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Acquisition, Modeling and Rendering of Bidirectional Texture Function of Ancient Japanese Noh Costume Fabrics

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Abstract

Noh is a Japanese historical play lasted for 600 years and Noh costumes are precious cultural heritage and are made of specially woven silk fabrics. The reflectance of such fabric surface is commonly represented by a large-scale of bidirectional texture function (BTF) from measured data by a gonioreflectometer with 2 degrees of freedom of the light source and 2 degrees of freedom of the observing direction. It requires an enormous amount of measurements. In this paper, we propose an efficient image-based method for acquiring, modeling and rendering of BTF of such woven fabrics. At first, we segment images of the woven fabrics into regions according to their colors. Next, we examine the relationship between the reflectance properties and micro facet surface geometry of a type of such woven silk fabrics. Then we develop an image-based method for generating the BTF for each segmented regions of woven fabrics from measurement of the reflectance cased by the incident light from any direction to the viewing direction perpendicular to the fabric's surface. The simulation results on rendering an arbitrary colored Noh Costume show the performance of the proposed approach.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Color, shading, shadowing, and texture

1. Introduction

Recent advances in 3D visualization from research on computer graphics (CG) and computer vision (CV) have stimulated vigorous research on the digital recording of precious cultural assets and heritage for preservation, archiving and production of media content. The materials and cultural assets possessed by museums include Noh costumes and other clothes. The deformation, luster and feel are characteristics of different kind of fabric, and realistic reproduction of those qualities is important in CG and CV.

Previously, the reflection characteristics of textured surfaces has been described with the Bidirectional Texture Function (BTF) [DGNK99]. The BTF is defined as the ratio of the irradiance from an arbitrary lighting direction to the radiance from any viewing direction at any point on a texture. Problems in conventional BTF representation include the development of measuring devices and the huge number of measurement images and computation time. Dana developed a BTF measuring device that uses a parabolic mirror under parallel lighting [DGNK01]. Muller have developed a BTF measurement device and proposed a serial method from measurement to rendering [MMS*04]. Both of those devices, however, have limitations on lighting and viewing direction. Muller have developed a system that employs multiple light sources and cameras to obtain the 3D geometry and BTF [MBK05]. However, a huge number of observation images are required to describe the BTF. Filip fit reflectance of the acquired BTF data with a Lafortune model [LFTG97] at each texel and render the image from compressed BTF data [FH04]. Schneider employs principle component analysis (PCA) to analyze and compress the BTF data for real-time rendering [Sch04]. Sekine proposed the BTF synthesis based vector quantities for macro-patterns for sweaters and flower-patterned towel material, which have low luster [SY04]. All of these methods target materials that have regular patterns, so it is sufficient to measure the reflected light for only a part of the object texture.

We take as our target material the Noh costume, which has complex patterning and finely detailed handwork, and aim for generation of a highly precise BTF. Fig. 1 shows a kind of Noh costume. The Noh costume is made from highly reflective gold leaf and silk fabric that has pattern woven into it, and the overall coloring is often vivid. Making use of the coloring, we first segment the material into regions based on color differences and obtain the positional information for each region from a fixed viewpoint. Then observation images are acquired with arbitrary light incidence directions. From the acquired images, the reflection characteristics for each color region are modeled and the BTF is generated.

Figure 1: *A kind of Noh costume.*

2. Acqiuiring BTF of Noh Costume Fabric

The reflection characteristic at any point on the surface of the object can be represented by the BTF. The geometry of the BTF is shown in Fig. 2. BTF is defined in a spherical coordinate system as the ratio of the irradiance (W/m^2sr) in the viewing direction **V**=(θ_r,ϕ_r) to the radiance (W/m^2) from the light direction of incidence **L**=(θ_i,ϕ_i) for texel (u,v), which is an arbitrary point on the surface of the object.

$$f_r(\theta_r,\phi_r,\theta_i,\phi_i,u,v) = \frac{dL_r(\theta_r,\phi_r,\theta_i,\phi_i,u,v)}{dE_i(\theta_i,\phi_i,u,v)}, \quad (1)$$

where $E_i(\theta_i,\phi_i,u,v)$ is irradiance at a texel (u,v) coming in from the direction **L**; $L_r(\theta_r,\phi_r,\theta_i,\phi_i,u,v)$ is radiance at a texel (u,v) in the direction of a viewpoint **V** reflected light from **L**. In this paper, **X**, **Y** and **N** are the vectors representing the directions of weft, warp and normal of fabric. About each angle, incident angle θ_i is the angle between **N** and **L**, the azimuth of the incident ray ϕ_i is the angle between **X** and **L** on the **XY** plane, the viewing angle θ_r is the angle between **N** and **V**, and the viewing azimuth ϕ_r is the angle between **X** and **V** on the **XY** plane. The reflection characteristic for one point on the surface of the object can be described by the bidirectional reflectance distribution function (BRDF). The BRDF can be thought of as the function $fr(\theta_r,\phi_r,\theta_i,\phi_i)$ focused on the point (u,v) among the BTF representations.

