Fast BTF rendering for appearance-based display using dichromatic reflection model

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Abstract

An appearance-based display system has been developed to reproduce the accurate gloss appearance of real object. For the reproduction of the gloss appearance of rough surface, BTF (Bi-directional Texture Function) rendering is thought to be used in this system. However, efficient compression and reproduction methods are required for real-time rendering. In this paper, we propose an efficient approach of BTF compression based on dichromatic reflection model. This proposed method separates the reflected light to the specular, the cast shadow and the invariant diffuse elements. The efficient compression for the BTF rendering is performed by applying the LPCA (Local Principal Component Analysis) to the specular and the cast shadow images, since their appearance depends on the direction of the viewing or illumination. This method performs accurate reproduction by fewer principal components in comparison with the conventional method. The final projection image in an arbitrary direction of the viewing and illumination is synthesized from the specular reflection image, the cast shadow image and the invariant diffuse reflection image. Finally, the proposed method is implemented on the appearance-based display, and demonstrated high-speed BTF rendering which is two times faster than the conventional method.

1. Introduction

Recently, a digital mock-up with 3D-CAD data becomes more important to use for the design and structure analysis of industrial products. It is also effective to evaluate the final appearance of finishing such as color and glossiness by using the computer graphics. To reproduce the real appearance of digital mock-up, rendering techniques and color matching have been developed by many researchers. However, it is difficult to match the appearance between real object and digital mock-up object displayed on the CRT or the LCD display for the differences of visual mode between surface color and illuminant color.

A projection display can reproduce the appearance of real object in the same visual mode as that of the reflected light, and we have already developed appearance-based display system with controlling the radiance of projector as shown in Figure 1 [1] [2]. In this system, the color-matching techniques with PCA-Spline model was used for the texture matching, and ray tracing techniques with Phong model was used for the gloss matching. It could also reproduce the gloss appearance in real-time, which moves according to the observer's eye position by using the electromagnetic position sensor and GPU (Graphics Processing Unit) [3] [4].

For the accurate gloss appearance, it is important to reproduce the detail reflection properties such as the graininess and cast shadow which are caused by the roughness of surface. Model-based rendering is not suitable to reproduce the detail of reflection properties, since it is necessary to calculate the huge number of points on the surface. Instead of model-based rendering, image-based rendering is useful for reproducing the gloss appearance of roughness surface. Image-based rendering can also perform the bi-directional reproduction according to the viewing or illumination direction called BTF (Bi-directional Texture Function) rendering [5]. However, it is necessary to prepare many images of various directions for this rendering with high quality. In a recent research, calculation cost of BTF rendering is improved by using the LPCA (Local Principal Component Analysis) [6] [7]. However, it is still difficult to render the BTF in real-time.

In this paper, we propose the efficient compression LPCA techniques based on dichromatic reflection model for real-time rendering. Because only glossiness and cast shadow depend on the direction of the viewing or illumination, the efficient compression for the BTF rendering is performed by applying the LPCA to the specular and the cast shadow images.

In the next section, we briefly introduce the conventional LPCA techniques. In section 3, we describe the compression method of the BTF data by the proposed technique and method for a high-speed rendering. The effectiveness of the proposed technique is evaluated by using the root mean square error (RMSE) in comparison with the conventional method in section 4. Finally, the proposed technique is implemented on the appearance-based display, and demonstrated as real-time BTF rendering according to the viewing direction in section 5.

