Investigation of Texture Effect on Visual Colour Difference Evaluation

John H. Xin,* Hui-Liang Shen, Chuen Chuen Lam

Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

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Abstract: The texture effect on visual colour difference evaluation was investigated in this study. Five colour centers were selected and textured colour pairs were generated using scanned textile woven fabrics and colour-mapping technique. The textured and solid colour pairs were then displayed on a characterized cathode ray tube (CRT) monitor for colour difference evaluation. The colour difference values for the pairs with texture patterns are equal to 5.0 CIELAB units in lightness direction. The texture level was represented by the half-width of histogram, which is called texture strength in this study. High correlation was found between texture strength and visual colour difference for textured colour pairs, which indicates that an increasing of 10 units of texture strength in luminance would cause a decreasing of 0.25 units visual difference for the five colour centers. The ratio of visual difference between textured and solid colour pairs also indicates a high parametric effect of texture. © 2005 Wiley Periodicals, Inc. Col Res Appl, 30, 341–347, 2005; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/col.20138

Key words: texture effect; colour difference; visual colour difference

INTRODUCTION

With the advances in information and electronic technologies, more and more colour information exchanges in areas of product design and product quality control rely on electronic means, which greatly shortened the exchange lead time. To visualize the colour information, cathode ray tube (CRT) devices have been widely used by many commercial companies. It is also common in many textile companies to visually evaluate the colour samples mapped with texture patterns. Although the influence of texture on colour difference evaluation is known, as a parametric factor to the colour difference equation, few reports on quantitative analysis of the influence have been published. A lightness tolerance threshold experiment was performed using the stimuli with a simulated texture of thread wound on a card, by Montag and Berns.[1] The suprathreshold lightness tolerances were investigated around neutral colour centers at CIELAB L^* equaling 10, 20, 40, 60, 80, and 100. The tolerances were compared among simulated full-textured samples, uniform samples, and samples with a simulated texture in between the two. Comparing with the uniform stimuli, the textured stimuli had an effect of increasing the tolerance thresholds by a factor of almost 2. Since only two types (full- and half-textured) of thread textures were used in that study, the quantitative investigation of texture effect on visual evaluation is limited.

In this article, we study the influence of texture levels on visual colour difference evaluation by using 15 samples with different texture patterns. These texture patterns were first generated using colour-mapping technique using the predetermined five colour centers and then displayed on a characterised CRT monitor. For each texture pattern, two comparison pairs (with ± 5 CIELAB difference) were used, and thus there were totally 150 (15 samples $\times$ 5 colour centers $\times$ 2 pairs) colour difference pairs that were evaluated using gray-scale method. The method of simulation and visual evaluation are discussed in detail in the following sections.

CHARACTERISTICS OF TEXTURE IMAGES

Fifteen differently woven cotton fabrics were selected in this study. The woven patterns are those mostly used in the textile industry, including plain, twill, rib, jacquard, and

*Correspondence to: Dr. John H. Xin (tcxinjh@inet.polyu.edu.hk)

rhomb. These physical samples were scanned using an EPSON GT-10000+ colour scanner. The automatic colour adjustment and image enhancement functions of the scanner were disabled in the scanning process. The resolution was properly chosen so that the scanned images gave approximately equal visual appearance to those of physical samples when viewed under normal viewing distance of about 40 cm. Considering the texture or spatial information that is mainly contained in the luminance channel, we calculate the luminance Y for each pixel, according to the Federal Communication Commission (FCC) colour space.[2]

$$Y = 0.299R + 0.587G + 0.114B \tag{1}$$

For textile fabric, the texture is quite regular, that is, the elementary woven pattern is repeated over the whole image. The texture level can be described by its coarseness index, in the sense that a rhomb fabric is coarser than a plain one under the same viewing condition. The coarseness index is related to the spatial repetition period of the local structure. A large repetition period implies a coarse texture, while a small period implies a fine one. Because of the regularity of texture patterns of textile fabrics, the coarseness index is considered to be effective for quantitative measurement of texture level. The shape of histogram is directly related to the coarseness of a texture. From Fig. 1, it is obvious that the histogram width of coarse texture is wider than that of fine texture. Although the histogram only describes the statistical distribution of Y channel of the texture image, we consider that it is quite effective for characterizing the texture in this study.

