A method for rendering and editing multispectral computer graphics

Masaru TSUCHIDA [1,2], Hiroyuki ARAI [3], Toshio UCHIYAMA [2], Masahiro YAMAGUCHI [1,4], Hideaki HANEISHI [1,5], and Nagaaki OHYAMA [1,4]

1) National institute of information and communications technology, Banzai bldg. 2-31-19 Shiba, Minato-ku, Tokyo, Japan
2) NTT DATA corporation, Kayaba-cho Tower, 1-21-2, Shinkawa, Chuo-ku, Tokyo, Japan
3) NTT corporation, 1-1 Hikari-no-Oka, Yokosuka-shi, Kanagawa, Japan
4) Tokyo Institute of Technology, 4259 Nagatsuta, Midori-ku, Yokohama, Japan
5) Chiba university, 1-33, Yayoi-cho, Inage-ku, Chiba, Japan

E-mail: tsuchidams@nttdata.co.jp

Abstract

We described a method of CG rendering that uses spectral reflectance and multispectral data obtained using different types of measurement systems. This method can be used to synthesize CG and live-action pictures with different numbers of bands. We experimentally created a short movie using multispectral CG and live-action pictures and demonstrated that we can generate natural and accurate color images.

1. Introduction

An ultimate goal in the area of computer-aided design is to replace the use of trial production with simulation using computer graphics (CG). For simulating color appearance accurately, using spectral data (e.g. spectral reflectance, multispectral bidirectional reflectance distribution function (BRDF), and multispectral images) seems to be effective [1]. However, when the number of channels of these spectral data is different respectively, these spectral data cannot be handled in the same system. Even when the data has the same number of channels, differences in the spectral sensitivity and the response curve of the sensor affect the simulation results, especially the color reproduction accuracy if different sensors were used to acquire the data. Differences in the spectral power distribution of the illumination also affect the color. For various types of spectral data to be handled on the same rendering system, all the spectral data must be converted into device-independent data or data with common measurement conditions. Converting the measured multispectral data into spectral reflectance based on Wiener estimation is one possible way, but the computation costs for image rendering are huge. To solve these problems, we applied the idea of a virtual multispectral camera (VMSC) [2] to data conversion for image rendering. The calculated multispectral data were used for image rendering, and objective simulation images were generated from the rendered multispectral CG using an illumination spectrum and display characteristics.

2. Method

2.1. Unified representation of spectral data captured under different sensor or illumination conditions

An observed spectrum of reflected light from a point on an object is calculated as follows. Let the spectral power distribution of illumination and spectral reflectance of the object be $W(\lambda)$ and $f(\lambda)$. The observed spectrum is represented as

$$v(\lambda) = W(\lambda) f(\lambda), \tag{1}$$

where λ is the wavelength. Let us consider a situation where the reflected light is captured using a sensor. Let the spectral sensitivity of the sensor be $\mathbf{S}$. Let the matrix whose diagonal elements represent the spectral power distribution of illumination be $\mathbf{W}$. Equation (1) can be rewritten into vector representation as

$$\mathbf{v} = \mathbf{W}\mathbf{f}. \tag{2}$$

Based on the Wiener estimation method, spectral is estimated from the camera signal, $\mathbf{c} = \mathbf{S}\mathbf{W}\mathbf{f} = \mathbf{H}\mathbf{f}$, as

$$\hat{\mathbf{f}} = \mathbf{G}\mathbf{c},$$

$$\mathbf{G} = \mathbf{R}\mathbf{H}'\{\mathbf{H}\mathbf{R}\mathbf{H}'\}^{-1}, \tag{3}$$

where $\mathbf{G}$ is the Wiener estimation matrix obtained from $\mathbf{H}$ and $\mathbf{R}$ is a priori knowledge about the spectral reflectance of objects [3].

Here, let us consider image capturing simulation using $\hat{\mathbf{f}}$, a virtual illumination spectrum $\mathbf{W}_v$, and a VMSC, whose spectral sensitivity is represented as $\mathbf{S}_v$. The calculated signal of the VMSC is represented as

$$\mathbf{c}_v = \mathbf{S}_v\mathbf{W}_v\hat{\mathbf{f}} = \mathbf{S}_v\mathbf{W}_v\mathbf{G}\mathbf{c}. \tag{4}$$

Equation (4) shows that multispectral data $\mathbf{c}$ can be converted into multispectral data captured using a VMSC with $\mathbf{S}_v$ and virtual illumination spectrum $\mathbf{W}_v$. Hence, a CG rendering system can handle various kinds of multispectral data at the same time by using $\mathbf{c}_v$, even when the original multispectral data were captured using measurement systems with different characteristics. In addition, the number of multispectral data channels can be decreased without degrading the accuracy of the spectral reflectance estimate when an optimized VMSC and ideal illumination are used.

