Analysis of BRDF/BTDF for the texture representation of woven fabrics based on the impression-evaluation model

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***Abstract*—To represent the texture of woven fabrics in computer graphics (CG), it is important to reveal the relation between their physical properties and the texture caused by them. For efficient representation of a realistic texture, a new layered model that links visual impressions with physical properties is required. Physical properties of woven fabrics include optical properties. They are reproduced by bidirectional reflectance distribution function (BRDF) and the bidirectional transmittance distribution function (BTDF). However, it is not easy to handle BRDF and BTDF because of the enormity of these data. Therefore, it is necessary to effectively integrate the dimensionality of BRDF and BTDF. In this paper, we propose the impression-evaluation model to link visual impressions with physical properties of woven fabrics. Moreover, to incorporate physical properties into the model, we investigate the main physical factors of reflection and transmission in woven fabrics using the multivariable analysis technique of principal component analysis (PCA) of BRDF and BTDF. As a result, three principal components of BRDF and two principal components of BTDF are obtained. Therefore, it becomes possible for inexpert people to make CG with realistic texture of woven fabrics more intuitively and easily by incorporating physical factors into the impression-evaluation model.**

I. INTRODUCTION

Realistic representation of visual texture of material is required in many fields, including computer graphics (CG) and design. However, it is difficult for inexpert people to set parameters for making CG with realistic texture. Then, a structured model is required to express the relationship between physical properties of material and visual impressions from it. It becomes possible for inexpert people to make CG intuitively and easily by using the model. In this study, we focus on woven fabrics that are arranged in CG and consider the relationship of these physical properties and impressions. Optical properties that belong to physical properties of woven fabrics are very important to represent the texture of woven fabrics. The bidirectional reflectance distribution function (BRDF) and the bidirectional transmittance distribution function (BTDF) reproduce optical properties. In particular, these properties are necessary to represent transparent fabrics such as lace curtain. However, these measurements take a considerable time and effort, and the amount of these data is enormous, so it is necessary to integrate many complex data of optical properties.

Based on the above, this paper proposes the impression-evaluation model to link visual impressions with physical properties of woven fabrics. Moreover, we investigate the main physical factors of reflection and transmission in woven fabrics with transparency using the multivariable analysis technique of principal component analysis (PCA) of BRDF and BTDF, and incorporate them into the impression-evaluation model.

Thus, it is realized to assume visual impressions from physical properties and identify physical properties from visual impressions more intuitively and easily.

II. RELATED WORKS

Some studies were conducted regarding the texture of fabrics in CG. Uno et al. proposed a BTDF model to represent realistic transparent fabrics[1]. Mizushima et al. recreated a 3D model that takes into consideration woven structure[2]. Nomura et al. and Tobitani et al. proposed a woven cloth microfacet BSDF model, the basis of the GGX[3][4]. Moreover, impressions of fabrics were researched. Impressions from real fabrics were compared with impressions from CG images of fabrics[5]. Impressions about softness were investigated using real fabrics[6], and impressions of fabrics color were researched under different lighting[7]. In addition, Tanaka et al. acquired tactile impression data about 13 kinds of fabric using the semantic differential method and composed material texture dimension by factor analysis[8]. Tanno et al. evaluated visual and tactile texture impressions of 12 kinds of fabric using 16 words and analyzed the result by PCA[9]. However, these studies have focused only on impressions of woven fabrics texture, and they have not mentioned their physical properties.

Our previous research examined the relation between motion impressions of lace curtain and their dynamic properties and suggested the possibility to estimate motion properties from visual impressions[10]. However, optical properties have not been assumed from visual texture impressions yet. On the other hand, Ferrero et al. interpreted many complex BRDF data by PCA[11]. However, they analyzed the spectral BRDF of a glossy, colored ceramic, and they have not analyzed BRDF and BTDF of woven fabrics by PCA. Therefore, it is necessary to extract their optical properties by PCA to associate the visual texture impression of woven fabrics with their optical properties.

III. THE IMPRESSION-EVALUATION MODEL

This paper proposes the impression-evaluation model (Fig.1) that hierarchically represents the cognitive mechanism of affective evaluation for products and explains the relationship between a material's physical properties that compose products and affective evaluation.

When users evaluate a product, they don't assume its specific physical properties, but they make a high order estimate, such as hierarchical impression, from physical properties and affective evaluation. This high order estimate is not directly made from physical properties. Actually, perceptual impressions primarily reflect physical properties, and recognitive impressions are formed by integrating them. These impressions are considered to become the standard affective evaluation regardless of awareness of them.

The impression-evaluation model is composed of the following three factors:

1. Physical factors are specific material properties.
2. Impression factors are formed from physical factors.
3. Affective factors are recalled from impression factors.