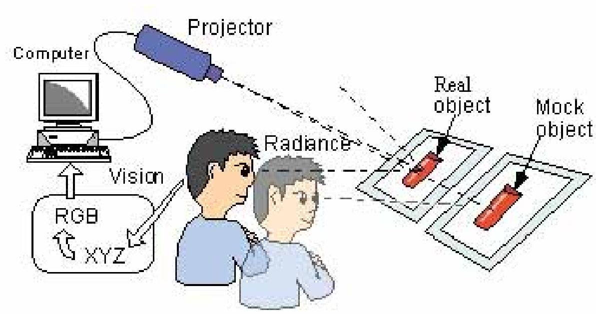
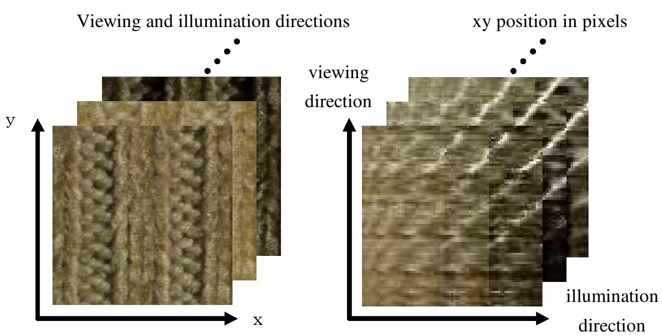


Fig.1 *Schematic illustration of the appearance-based display system*

2. BTF Compression with conventional LPCA

In this section, we introduce a BTF compression method based on LPCA, which was introduced by Müller et al. The BRDF-wise arrangement is applied to the BTF dataset which change the pixel according to the viewing or illumination direction shown in Figure 2. According to this operation, it is possible to uniform the pixel value which is measured in various directions. The LPCA method classify this dataset using the k-means clustering and local linearity technique, which is calculated iteratively on the basis of the similarity of directional variation. By applying the k-means clustering to the dataset, the BTF images are transformed to the similar characteristic dataset of reflectance value. Principal component analysis (PCA) is applied to these clusters as shown in Figure 3. The BRDF-wise arrangement and the k-means clustering are useful for the PCA, since the similarity of dataset permits accurate reproduction using only a few principal components. The flow chart of conventional LPCA compression and decompression is shown in Figure 4.

Figure 5 shows the result of comparison for principal components between simple and complex image by calculating with conventional LPCA. It is obvious that the number of necessary principal compornent depend on the complexity of image, since the result of k-means clustering is influenced by the variation of pixel value in this method. For real-time rendering, it is necessary to reproduce the BTF image only a few number of principal compornent. Therefore, it is difficult to perform the real-time rendering of BTF image by using the conventional LPCA method.