Spectral reflectance $\hat{\mathbf{f}}_v$ can be estimated from $\mathbf{c}_v$:

$$\hat{\mathbf{f}}_v = \mathbf{G}_v\mathbf{c}_v = \mathbf{G}_v\mathbf{H}_v\mathbf{G}\mathbf{c}, \tag{5}$$

where $\mathbf{G}_v = \mathbf{R}_v\mathbf{H}_v'\{\mathbf{H}_v\mathbf{R}_v\mathbf{H}_v'\}^{-1}$, $\mathbf{H}_v = \mathbf{S}_v\mathbf{W}_v$, and $\mathbf{R}_v$ is a priori knowledge about the spectral reflectance of objects. When a spectrometer is used to measure data, $\mathbf{c}$ corresponds to the spectral power distribution of the light reflected from the object. The calculated $\mathbf{c}_v$ is used for CG rendering.

2.2. Image generation

Prior to CG rendering, the original multispectral data are converted into $\mathbf{c}_v$ based on equation (4). Matrix $\mathbf{G}_v$ is calculated and kept with $\mathbf{c}_v$, which is necessary for color reproduction. The CG rendering method proposed by Tsuchida et al. [1] is then used for image generation. This process is divided into two steps: image rendering using geometrical information and color reproduction using spectral information and the display characteristics. Figure 1 shows the diagram of image generation process.

2.2.1. CG rendering

In the image rendering step, shading and texture mapping are done to generate multispectral CG. Here, multispectral data $\mathbf{c}_v$, 3-D shape data, and geometrical lighting and observation information are used. Note that information corresponding to the spectral power distribution of illumination is not used in the shading process. Only the intensity and incident angle of the illumination light are considered. This is to avoid losing spectral accuracy caused by multiplying multispectral data by multispectral data.

2.2.2. Superimpose with live-action pictures and edit

Live-action pictures can also be converted into $\mathbf{c}_v$ based on equation (4), and the rendered CG can be superimposed onto the pictures. Editing processes are carried out using the converted CG and live action. The generated time-sequenced multispectral images are saved on a PC with matrix $\mathbf{G}_v$.

2.2.3. Color reproduction

In the color reproduction step, the generated multispectral images are converted into images for display using spectrum of observation illumination, and characteristic of display device.

First, the spectra to be reproduced are calculated using

$$\hat{\mathbf{v}} = \mathbf{W}'\mathbf{G}_v\mathbf{c}_v, \qquad (6)$$

where $\mathbf{W}'$ represents the spectral power distribution of illumination required for simulation. When illumination replacement is required (e.g. daylight to incandescent lamp), the spectra are re-calculated based on equation (6). Note that calculations, such as ray tracing, are not necessary for the illumination replacement.

After that, the estimated spectral radiance is converted into device-dependent signals using the spectral sensitivity of people and the display characteristics (e.g. primary color spectra, tone curve, dark currents). When multiprimary color display [4-6] is used, the spectral image is converted into multichannel signals [7-9].

3. Experiments

We created a fashion-show-like movie combining CG and live-action motion pictures based on the method described in sec. 2. Three types of spectral or multispectral data were used for the CG rendering:

1) spectral reflectance data measured using a spectrometer under daylight lamp,
2) 16-channel image data captured under daylight lamp as texture images,
3) 16-channel BRDF data measured using a multispectral goniometer [1] under a xenon lamp,
4) 6-channel image data captured under an incandescent lamp.

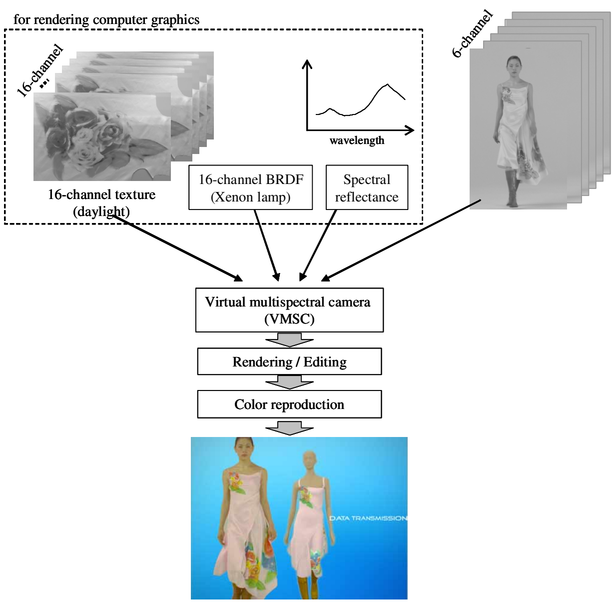

Figure 1. Diagram of rendering and editing multispectral CG and live-action picture

Figure 2. Rendered CG images.