In addition, impression factors include psychological processes from lower order to higher order. It is considered to be able to assume affective evaluation of a product or to configure a product from affective evaluation by revealing the relation of each factor.

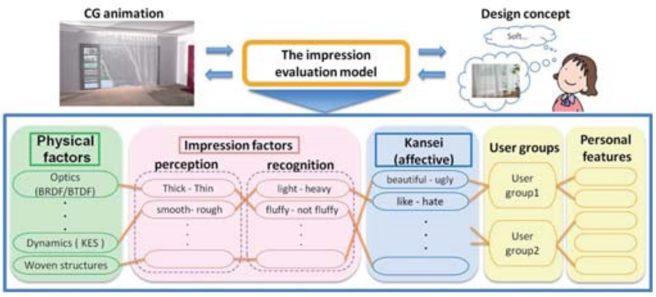


Fig. 1. The impression-evaluation model

IV. OPTICAL PROPERTIES OF WOVEN FABRICS

Optical properties are different for each woven fabric. Therefore, we measured optical properties, such as reflectance, and transmission properties of woven fabrics to make high-quality CG.

17 kinds of white polyester fabrics (plain fabrics) to be used for making lace curtains were prepared (Fig.2).

A. the measuring instrument

BRDF and BTDF ware measured with S-OGM (Spectrum - Optical Gyro Measuring) by rotating two axes of light and two axes of the sample (Fig.3).

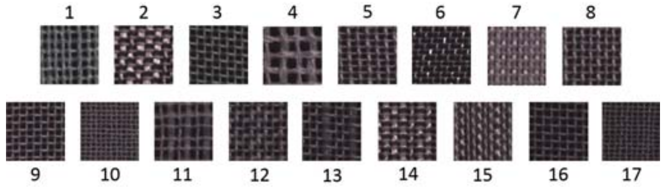


Fig. 2. close-up images of samples

Fig. 3. S-OGM

1) measurement conditions: In the coordinate system for the measurement (Fig.4), the X-axis is the weft direction, the Y-axis is the warp direction and the Z-axis is the normal vector of the specimen plane. V is the viewpoint vector. L is the light source vector. N is the normal vector of the fabrics. H is the half vector of V and L. The number of measurement points is 9216 points. Elevation angles of the camera θ_c take the values from 10 degrees to 80 degrees per 10 degrees. Azimuth angles of the camera ϕ_c take the values from 0 degrees to 330 degrees per 30 degrees. Elevation angles of the light θ_L take the values from 10 degrees to 80 degrees per 10 degrees. Azimuth angles of the light ϕ_L take the values from 0 degrees to 330 degrees per 30 degrees.

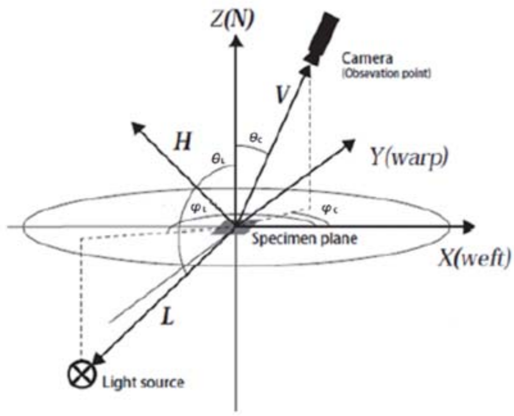
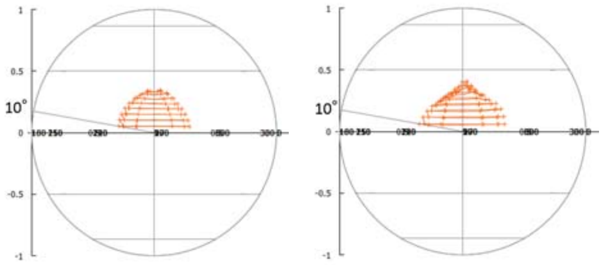


Fig. 4. Coordinate system for the measurement

B. measurement results

An example of the measured BRDF is shown in Fig. 5, and the angle of incidence from the specimen plane is 10 degrees. Tendencies of reflection were greatly divided into two in 17 kinds of woven fabric. The factor of the difference in the tendencies of reflection is considered to be an imitation linen finish. An imitation linen finish is the processing method to give a hard texture such as linen to woven fabric. It is possible that 4 kinds of woven fabric (Fig. 5(b)) have been processed with an imitation linen finish. Therefore, 13 kinds of woven fabric (Fig. 5(a)) are analyzed using PCA in chapter 5.



