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Highlight Separation Using Multiple Images with Intensities and Ranges

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Abstract

In this paper, a method for extracting influences of specular reflection and shade from multiple color images is described. As regards extraction, the di-chromatic reflection model is applied. First, the same point on an object is observed from multiple viewpoints, and the pixel values in a window in which the fixation point is being imaged are projected into RGB color space. The shape of each cluster is linear, and, when one of the images observed the specular reflection, the clusters intersect . By using this phenomenon a specular reflection is extracted. To register each color image, range images are measured. Each range image is measured from the same viewpoint with a color image. In this paper, using image extracted specular and shade as texture data, a color object is reconstructed by the use of computer graphics images.

1 Introduction

Object surface color is one of the most important pieces of information for computer vision, which has as its goal the recognition of a 3D scene using images. However, the colors recorded as images do not express the true color of object surfaces. It is influenced by a light source. The typical effects of a light source are specular reflection and shade. Therefore, the separation of these optical effects is an important task in order to realize robust vision tasks.

Such optical effects cause trouble not only in computer vision but also in computer graphics (CG). To make CG images, we input a object shape and texture information. In recent papers, their authors measured the real scene by means of rangefinder in oreder to obtain shape and texture information and made detailed CG images. As regards texture information, they use color images which are measured by a color camera and a light source that are built into the rangefinder[1]. However, the color image already includes some optical effects such as specular reflection and shade influence. Therefore, the CG image that uses measured images as the texture information is unnatural because the double optical effects are included in the CG images. A process that can separate this kind of optical effect is necessary in order to make real CG images.

In this paper, we have described a method for separating "specular reflection" and "shade" from color images and reproducing the true color of an object surface. Using the true color as the texture information, we have made some CG images.

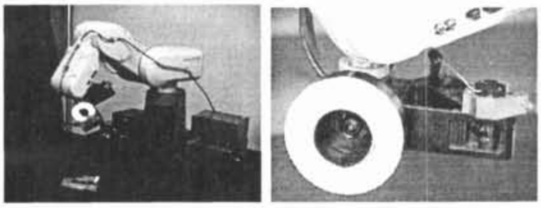
Fig.1. Cubicscope.

2 Previous work

Shafer et al. modeled the reflection of di-electric objects illuminated by a single light source[2],[3]. Their reflectance model consisted of two factors Lambertian-reflection component and specular-reflection component which express an object surface's color and illuminant color, respectively. They called that model a dichromatic-reflectance model. Using this model, they proposed a method to separate specular reflection from a image of uniformly colored object. In this method, they assumed that the direction of normal vectors on an uniformly colored object surface were widely distributed. This is a rigid assumption as regards a real scene.

Several photometric-stereo-type approaches have obtained the specular and Lambertian reflectance properties using two or more illuminations[4]-[7]. These methods require that the accurate locations of illuminations be known. However, it is difficult to locate illuminations at the best position for arbitrary objects.

Lee et al. proposed a specular separation method which is based on the Lambertian consistency[8]. In this method, the irradiance change depends on the viewing direction, which causes a change in specular reflection. However, this method requires that a light source is located at a same position for every imaging. This is a disadvantageous if one wants to apply the texture modeling to CG.

In this paper, we have proposed a method for separating the influences of specular reflection and shade from multiple color images. We have assumed that the reflections satisfy the di-chromatic reflectance model. When we observe the same point on the object surface from different viewpoints, their distributions in RGB color space are linear for every image and they are also co-planer. If specular reflection is observed in one of the images, the linear distributions intersect. They are co-linear, however, if no specular reflection is observed. By using this phenomenon, this method can extract a specular reflection.

This method requires only one condition that the specular reflection is not observed on the object surface on which a specular reflection has been observed in another image. Therefore, this method does not require a fixed light position. Furthermore, it does not require knowledge about the light position in order to extract the

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specular reflection. This knowledge, of course, makes the measurement easy (for example, as regards viewpoint selection).

