Color Simulation of Surface of Glossy Object on Computer Graphics

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Abstract

A new approach for Image-Based Lighting (IBL) method is proposed. The new IBL uses reflectance image instead of captured image. This enables us to change illumination of rendered image without re-shading process such as ray-tracing. This means that once image is rendered using CG rendering software, changing rendering illumination can be done without using CG rendering software. In the experiments, measured spectral reflectance was converted into 6-bands data. 3-band omni-directional camera system was used for capturing background image. The captured background image was converted into 6-bands image based on the method of the unified representation of multispectral images [1]. Then, CG rendering was done using obtained 6-bands data. The resultant image was displayed on a color LCD monitor and was compared with the real object.

Introduction

When we observe glossy object such as exterior of automobile, reflection image of background on the surface of the observed object affects its color. In the coloring simulation using computer graphics (CG) technique, an image rendering method called image-based lighting (IBL) is often used to obtain high-quality reflection image. In IBL, background image is used as illumination map. In general, a high-dynamic range image (HDRI) captured by camera is used for IBL. When changing illumination lighting background is requested, the background image captured under the illumination is required. And re-shading process such as ray-tracing should be done using CG rendering software.

In this paper, a new approach for IBL is proposed. The proposed method uses reflectance image instead of captured radiance image. This enables us to change illumination of rendered image without re-shading process. This means that once image is rendered using CG software, changing rendering illumination can be done without using CG rendering software.

Method

Representation of observation light from object surface

Let's us consider a reflected light from an object surface (see Fig.1). The object's surface reflects light from illumination ((a) in Fig.1) and light from background ((b) in Fig.1). And the sum of the two reflection lights is observed. Let's illumination spectrum and light from background be E(λ) and I_{back} (λ) . The observed light I (λ) is described as

$$I(\lambda) = f(\lambda)E(\lambda) + f(\lambda)I_{back}(\lambda), \qquad (1)$$

where f(λ) represents spectral reflectance of the object surface. In conventional CG system, HDRI captured by camera is used as background corresponding to I_{back} (λ) and CG is rendered. If background image is captured as multispectral image for estimating I_{back} (λ) and rendering system is extended to multispectral process, accurate color simulation can be done.

Here, let's us consider the case of changing illumination color (e.g. daylight at noon into that of early evening). According to Eq.(1) and Fig. 1, preparing background images under the rendering illumination is requires, and rendering process must be carried out again everytime the illumination color is changed. Preparing background images of all considerable illumination condition is not in practical.

Principle of proposed method

Let's us consider spectral reflectance image of background instead of background image. Let spectral reflectance of background object be $f_{back}(\lambda)$. Fig. 1 is rewritten into Fig.2 and the observed light I (λ) can be described as follow.

$$
\begin{aligned}
I(\lambda) &= f(\lambda)E(\lambda) + f(\lambda)f_{back}(\lambda)E(\lambda) \\
&= F(\lambda)E(\lambda), \qquad (2)
\end{aligned}
$$

where

$$
\begin{aligned}
F(\lambda) &= f(\lambda) + f(\lambda)f_{back}(\lambda) \\
&= f(\lambda)\left(u(\lambda) + f_{back}(\lambda)\right), \qquad (3)
\end{aligned}
$$

where u(λ) =1. Eqs. (2) and (3) show that rendering process can be separated into 2-steps.

Step.A: image rendering using reflectance and reflectance image of background (corresponding to Eq. (3)).

Step.B: multiplying illumination spectrum and calculating color (corresponding to eq. (2)).

Note that resultant image of step A is independent of spectrum of illumination light. Background and brightness of illumination light affect the rendering results. This enables us to change illumination color without re-rendering process such as ray-tracing.

Multispectral Computer Graphics rendering

Although full-spectral CG rendering makes possible to simulate reflection on object surface, its computing cost becomes large and is not in practical, especially for real-time CG rendering. In this paper, CG rendering is carried out using multispectral data instead of full-spectral data. The diagram of multispectral rendering in this paper is shown in Fig. 3.

Step. A

Spectral reflectance of sample materials is measured by spectrometer. Measured spectral reflectance is converted into multispectral data based on the idea of simulating multispectral capturing by virtual camera [1]. Let the number of band of the multispectral reflectance be N .

Based on the wiener estimation, spectral reflectance image of background is estimated from multispectral image captured by camera. The estimated spectral image is converted into N -band image as same as measured spectral reflectance. Note that the spectral sensitivity of the virtual camera is same to that used for calculating multispectral reflectance. The wiener estimation matrix is calculated using the spectral sensitivity of the virtual camera and is memorized on this system.

Using N –band reflectance and reflectance image of background, N -band CG is rendered ((i) in Fig.3) [2]. In this rendering process, w = [k, k,…, k] is used as illumination spectrum and the generated CG is corresponding to reflectance image.

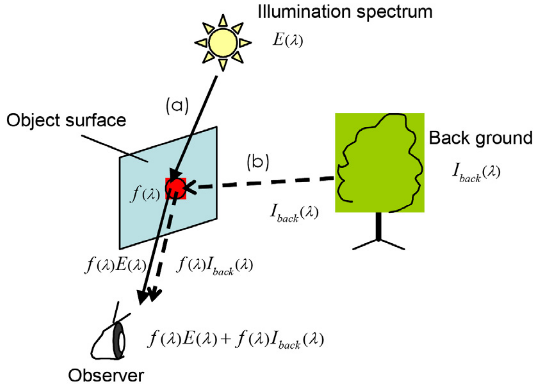

Figure 1. Model of observed reflection light.