We use the half-width W_Y of histogram in FCC luminance scale to quantify the coarseness of a texture, which is called texture strength in this study. Suppose luminance Y_C contains maximum pixel number V, half-width W_Y is defined as the distance between the higher luminance Y_R and lower luminance Y_L containing $V/2$ pixel number.

$$W_Y = Y_R - Y_L \tag{2}$$

Figure 2 clearly illustrates the definition of texture strength in luminance channel Y. Before the calculation of W_Y using Eq.(2), the histogram is smoothed using one-dimensional convolution kernel [0.25, 0.50, 0.25] to remove spurs. Fifteen textures were selected from over 80 scanned fabric images with different texture strength ranging from 11 to 80 at an interval of about 5.

It is seen from Fig. 1 that the distributions of the histogram of some texture images deviate from normality. Therefore, in addition to the half-width W_Y, we use two more statistics, namely skewness and kurtosis, to describe the characteristic of histogram distribution.[3] Skewness is defined as a measure of the lack of symmetry in a distribution. Kurtosis is defined as a measure of the degree of peakedness in the distribution. A normal distribution has zero skewness and zero kurtosis. The calculations of skewness and kurtosis are given by Eqs.(3) and (4) respectively,

$$\text{skew} = \frac{1}{\sigma_Y^3} \sum_{Y=0}^{255} (Y - \bar{Y})^3 P(Y) \tag{3}$$

$$\text{kurtosis} = \frac{1}{\sigma_Y^4} \sum_{Y=0}^{255} (Y - \bar{Y})^4 P(Y) - 3 \tag{4}$$

where $\bar{Y}$ and σ_Y are mean and SD of luminance, respectively, and $P(Y)$ is the normalized probability of luminance Y. Table I provides the texture pattern, texture strength W_Y, skewness, and kurtosis values of each texture image in Fig. 1. It is found that some histograms are quite peaky and significantly deviate from normal distribution, especially those of fine textures. We note that, in the calculation of W_Y, the symmetry and bell shape are not necessary conditions. Therefore, the half-width W_Y provides a simple and intuitive way to quantify texture level, when the histogram is single peaked.

COLOUR-MAPPING ON TEXTURE IMAGES

As textured colour samples would be used in the visual evaluation, solid colours should be mapped onto texture images. It means to generate pixel-wise three-dimensional spatial distribution of red, green, and blue channels from the existing one-dimensional spatial distribution of the Y channel. The colour-mapping is possible because the RGB channel is highly correlated.[4] Let $Y(p)$ be the luminance at pixel p, the deviation of pixel p to mean luminance $\bar{Y}$ of the texture image can be calculated as

$$\Delta Y(p) = Y(p) - \bar{Y} \tag{5}$$

Once a target colour S_n in RGB colour space is selected, it can be mapped to Y channel to synthesize textured colour images. The channel output at pixel p is calculated as

$$M_n(p) = S_n + \Delta Y(p) \tag{6}$$

where n represents red, green, or blue channels. For instance, when $\Delta Y(p) = 10$ and a target colour with $R = 100$, $G = 150$, and $B = 200$ being used to map to pixel p, the new colour becomes $R' = 110$, $G' = 160$, and $B' = 210$. When $M_n(p)$ is smaller than 0 or larger than 255, it should be clipped to 0 and 255, respectively. According to the previous study involving numerical and psychophysical evaluations, the generated texture images are perceptually very close to the actual physical samples.[4]

After colour mapping, we can also calculate the texture strength in a much perceptual scale of lightness L^*, denoted as W_{L^*}. In this study, the experiment was conducted on a Sony Trinitron 21 inch CRT monitor. The monitor was calibrated and characterized using the gain, offset, and gamma (GOG) model with additive terms for ambient flare and interreflection.[5–7] Let (L_n^*, a_n^*, b_n^*) be a target colour specified in CIELAB space, it can be first converted to RGB space and then mapped onto a texture