To registrar each color image, we used range images that were measured from the same viewpoints with color images. To obtain these range images, we use a rangefinder "Cubicscope" [9]. This rangefinder consists of a color CCD camera and a scanner mirror that can scan a slit ray and allows it to obtain color and range images using the same lens (see fig. 1). We installed this rangefinder onto a 5-axis robot manipulator and we accomplished arbitrary viewpoint selection. As we described above, this method does not require fixation of the light source. Therefore, we attached a ring light as a light source in front of the camera, so that the object is always irradiated from the front. This illumination creates a minimum shadow.

3 The di-chromatic reflectance model

The di-chromatic reflectance model assumes that a light reflected onto a di-electric object surface is a mixture of the following two elements a Lambertian reflection component and a specular reflection component. In this model, the former refers to a color on the object surface, and the latter refers to an illuminant color. This model then describes reflected light $I(\lambda, \phi, \psi, \theta)$ as a linear combination of Lambertian color $C_L(\lambda)$ and specular color $C_S(\lambda)$ (eq(1)).

$$I(\lambda,\phi,\psi,\theta) = m_L(\phi,\psi,\theta)C_L(\lambda) + m_S(\phi,\psi,\theta)C_S(\lambda) \quad (1).$$

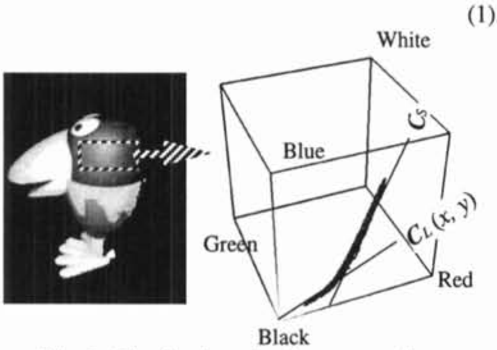

Fig. 2. Distribution of reflectance color.

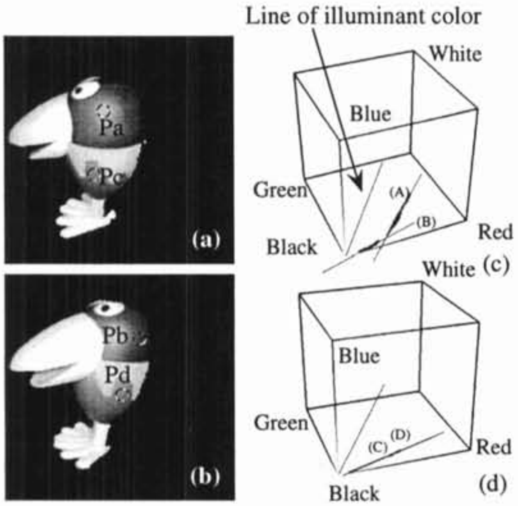

Fig. 3. Principle of specular sepalation.

Here, λ is the wavelength, and the parameters ϕ, ψ, and θ describe the angles of the incident and the emitted light and the phase angle. The terms, $m_L()$ and $m_S()$, are the geometric scale factors.

A TV camera senses a color using 3 sensors (which sense red, green and blue, respectively) and the response of the camera forms a 3 × 1 color vector. Thus, we can express the wavelength λ functions, $I(\lambda, \phi, \psi, \theta)$, $C_L(\lambda)$ and $C_S(\lambda)$, as vector values in the following:

$$\boldsymbol{C}(x,y) = m_L(\phi,\psi,\theta)\boldsymbol{C}_L(x,y) + m_S(\phi,\psi,\theta)\boldsymbol{C}_S \quad (2).$$

This equation means that observed color $\boldsymbol{C}(x, y)$ is distributed on a plane which is spanned by two basis vectors $\boldsymbol{C}_L(x, y)$ and $\boldsymbol{C}_S$ (see fig. 2). The term $\boldsymbol{C}_S$ does not depend on the pixel position (x, y), because it is a singular illumination color. The separation of specular reflection, (which is the goal of this paper), is to obtain the Lambartian component $m_L(\phi, \psi, \theta)\boldsymbol{C}_L(x, y)$ and specular component $m_S(\phi, \psi, \theta)\boldsymbol{C}_S$ for each pixel.