To obtain the BTF from the measurement data, it is necessary to acquire the reflectance data for any point on the texture as well as any light direction of incidence and viewing direction. Detailed and exquisitely made objects such as a Noh costume also require very high resolution. Accordingly, acquisition of the BTF of a Noh costume requires a huge number of observation images.

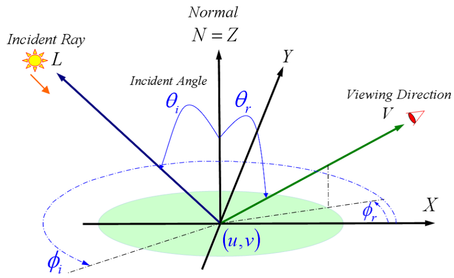

Figure 2: *Geometry of BTF.*

2.1. Noh Costume Fabric

The piece of fabric from a Noh costume shown in Fig. 3 is a red base fabric interwoven with gold leaf and patterns of flowers, leaves and branches using blue, green and white thread. A detailed view of the pattern texture shown in Fig. 3 is presented in Fig. 4. The pattern uses threads of various colors woven into the red base fabric to represent flowers, leaves and branches. We can see the shadows from the raised parts and the direction of the threads in the pattern in the figure.

Figure 3: *A Noh costume fabric.*

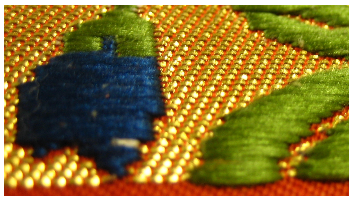

Figure 4: *The close-up image of a Noh costume fabric.*

2.2. BTF Acquisition System

The Optical Gyro Measuring Machine (OGM), which is the omnidirectional anisotropic reflectance measurement system used in this research for BTF acquisition, is shown in Fig. 5. For the image capture, 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 viewing direction for any direction of light incidence. We also obtained High Dynamic Range (HDR) images by combining images acquired at multiple exposure times [DM97].

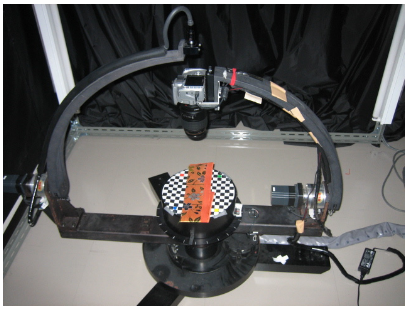

Figure 5: *Optical Gyro Measuring Machine (OGM).*

2.3. The Problem in Multiple Viewpoint Image Acquisition

In conventional multiple viewpoint image acquisition systems [MMS*04] for generating BTF, the object is held on a rotating stage with pressure from above and below and markers are used to acquire the object attitude and position. For objects of precious cultural value such as the costume fabric used in our research, however, non-contact handling that minimizes effects on the sample is required. We constructed a system in which a multiple viewpoint OGM is used to calibrate the camera and obtain the image transformation matrix, and the image is converted to a front view. However, a conversion error of a few millimeters remained. That is problematic for modeling the BTF of the Noh costume fabric from the observations, because the gold leaf woven into the fabric are only about 1 mm thick. In this way, we generate the BTF for arbitrary lighting directions for a fixed viewpoint from images acquired from a fixed viewpoint with varying lighting direction.

3. Image-based Anisotropic Reflectance Modeling of Gold Leaf Region under the Constant View Point

Here we explain a modeling method in which the reflection characteristics of each color region are extracted from the acquired Noh costume fabric images. The Noh costume has fine coloring patterns from the gold and silver leaf and natural silk, etc. These large color differences led us to try semgenting the sample into regions based on those color differences. By doing so and modeling the reflection for each region, we reduced the amount of image data needed to represent the BTF for the costume fabric shown Fig. 3.

3.1. Color Segmentation

The method we used for segmentaion of the sample into color regions is clustering by evaluation of the Mahalanobis distance based on color difference. In color space, each color distribution is not spherical. So, we cannot evaluate euclidean distance to segment each color region.