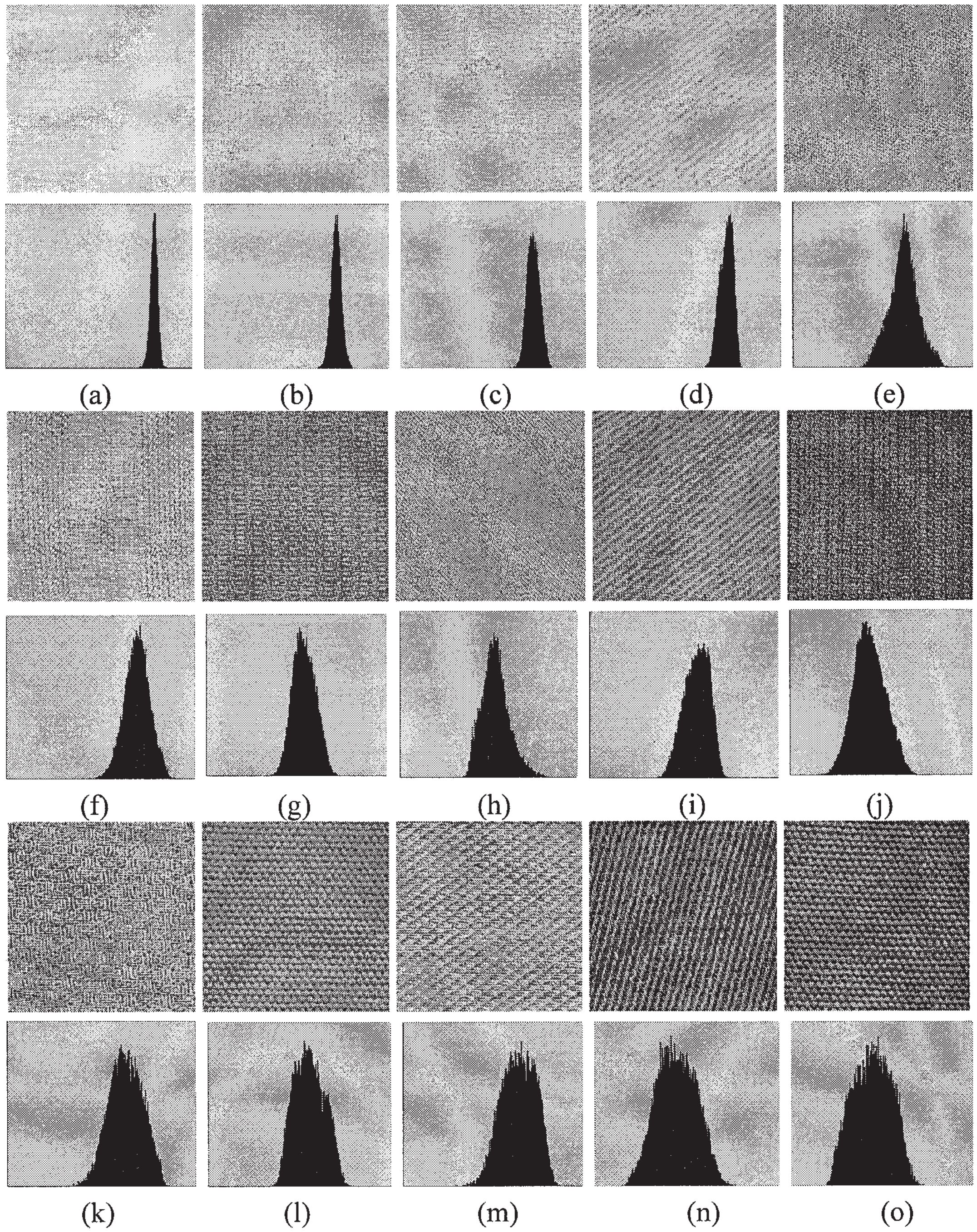

FIG. 1. The 15 texture images labelled from (a) to (o) and their histograms employed in this study.

