Limiter Identification Model of Color Difference & Bias Based on the RGB Distribution of Fabric Image

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***Abstract* — To solve the problems of real-time color detection in the production of dyes, the method of identifying color differences & color bias is proposed by using the RGB values of the image. After the digital image of the fabric is produced, pre-processing of the image is executed first, and then the models of color difference and color bias based on RGB are set up through transforming RGB color to L*a*b* color. Because the color of an image affects the response of all pixels, the effect of RGB distribution is considered during identifying color difference & bias. Hence, adjusting the model is necessary by introducing the similarity of color moment. In the experiment, 10 pairs of fabric samples with different colors are tested. The results show that the models of color difference & bias are feasible and the adjusted models have better accuracy.**

Keywords - ponent; RGB distribution; color difference; color bias; identification model

I. INTRODUCTION

In the judgment to the color difference and color bias of the fabric in the dyeing production, two ways including the artificial color inspection and the instrument measuring exist currently. The artificial color inspection relies on the observation from the naked eye, and the result is usually affected by the sensitive degree of optic nerve to the color, easily to observe the influence of individual difference and experience etc., and the accuracy rate is not high, its judgment is preliminary and qualitative[1]; The color measuring from the color meter is to get the reflection coefficient of different spectral reflectance by measuring the reflection ratio of the fabric's surface to the visible light (380nm - 780nm), then get XYZ tristimulus values, the color difference and the color bias according to the principle of color mixing[2]. The accuracy from the color meter is high, but the method is only suitable for small area (color measuring window) and difficult for large area, and meanwhile the measured surface of the fabric must be smooth and dry, the real-time is also not high.

As for color measuring by image, some scholars have done some research related. In the judgment of color difference, Yang Zhenya [3] proposed a color difference formula based on the distance of RGB and the vector angle in RGB space, but it is only limited to the measurement of color difference regardless of the expansion to the image; In the analysis of color image, Francesca[4] and Xu Xiaoshao [5] judged the bias position and bias degree by using color factor and color center, but no study on color difference; In the judgment of color bias, Zheng Jianhua [6] used the position of RGB distribution curve, but not considering the actual color effect when mixed.

In order to achieve the color measurement upon the large area, the method of using the RGB value of the image to identify the color difference and color bias of fabric is put forward and the calculation models of color difference and bias are set up in the article. The method is: 1) Obtaining the digital image through the photography upon the dyed fabric; 2) Pre-processing the image for color measurement; 3) Establishing the models of color difference and bias based on RGB values using the conversion model from RGB space to CIE1976 L*a*b* space; 4) Adjusting the models considering the characteristics of RGB distribution and the similarity of the color moment between the reference sample and the one to be tested. The modeling flow is seen in Fig.1.

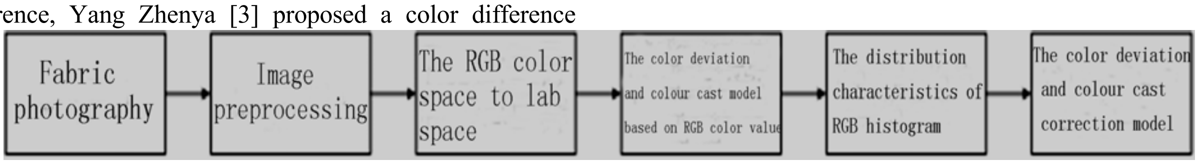


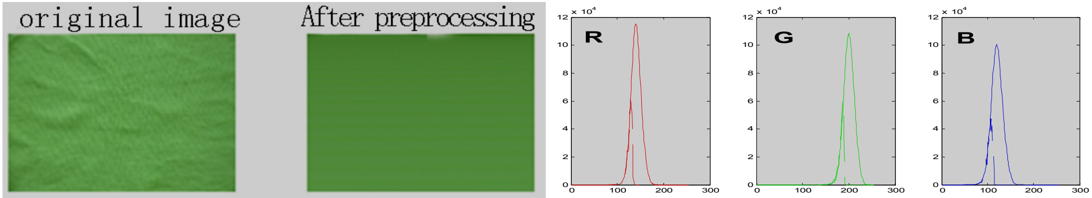
Figure. 1 The modeling flow of RGB color difference & bias

