Characterization of Fabrics using the Light Reflectance and the Surface Geometry Measurements

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Received 4 December 2012; accepted for publication 4 June 2013

Abstract

In order to characterize a fabric, the use of light reflectance from the surface of a fabric was attempted as well as the surface roughness (SMD obtained from the KES-F system) as an important parameter to describe the tactile sense of fabric smoothness. Light reflectance distribution was measured by using a gonio-spectrophotometric color measurement system. It was found that the reflectance measurement should be made not only at various illumination and viewing angles but also at various fabric rotating angles. The differences in the weave structures were reflected in the $L^*$ distribution patterns measured at various fabric rotating angles. The reflectance of fuzzy-surface fabrics were found to be constant at any measurement geometries, meaning a constant $L^*$ distribution pattern might be one of the characteristics for fuzzy fabrics.

Key Words: Light reflection, Surface roughness, Weave structure

1. Introduction

For the evaluation of fabric quality, both tactile and visual senses are used. Hollies presented relationships of visual and tactile senses with textile quality and reported the language-based perception analysis [1]. Aisling Whitaker et al. reported the contribution of tactile and visual senses to the perception of textures in an independent but complementary manner [2]. The influence of fabric color on tactile and visual evaluation was also reported [3, 4]. The tactile sense obtained from a fabric can be estimated through the combination of mechanical and surface properties by using the KES-F system developed by Kawabata and Niwa [5]. This system can detect differences in fiber, yarn, weaving structure and fabric finishing as representative characteristic values. Unfortunately this system is not concerned with the visual parameters such as light reflection, color and gloss. Light reflectance measurements or color measurements have been used to simulate the appearance of fabric or as a means to correlate with the visual impression of fabric; however the measurement geometries such as illumination and viewing which were used in the previous study were limited and also a fabric was not rotated in the measurements [6, 7, 8, 9]. When a carbon fiber woven fabric was rotated in a surface, the rapid change of the $L^*$ value was observed and this change was detected perceptually [10]. The carbon fiber showed the strong light reflection but this technique to rotate a fabric can be useful for characterization of ordinary fabric.

The final goal of this study is to find a parameter that can be associated with the visual sense of fabric in addition to parameters obtained from the KES-F system which is concerned with tactile sense, although parameters obtained from the KES-F system may not cover the various tactile properties. In this study, the surface geometrical smoothness was focused and deviations of surface contour (SMD) values obtained from KES-F system were evaluated as the SMD parameter is highly correlated to smoothness of fabrics\textsuperscript{4}. Fabrics were evaluated using parameters obtained from light reflectance measurements. The various reflectance measurement geometries were utilized and the influence of the geometries was investigated.

2. Experiment

2.1 Samples

Fifteen black woven wool fabrics were used. The specification of the samples is given in Table 1 and their surface pictures captured by Digital Microscope (VHX-900, Keyence) are given in

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Fig. 1. As shown in Table 1, samples No. 1 to No. 7 are made of the same raw wool materials (fineness 20.6 μm, 73 mm length) with the same yarn counts (16.6 × 2 tex). Samples No. 1 to No. 3 are plain weave fabrics with the same finishing but different dyeing processes. Samples No. 4 to No. 7 are twill fabrics prepared by the same dyeing process but each with a different finishing. The differences in finishing among the samples are expected to change the fabrics’ flatness.

Basic weave structures of Samples No. 8 to No. 11 are twill. The surfaces of No. 8 to No. 10 are mostly covered by fuzz and diagonal lines on the face are not clear as shown in Fig. 1. No. 11 is a combination of twill weaves in which the direction of the twill is reversed.

Samples No. 12 to No. 15 are all 3 by 1 twill weave with the same finishing processes. In terms of the visual aspect, the difference of these samples is the clearness of the weave structure which may be related to the reflection of light from the fabric. The weave structures of the samples can clearly be observed except No. 8 to No. 10.

2.2 Measurements

2.2.1 Surface properties

Surface roughness (SMD) was measured using a KES-SE-SR-U friction and roughness tester (KATO TECH CO., LTD, Japan) at 0.1 N contact force along warp and weft directions for all the samples. Additionally, a bias direction for the plain fabrics and the perpendicular direction to the twill rib, which had an angle against weft direction of 45° to 63°, were also measured. All measurements were carried out in three different places of a fabric at an ambient condition of 20 °C and 60 %RH.

2.2.2 Light reflectance

The spectral reflectance of the samples was measured using a gonio-spectrophotometric Color Measurement System GCMS-4 (MURAKAMI COLOR RESEARCH LABORATORY CO., Ltd.). Fig. 2 shows the measuring geometry; the combinations of illumination angle (θ_i), viewing angle (θ_v) and also rotating angle (θω) of a fabric are denoted as (θ_i / θ_v / θω). As an example, the illustration of the angles (θ_i / θ_v = 30° / 0°), (θ_i / θ_v = 30° / 30°) and (θ_i / θ_v = 30° / −60°) is given in Fig. 3.