(a) measured images (b) BRDF-wise images

Fig.2 *Sample images to perform the BRDF-wise arrangement*

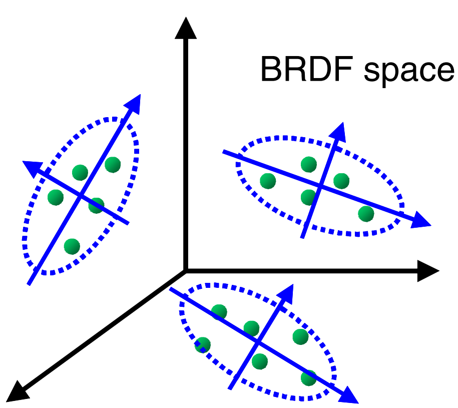


Fig.3 *LPCA in BRDF space*

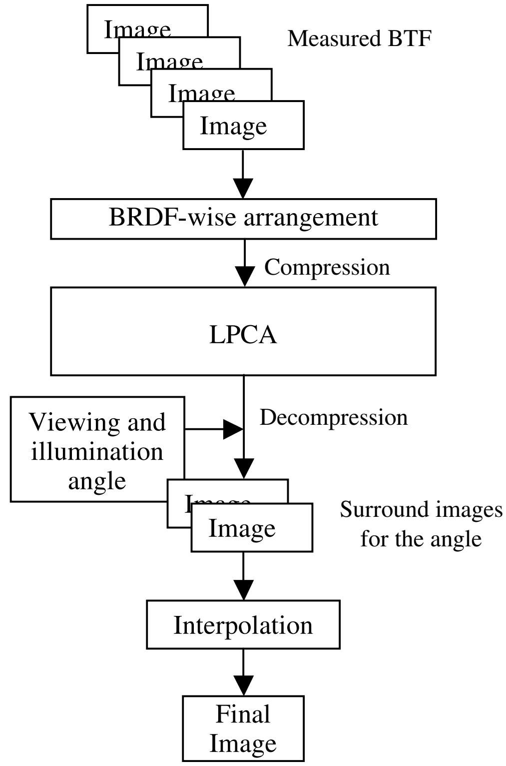
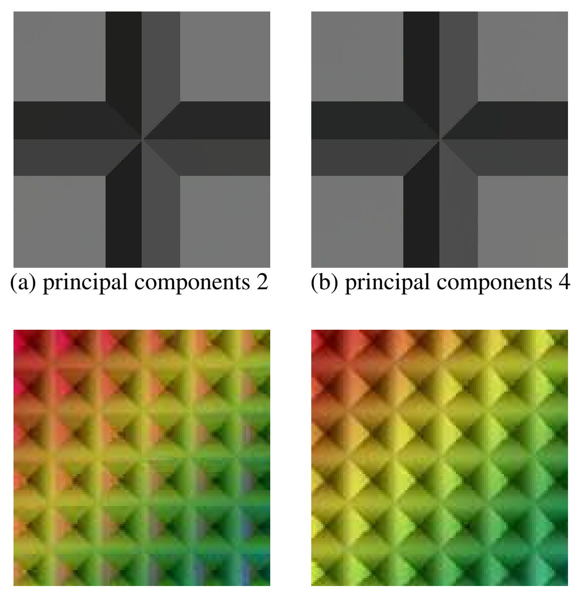


Fig.4 *Flow chart of conventional LPCA method*


(a) principal components 2 (b) principal components 4

(c) principal components 2 (d) principal components 4

Fig.5 *Result of restored simple images and complex images*

3. Proposed LPCA method based on separation of the glossiness

For the real-time rendering with LPCA, it is necessary to reduce an accurate BTF image using a few number of principal component even if the image is complex. As shown in Figure 5, the complexity of image depends mainly on the texture such as the diffuse image rather than the BTF variation for the viewing or illumination direction. Therefore, we propose the improved LPCA method which operate the separated specular, the cast shadow and the diffuse images.

Figure 6 shows the flow chart of proposed LPCA compression and decompression. To reduce the principal components, we separate an original image to specular, the cast shadow and the diffuse images. Here, we assume that a surface reflection of the object has isotropic property. It is clear that the specular image and the cast shadow image are influenced by the change of viewing or illumination direction. The BRDF-wise arrangement and LPCA calculation are applied only these images. Since these two images regard as monotone and simple image, the cost of the calculation can be greatly reduced. In contrast, conventional method needs applying the BRDF-wise arrangement and LPCA to all RGB images. The image that should be calculated is more complex, since diffuse image which has various change of pixel value is included. Therefore, our proposed method is effective to reduce cost of calculation and the number of principal components in reproducing process of BTF image.