II. THE COLOR DIFFERENCE AND BIAS MODELS OF RGB

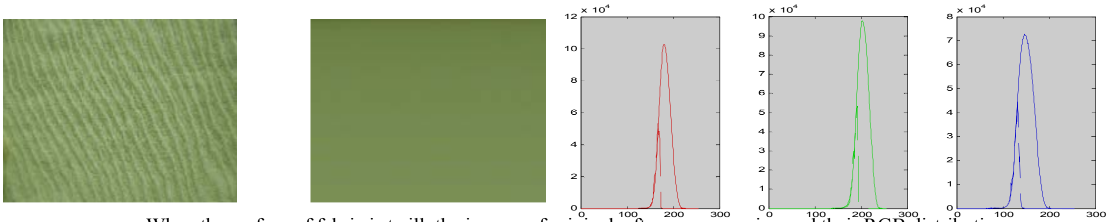
Because of the roughness existing in the surface of fabric inevitably and the interference of noise (from the background and thermal factors etc.), the digital images of fabric are often not suitable for direct color measurement but to be processed at first.

A. Image Preprocessing

The fact of preprocessing image is that the pixels with the significantly different color value are removed from the image. The method of preprocessing has many kinds [7] [8] [9]. It is found through the study that preprocessing the image using the improved k-means clustering method has good effect and fast speed [10]. The RGB distributions of preprocessed image are more concentrated, and can reach the requirement for color measurement (see Fig. 2).



When the surface of fabric has roughness, the images of original, after-preprocessing and their RGB distribution (solid line for original, dash line for after-preprocessing)



When the surface of fabric is twill, the images of original, after-preprocessing and their RGB distribution

Figute.2 The original image, after-preprocessed image and RGB distribution

B. The Color Difference Model of RGB

1) The model form RGB to XYZ

Because the RGB values of the digital image are associated with the device, RGB values can be converted into CIE1931 XYZ values after the camera linearization. Let P=[R G B] 1×3 denote the color values in RGB space and let Q=[X, Y, Z]1×3 denote the tristimulus values, the transforming method from RGB to XYZ is as follows:

$$Q = P * M + \varepsilon \tag{1}$$

Where M= $\begin{bmatrix} \beta_{1,1} & \beta_{1,2} & \beta_{1,3} \\ \beta_{2,1} & \beta_{2,2} & \beta_{2,3} \\ \beta_{3,1} & \beta_{3,2} & \beta_{3,3} \end{bmatrix}$ is the transforming matrix,ε is the error and satisfies the Gauss distribution.

For the different equipments, the values of Q and P can be obtained by the experiment, and M can be obtained by least square method as below:

$$\hat{M} = (P^T P)^{-1} P^T Q \tag{2}$$

Through lots of experiments, the matrix $\hat{M}$ of camera in the experiment can be obtained,

$\hat{M}$ = [M1 M2 M3] T = [0.1510 0.0938 -0.0730; 0.1714 0.3110 0.0334; -0.0580 -0.1323 0.3228].

Hence, the relationship model between RGB and XYZ is following:

$$Q = P * \hat{M} \tag{3.1}$$

Eq. (3.1) can be written in details:

$$\begin{cases} X = 0.1510R + 0.1714G - 0.058B \\ Y = 0.0938R + 0.3110G - 0.1323B \\ Z = -0.073R + 0.0334G + 0.3228B \end{cases} \tag{3.2}$$

Eq. (3.2) establishes the relationship between RGB values of photographic equipment and XYZ tristimulus. Moreover, XYZ tristimulus values is needed to be transformed into L*a*b* values in CIE1976 L*a*b* uniform color space so as to calculate the color difference and color bias.

