

Reconstructing and Rendering Transparent Woven Fabrics Based on Reflection Analysis

Ryo OZAKI † and Yuki TAKEDA † and Hiromi T.TANAKA †

†:College of Information Science and Engineering, Ritsumeikan University,
ozaki@cv.ci.ritsumei.ac.jp, takeday@cv.ci.ritsumei.ac.jp, hiromi@cv.ci.ritsumei.ac.jp

Abstract Recently, several researches advance the digital archiving of cultural assets and heritages. There are some Noh costume that has space between yarns and yarns. Transparent woven fabrics have peculiar feeling of quality and luster that is the origin from woven structure. In order to render the transparent woven fabric in Computer Graphics, it is important to make the 3D woven structure of the transparent woven fabric clear. We assumed the structure of the fabrics is composed of diameter, interval and inclination. We propose the method to extraction these factors. At first, diameter and interval of the yarn is extracted with texture analysis. Then, transmissivity of the yarn is estimated from the average transmissivity of the area of transparent woven fabric. We extract inclination of the yarn from reflection analysis. We show the result of 3D woven structure of the transparent woven fabric.

1 Introduction

To pass on tangible and intangible cultural properties from present to the future, and also with the great improvement of the computer graphics technology, computer vision research, and hardware performance, technology to digitalize cultural assets and preserve them as the digital archive and contents made a notable progress.

The fabrics of the traditional masked dance-drama Noh costume, which also is one of the tangible cultural heritages, have peculiar feeling of quality and luster in its fabrics, therefore it is important for CG and CV technology to express and reproduce its unique characteristics. As shown in Fig. 1, yarns can leave spaces in Noh costume, and sometime there are woven fabrics with highly complicated pattern that made by metallic leaf such as gold and silver. Thus, in addition to the characteristics of the reflection of woven fabric, it is necessary to model the characteristics of transparent patterns accurately.

In the field of image processing, there is a technique called Chroma-key that separates or integrates background and object.[1] Based on the Chroma-key, the method of separating the object which causes simple transparency and background was established. Moreover, by measuring in the image of translucent objects, the research to acquire the shape of the objects was conducted.[2][3][4][5].

However, the object is limited to the material that causes the reflection and transparency homogeneously and isotropic. The method can't treat modeling of reflection and transparency characteristics of the object that has microscopic geometric structure like fabrics.

The research that generates automatic high-minute expression by not only analyzing the light that is internally refracted and scattered, but also by observing object by interactively changing lighting and observing points has been performing.[6][7][8] But this has not reached the level of analyzing transparency characteristic of the object.

The research to analyze reflection and transparency characteristics by measuring the multi viewpoint images of the woven fabric has been performed recently.[9] However, due to the technical difficulty of expressing woven structure of fabrics, current level of technique stays at the point of expressing object with plastic-like surfaces.

Transparent woven fabrics have peculiar feeling of quality and luster that is the origin from structure. As shown in Fig. 2, we assumed structure of the fabrics is composed of diameter, interval and inclination. In this paper, we assume the object is the woven fabric with transparency characteristic, and propose the technique to lay out the transparent of yarns that is a factor for the transparent woven fabrics, diameter and intervals of the warp and

weft, and the inclination by woven structure. First, conduct the texture analysis and find out the intervals and diameter of each yarn. Second, acquire the transmissivity of the woven fabric extracted from the multi viewpoint images by OGM (Optical Gyro Measuring Machine). Third, extract the reflection characteristic of woven fabric from the reflection distribution by OGM, and the inclination of yarn in woven fabric from the analysis of reflection characteristic. Finally, we reconstruct the woven structure of woven fabric by those acquired diameter, interval and inclination of woven fabric.

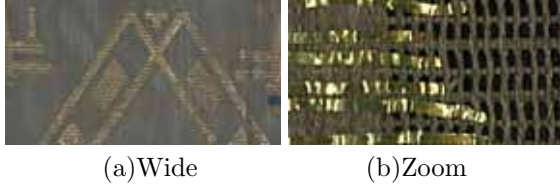


Fig. 1: Noh costume.

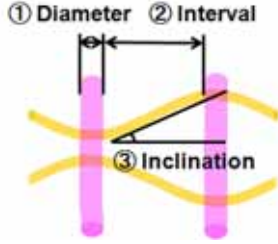


Fig. 2: Structure of woven fabric.