image represented by FCC luminance Y. The texture strength W_{L*} defined in lightness scale can be calculated in four steps: (a) converting L_n^* into luminance Y' using the GOG model, (b) calculating the left luminance $Y'_{\mathrm{L}} = Y' - (Y_{\mathrm{C}} - Y_{\mathrm{L}})$ and right luminance $Y'_{\mathrm{L}} = Y' + (Y_{\mathrm{R}} - Y_{\mathrm{C}})$, (c) converting Y'_{L} and Y'_{R} to lightness scale L_{L}^* and L_{R}^*, respectively, using the GOG model, and (d) calculating texture strength $W_{L*} = L_{\mathrm{R}}^* - L_{\mathrm{L}}^*$. In the data analysis of experimental results, we will investigate whether W_{L*} could provide better correlation with visual difference of textured pairs when compared with that of W_Y.

COLOUR-DIFFERENCE PAIRS AND THE VISUAL ASSESSMENT

Heigie *et al.* found that in some colour regions, the disagreements among CMC, CIE94, and BFD colour-difference formulae are quite high.[8] These regions are orange, yellow, green, and blue with hue angle close to 55°, 90°, 190°, and 290°, with chroma less than 25. In this study, five colour centers were selected based on this finding. Table II shows the colorimetric values of these colour centers. These colour centers were converted to display RGB space, according to the GOG model of the CRT monitor. For each

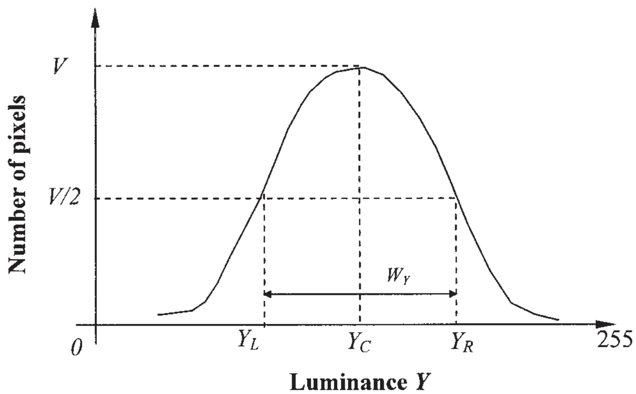

FIG. 2. Definition of texture strength W_Y.

colour center, 30 colour-mapped texture image pairs were generated, two pairs for each of the 15 textures. A PhotoResearch PR704 spectroradiometer was used to measure the colour difference of textured colour pairs. The distance between the spectroradiometer and the displayed texture image was about 40 cm, and the average colour of a relative large area was measured.

It is known that the human visual system is more sensitive to luminance contrast compared with chromatic contrast.[9] Therefore, in this study, we consider only the luminance difference. Montag and Berns found that, because of the parametric effect of texture, the suprathreshold lightness tolerances were approximately twice larger than those of solid colours.[1] Xin and Shen[4] also found that observers can hardly perceive the difference between two texture images when the measured colour difference was as large as 1.3 ΔE^*_{ab}. Therefore, in this study, we investigate the texture effect on medium colour difference about 5.0 CIELAB units. This range is also on the borderline of the CIE recommended colour difference magnitude for applying CIE94.[10] The target solid colour S_n was fine-tuned until the generated textured colour pairs having a colour difference of $\pm 5.0\ \Delta E^*_{ab}$ units in lightness direction.

Two methods, namely gray-scale comparison method and constant stimuli method, can be used in visual assessment of colour difference.[1,10–12] Montag and Wilber investigated the validity and prevision of these two methods, using same colour-difference pairs and concluded that the constant stimuli method was preferable.[13] In the textile industry, where colour difference assessments mainly involve textured fabric samples, the gray-scale method is a standard method for assessing colour change[11], and therefore it is preferred for this study.