*2) The model from XYZ to L*a*b**

The method of converting XYZ tristimulus values into L*a*b* is [11]:

$$\begin{cases} L^* = 116 f(Y/100) - 16 \\ a^* = 500[f(X/94.825) - f(Y/100)] \\ b^* = 200[f(Y/100) - f(Z/107.381)] \end{cases} \tag{4}$$

Where L* is the lightness, a* and b* is the chroma of red-green and yellow-blue respectively. Under the condition of 10° view angle and D65 standard light source, the color values of reference point are (Xn = 94.825, Yn = 100, Zn = 107.381). Eq. (4) may be specific as:

$$\begin{cases} f(X/94.825) = \begin{cases} (X/94.825)^{1/3} & X > 0.8398 \\ 7.787(X/94.825) + 16/116 & X \le 0.8398 \end{cases} \\ f(Y/100) = \begin{cases} (Y/100)^{1/3} & Y > 0.8856 \\ 7.787(Y/100) + 16/116 & Y \le 0.8856 \end{cases} \\ f(Z/107.381) = \begin{cases} (Z/107.381)^{1/3} & Z > 0.951 \\ 7.787(Z/107.381) + 16/116 & Z \le 0.951 \end{cases} \end{cases} \tag{5}$$

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The transformation from RGB to L*a*b* can be divided into 2 cases. It is found through calculation that the corresponding color is dark when ($X\leq0.8398, Y\leq0.8856, Z\leq0.951$)[12]. It is not included in the study because of the nonlinear optical response of photographic equipment and large error to the dark color. Therefore, eq. (4) can be simplified to:

$$\begin{cases} L^* = 116(Y/Y_n)^{1/3} - 16 \\ a^* = 500[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}] \\ b^* = 200[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}] \end{cases} \quad (6)$$

Where, replacing (Xn, Yn, Zn) with their values and eq. (6) can be simplified to:

$$\begin{cases} L^* = 25(Y)^{1/3} - 16 \\ a^* = 109.66(X)^{1/3} - 107.74(Y)^{1/3} \\ b^* = 43.1(Y)^{1/3} - 42.11(Z)^{1/3} \end{cases} \quad (7)$$

Eq. (7) constructs the relationship between XYZ and L*a*b*. 2.2.3 The model from RGB to L*a*b*

Eq.(7) combined with eq. (3.2), the relation between RGB and L*a*b* is below:

$$\begin{cases} L^* = 25(0.0938R + 0.311G - 0.1323B)^{1/3} - 16 \\ a^* = 109.66(0.151R + 0.1714G - 0.058B)^{1/3} - \\ \quad 107.74(0.0938R + 0.311G - 0.1323B)^{1/3} \\ b^* = 43.1(0.0938R + 0.311G - 0.1323B)^{1/3} - \\ \quad 42.08(-0.073R + 0.0334G + 0.3228B)^{1/3} \end{cases} \quad (8)$$

3) The model of color difference

In CIE1976 L*a*b* uniform color space, the calculation method of color difference is below:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (9)$$

Substituting two RGB values with the different colors into equation (8) to figure out L*a*b*, and then substituting L*a*b* into eq. (9), the color difference ΔE can be worked out.

C. *The Color Bias Model of RGB*

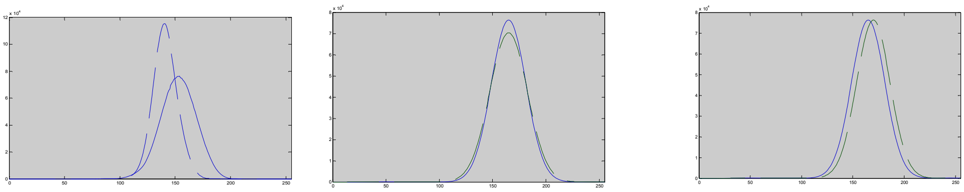
According to the theory of colorimetry, the human perception to color depends on the hue. The calculation method of hue as follows:

$$H = \arctan(b^* / a^*) \quad (10)$$

Where H is hue, a* and b* are the chroma values. Substituting a* and b* from the reference sample and the tested sample respectively into equation (10) to get the corresponding H, and then their difference is the color bias.