2 The Transparent Woven Fabric

We use chambray organdy as an objective transparent woven fabrics as shown in Fig. 3. The "chambray" refers the woven fabric that uses yarns dyed in different color. Therefore, the colors of fabric seem to change when seen from different angles. The "organdy" is a thin plain weave fabric basically made of cotton. The plain weave fabric is a style of a weave in which the weft alternates over and under the warp. Fig. 3(b) shows the weft is thin yellow yarn and the warp is thick red yarn.

The reason why we chose chambray organdy is because the weave is a plain weave with the ratio of the warp and the weft one to one. And the each yarns' feature of the color, diameter, and cross-section shape are different. Therefore, we assumed that the object provides us stable measurement result of the anisotropic transparency and reflectance.

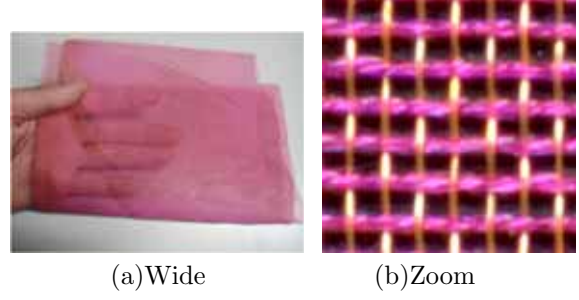


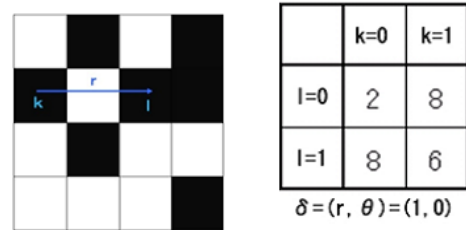
Fig. 3: Chambray organdy.

3 Image-based Modeling of Transparent Woven Fabrics

3.1 Texture Analysis

We obtain the periodicity where yarns appear in image by analyze the repetition pattern of the object woven fabric. We extract diameters and intervals of wefts and warps by texture analysis. Gray level cooccurrence matrix and distribution of yarns distance was used by using the binary image for the texture analysis. Gray level cooccurrence matrix is generated from occurrence frequency $P(k, l|\delta)$. $P(k, l|\delta)$ indicates that the pixels of gray level l appear in constant relativity position $\delta = (r, \theta)$ from the pixels of gray level k in a certain small area. Fig. 4 shows the example of binary image in the case of $r = 1$ and $\theta = 0$.

$$I(\delta) = \sum_{k=0}^1 \sum_{l=0}^1 (k - l)^2 P(k, l|\delta) \quad (1)$$



(a) Sample image (b) Occurrence frequency

Fig. 4: Sample of the gray level cooccurrence matrix.

3.2 Relation to the Transmissivity of the Woven Fabric and Weaving Yarns

The transmissivity of the woven fabric declines by adding inclination. Fig. 6 shows the transmissivity of the chambray organdy[9]. As shown in Fig.

5, there are two reasons why transparency declines by inclining the woven fabric. First, those lattice spaces become small when the woven fabric is inclined. Second, the distance of light through a yarn increases. We make following two equation (2), (3) for these two reasons. T_r is transmissivity of the fabric when it inclined to weft direction and T_y is transmissivity of the fabric when it inclined to warp direction. d_r is diameter of weft and d_y is one of warp. s_r is interval of weft and s_y is one of warp. ρ_r is transmissivity of weft and ρ_y is one of warp. In addition, θ is the angle between the surface normal and light direction. We assume that the wefts and warps are columns.

$$T_r = \frac{d_r(s_y \cos \theta + d_y)d_r\rho_r}{(d_r + s_r)\cos \theta} + \frac{d_y(d_r + s_r)d_y\rho_y}{s_y \cos \theta + d_y} + \frac{s_y \cos \theta s_r}{(s_y \cos \theta + d_y)(s_r + d_r)} \quad (2)$$

$$T_y = \frac{d_r(s_y + d_y)d_r\rho_r}{s_r \cos \theta + d_r} + \frac{d_y(s_r \cos \theta + d_r)d_y\rho_y}{(d_y + s_y)\cos \theta} + \frac{s_r \cos \theta s_y}{(s_r \cos \theta + d_r)(s_y + d_y)} \quad (3)$$

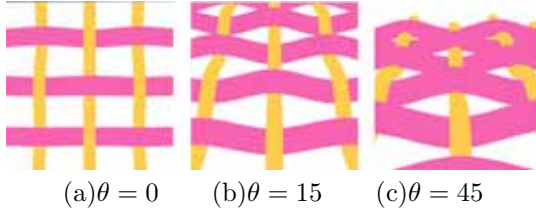


Fig. 5: The simulation of lattice spaces in the different viewing angle.