TABLE I. The texture and corresponding information.

Texture label	Woven pattern	W_Y	Skewness	Kurtosis
(a)	Plain	11	4.17	16.91
(b)	Rib	16	3.32	10.11
(c)	Jacquard	23	2.73	6.12
(d)	Twill	25	2.59	5.38
(e)	Rib	34	1.66	1.62
(f)	Rib	38	1.74	1.63
(g)	Jacquard	41	1.68	1.28
(h)	Rib	36	1.64	1.37
(i)	Twill	47	1.54	0.75
(j)	Jacquard	55	1.29	0.17
(k)	Broken twill	60	1.12	−0.35
(l)	Basket	64	1.12	−0.42
(m)	Rhomb	70	0.95	−0.86
(n)	Twill	76	0.79	−1.07
(o)	Basket	80	0.72	−1.22

TABLE II. Colorimetric values of colour centers used in the colour difference evaluation.

Colour center	Orange	Yellow	Gray	Green	Blue
L^*	48.33	69.28	68.25	28.69	28.96
a^*	13.14	4.48	3.21	−17.83	4.43
b^*	16.87	19.11	0.29	−0.50	−9.13

Five gray scales (from grade 1 to 5) were used in this experiment. The gray scale of grade 5 served as standard. The CIELAB values for each grade under CIE D65 illuminant and 1964 standard observer are given in Table III, together with the colour difference (ΔE^*_{ab}) and lightness difference (ΔL^*) calculated between each grade and the standard. It can be seen that ΔE^*_{ab} and ΔL^* are almost the same, indicating that the colour differences are attributed to the lightness differences. The gray-scale grade G can be transformed into visual difference ΔV using Eq.(7).

$$\Delta V = -0.5513G^3 + 5.6139G^2 - 20.496G + 29.052 \tag{7}$$

The coefficients in Eq.(7) were calculated by fitting a third-order polynomial function using G and ΔE^*_{ab} listed in Table III. The R^2 value of this third-order polynomial fitting is 1.0, indicating an excellent fitting.

The experiment was conducted in a complete dark room and thus influence of ambient illumination was eliminated. The graphic-user-interface for visual colour difference was written in Borland Delphi®. The arrangement of gray scales and textured pair (or solid pair) on CRT monitor is shown in Fig. 3. The size of the displayed samples, including the gray scales, was 3 inch square. All the samples displayed had no black frame and there was no dividing line between the pairs. Totally 10 observers were asked to rate the colour difference using the uniform gray-scale grades. The viewing distance is the same as that of spectroradiometer, and the viewing angle is 0° degree to the normal of the sample. At the beginning of each assessment, the right patch of the

TABLE III. Colorimetric values of the gray scales used in the experiment.[a]

Grade (G)	L^*	a^*	b^*	ΔE^*_{ab}	ΔL^*
5[a]	43.1	0.1	−0.6	-	-
4	44.7	0.1	−0.7	1.6	1.6
3	46.3	0.1	−0.7	3.2	3.2
2	49.2	0.0	−0.4	6.1	6.1
1	56.7	−0.6	−0.6	13.6	13.6

[a] Grade 5 served as standard.