III. THE ADJUSTED MODEL OF RGB COLOR DIFFERENCE AND BIAS

The models of color difference and bias obtained in section 2.2 and 2.3 are suitable for the color whose RGB values are known. As for an image, it means the color of a pixel satisfies the said models. But the color of an image is the overall reaction to all pixels from the human eye, the RGB values of each pixel in an image are not the same, so it is necessary to determine the color of an image considering the global features of the image. Meanwhile, for the calculation of color difference and bias upon two images as per the models in section 2.2 and 2.3, the result may be accurate when the distribution of two images is normal if the average RGB values were used (Fig.3a). But in some special cases such as the same mean and different variance (Fig.3b) or the same variance and different mean (Fig.3c), the said models will probably lead to misjudgment. Therefore, it is necessary to adjust the models of color difference and bias based on the actual RGB distribution.



(a) Normal distribution (b) The same mean and different variance (c) The same variance and different mean

Figure.3 Various RGB distribution

A. *The Characteristics of RGB Distribution*

The histogram distribution can be available by extracting RGB components from a fabric image (Fig. 4). According to the theory of Stricker and Orengo [13], the color information of an image can fully be expressed by the low order color moments such as one order moment (mean), two order moment (variance) and three order moment (skewness). Therefore, RGB color information of an image can be described by nine color moments (3 color components of RGB * 3 color moments of each component). The calculation methods are below [14]:

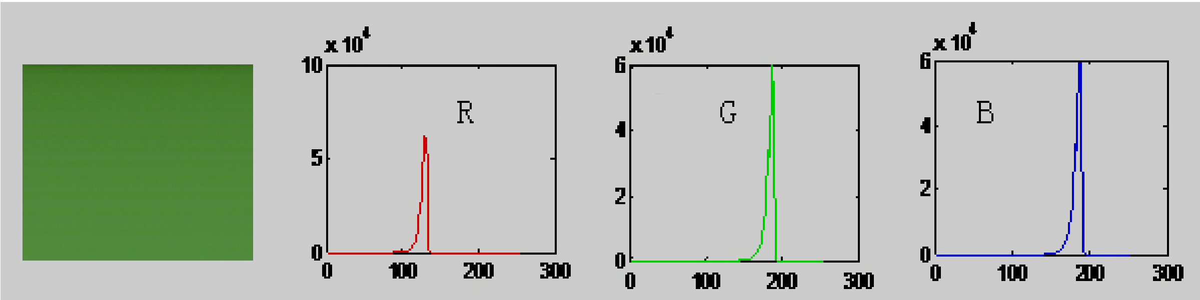


Figure.4 The image of fabric and its color histogram

One order moment $$m_i = \frac{\sum_{j=1}^{N} C_{i,j}}{N} \quad (11)$$

Where, Ci, j is the RGB value of pixel j ($i \in \{R, G, B\}$), N is the number of all pixels in one image, mi is the mean of color.

Two order moment $$s_i = \sqrt{\frac{\sum_{j=1}^{N}(C_{i,j} - m_i)^2}{N}} \quad (12)$$

Where mi、N、Ci,j is same as in eq.(11), and si is the standard deviation of color.

Three order moment $$sk_i = [\frac{1}{N}\sum_{j=1}^{N}(C_{i,j} - m_i)^3]^{1/3} \quad (13)$$

Where, ski is the skewness of RGB distribution, the others are same as eq. (11) and (12).

From Fig.3 and Fig.4, it is shown that the overall perception will be effected along with the different shape of RGB distribution. Therefore, the color moments of an image can be used to adjust the said models when identifying color difference and bias.