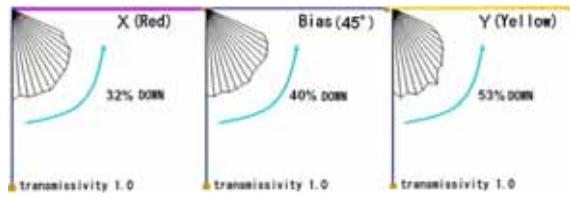


Fig. 6: The attenuation of transmissivity of the chambray organdy.

3.3 Inclination of Weaving Yarns and Relation to Reflectance Distribution

We analyze the image captured by OGM to obtain the inclination of each weaving yarns of the object

woven fabric. Fig. 7 shows the structure of weaving yarns, the angle of light, and the normal of the weaving yarns, in short, the relation of the angle to the inclination of weaving yarns. Half of the incoming angle X where the strongest reflectivity appears becomes normal angle.

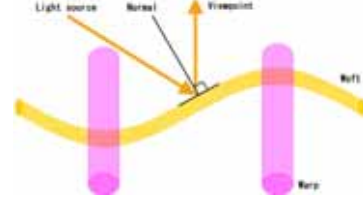


Fig. 7: The relation of reflectance and inclination of weaving yarns.

4 Experimental Result

4.1 Measurement Environment

Fig. 8 shows the Optical Gyro Measuring Machine (OGM), which is the omnidirectional anisotropic reflectance measurement system. For the image capturing, we used a Canon EOS Kiss Digital X camera, which has a resolution of 3888 by 2592 pixels and an effective pixel count of about eight million pixels. For the lighting, we used an Asahi Spectra Lax-102 Xenon optical source. The OGM has a total of four rotational degrees of freedom, two for the light sources, one for the camera, and one for the stage. Combining these degrees of freedom makes it possible to measure the reflected light from the arbitrary viewing direction for any direction of light incidence. In our experiment, viewing angle was fixed and light direction was inclined from 0 degrees to 80 degrees in 5 degrees increments.



Fig. 8: OGM(Optical Gyro Measuring Machine)

4.2 Extracting the Diameter and Interval

We generate the binary image from the color image of objective woven fabrics shown in Fig. 3(b). We calculate the occurrence frequencies $P(0, 0|\delta)$ by

processing the binary image in vertical(warp) and horizontal(weft) direction. Fig. 9 shows the occurrence frequency. In the binary image, there are dispersions in the intervals and diameters of yarns, and it is difficult to distinguish neither the diameter nor the interval of yarns. A constant cycle is observed at the peak in vertical and horizontal direction. The distance between the peaks refers to the total distance of yarn diameter and interval. Therefore, the distance is 75 pixels in vertical direction and 69 pixels in the horizontal direction.

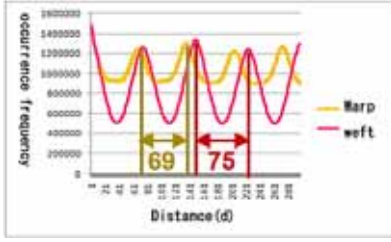


Fig. 9: Occurrence frequency of woven fabric.

We next obtained the diameter from the distribution of distance of yarns by using the binary image. Fig. 10 shows the diameter distribution of the weaving yarns in vertical and horizontal direction. In the vertical direction, the peak of diameter distribution is at 30 pixels, which means that the diameter of weft is 30 pixels. Therefore, the interval is 45 pixels. In the horizontal direction, there are several peaks. By calculating weighted average, the diameter of warp is 17 pixels, and the interval is 52 pixels. We considerably disregard the phenomenon that both of the graphs have a peak at the distance 2 pixels and consider these are noises. Fig. 11 (b) shows the part where enclosed by a rectangle in Fig. 11 (a), and the distances from a black pixel to the following black pixel are 2 pixels in the circled part when it is seen horizontally. Since many of similar examples are observed, there is a peak once at the point of 2 pixels.

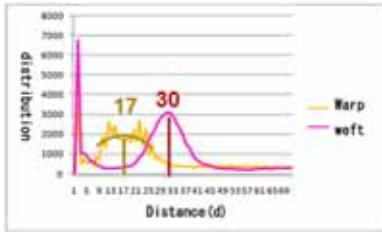


Fig. 10: The diameter distribution of yarns.