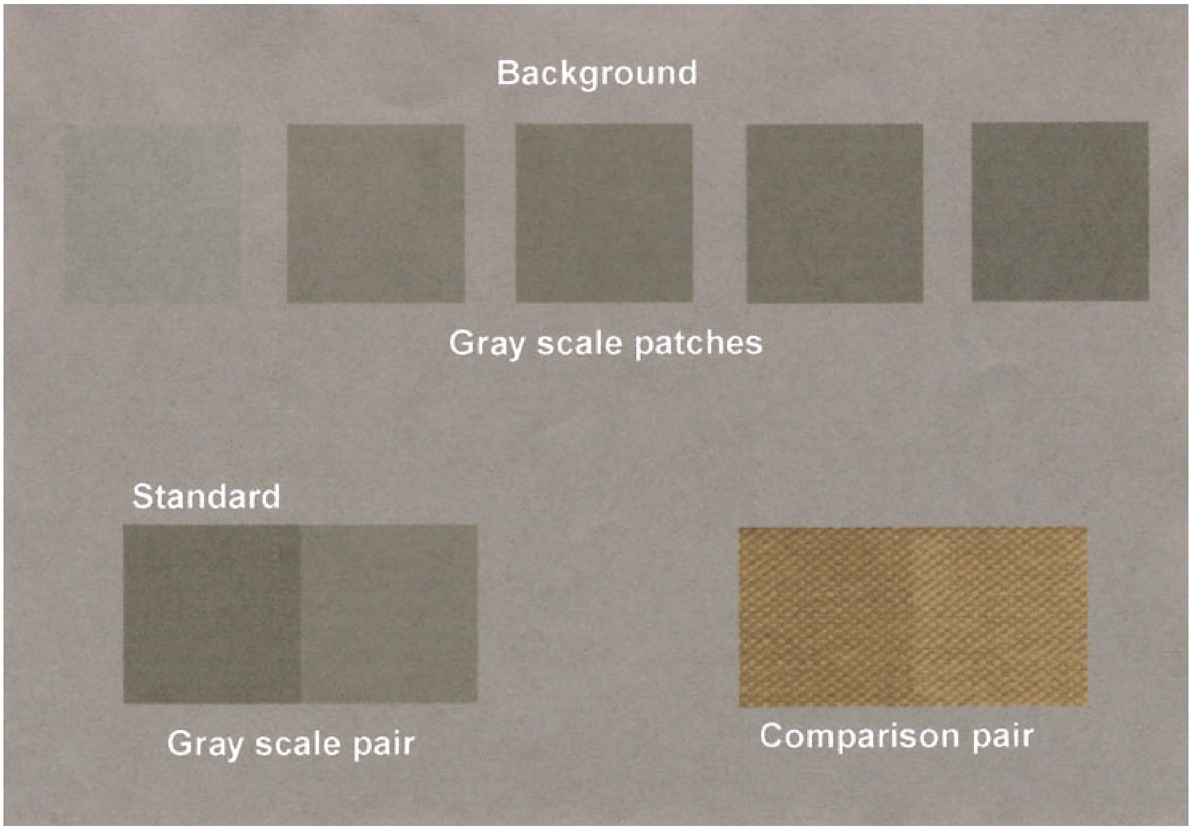

FIG. 3. Arrangement of sample pairs and gray scales on a CRT monitor.

gray-scale pair was the same as the left one (standard). When the observer clicked one gray patch on top, the right patch of the gray-scale pairs changed to that gray. Observers were asked to give a gray-scale grade that produced approximately the same colour difference as the comparison pair. If the grade of a sample pair did not equal the grade of the closest gray-scale, observers were encouraged to provide an intermediate step. For example, an observer would give 2.4 for colour difference in the comparison pair that was greater than gray-scale grade 3 but smaller than gray-scale grade 2. To evaluate the texture effect, a reference experiment using solid colour-difference pairs with the same measured colour difference corresponding to the texture mapped pairs was also conducted under the same viewing condition.

It is well known that the reliability of the results is critical in psychophysical experiments. The observer accuracy and repeatability tests were employed to check the reliability of the results. Observer accuracy represents the average deviation between each individual and the mean visual result of a panel, while observer repeatability represents the variation of the visual assessment of a particular observer. The performance factor (*PF/*3) has been widely used as an indicator for the observer accuracy and the performance of colour-difference formulae in comparison with visual results.[10,14] A *PF/*3 combines three measures of fit: gamma factor γ, coefficient of variation *CV*, and V_{AB}. The calculation of *PF/*3 is given as