B. The Method of Adjusting Model

The mean is the main character of the distribution. When calculating the color difference and bias, the means of RGB can be used. The identification to color is based on the color of reference sample, which means the color adjustment is just made on RGB means. The correction coefficient is introduced as follows:

1) The correction coefficient

Let IMG0 be the image of reference sample, and let IMG be the one of the tested sample, their color moments are respectively:

$$\{m^0{}_R, s^0{}_R, sk^0{}_R, m^0{}_G, s^0{}_G, sk^0{}_G, m^0{}_B, s^0{}_B, sk^0{}_B\}$$

And

$$\{m_R, s_R, k_R, m_G, s_G, k_G, m_B, s_B, k_B\}$$

The color similarity between IMG0 and IMG is:

$$\rho_i = \frac{\sum_{k=1}^{3} x^{IMG0}{}_{ik} \bullet x^{IMG}{}_{ik}}{\sqrt{\sum_{k=1}^{3}(x^{IMG0}{}_{ik})^2} \bullet \sqrt{\sum_{k=1}^{3}(x^{IMG}{}_{ik})^2}} \quad (14)$$

Where i is one of RGB components ($i \in \{R, G, B\}$), x is the value of 1-3 order color moment, ρ_i is the similarity of RGB between the reference image and the tested sample image ($|\rho| \le 1$. The bigger $|\rho|$ is, the more close the color of two images is), k (k=1, 2, 3) is one among three color moments. Note that, because the one moment is the chroma and it is usually greater than two order and three order moment, its standardization is desired by divided by 255 to a value in [0,1].

2) The method of adjustment

When adjusting the mean of the tested color, the rule is following:

$$\begin{cases} if \quad m_i^{IMG0} \ge m_i^{IMG}, then\ m_i^{IMG}* = m_i^{IMG} / \rho_i \\ \quad else \quad m_i^{IMG}* = m_i^{IMG} \cdot \rho_i \end{cases} \quad (15)$$

Where $m_i^{IMG}*$ is the adjusted RGB mean of the tested color, the other parameters are same as the above. It can be seen from eq. (15) that the adjusted RGB mean is closer to the one of reference sample than non-adjusted one, its purpose is to minimize the measurement error. Eq. (15) can uniformly be expressed as:

$$m_i^{IMG}* = r_i \cdot m_i^{IMG} \quad (16)$$

Where ri is the correction coefficient of the tested color.

C. The Model of Adjusted Color Difference and Bias

Combined eq. (8), (9), (10) with (11), (12), (13), (14), (15), (16), the models of adjusted color difference and bias can be obtained. The method is: 1) Calculating the color similarity of the reference image and the tested image after their 1-3 order moment figured out by taking advantage of eq. (11), (12) and (13); 2) The adjusted means of the tested color can be got according to the formula (15), (16); 3) Substituting RGB means of the reference color and the tested color into eq. (8) to get (L*a*b*)0 of the reference color and (L*a*b*) of the tested color; 4) Substituting (L*a*b*)0 and (L*a*b*) into eq. (9) and (10) to get the adjusted models of color difference and bias. The models are below:

$$\begin{cases} \begin{cases} L^{0*} = 25(0.1714R^0 + 0.311G^0 + 0.0334B^0)^{1/3} - 16 \\ a^{0*} = 109.66(0.1510R^0 + 0.0938G^0 - 0.073B^0)^{1/3} - 107.74(0.1714R^0 + 0.311G^0 + 0.0334B^0)^{1/3} \\ b^{0*} = 43.1(0.1714R^0 + 0.311G^0 + 0.0334B^0)^{1/3} - 42.08(-0.058R^0 - 0.1323G^0 + 0.3228B^0)^{1/3} \end{cases} \\ \begin{cases} L^* = 25(0.1714R^* + 0.311G^* + 0.0334B^*)^{1/3} - 16 \\ a^* = 109.66(0.1510R^* + 0.0938G^* - 0.073B^*)^{1/3} - 107.74(0.1714R^* + 0.311G^* + 0.0334B^*)^{1/3} \\ b^* = 43.1(0.1714R^* + 0.311G^* + 0.0334B^*)^{1/3} - 42.08(-0.058R^* - 0.1323G^* + 0.3228B^*)^{1/3} \end{cases} \\ \Delta E = \sqrt{(L^{0*} - L^*)^2 + (a^{0*} - a^*)^2 + (b^{0*} - b^*)^2} \\ \Delta H = \arctan(b^{0*} / a^{0*}) - \arctan(b^* / a^*) \end{cases} \quad (17)$$