By converting pixel into mm, we obtain the result of actual diameter and interval. Wefts have a diameter of 0.121mm and the interval is 0.182mm.

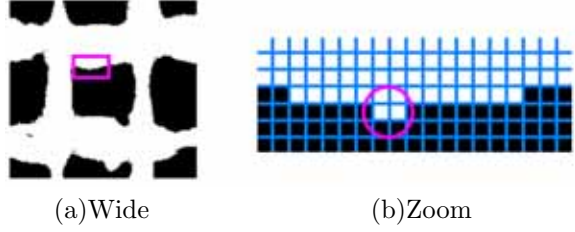


Fig. 11: Cause of noise.

Warps have a diameter of 0.069mm and the interval of 0.210mm.

Fig. 12(a) shows synthesized image from the diameter and interval of yarns obtained by texture analysis. And Fig. 12 (b) is overlapped image of Fig. 12 (a) and Fig. 3 (b). There is almost the same in weft direction. There is 4 pixels error par 500 pixels in warp direction.

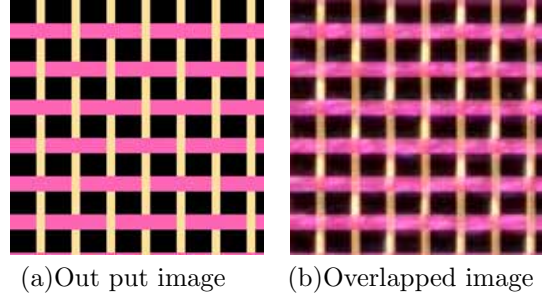


Fig. 12: Comparison of texture image.

4.3 Extraction of Weaving Yarns Transmissivity

We obtained the transmissivity of the warps and wefts by fitting equation (2) and (3) by using measurement data showed in Fig. 6 and the least square method. Fig. 13(b) indicates fitting result when light is inclined toward the direction of wefts. Each red point in both Fig. 13 (a) and (b) refer to measurement data and the actual line indicates the result of fitting equation (2) or (3). The vertical axis is the transmissivity, the horizontal is the angle between the woven fabric normal and observing axis. X-axis is the transmissivity and Y-axis is the angles formed where normal of fabric and viewpoint. 1 indicates everything is transparent and 0 indicates nothing is transparent. As a result, the transmissivity of the wefts (red) turns out to be 3.32665×10^{-5} and the transmissivity of warps (yellow) turns into 3.44996×10^{-5} . Since the transmissivity of the entire woven fabric exceeds 0.5 when light is in direction of normal line against woven fabric, the transmissivity of weaving yarns is considered to be less than the transmissivity of the entire woven fabric.

Therefore, we considerably ignore the transmissivity of weaving yarns in this paper.

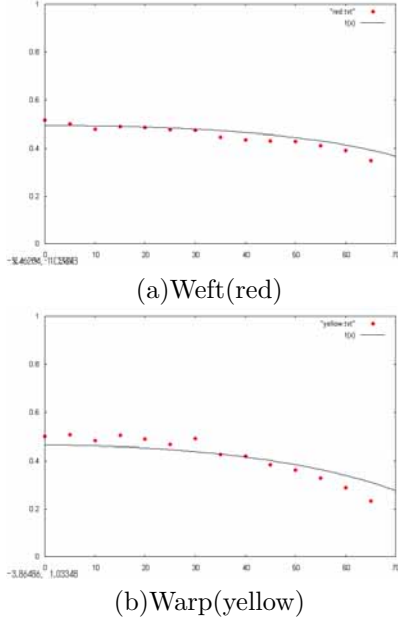


Fig. 13: The transmissivity of the weft and warp.

4.4 Extracting Inclination of Weaving Strings

Fig. 14 (a) shows the reflectance distribution of wefts and (b) refers to the warps in the process of changing the light source. The horizontal line in (a) refers x-axis, and suggests direction of wefts (red) if the woven fabric is assumed to be a plane surface, the horizontal line in (b) notifies Y-axis, and also suggests the direction of warps (yellow). Both of the vertical lines are shown as Z-axis, and suggest vertical direction to the woven fabric. Colors displayed in the figure are actual colors and each point indicates reflectance 1. Images were shot in every interval of 5 degrees. In the interpolated result, the angle of the strongest reflectance of wefts is around 26 degrees, 38 degrees with warps, and each degree of normal lines are 13 degrees and 19 degrees.