$$PF/3 = 100[(\gamma - 1) + V_{AB} + CV/100]/3 \qquad (8)$$

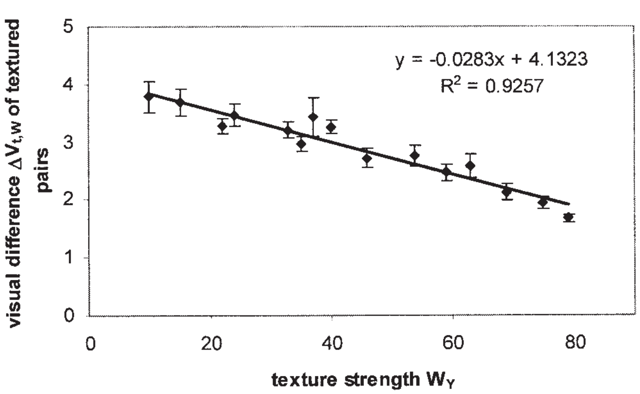

FIG. 4. Visual difference $\Delta V_{\mathrm{t,W}}$ against texture strength W_Y for the orange colour center. The Y-error bars show ±1 SD.

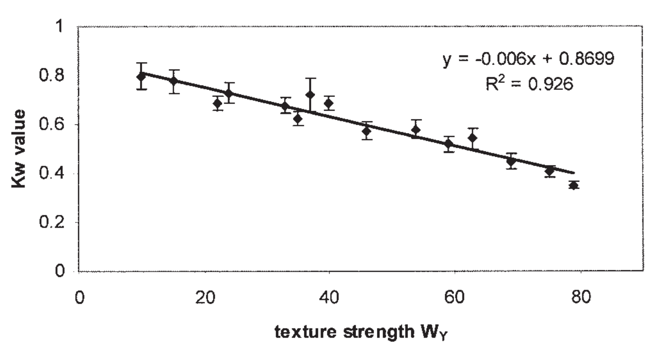

FIG. 5. K_W value against texture strength W_Y for the orange colour center. The Y-error bars show ±1 SD.

TABLE IV. Mean and SD of visual difference of solid pairs for the five colour centers.

	Orange	Yellow	Gray	Green	Blue
Mean of ΔV_s	4.75	5.05	4.77	4.70	4.50
SD of ΔV_s	0.98	0.78	1.05	0.99	1.10

In an ideal case, that is , when two variables are the same, *PF/*3 is equal to 0. A low *PF/*3 value indicates a small difference between two variables. In the experiment, 10 observers were asked to assess each textured and solid colour pairs twice. The observer accuracy and repeatability were 26.7 and 32.1, respectively. Considering the comparability of these results to our previous study,[10] all of the 10 observers' results were used in the study.

RESULTS AND DISCUSSION

Let $\Delta V^{+}_{t,W}$ and $\Delta V^{-}_{t,W}$ be the visual difference of textured colour pairs of strength W_Y, with an increasing and decreasing of 5.0 units ΔE^*_{ab} in lightness scale, the average visual difference $\Delta V_{t,W}$ is

$$\Delta V_{t,W} = \frac{1}{2}\left(\Delta V^{+}_{t,W} + \Delta V^{-}_{t,W}\right) \quad (9)$$

Very high correlation was found between visual difference $\Delta V_{t,W}$ and texture strength W_Y for the 5 colour centers used. Figure 4 shows the relationship between $\Delta V_{t,W}$ and W_Y of the orange colour center. The relationships of other colour centers are similar.

The visual differences of solid colour pairs and the corresponding SD are shown in Table IV. From Fig. 4 and Table IV, it can be found that the SD of solid pairs are larger than those of textured pairs. This finding indicates that observers were more likely to give similar visual judgement for textured pairs, especially when texture strength is high. Let K_W be the ratio between visual difference of textured colour pair with strength W_Y and that of solid colour pair:

$$K_W = \frac{1}{2}\left(\frac{\Delta V^{+}_{t,W}}{\Delta V^{+}_{s}} + \frac{\Delta V^{-}_{t,W}}{\Delta V^{-}_{s}}\right) \quad (10)$$

where ΔV^{+}_{s} and ΔV^{-}_{s} are visual differences of the solid colour pairs with an increasing and decreasing of 5.0 in lightness with respect to the colour center. We note that in the calculation of K_W, the variation of visual difference of solid pairs for individual observers are not considered, that is, ΔV^{+}_{s} and ΔV^{-}_{s} are the mean visual difference of solid colours of all observers. It is reasonable because the purpose of K_W is to compare the visual difference of textured samples and solid samples, but not observer variations in solid colour evaluation.