Where (R*,G*,B*) are the values of adjusted color, (R0,G0,B0) are the color values of reference sample, (L*, a*, b*) are the chroma values of the tested sample,(L0*,a0*,b0*)are the chroma values of the reference sample. The calculated bias value in eq. (17) is the direction and extent of bias of the tested sample.

IV. THE EXPERIMENTAL VERIFICATION AND ANALYSIS

In order to evaluate the models of the adjusted color difference and bias, 10 pairs of fabric samples with the different color are tested (one reference sample and one tested sample are included in each pair).

A. Experiment Conditions

H-24SE small dyeing machine, 32s cotton fabric as dyeing material, SF600X color meter from Datacolor inc., Nikon D90 (with the tripod) as photograph instrument, the light box is Gretag Macbeth from KMS inc.(using the D65 as the standard light source, its color temperature is 6500±200K).

B. Experiment Method

1) Sampling. Getting 10 pairs of dyed fabric samples according to the normal dyeing process; 2) Taking photos on 10 pairs of samples. All samples are placed in the light box under the condition of the distance of lens equal to 80cm; 3) Preprocessing the images; 4) Measuring L*a*b* values of all samples in the color meter, which is treated as the standard values; 5) Calculating the color moments and the color similarities upon the above samples as per described in section 3, and then calculating the color difference and bias of the tested samples comparing to the reference samples as per the models of color difference and bias. The experimental images are seen in attachment 1.

C. The result of Experiment and Analysis

1) The verification of color difference model

The purpose of experiment is to verify the effectiveness of the adjusted models in section 3.3. Because RGB values of an image are the base of calculating the color difference and bias, the change of RGB values is discussed at first. RGB values in three situations are obtained, which is from the image of reference sample and the pre-adjusted values of tested sample, as well as the adjusted values (Tab.1). It can be seen from Tab.1 that the change of RGB values has 2 different cases: one is the change to be tiny (such as 1 #, 2 #, 5 #, 7 #, 10 #), another is no change (such as 3 #, 4 #, 6 #, 8 #, 9 #). The reason to no significant change of RGB values is that RGB distributions of the tested image are actually very similar to ones of the processed reference image (ρ very close to 1). The improvement of similarity means the clustering processing on images is necessary when measuring the color of fabric.

TABLE I RGB values of image

No.	reference sample			Pre-adjusted value of tested sample			Adjusted value of tested sample		
	R	G	B	R	G	B	R	G	B
1#	190	204	107	173	193	85	172	193	85
2#	247	230	154	250	233	153	247	230	152
3#	168	95	135	181	79	114	181	79	114
4#	224	176	202	227	175	205	227	175	205
5#	235	236	168	237	234	164	235	234	164
6#	248	231	152	247	230	149	247	230	149
7#	196	42	91	198	42	90	198	43	92
8#	231	232	157	230	231	160	230	231	160
9#	231	230	153	231	232	157	231	232	157
10#	90	176	86	92	178	85	91	178	85

As for the color difference, they are also discussed in three situations, which includes the color contrast of the pre-adjusted versus the reference, the adjusted versus the reference, as well as the original fabric versus the reference fabric in color meter (Fig.5). It is seen from Fig.5 that the color difference measured by the color meter is smallest and most accurate, while the color difference of the adjusted versus the reference is smaller and closer to the intrinsic color than one of the pre-adjusted versus the reference. Hence, it is also showed that RGB values should be adjusted in order to obtain the more accurate values of color difference and bias.