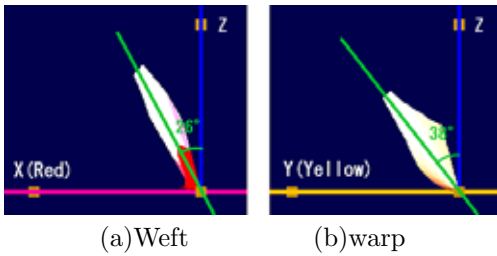


Fig. 14: Reflection distribution.

Fig. 15 shows cross-section model of the woven

fabric based on refraction analysis. Fig. 16 shows an image that had zoomed 500 times with microscope. Fig. 17 shows overlapped images of Fig. 15 and Fig. 16. Each of images is prepared based on the diameters and intervals of yarns from texture analysis, and inclination of normal lines from reflectance distribution. We assumed that each yarns are collapsed into oval shape in the intersection of weaving yarns. Each woven fabrics are inclined at these angles degrees. Both errors are less than 1 degree. The model based on information of 3D woven structure is shown by Relief Mapping[10] in Fig. 18.



Fig. 15: Cross section models in each yarn direction.



Fig. 16: Cross section pictures in each yarn direction.

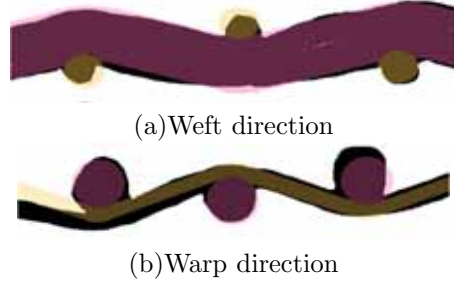


Fig. 17: Overlapped images of cross section in each yarn direction.

5 Conclusion

In this paper, first we extracted the microscopic geometry structure of woven fabric from texture analysis. Second, we observed object transparent woven fabric by using OGM, and examined the transmissivity characteristic of yarns. Third, we reconstructed 3D structure of the woven fabric by obtained inclination of weaving yarns from reflection characteristic. The comparison result shows effectiveness of our proposed method in texture analysis, transmissivity characteristic of yarns, and the inclination of yarns.

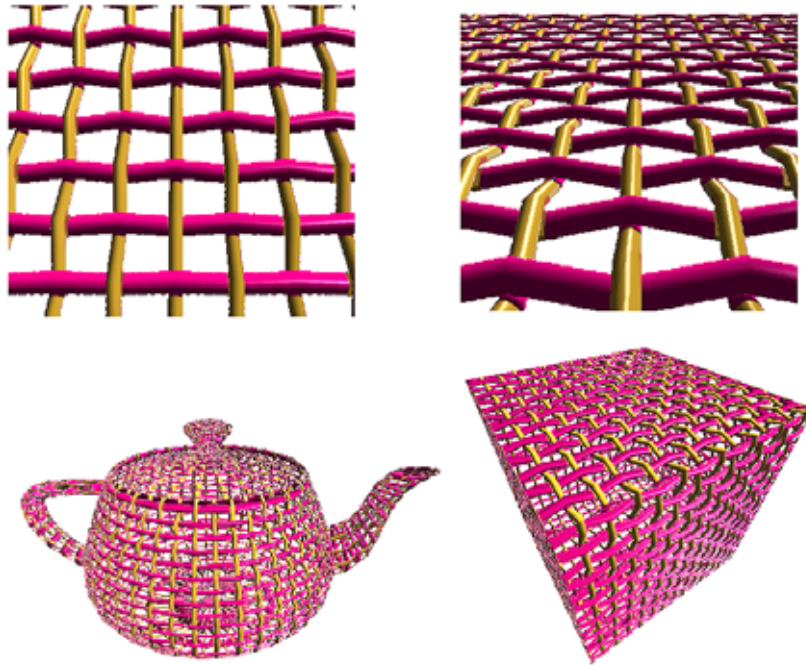


Fig. 18: The rendering result using relief mapping.

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Ryo OZAKI: received the B.S. degree in engineering from Ritsumeikan University, Japan, in 2007.

Yuki TAKEDA: received the B.S. degree in engineering from Ritsumeikan University, Japan, in 2003.

Hiromi T.TANAKA: received the B.S. degree in engineering from Ochanomizu University, Japan, in 1975, the M.S. degree in computer science from Rochester University, USA, in 1981 and the Ph.D. degree in engineering from Osaka University, in Japan, in 1988