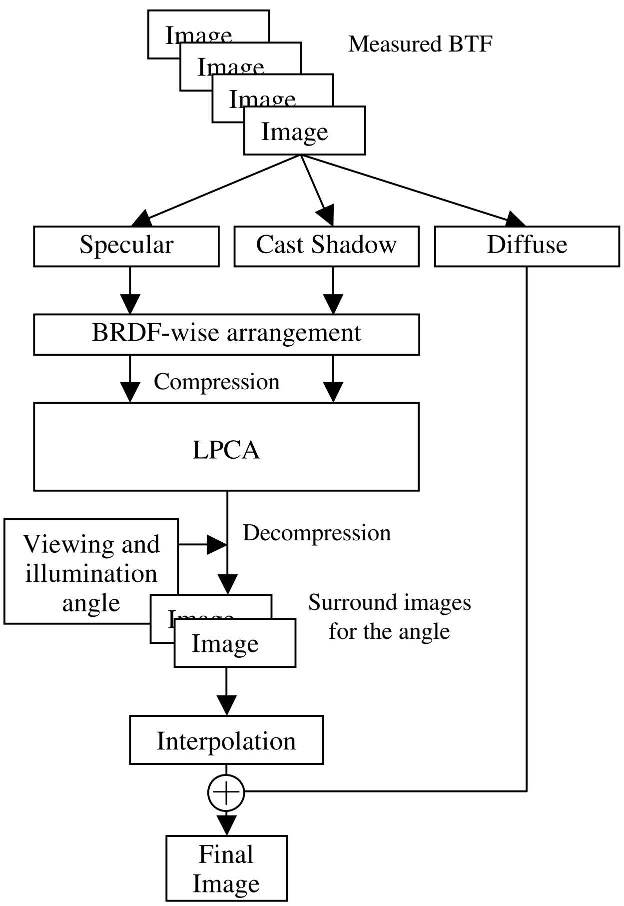


Fig.6 *Flow chart of proposed LPCA method*

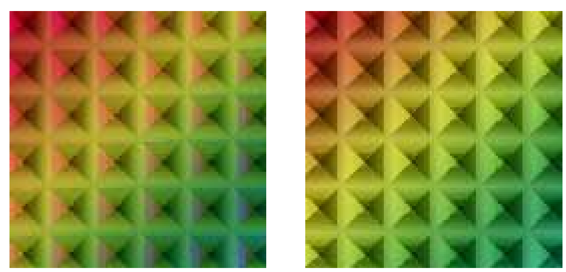
4. Computer simulation by using Phong model

To verify the accuracy of reproduction, the computer simulation is performed to compare proposed method with conventional method by using the Phong model. The Phong model is based on the dichromatic reflection model by using the following equation,

$$f(\lambda,\theta) = g_d(\lambda) f_d(\theta) + g_s(\lambda) f_s(\theta)\,, \qquad (1)$$

where $g_d(\lambda)$ is diffuse reflectance, $g_s(\lambda)$ is specular reflectance, $f_d(\theta)$ and $f_s(\theta)$ is geometry factor of diffuse reflectance and specular reflectance, respectively. Based on this equation, specular and diffuse images can be separated.

In this simulation, it is assumed that the viewing direction is fixed to vertical to a measurement object. The BTF images are measured by 81 illumination directions. Figure 7 shows the restored images using proposed method and conventional method. Figure 8 shows the result of RMSE evaluation to compare the quality of each reconstructed image. For conventional method, more than 4 principal components are needed to match the quality achieved by using 2 components with proposed LPCA method. Therefore, our proposed method is more accurate even if it is only a few principal components.



(a) conventional method with 2 components

(b) proposed method with 2 components

Fig.7 *Restored image*

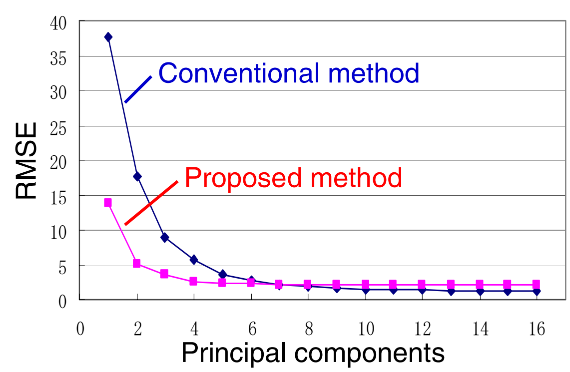


Fig.8 *Comparison of RMSE*

5. Experiment

Figure 9 shows the measurement system using corrugated sheet sample with gloss. In this system, it is necessary to measure images which are separated the specular, the cast shadow and the diffuse components. We use polarizer both camera and illumination for the separtation of those components. For the illumination, the projector is used as white light and the polarizer is mounted in front of the lens. The color camera (D1x, Nikon) is used for taking the image and the polarizer is also mounted in front of the lens. The polarizer that mounted in front of the camera can rotate 90 degrees. Incidence light that passed the polarizer becomes a linear polarized light. When the light is reflected at the rough surface, the diffuse reflection element becomes non-polarized light by the diffused reflection. On the contrary, the specular reflection element is still in the state of linear polarized light. By using these characteristics, the reflected light is separated to the specular and the diffuse elements. The diffuse reflection image is obtained under the cross condition that the azimuths of the two polarizers are kept at 90 degrees angles to one another. In contrast, the image which includes the specular and the diffuse elements is obtained under the parallel condition that the azimuths of these polarizers are kept at the same angle. To measure the BTF image with various angles, the position of the camera is fixed and the position of projector is moved only to the horizontal direction, which is a range of ±60 degrees in 5 degree pitch against an optical axis of the camera. Therefore, the BTF images are measured by 25 illumination directions.