4 Principle of specular separation

As we shown in fig. 2, reflection in a di-chromatic reflection model consists of two basis vectors $\boldsymbol{C}_L(x, y)$and $\boldsymbol{C}_S$. The distribution of pixel values in RGB color space is on two lines whose direction are the same as similar such basis vectors. We can confirm that this phenomenon also occurs when we observe the same point on an object surface from several different view points. We have shown the observed results of this phenomenon in figs. 3. Points Pa, Pb and Pc, Pd are the pixels which gaze at the same points on the object surface, respectively. When we investigated the local color variation at each point, all distributions are linear (see fig. 3c A, B and fig. 3d C, D). When we could not observe specular reflection at both of the pixels which gaze at the same surface, the distributions were co-linear (fig. 3d C, D). When we observed specular reflection at one of these pixels, the distributions intersected. Then we found that specular reflection is observed on the distribution parallel to illuminant vector $\boldsymbol{C}_S$. In this paper, we measured the term $\boldsymbol{C}_S$ using Tominaga's method[11] in advance.

We have separated the specular reflection as follows. Let (x_i, y_i) $(i = 1,...,n)$ be a pixel which gazes at point $\boldsymbol{P}$ on the object surface from the i^{th} viewpoint. The local color variations at each pixel (x_i, y_i) make n linear clusters in RGB color space (see fig. 4a). Let each line be l_i.

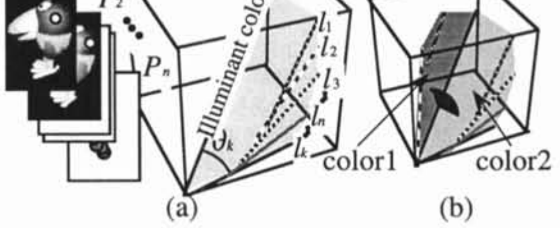

Fig. 4 Specular separation using multiple images.

First, we determined which line describes the Lambertian reflection. To determine it, we calculated the angles between illuminant vector $\boldsymbol{C}_S$ and each line l_i. We determined that the line which makes the largest angle as regards $\boldsymbol{C}_S$ is the distribution of Lambertian reflection. Let that line be l_k ($1 \leq k \leq n$). Then we will regard the directional vector of l_k as $\boldsymbol{C}_L(x_i, y_i)$, the color vector on $\boldsymbol{P}$.

Last, we separated a specular reflection component for each pixel (x_i, y_i) $(i \neq k)$, whose color value includes a specular reflection. As described above, the goal of specular reflection separation is to obtain the two terms in eq. 2, $m_L()\boldsymbol{C}_L(x_i, y_i)$ and $m_S()\boldsymbol{C}_S$. Now, the two basis vectors $\boldsymbol{C}_L(x_i, y_i)$ and $\boldsymbol{C}_S$ have already been obtained. Therefore, we can obtain these two terms by solving equation 2 for $m_L()$ and $m_S()$ (see fig. 5). We performed a series of these operation for all the pixels of n images.

In a series of these operations, we assumed that each pixel (x_i, y_i) gazed at the same point $\boldsymbol{P}$. However, the range data and registration error sometimes caused a small discrepancy in $\boldsymbol{P}$. To solve this problem, we classified lines l_i into groups in which the lines are co-planer with an illuminant color vector (see fig. 4b). We believe that the co-planer lines indicate the reflection on the same color surface. Then we applied a series of these operations to all line groups.