3.2. BTF Modeling of Gold Leaf Region

The gold leaf region has gold leaf incorporated into the red base fabric in the weft direction of the weave (Fig. 4). Both regions can also be considered to have an orthogonal normal vector distribution. The anisotropic reflection is modeled on the basis of the orthogonal normal vector distribution [TVST05, TT06]. We extracted the anisotropic reflection characteristic on the basis of the texel position from images acquired from a fixed viewpoint with arbitrary changes in the lighting direction, and modeled it.

Optimization of the Proposed Model

The reflectance at a texel acquired by varying the direction of incidence **L**=(θ_i,ϕ_i) is shown in Fig. 6. We see that the reflectance is most intense at **L**=$(60^\circ,145^\circ)$, because of specular reflection. For θ and ϕ directions, the specular reflection direction is approximated by a Gaussian function. Accordingly, the reflection characteristic of the gold leaf region is anisotropic and orthogonal to the θ and ϕ directions, and can be described with two Gaussian functions.

We propose the following reflection model for the gold leaf region.

$$f_r(\theta_r,\phi_r,\theta_i,\phi_i,u,v) = f_{u,v}(\theta_r,\phi_r,\theta_i,\phi_i), \quad (2)$$

$$f_{u,v}(\theta_r,\phi_r,\theta_i,\phi_i) = C_s e^{-(\frac{\theta_h-\theta_n}{dt})^2-(\frac{\phi_h-\phi_n}{dp})^2} + C_d cos\theta_i, \quad (3)$$

where, $f_{u,v}(\theta_r,\phi_r,\theta_i,\phi_i)$ is the BRDF at point (u,v), C_s is the color of the specular reflected light, dt is the dispersion in the θ direction, dp is the dispersion in the ϕ direction, and C_d is the color of the diffused reflected light. The normal vector at (u,v) is **n**=(θ_n,ϕ_n) and the intermediate vector for the the lighting vector **L** and the observation vector **V** is the half vector **H**=(θ_h,ϕ_h).

The proposed model is optimized for $T_l(u,v)$ at each texel. However, the following procedure is used to reduce the computational cost.

1. Find the light direction of incidence for which the value for $T_l(u,v)$ is the maximum, take that direction as **H=n**, and obtain the normal vector **n**.
2. To obtain the diffuse reflection, obtain C_d for azimuth angle $\phi=\phi_n+\pi$, where the specular reflection is slight.

3. Subtract the obtained diffuse reflection from $T_l(u,v)$ to extract the specular reflection.
4. For the extracted specular reflection, obtain C_s, dt, and dp using $\mathbf{n}$ as the reference.

In the above way, the proposed model is optimized for all texels.

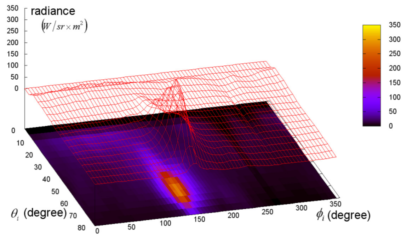

Figure 6: $T_l(u,v)$.

4. Experimental Result

We rendered the gold leaf region by the proposed method using the Noh costume images acquired from a fixed point of view as input. First, to serve as the input, 1224 images were acquired by varying the lighting direction of incidence (θ_i,ϕ_i); θ_i was varied from 0 degrees to 80 degrees in 5-degree increments and ϕ_i was varied from 0 degrees to 355 degrees in 5-degree increments. Because five different exposure times (1/25, 1/100, 1/250, 1/1000, and 1/4000 second) were used for each incident direction, there was a total of 6120 input images. Next, we generated an 128 pixel by 128 pixel HDR images for the gold leaf region from the images of multiple exposure times. We optimize the proposed model at each $T_l(u,v)$. The image was then rendered from the BTF obtained in the above way for the gold leaf region are shown in Fig. 7. The 3D geometry for the Noh costume was acquired with a VIVID 910 3D digitizer. The gold leaf region is rendered from the BTF generated by our method; the other areas were rendered by applying a texture.

Figure 7: *The rendering image of a part of gold leaf region of Noh costume.*

5. Conclusions

We have proposed a method for representing the visual effect of a gold leaf region of Japanese Noh costume fabric based on images of multi-lighting directions acquired from a fixed viewpoint. The results of the experiments demonstrated that the visual effect of the gold leaf region can be represented realistically. Issues for future work include modeling of the pattern areas of the fabric.

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