The measurements were carried out at the three combinations of angles:

θ_i/θ_v/θω:  
- a) 30°, 70°/−70°/−70° at 10° intervals/0°, 45°, 90° (for Sample No. 1–No. 5)
- b) 0°/−70° at 10° intervals/−60°/0°, 45°, 90° (for Sample No. 1–No. 5)
- c) 0°, 30°, 70°/−60°/−180° at 5° intervals (for All samples)

where, θω = 0° corresponds to the fabric warp direction.

From the reflectance data, CIELAB L* values [8] were calculated by assuming a standard illuminant D65 condition and thus spatial L* distributions were obtained.
Fig. 1 Surface pictures of fabric samples.

Fig. 2 The measuring geometry, illumination angle ($\theta_i$), viewing angle ($\theta_v$) and rotating angle ($\theta_\omega$)

Fig. 3 The illustration of the angles. (a) $\theta_i/\theta_v = 30^\circ/0^\circ$ (b) $\theta_i/\theta_v = 30^\circ/30^\circ$ and (c) $\theta_i/\theta_v = 30^\circ/-60^\circ$
3. Results and Discussion

3.1 Effect of weave structure on surface roughness (SMD)

Fig. 4 shows SMD values of the plain weave samples (No. 1, 2 and 3) and the 2 × 2 twill weave samples (No. 4, 5, 6 and 7); all these samples had the same yarn count. The SMD values of the plain weave samples are higher than those of the twill weave samples for both the warp and weft directions, respectively. However, the SMD values measured perpendicular to the rib direction for the twill weave samples are larger than those measured in the bias direction for the plain weave samples. As shown in Table 1, the finishings of the 2 × 2 twill weave samples No. 4, 5, 6 and 7 are “clear”, “glossy clear”, “milling” and “glossy milling”, respectively. The difference in finishing between “clear” and “milling” cannot be observed from the SMD values; however, the results showed that the SMD values for “glossy clear” were lower compared to “clear” and also the SMD values for “glossy milling” were lower compared to “milling”. This is most likely due to the smoothness of the glossy finishing.

Similarly, the SMD values of samples No. 8 to No. 11 and samples No. 12 to No. 15 are shown in Fig. 5 and Fig. 6, respectively. As seen in Fig. 6, the SMD values of the 3 × 1 twill samples perpendicular to the rib show much higher values than those of the other two directions. On the other hand, as shown in Fig. 5, the SMD values of samples No. 8 to No. 10 show the smaller differences between the three directions (warp, weft and perpendicular to the rib). As shown in Fig. 1, samples No. 8 to No. 10 had fuzzier surfaces than the other samples.

Therefore, these directional SMD characteristics could be associated with the weave structure and the surface geometry. The effect of the finishing can also be associated with the SMD values.

