Estimation of Reflection Properties of Silk Textile with Multi-band Camera

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Abstract: We propose a method for digital archiving of the silk textile based on multi-spectral reflection model. Then we estimate a various reflection model parameters using both two-shot 6 band digital camera with optical filter and a device for measuring reflection intensity. In this study, we develop a simple spectral calibration method for multi-band camera system with statistical analysis of spectral reflectance. We develop the measuring system for measuring goniometric multi-spectral reflectance. The device consists of a lighting system, goniometric rotating arms, and a vision system with two-shot 6 band digital camera. First, we develop a multi-spectral reflection model for describing silk textile surface reflection. Second, the reflection properties of the silk textile are estimated from images using the device. In order to estimate multi-spectral reflectance of the silk textile surface from camera outputs, spectral reflectance of the Macbeth color chart is statistically analyzed. Third, the reflection model parameters as the reflection properties are estimated from the camera measurements for reflection intensity of the silk textile surface at different angles of illumination and viewing. Finally, we render a realistic 3DCG image of the silk textile and confirm the validity of the proposed method visually.

Key words : Silk Textile, Reflection Model, Multi band Camera, 3DCG

1. Introduction

Silk textiles are known for having beautiful gloss and texture. We propose a method for digital archiving of the silk textile based on multi-spectral reflection model. It is necessary to estimate reflection properties of the silk textile. Then we estimate a various reflection model of parameters using both two-shot 6 band digital camera with optical filter and a device for measuring reflection intensity. However RGB color data from an imaging device are dependent on the camera sensitivity and scene the influence of illuminant.

In this study, we develop a simple spectral calibration method for multi-band camera system with statistical analysis of spectral reflectance. The feature of present paper is that the multi-band camera system is independent of camera sensitivity functions. We develop the measuring system of goniometric multi-spectral reflectance. The device consists of a lighting system, goniometric rotating arms, and a vision system with two-shot 6 band digital camera. Firstly, we develop a multi-spectral reflection model for describing silk textile surface reflection based on the Torrance-Sparrow model. Secondly, the reflection properties of the silk textile are estimated from images using the device. In order to estimate multi-spectral reflectance of the silk textile surface from camera outputs, spectral reflectance of the Macbeth color chart is statistically analyzed. To estimate spectral reflectance, multi-spectral sensitivity characteristics of the camera and the influence of illuminant are removed by the system conversion matrix. The spectral reflectance is sampled at 5nm intervals in the visible light wavelength region (400-700nm).

Then the estimated spectral reflectance is compares accuracy with case of RGB (3band). Thirdly, the reflection model parameters as the reflection properties are estimated from the camera measurements for reflection intensity of the silk textile surface at different angles of illumination and viewing. Finally, we render a realistic 3DCG image of the silk textile and confirm the validity of the proposed method visually. It can precisely create the CG images under ambient light conditions. We implement the proposed method to Graphics Processing Unit (GPU) for real-time rendering of the silk textile image.

2. Reflection model of surface for the silk textile surface

The surface reflection on the silk textile is described using the geometric relationship between light, the object, and the visual system. Figure 1 shows the reflection geometry of the Torrance-Sparrow model [1]. The color-signal $C(\lambda)$ of the visual system from the surface of a reflective silk textile is described as follows:

$$C(\lambda) = \alpha \cos\theta_{\mathrm{i}} S(\lambda) E(\lambda) + \beta \frac{F(n,\theta_{\mathrm{H}}) D(\mu,\varphi) G(\mathbf{N},\mathbf{V},\mathbf{L})}{\cos\theta_{\mathrm{r}}} E(\lambda), \tag{1}$$

where the first and second terms are the diffuse and specular reflection, respectively. α and β are the weighting coefficients of the diffuse and specular reflection component, respectively, and $S(\lambda)$ and $E(\lambda)$ are the spectral surface reflectance and spectral distribution, respectively. In addition, λ is the wavelength, F is the Fresnel function, n is the refractive index of the silk textile surface, D is the distribution function of the micro-facet, μ is the surface roughness parameter, φ is the phase angle of the micro-facet, G is the attenuation coefficient, **V** is the viewing vector, **N** is the normal vector of the silk textile surface, the vector **L** is the incident light, θ_{i} is the angle between **N** and **L**, and θ_{r} is the angle between **N** and **V**. The normal vector of the micro-facet is **H**, while θ_{H} is the angle between **L** and **H**.