We note that K_W value deviating from 1.0 indicates a parametric effect. The relationship between K_W and texture strength W_Y for the orange colour center was shown in Fig. 5. When the half-width of the Y channel W_Y is very low, which indicates low texture strength, the K_W value is closer to 1.0. However, when W_Y increases, the K_W value becomes smaller, indicating a stronger parametric effect.

Figure 4 and Figure 5 show that the simple linear fitting could successfully reveal the texture effect on visual difference evaluation satisfactorily, and thus, the fitting using high-order polynomial function was not used. We also investigated the correlation between visual difference and texture strength in lightness scale L^*, as listed in Table V. It can be found that the correlation using luminance Y and lightness L^* were almost the same.

The slope D value of the fitting line can be used to further quantify the variation of visual difference with respect to texture strength. From Table VI, the D values for five colour centers are quite close. The quantitative analysis found that every increasing of 10 units of texture strength in luminance scale will cause 0.25 decreasing of visual difference and 0.05 decreasing of colour ratio value. The variations of visual differences and K_W values against texture strength in lightness scale are almost twice those in luminance scale. On the basis of these fundamental quantitative results, we consider that it is possible to introduce the parametric effect of texture effect into a colour-difference equation as a scale factor related to texture level, provided more colour differences are investigated.

CONCLUSION

The influence of the texture on the visual colour difference of textile fabrics was investigated in this study. The results clearly showed that the visual colour difference evaluation is strongly influenced by the texture of the sample pairs. The ratio between the visual colour differences of the textured colour pairs to those of the solid colour pairs clearly shows a strong parametric effect of texture strength. The quantitative analysis found that every increasing of 10 units of texture strength in luminance will cause 0.25 decreasing of visual difference.

In this study, the texture strength is represented by the half-width of histogram by the assumption that the histogram contains a single peak. However, it should be noted that two different texture images may have the same histogram, as histogram ignores the spatial distribution of image. Therefore, in the future study, it may be desired to use additional textural features such as coarseness, contrast, busyness, and complexity to represent visual properties of texture.[15] It should also be pointed out that this study only considered the colour difference in the lightness direction

TABLE V. Correlation (R^2 value) between visual difference $\Delta V_{t,W}$ (and K_W value) and texture strength (W_Y and W_{L^*}).

		Orange	Yellow	Gray	Green	Blue
R^2 of $\Delta V_{t,W}$	W_Y	0.925	0.909	0.903	0.901	0.935
	W_{L^*}	0.926	0.909	0.903	0.903	0.937
R^2 of K_W	W_Y	0.926	0.909	0.903	0.905	0.935
	W_{L^*}	0.926	0.909	0.903	0.907	0.936

TABLE VI. Slope of fitting line of visual difference $\Delta V_{t,W}$ and K_W value with texture strength (W_Y and W_{L*}).

		Orange	Yellow	Gray	Green	Blue
Slope of $\Delta V_{t,W}$	W_Y	−0.0283	−0.0271	−0.0231	−0.0232	−0.0263
	$W_L{}^*$	−0.0576	−0.0594	−0.0505	−0.0425	−0.0484
Slope of K_W	W_Y	−0.0060	−0.0054	−0.0049	−0.0050	−0.0059
	$W_L{}^*$	−0.0121	−0.0118	−0.0106	−0.0092	−0.0108

based on the finding that the human visual system is more sensitive in luminance change than in chromaticity contrast. However, chroma and, to a lesser extent, hue may also be influenced by texture effect. In addition, further investigation of the texture effect on different magnitudes of colour differences, especially small colour differences, would also be useful in industrial colour quality evaluations.

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