(a)The tendency of reflection 1 (b)The tendency of reflection 2

Fig. 5. Comparison of tendencies of BRDF (sample.1)

V. PCA of optical properties

To integrate and interpret the enormous data of BRDF and BTDF, these data to be taken from 13 kinds of woven fabric selected at chapter 4 were analyzed using PCA.

A. BRDF

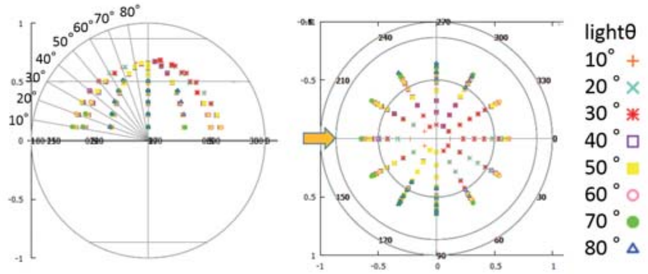
The main reflectance properties were obtained from PCA of 9216 BRDF data.

1) results and discussions: The distance from the origin of the coordinate axes to points plotted represents the strength of reflectance. Three principal components were extracted from 9216 data of measured BRDF. Each contribution was as follows: the first principal component (PC1) is 68.6 %, the second principal component (PC2) is 15.1 % and the third principal component (PC3) is 7.3 %. Fig. 6 explains that a BRDF with high principal component loading was plotted for each main component. PC1 is the BRDF's diffuse component (Fig.6(a)) because reflected light diffuses in all directions. PC2 and PC3 are the BRDF's specular component (Fig.6(b),(c)) because the incident light is reflected in the specular direction. In PC3, components were extracted at 90 degrees, 120 degrees, 150 degrees, 210 degrees, 240 degrees and 270 degrees of ϕ_L. More components of PC3 were extracted at a higher incident angle of light than PC2. The difference of PC2 and PC3 is considered to relate to the woven structure.

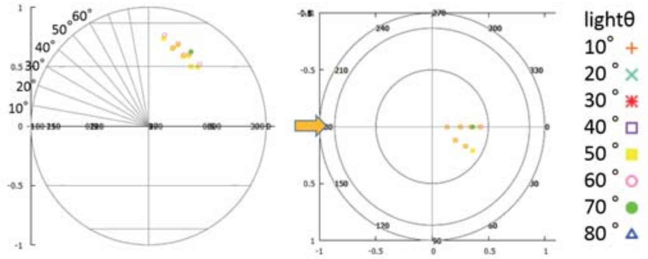
B. BTDF

The main transmission properties were obtained from PCA of 9216 BTDF data.

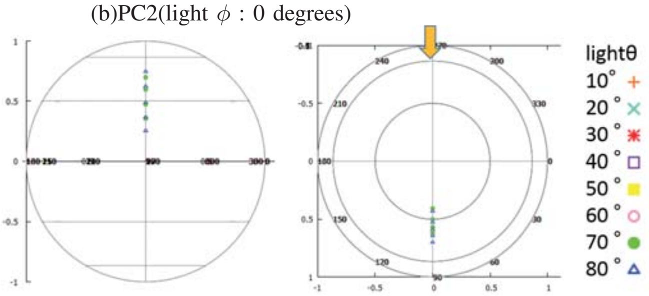
1) results and discussions: Two principal components were extracted from 9216 data of measured BTDF. Each contribution was as follows : the first principal component (PC1) is 58 %, and the second principal component (PC2) is 23.5 %. Fig. 7 explains that a BTDF with high principal component loading was plotted for each main component. PC1 is the BTDF's diffuse component (Fig.7(a)) because transmitted



(a)PC1(light ϕ : 0 degrees)



(b)PC2(light ϕ : 0 degrees)



(c)PC3(light ϕ : 90 degrees)

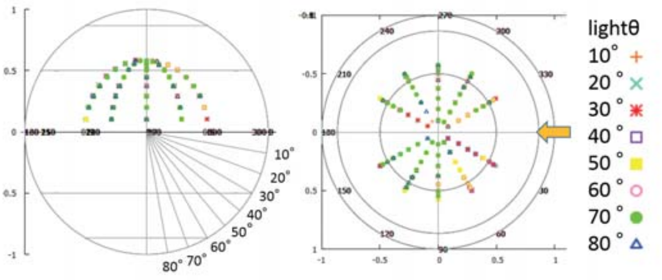
Fig. 6. PC's of BRDF

light diffuses in all directions. PC2 is the BTDF's specular transmission component (Fig.7(b)) because the incident light is transmitted in the specular transmission direction. Specular transmission components are divided into the directional transmission component, which goes through the thread, and the direct transmission component, which goes through a space between threads[3]. This time, ϕ_L is set for each 30 degrees. Therefore, if ϕ_L becomes smaller, the difference of the directional transmission component and the direct transmission component may appear.