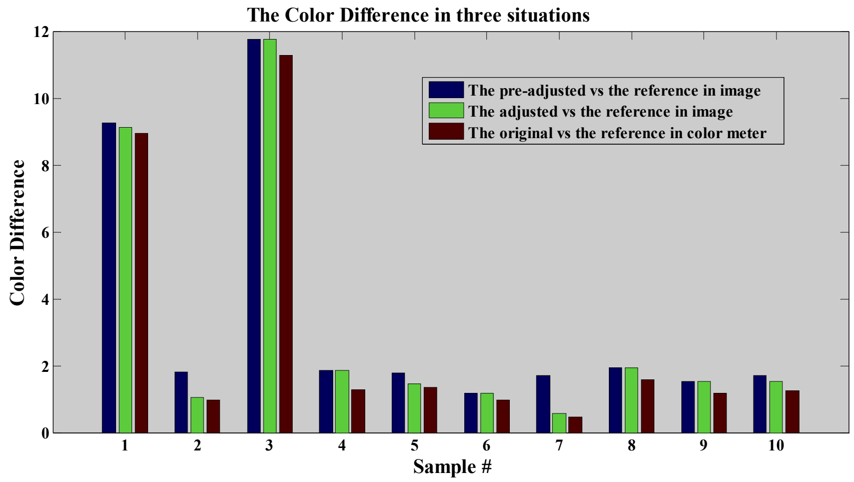


Figure.5 The color difference in three situations of the original, the pre-adjusted and the adjusted

2) The verification of color bias

Because the dyes used in the actual production are divided into three types covering the reactive red, the activate yellow and the activate blue, the inspection to the color bias of fabric is actually that testing the color of dyed fabric tends to some color among three colors so as to adjust the dye recipe. For the judgment of the color bias, the simplified model illustration of L * a * b * can be utilized (see Fig. 6) [15]. The method is: firstly the position of hue is to be determined in L * a * b * model, and then the bias direction to red, yellow or blue is decided. Because the green color is the mixture of yellow and blue, the judgment to green can be also further returned to the judgment to yellow or blue.

It can be seen from Tab. 2 that the direction judgment to the bias by image is same as one by measuring in the color meter, although the value of the former is bigger than one by the latter, which also shows that the color bias of fabric can be judged from its image.

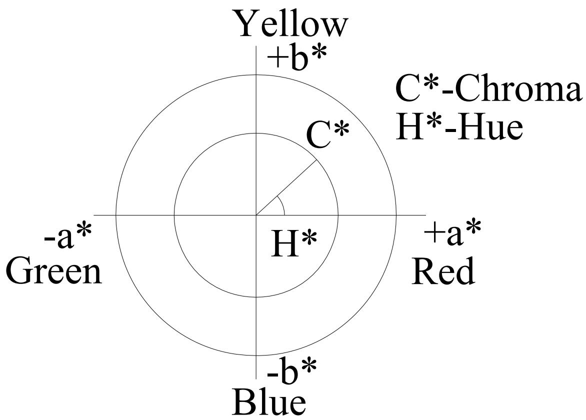


Figure.6 The simplified model illustration of L * a * b *

TABLE II The color bias of 10 pairs of samples

	Image of reference sample				Adjusted of tested sample					By color meter	
No.	L*	a*	b*	Hue	L*	a*	b*	Hue Diff.	Bias	Hue Diff.	Bias
1#	85.58	-14.69	48.15	107	84.46	-18.19	56.50	0.85	Blue	0.53	Blue
2#	89.1	-5.86	38.06	98.75	89.22	-6.14	39.06	0.18	Blue	0.12	Blue
3#	59.4	29.65	-6.97	-13.23	58.49	35.08	3.42	18.80	Red	4.47	Red
4#	75.48	15.71	-2.03	-7.36	75.22	17.14	-3.18	-3.15	Blue	-2.39	Blue
5#	88.57	-7.13	30.67	103.09	88.53	-7.18	32.12	-0.49	Yellow	-0.38	Yellow
6#	89.41	-6.25	39.44	99	89.41	-6.56	40.58	0.18	Blue	0.15	Blue
7#	51.18	56.84	8.76	8.76	51.6	56.55	9.03	0.31	Yellow	0.27	Yellow
8#	88.49	-8.25	34.4	103.49	88.11	-7.71	32.57	-0.17	Yellow	-0.12	Yellow
9#	88.45	-8.31	35.93	103.02	88.49	-8.25	34.4	0.47	Blue	0.11	Blue
10#	77.18	-30.47	34.31	131.61	77.69	-30.9	35.7	-0.73	Yellow	-0.26	Yellow