Figure 11(a) shows the measured image under the parallel. This image is obtained when the position of the projector is 30 degrees against an optical axis of the camera. Figure 11(b) shows the measured image when the position of the projector is same angle under the cross condition. Figure 11(c) shows the measured image which is obtained when the position of the projector is approximate 0 degrees against an optical axis of the camera under the cross condition. The specular reflection image shown in Figure 12(a) can be acquired by subtracting Figure 11(b) from Figure 11(a). Furthermore, the cast shadow image shown in Figure 12(b) can be separated by subtracting Figure 11(b) from Figure 11(c).

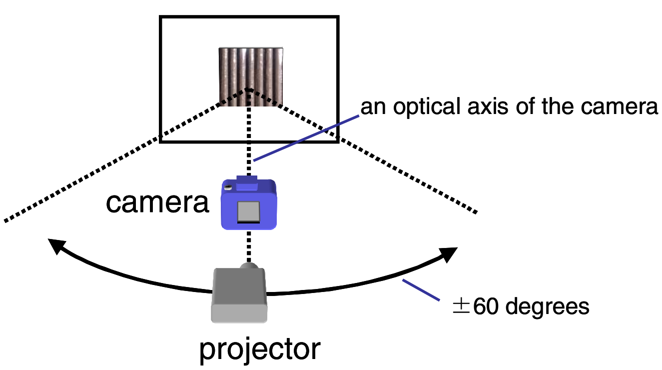


Fig.9 *Measurement geometry*

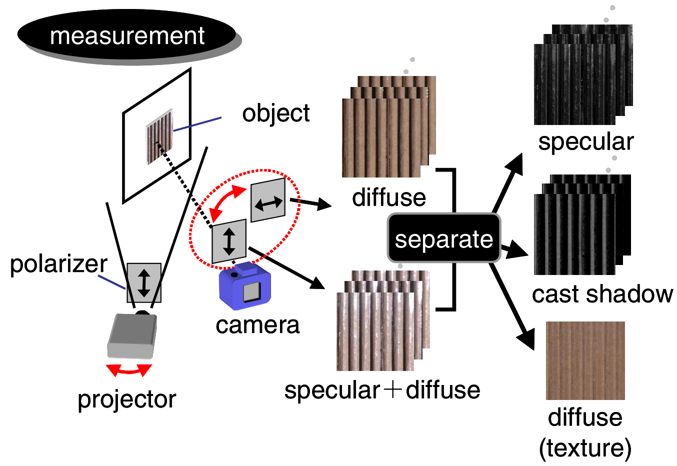
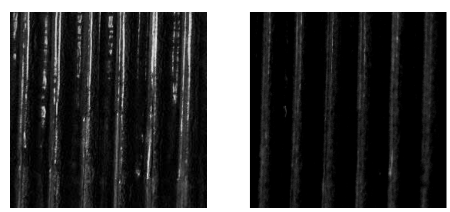


Fig.10 *Measurement system of proposed LPCA method*

(a) specular and diffuse (b) diffuse (c) diffuse (texture)

Fig.11 *Measured sample image*



(a) specular (b) cast shadow

Fig.12 *Separated images*

The result of reproduction for BTF image is evaluated as shown in Figure 13. The BTF image reproduce the appearance according to change the direction of the object under the viewing and illumination directions are fixed the direction of the object is detected by an electromagnetic position sensor. Arbitrary specular reflection and cast shadow images are reconstructed from the compression data. The projection image in an arbitrary direction of the object is synthesized the specular reflection, the cast shadow, and the invariant diffuse reflection images. The final image projects on the real object. Figure 14 shows the reconstruction images by using proposed LPCA method.