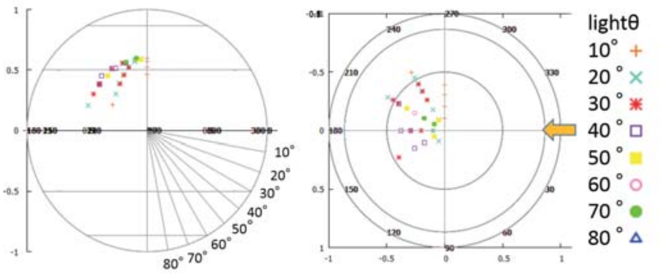
VI. Conclusion

We have proposed the impression-evaluation model which represents the relationship between physical properties of material and its impressions. In addition, measured BRDF and BTDF data were analyzed using PCA. As a result, the diffuse component and the specular component were obtained in BRDF, and the specular component was divided into two by the incident angle. The diffuse transmission component and the specular transmission component were obtained in BTDF.

In the future, we plan to experiment on visual impression evaluation of woven fabrics, and to link it with optical properties obtained from PCA. Finally, it becomes possible to assume optical properties from visual impressions without measuring BRDF and BTDF. Therefore, it becomes easy to make realistic



(a)PC1(light ϕ : 0 degrees)



(b)PC2(light ϕ : 0 degrees)

Fig. 7. PC's of BTDF

texture of woven fabrics in CG, and it will be possible to widely apply to the representation of other material's texture.

REFERENCES

[1] H.Uno, Y.Mizushima, N.Nagata, and Y.Sakaguchi : Lace curtain : Measurement of BTDF and rendering woven cloth production of curtain catalog,ACM SIGGRAPH 2008,Talks,Measurement and Textures,Full conference DVD-ROM,0960-abstract.pdf,Winner of 3rd place ACM Student Research Competition,2008

[2] Y.Mizushima, S.Nomura, G.Umeizumi, N.Nagata, and Y.Sakaguchi : Lace curtain : Modeling and Rendering of Woven Structure using BRDF/BTDF - Production of a catalog of curtain animations - ,ACM SIGGRAPH 2009,posters,modeling,Full conference DVD-ROM,773-mizushima.pdf,2009

[3] S.Nomura, A.Ishida, E.Ishigo, T.Okamoto, Y.mizushima, N.Nagata : Lace curtain : Modeling and Rendering of Woven Cloth using Microfacet BSDF -Production of a catalog of curtain animetions-,ACM SIGGRAPH 2011,posters,modeling,71,Selected as a Semi-finalist for ACM student Research Competiton(SRC),2011

[4] K.Tobitani, A.Ishida, S.Nomura, N.Nagata : Modeling and Rendering of Woven Cloth Using Microfacet BSDF -Production of curtain catalog animetions-,The Japan Society for Precision Engineering,Vol.79,No.11,2013

[5] Hyun-Ju TAK, Yukio YAMASHITA, "Subjective Evaluations of Appearance of Fabric Images Drawn by Computer Graphics and Influence of Rendering Parameters". VISION Vol.23,No.1,19-33,2011

[6] K.Morimoto, Choi Dong, Koo Kang. : Characteristics of KANSEI Words Used for Subjective Evaluation of Textiles into Korean,SENI GAKKAISHI,Vol.63,3,pp.63-66,2007

[7] Hisa Takamori and Megumi Riki "Fundamental Research about How the Color of Cloth Looks And What Impression It Gives in Different Illumination",Kumamoto University Faculy of Education,natural sciences,53,147-152,2004

[8] Y.Tanaka, M.Tanaka and S.Chonan : Development of a Sensor System for Measuring Tactile Sensation; Proc.IEEE Sensors,554-557,2006

[9] Masataka Tanno, Noriko Ito, and Mamijo Sakata : KANSEI Words Expressing Fabrics Texture and Their Relationship with Visual and Haptic Senses ; Japanese Cognitive Science Society,27,643-648,343-349,2010

[10] Ishida.A, Ishigo.E, Aiba.E and Nagata.N : Lace Curtain Rendering Animation of Woven Cloth using BRDF/BTDF Estimating physical characteristic from subjective impression,ACM SIGGRAPH 2012 : posters,Animation,6,p.5:50,2012

[11] A.Ferrero, J.Campos, A.M.Rabel, A.Pons, M.L.Hernanz, and A.Corrons : Principal components analysis on the spectral bidirectional reflectance distribution function of ceramic colour standards,Optics Express,Vol.19,Issue 20,pp.19199-19211,2011)