V. CONCLUSION

Although the accuracy of color difference and bias measured by the photography in the article is not good as one by the color meter, the result of experiment shows that the method is still correct and feasible for the identification of color difference and bias, and the former is more fast and convenient. The identification models of color difference and bias are based on the clustering processed images, and the way to processing the images has important influence on the applicability of the models. The RGB distributions of the tested samples and the reference samples have almost the shape, which weakens the effect of the models, hence the further research on the project is needed. Moreover, sometimes the generalization ability of the transforming model from RGB space to XYZ space is also weak, the more robust transforming model is to be established. All the above problems will be the focus in next study.

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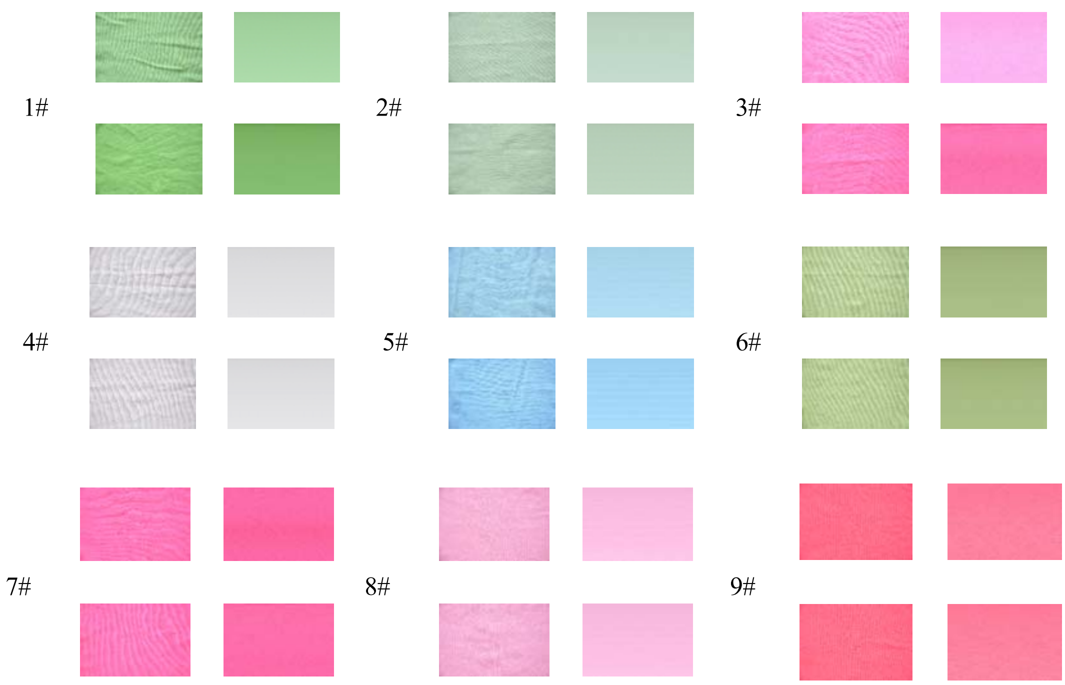
[ATTACHMENT 1] THE IMAGES OF 10 PAIRS OF DYED FABRIC



10#

(Note: In each pair, the upper left image is for reference sample, the upper right image is for after-processed reference sample, the lower left image is for tested sample, the lower right image is for after-processed tested sample)