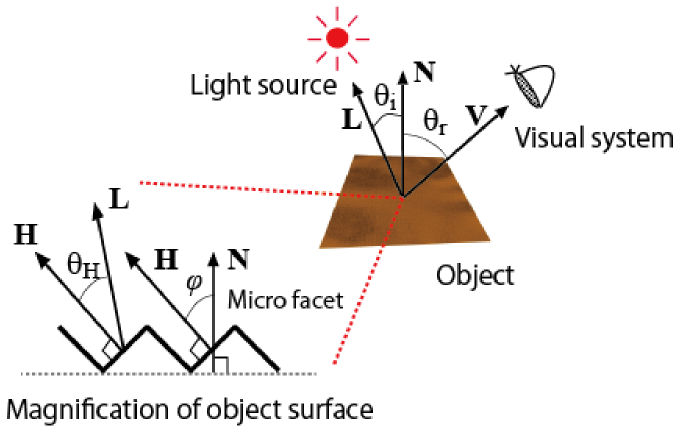
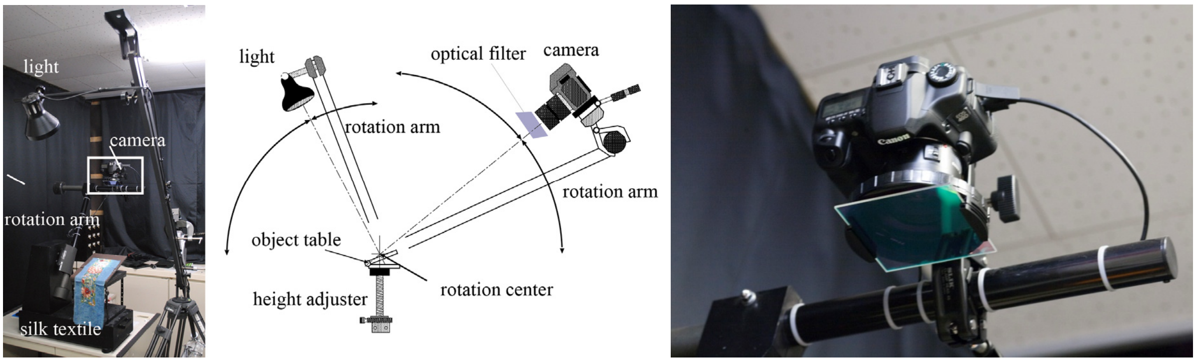


Figure.1 Reflection geometry of the model

3. Measuring surface reflection properties

The reflection model parameters are estimated as the surface reflection properties. The device consists of a light source, two goniometric rotating arms, and the two-shot type Multi-band digital camera system. We use a multi-band camera for multi-spectral imaging. The multi-band system is realized with a comb-type spectral filter and an RGB digital camera. The camera is used to take two shot images. In the first shot, an image is taken with a comb-filter. In the second shot, another image is taken without a comb filter. Figure 2 (a) depicts the measurement system for measuring spectral reflectance and reflection properties. Figure 2 (b) shows 2shot type multiband camera system.



(a) Measuring system (b) Multi band camera

Figure.2 *Measurement system*

4. Estimation algorithm of reflection properties

We propose a statistical analysis method for the estimation of spectral reflectance using the color chart [2]. To make a database of spectral reflectance, 176 color patches are simultaneously measured with a multi-band camera and a spectrum photometer. The correspondence relation of six-band camera outputs and spectral reflectance are estimated from measured data. The spectral reflectance is sampled at 5nm intervals in the visible light wavelength region (400–700 nm). Image data from the device are used to estimate model parameters on the silk textile surface. Unknown parameters α, β and μ are estimated as follows:

$$\sum_j \left[\alpha \cos\theta_{ij} + \beta \frac{F(n,\theta_{Hj}) D(\mu,\varphi_j) G(\mathbf{N}_j,\mathbf{V}_j,\mathbf{L}_j)}{\cos\theta_r} - \rho_{Gj} \right]^2 . \quad (2)$$

5. Estimation algorithm of normal vector of silk textile surface

We propose a method for estimating surface geometry of silk textile as normal vector map by photometric stereo method. First, lighting direction is calibrated with mirrored ball. The camera is perpendicularly fixed to silk textile. Let $\mathbf{Y}$ is matrix of image intensity. Let $\mathbf{N}$ is matrix of normal vector. Let $\mathbf{L}$ is matrix of light vector. Three relations are indicated as $\mathbf{Y} = \alpha(\mathbf{N} \cdot \mathbf{L})$ based on Lambert's cosine law. α is the weighting coefficient of the diffuse reflection component. If $\mathbf{N}' = \alpha \mathbf{N}$, $\mathbf{N}' = \mathbf{Y}' \cdot \mathbf{L}^+$ is obtained using generalized by pseudo inverse of **L**. Then, normal vector is estimated as $\mathbf{N} = \mathbf{N}' / \|\mathbf{N}'\|$.