3.2 Effect of weave structure on CIELAB L* distribution pattern

The reflectance was measured at the illumination angle of \( \theta_i = 30^\circ \) and the rotating angles of \( \theta_0 = 0^\circ, 45^\circ \) and \( 90^\circ \) by changing the viewing angles from \( \theta_v = -70^\circ \sim 70^\circ \) at \( 10^\circ \) intervals. The CIELAB L* values of samples No. 1 and No. 4 were plotted in Fig. 7. For both samples when the illumination angles were \( 30^\circ \) or \( 70^\circ \), the differences between the L* values measured at the rotating angles \( 0^\circ, 45^\circ \) and \( 90^\circ \) were small at the viewing angles above \( 0^\circ \). Additionally, the sample No. 1 and No. 4 had similar L* values as well as the shapes of the L* curves. In comparison, the disparity in the L* values were found at the viewing angles below \( 0^\circ \) and these differences were not the same for samples No. 1 and No. 4. Since both samples were dyed in the same manner and had the same finishing, these differences were considered to be originated to their weave structures. During the next stage, the measurements were made at the viewing angle of \( \theta_v = -60^\circ \) and at the rotating angles of \( \theta_0 = 0^\circ, 45^\circ \) and \( 90^\circ \) by changing the illumination angles from \( \theta_i = 0^\circ \) to \( \theta_i = 70^\circ \) at \( 10^\circ \) intervals in order to see the influence of the illumination angles as shown in Fig. 8. The differences between the L* values measured at the rotating angles \( \theta_0 = 0^\circ, 45^\circ \) and \( 90^\circ \) were the largest at \( \theta_i = 70^\circ \).
and relatively small difference toward $\theta_i = 0^\circ$. This tendency was similar between samples No. 1 and No. 4. Thus, the illumination angles of $\theta_i = 0^\circ, 30^\circ, 70^\circ$ and the viewing angle of $\theta_v = -60^\circ$ were utilized and the measurements were made at the rotating angles of $\theta_\omega = 0^\circ \sim 180^\circ$ at 5° intervals. The $L^*$ values for samples No. 1 to No. 11 were plotted in Fig. 9. It can be seen that the $L^*$ distribution patterns of the plain weave samples (No. 1, No. 2 and No. 3) were similar and those of the $2 \times 2$ twill weave samples...
(No. 4, No. 5, No. 6 and No. 7) were also similar as well as those of the 3 × 1 twill weave samples (No. 12, No. 13, No. 14 and No. 15). This indicates a link between the L* distribution pattern and the weave structure. For the plain weave samples, the L* values remained relatively constant throughout the rotating angles of $\theta_w = 0^\circ$–$180^\circ$ at the measurement geometries of $(\theta_i/\theta_v) = (0^\circ/ -60^\circ)$ and $(30^\circ/ -60^\circ)$ as shown in Fig. 9 (a, b), but were largely changed along with the change in the rotating angles when the measurement geometry was $(\theta_i/\theta_v) = (70^\circ/ -60^\circ)$ as shown in Fig. 9 (c). In the case of the 2 × 2 twill weave samples, the L* values were relatively constant at $\theta_w = 0^\circ$–$180^\circ$ as shown in Fig. 9 (a). But, the L* values were higher at the rotating angles of about $0^\circ$ and $165^\circ$ (close to the direction of the warp) and also $80^\circ$ (close to the direction of the weft), and lower at the angle near $45^\circ$ and $120^\circ$ shown in Fig. 9 (b, c). From the 3 × 1 twill weave samples, the higher L* values were observed at the rotating angle of about $80^\circ$, but unlike the 2 × 2 twill weave samples, little increase was seen at the angle of $0^\circ$ and $165^\circ$ as shown in Fig. 9 (b, c). Whilst samples No. 4 to No. 7 and samples No. 12 to No. 15 were both twill weave, neither had the same weave structure at 2 × 2 and 3 × 1 respectively and the L* patterns showed a different characteristic as well as the SMD values as seen in Fig. 4 and Fig. 5. In the case of the 3 × 1 twill weave samples, the SMD values measured perpendicular to the rib showed much higher values than those of the other two directions. Therefore, the light reflectance is considered to be influenced by the shadow which was made by the ribs.

Similarly, the L* distribution patterns of samples No. 8 to No. 11 are shown in Fig. 10. Unlike the other samples, no influence of the rotating angle was found from all the illumination and viewing geometries $(\theta_i/\theta_v) = (0^\circ/ -60^\circ)$ $(30^\circ/ -60^\circ)$ and $(70^\circ/ -60^\circ)$. The samples No. 8 to No. 10 had many fuzz on the surface thus the light was diffused at the surface and the effect of the weave structure became irrelevant. This suggests that the constant L* values can be an indication of a fuzzy-surface.

The difference between the SMD and L* values is that the SMD measurement gives a single value for each direction. By contrast, the L* values change according to the illumination, viewing and rotating angles. This means that the L* values can characterize a fabric in a different way which does not only concern the fabric itself but also the illumination and viewing conditions related to a subject’s observation condition.

4. Conclusion

In order to characterize a fabric, the use of light reflectance from
the surface of a fabric was attempted as well as the surface roughness (SMD) as an important parameter to describe the tactile sense of a fabric’s smoothness. The results indicated that the SMD values tend to reduce as a result of glossy finishings. The differences in the weave structures and the surface characteristics were also found to be reflected in the SMD values; the weave structures resulted in the different patterns of the directional SMD values and the fuzzy-surface resulted in the relatively constant SMD values. However, in order to describe the characteristic of a fabric, it is important to take into account parameters not only concerning tactile sense but also in term of visual sense. Therefore, a reflectance measurement was carried out in this study. This is because the reflectance measurement is not only relevant to the fabric itself but can also take into account the conditions which a subject perceives the fabric. An important finding from this study was that the reflectance measurement should be made not only at various illumination and viewing angles but also at various fabric rotating angles. The differences in the weave structures were reflected in the L* distribution patterns measured at various fabric rotating angles. The reflectance of the fuzzy-surface fabrics were found to be constant at any measurement geometries, meaning a constant L* distribution pattern might be one of the characteristics for the fuzzy fabrics.

These results indicate that the reflectance measurements, especially at various fabric rotating angles, can describe different properties of a fabric and can be used as a parameter for visual sense. Although further investigation needs to be made to establish the relationship between the L* distribution pattern and visual sense, evaluation using the reflectance in addition to the parameters obtained from the KES-F system would help to accurately describe characteristics of fabrics.

Acknowledgements
This work was supported by grant from Japan Wool Industrial Technology Development Association.

References