By evaluating the rendering speed, we use the FPS (flame per second) in the same number of clusters and principal components. It is clear that our proposed method performed two times faster than the conventional method in every number of principal components as shown in Figure 15.

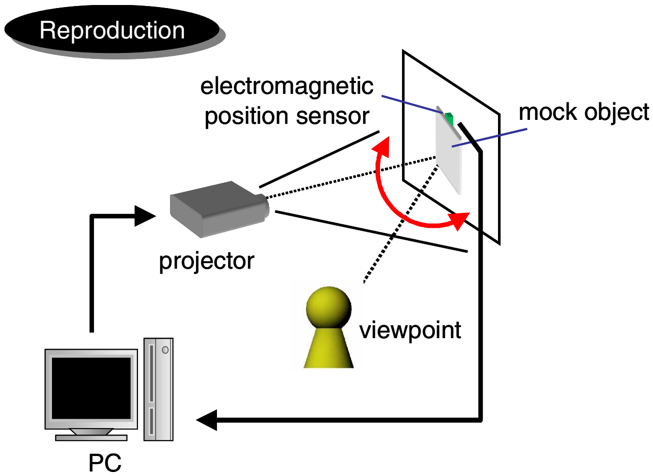


Fig.13 *Reproduction system of proposed LPCA method*

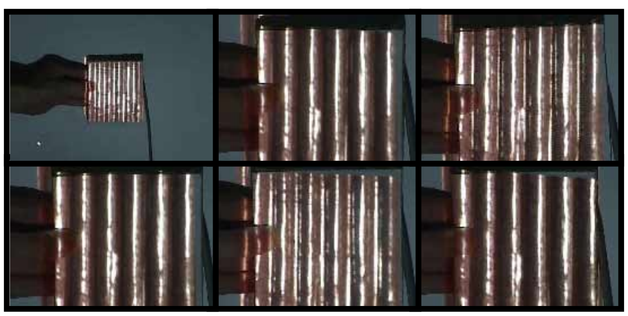


Fig.14 *Reconstruction images*

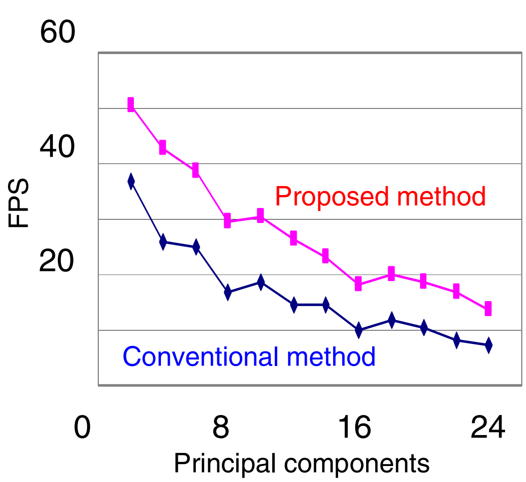


Fig.15 *Comparison of FPS*

6. Conclusions

We have developed a BTF compression method for the appearance-based display by using the improved LPCA. For the improvement of the BTF compression method, we separated the specular reflection, the cast shadow and the diffuse reflection images. Assuming that the object has isotropic reflected surface and the reflected light from object is based on the dichromatic reflection model, the reflected light can be separated to the glossiness as the specular reflection, cast shadow, and the texture as the invariant diffuse reflection using a polarizer. The BRDF-wise arrangement convert the measured BTF images into simple variation images, since the specular and the cast shadow images are only influenced by the change of viewing or illumination direction. In addition, LPCA is applied to only the specular and the cast shadow images, since the diffuse image is invariant for the direction of viewing or illumination. We showed that the proposed method used less principal components is more accurate than the conventional method by the computer simulation using the Phong model. It became clear that the rendering speed by the proposed method is two times faster than that of conventional method. As the result, it is shown that the proposed method is significant for the accurate gloss appearance of a digital mock-up.

Acknowledgments

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Author Biography

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