^*=0), E_w is defined as following equation (5);

$$\Delta E_w \sqrt{(100-L^*)^2+C^{*2}} \quad \cdots\cdots\cdots\cdots (5)$$

The rate of changes in *WI* and *YI* by ΔE_w were depending on hue as shown in Figure 3. Where ΔE_w =6 which means the color is closer to the white point, *WI* and *YI* were nearly same values in the whole hue. However, where ΔE_w was increased, the contribution rate to *WI* and *YI* were diffused by hue.

In addition, there were two hue transition points of rate of changes in *WI* and *YI*. These hue transition points were the reference points to divide the hue contribution to *WI* and *YI*.

The hue transition points were not the point of h=0 and h=180. The hue transition points of *WI* were h=208 and h=300, thus the h scope of positive contribution to *WI* was 92. In other words, the h scope of negative contribution to *WI* was 268 that is much larger than the positive contribution scope.

On the other hand, the hue transition points of *YI* were h=157 and h=335, therefore the h scope of positive and negative contribution were 182 and 178 respectively that is nearly the same.

In terms of the measuring concept of *WI* and *YI*, there were two considerations: the limits of *WI* and the negative *YI*. The limits of *WI* are to define the range of white color, and negative *YI* is to indicate that the color is not including yellowness. The *WI* limits 40 < *WI* < (5 y_{10}-280) was applied to the lower *WI* of R-YR-Y-GY group, G, P, and the higher *WI* of BG-B-PB group as shown in Figure 4.

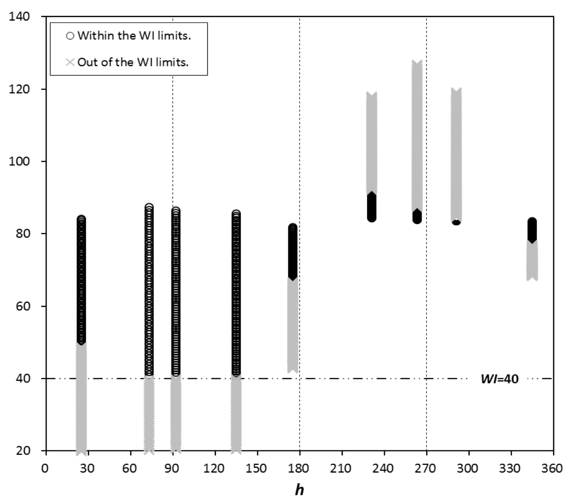

Figure 4. The range of the limits of *WI*.

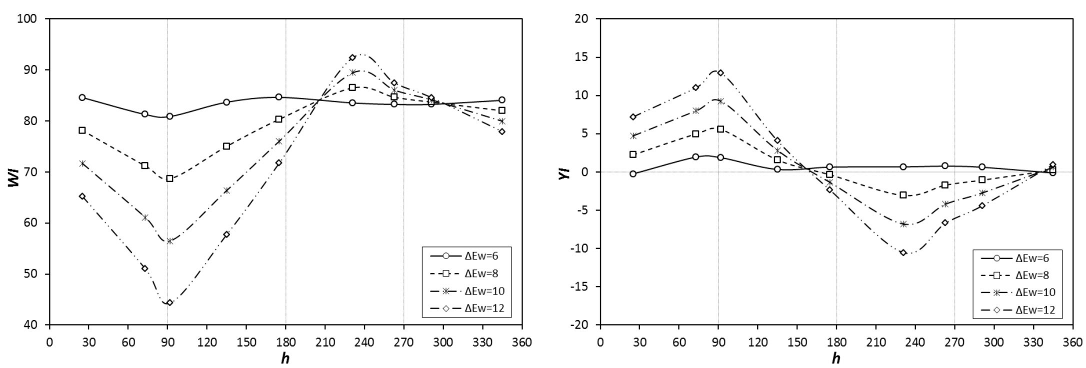

Figure 3. *WI* and *YI* against of hue angle (h) corresponding to ΔEw.

In addition, the applied range of the *WI* limits was depended on hue. The range of applicable *WI* was larger to R-YR-Y-GY group than BG-B-PB group.

Therefore, the appropriable colors within the limits of *WI* and the positive *YI* (R-YR-Y-GY group and P) estimated to compare the color properties of the *WI* and *YI* on the CIELAB as shown in Figure 2 (right).

The results of correlations between *WI* and *YI* of the colors within the limits of *WI* and the positive *YI* indicated totally a linear relationship of each hue (negative correlations r^2=0.99) as shown in Figure 5. Therefore, the *WI* of each hue was able to calculate by a linear function of *YI*. The rate of change (slope) of each hue was different. Practically, when *WI* were decrease, *YI* of R-YR-Y-GY group were more increased than *YI* of BG-B-PB group, GY and P.

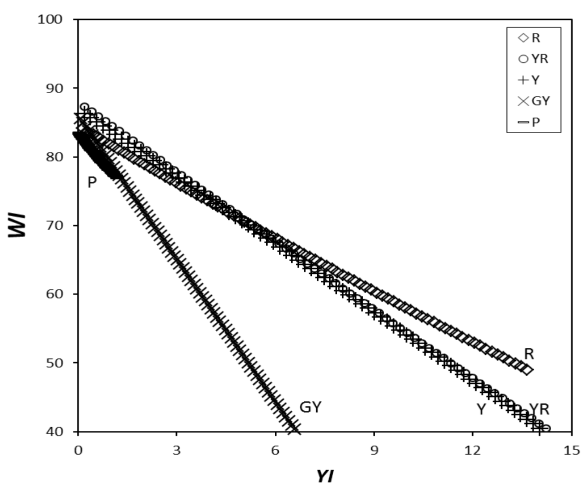

Figure 5. The correlations between the *WI* and *YI* of each hue.

5. Conclusions

In this study, the properties of *WI* and *YI* on the CIELAB were identified through the simulations of estimation data. The four points were figured out from this study as followings.

1. The relationship of *WI* and *YI* was a negative correlation generally, however the coefficients of correlation function between *WI* and *YI* were depended on hue, especially yellowness-blueness.
2. Both *WI* and *YI* had two hue transition points, these points were not the point of *h*=0 and *h*=180 and asymmetric.
3. In terms of the measuring concept of *WI* and *YI*, there were two considerations: the limits of *WI* and the negative *YI*. The applied range and direction of the *WI* limits was depended on hue. In addition, the range of negative *YI* was 157 < h < 335.
4. There was a linear relationship of each hue (negative correlations r^2=0.99) between *WI* and *YI*. The rate of changes in *WI* and *YI* by ΔE_w were depending on hue because the rate of change (slope) of each hue was different.

The obtained results indicated that *WI* and *YI* were strongly influenced by hue. In terms of the hue contribution to *WI* and *YI*, the direction to yellowness and blueness were more effective than redness and greenness. However the hue transition points were not the point of *h*=0 and *h*=180 which are b^*=0, and the contribution rates of both directions were asymmetric.

This study was carried on using estimation data of *WI* and *YI*. Generally, *YI* is calculated using the color changes ΔYI from the original white toward yellow. Therefore, *YI* may more relate to the color fastness to daylight or to washing and laundering, etc. The colors were not considered the hue direction by the damages. In the further study, it is necessary to understand to the relationship between *YI* and the color fastness using the practical color samples.

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