(Color was reproduced for an LCD monitor.)

These four types of full- or multispectral data were converted into 16-channel data (or images) captured using a virtual multispectral camera under a daylight lamp.

3.1. Rendering computer graphics

We used commercially available CG rendering software (Alias Maya^{TM}) and custom plug-in software to generate the CG. The plug-in software supports BRDF-based rendering. This software can import only three-channel data and images. The 16-channel data ware decomposed into five three-channel data and one monochrome data. The rendering was carried out by each of the three channels. Figure 2 shows the rendered images. Spectral reflectance measured with a spectrometer was used for the dummy body and background, 16-channel BRDF

Figure 3. CG and live-action picture after changing illumination conditions

data was used for the cloth (pink area), and a 16-channel image was used for the texture image (flower patterns).

3.2. Superimpose with live-action pictures and edit

Adobe Premier^{TM} and After Effect^{TM} were used to edit and synthesize the CG and live-action pictures. Like CG rendering, this process was carried out on each of the three channels. The three-channel images were re-combined into 16-channel images. After that, under a daylight lamp, the RGB images were calculated using the 16-channel images, the spectral power distribution of the daylight lamp, and the display characteristics. Figure 3 shows a rendered CG and a real-action picture for comparison. Illumination condition of each image was converted into a same illumination condition to confirm the color accuracy. Figure 4 shows a part of time sequential image generated by the proposed method. Captions and CG ware superimposed into real-action pictures. A comparison of these images, especially the CG with the live-action image, shows that the CG look very natural and the colors were well simulated. These images were also compared with the actual dress afterwards, and the subjects asked to evaluate the images all agreed that the color and gloss were well simulated.

3. Summary

We described a method of CG rendering that uses spectral reflectance and multispectral data obtained from different types of measurement systems. This method can make us handle several types of multispectral data (e.g. pictures with different numbers of bands captured by different multispectral camera, multispectral BRDF, and spectral data measured by spectrometer) on the same image rendering or editing system. In the experiments, a short fashion-show like movie superimposed CG into real-action pictures was generated. And we demonstrated that we can generate natural and accurate color images. Observers who work for apparel industry agreed that the color and gloss were well simulated.

Figure 4. A part of time sequential image. Captions and CG were superimposed into Real-action pictures

(Color was reproduced for an LCD monitor.)

References

[1] M.Tsuchida, H.Arai, M.Nishiko, Y.Sakaguchi, T.Uchiyama, H.Haneishi, M.Yamaguchi,N.Ohyama, “Development of BRDF and BTF Measurement and Computer-aided Design Systems Based on Multispectral Imaging.”, Proc. AIC Colour 05, pg129-132, (2005).

[2] 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, pg. 120- 124, (2004).

[3] W. K. Pratt, and C. E. Mancill, “Spectral estimation techniques for the spectral calibration of a color image scanner”, Applied Optics, OSA, 15, pg. 73–75, (1976).

[4] T. Ajito, T. Obi, M. Yamaguchi, and N. Ohyama, "Six-primary color projection display for expanded color gamut reproduction," Proceedings of International Symposium on Multispectral Imaging and Color Reproduction for Digital Archives, Chiba, Japan, (1999) 135-138

[5] H. Motomura, N. Ohyama, M. Yamaguchi, H. Haneishi, K. Kanamori, S. Sannohe, "Development of Six-Primary HDTV display system," Proc. Int. Display Research Conference, (2002) 563-566

[6] S. Komura, I. Hiyama, and N. Ohyama,, "Four-Primary-Color LCD for Natural Vision," Information Display, 8/03 (2003) 18-21

[7] T. Ajito, K. Ohsawa, T. Obi, M. Yamaguchi, and N. Ohyama, "Color conversion method for multiprimary display using matrix switching," Optical Review, vol.8, no.3, (2001) 191-197

[8] M. Yamaguchi, T. Teraji, K. Ohsawa, T. Uchiyama, H. Motomura, Y. Murakami, and N. Ohyama, “Color image reproduction based on the multispectral and multiprimary imaging: Experimental evaluation”, Proc. SPIE Vol.4663, 15-26(2002).

[9] H. Kanazawa, "Spherical average multi-primary color decomposition method," 12th Color Imaging Conference (2004)

Author Biography

Masaru Tsuchida received his Ph.D. degree in Engineer from the Tokyo Institute of Technology, Japan in 2002. He joined NTT Communication Science Laboratories in 2002. Since 2003 he has worked in NTT DATA Corporation. And he joined Natural Vision project of National institute of information and communications technology, Japan in 2003 to 2005. His research interests include 3-D image display, computer vision, image recognition and multi-spectral imaging.

.