5 Experimental results

Fig. 6 indicates the extraction sequence for a specular reflection. First, we registered range images[10]. Next, we calculated color distribution based on the eigenvalues and eigenvectors of the pixel values[2][3]. To guarantee robustness, we hierarchically changed the window size for distribution calculation using a quaternary tree (see fig. 7). After that, using that distribution, we extracted a specular reflection. We then removed shade influence. Shade removal assumes that the light recorded in the specular extracted image satisfies the Lambertian reflection model[12]. It removes the shade influence using a normal vector and the information about a intensity distribution of a ring light. Finally, we mapped this image onto the range image and made CG images.

Figs. 8a, b shows the color images that were used in this experiment. Figs. 8c, d shows the range images that were measured from the same viewpoint with figs. 8 a, b, respectively. Using these images, we extracted specular reflection and shade influences. The white areas in figs. 9 a, b shows the domains where specular reflection was observed, and figs. 9c, d shows the results of specular reflection separation. Figs. 10 a, b shows the results that removed the shade influence from figs. 9 c, d respectively, and figs. 10 c, d shows the pixel values of red planes at the same columns of fig. 8a, 10a and fig. 8b, 10b respectively.

By extracting specular reflection and shade influence from 7 color images as indicated in figs. 11 a-g, we reconstructed a measured object using CG images. Figs. 11 h-j shows the reconstructed CG images.

6 Conclusion

In this paper, we proposed a method for extracting specular reflection and shade influences from multiple range and color images. The extraction method is based on the di-chromatic reflection model. This method does not require restrictions in regards ot the positioning of camera and light sources. Therefore, we can extract these types of influences from images that were obtained from arbitrary viewpoints. This method is therefore suited to CG modeling.

In this method, we gave the specular reflection and shade as the reasons why a color image does not express the true color of an object's surface. It is however necessary to consider the influence of inter-reflection in order to obtain a more accurate object color.

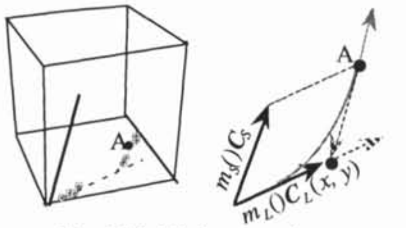

Fig. 5 Highlight separation.

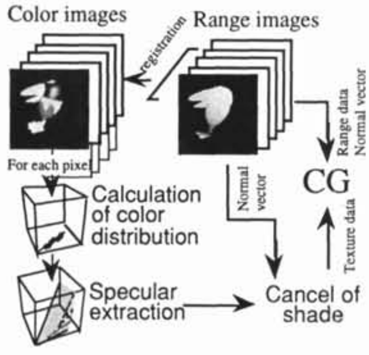

Fig. 6 Sequences of highlight separation.

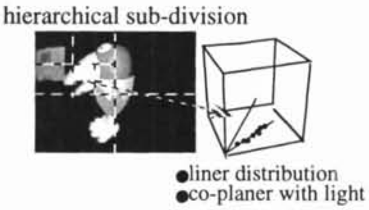

Fig. 7 Calculation of color distribution.

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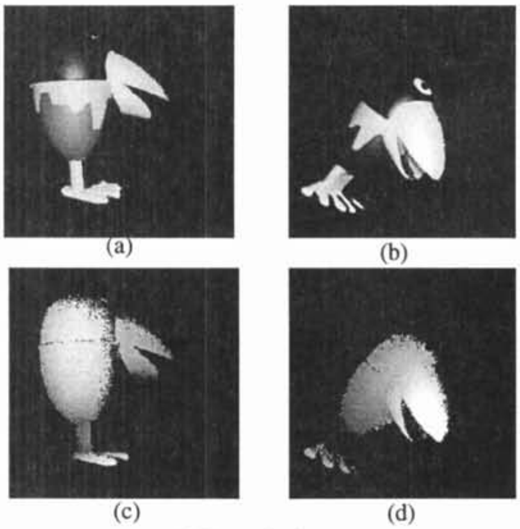


(a),(b) Intensity images
(c),(d) Range images

Fig. 8 Input images.