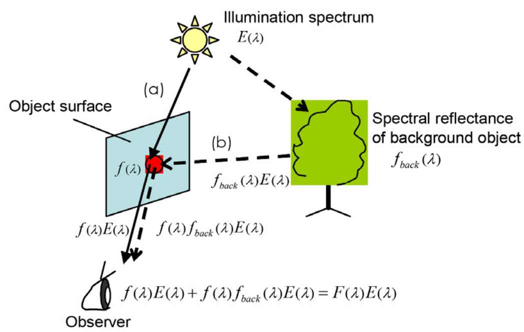

Figure 2. Model of reflection light in the proposed method. .

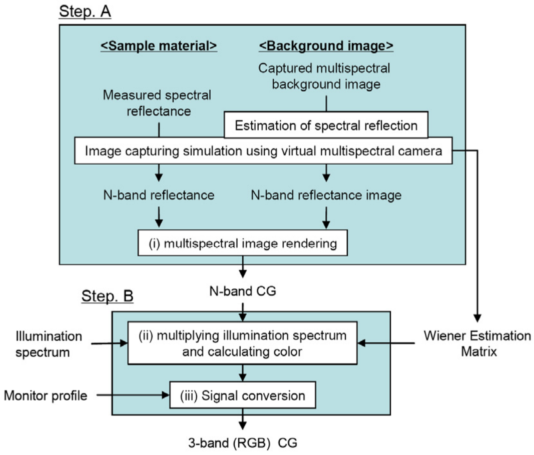

Figure 3. Diagram of multispectal CG rendering.

Step. B

The generated N –band CG is converted into spectral reflectance image using the wiener estimation matrix calculated from the sensitivity of the virtual camera. And the spectral reflectance image is multiplied with illumination spectrum so that spectral radiance image is obtained ((ii) in Fig. 3).

Finally, the spectral radiance image is converted into RGB image by using the color matching function and display profile; spectra of primary colors and response curve of display device ((iii) in Fig. 3).

Experimental results

Spectral reflectance of colored metal plate was measured by spectrometer and used for image rendering.

For capturing background image, an omni-directional camera system (Ladybug2, Point Grey Research) was used (see Fig. 4). This system consists of six RGB digital cameras. For estimating spectral reflectance from captured image, spectral sensitivity and response curve of the cameras were measured. As bit depth of output image of the camera is 8-bit, several images of different shutter speed were captured and combined into a 16-bit high-dynamic range image. A generated background image is shown in Fig. 5.

A captured background image and measured spectral reflectance were converted into 6-band image and data. For CG rendering, 6-band CG rendering software was developed. 3-band or 6-band data can be read into the software. Rendering 6-band CG and color reproduction can be done almost in real-time.

Figure 4. Camera head of omni-directional camera .

Figure 5. Captured omni-directional image.

Fig. 6 shows a resultant image after rendering and color reproduction. The color accuracy of the resultant image was evaluated by eye and it was agree that the color simulation of glossy object could be done well.

Figure 6. Resultant image afer rendering and color reproduction.

Future works

The proposed method was implemented in CG rendering software and evaluating color accuracy was carried out qualitatively. As a next step, quantitative color evaluation will be done. And also, experiments using various materials will be done. As for preparation of next experiences, color samples of automobile were measured.

In this measurement, 300 color samples in “2006 Auto

Paint Colors" (published by Japan Paint Manufacturers Association, http://www.toryo.or.jp/) were used. Spectrometer SR-3 (TOPCON) was use for measuring spectral reflectance and 401-demensional data (from 380nm to 780nm at 1nm interval) were obtained. The measurement results ware plotted on u'-v' chromaticity diagram shown in Fig. 7. The color gamut of sRGB and Adobe RGB were also figured on the same diagram to confirm that which colors could not be presented on monitor. Fig. 7 shows that almost all samples except several vivid red and yellow were in color gamut of monitor.

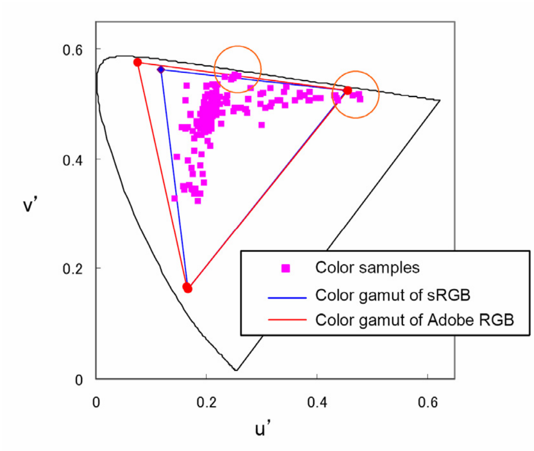

Figure 7. Color distribution of u' -v' chromaticity diagram.

Conclusion

A new approach for multispectral CG rendering based on IBL was proposed. In this method, multispectral reflectance image of background is used for calculating reflection. And after rendering multispectral CG, illumination spectrum is multiplied with the rendered CG. This means that illumination for image rendering can be changed without re-shading process such as ray-tracing. The proposed method was implemented into 6-band CG rendering software and good rendering results were obtained.

References

1. T. Uchiyama, M. Yamaguchi, H. Haneishi, N. Ohyama, and S. Nambu, "A Method for the Unified Representation of Multispectral Images with Different Number of Bands", The Journal of Imaging Science and Technology, Vol. 48, No. 2, pp. 120-124, (2004).
2. M. Tsuchida, H. Arai, M. Nishiko, Y. Sakaguchi, T. Uchiyama, M. Yamaguchi, H. Haneishi, and N. Ohyama, "Development of BRDF and BTF Measurement and Computer-aided Design Systems Based on Multispectral Imaging.", Proc. AIC Colour 05, pp 129-132, (2005)