6. Image rendering

We developed the rendering system using a 3D color management system. In the system, the CG image is rendered based on human’s visual properties (Figure 3). In this system, after we obtain all the rendering parameters, we can precisely create the CG images under ambient light conditions. The proposed method is implemented on a graphics processing unit (GPU), assuming a color monitor as the display device. The tristimulus values CIE-XYZ of the spectral radiance are calculated as

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \int C(\lambda) \begin{bmatrix} \overline{x}(\lambda) \\ \overline{y}(\lambda) \\ \overline{z}(\lambda) \end{bmatrix} d\lambda \,. \tag{3}$$

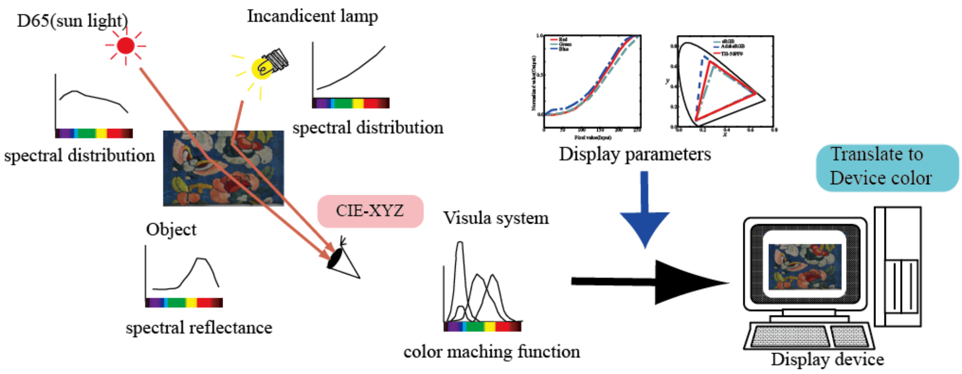
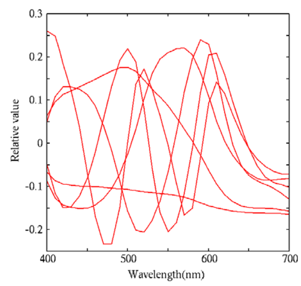


Figure.3 Color reproduction based on human visual system

7. Experimental Results

A silk textile is measured and reproduced using our proposed method. First, the color chart is measured with the multi-band camera and spectrum photometer to calibrate the imaging system (Figure 4 (a)). Figure 4 (b) shows the basis function of the color chart. The reflection intensity distribution is measured for the real object with the device. Figure 5 shows the measured silk textile. Figure 6 (a) shows the estimated spectral reflectance of the silk textile. The red line is a direct measurement using the spectrum photometer, while the green line is the estimated result using the six-band camera. Figure 6 (b) shows the estimated results of the reflection intensity. The red line represents the measurement values, while the blue line shows the estimated results using the reflection model. Figure 7 shows the estimated results of normal vector of the silk textile surface. The red line represents the slope of normal vector. The Green point represents the point of the pixel. The silk textile is reproduced using the proposed method. Figure 8 shows the rendering results of the silk textile.

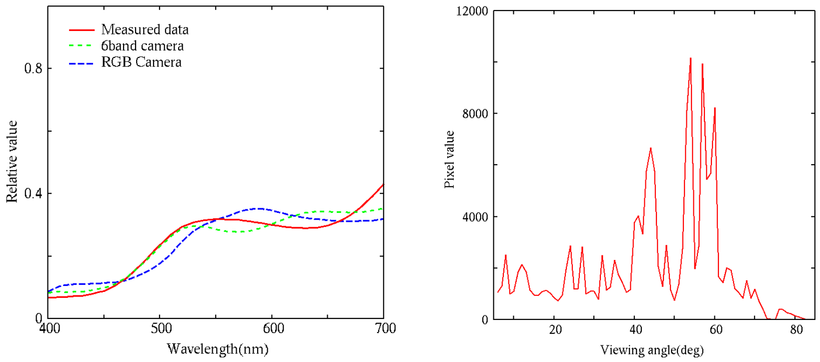
(a)Color chart



(b)Basis function

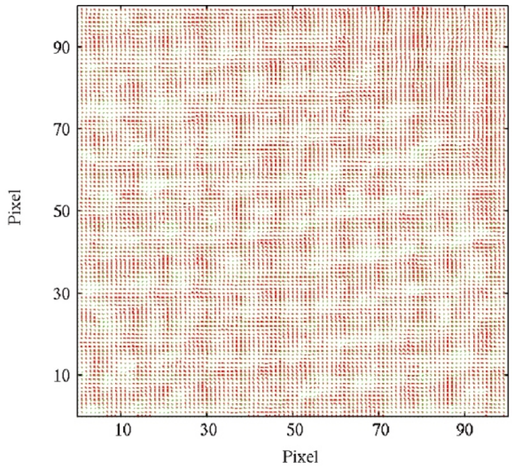
Figure.4 Color chart and basis functions

Figure 5. Measured object (silk textile)



(a)Reflectance (b)Reflection intensity

Figure.6 Estimated results of reflection properties



Silk textile

Figure.7 Needle map and estimated area

Figure.8 The silk textile of reproduction CG image

8. Conclusions

We have proposed a method for estimating the multi-spectral reflectance and various reflection model parameters using a multi-band camera without a camera sensitivity function. The device used to measure the reflection intensity is developed for the estimation of model parameters. Moreover, we developed a rendering system with a 3D color management system based on human visual properties. To show the validity of the system, we compared the real silk textile with the reproduced CG.

References

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