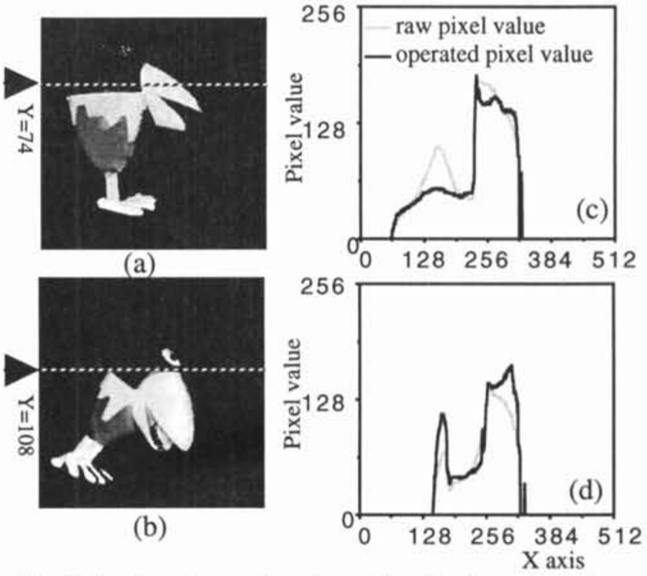
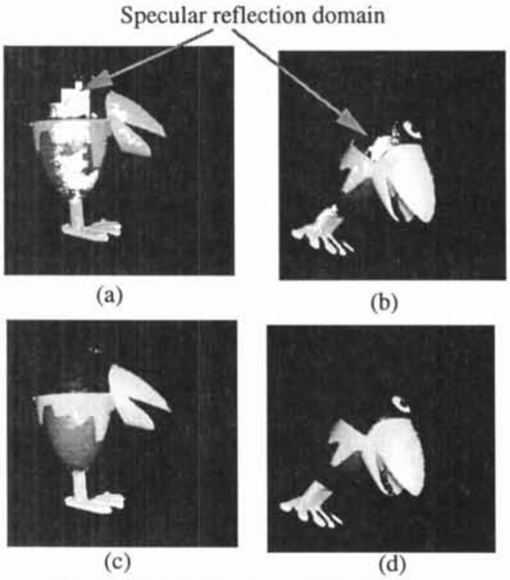


Fig. 10 Results of extraction of specular reflection and shade.



(a),(b):Highlight areas are marked.
(c),(d) Specular reflection is removed.

Fig. 9 Results of highlight separation.

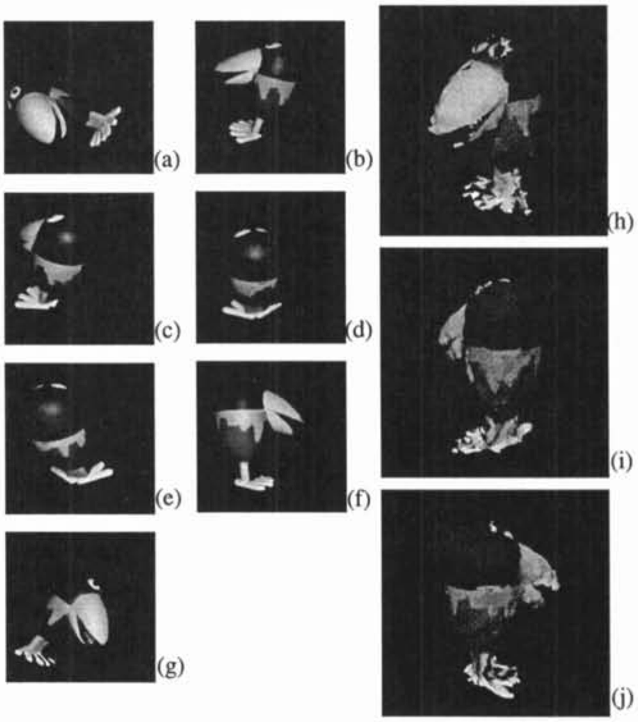


Fig. 11 CG images using images extracted specular and shade influences.