Spectral Based Color Reproduction for E-commerce with High Compatibility

Norimichi Tsumura,[,**] Kunlaya Cherdhirunkorn,[*] Testuo Ikeda,[*] Daisuke Nakao,[*] and Yoichi Miyake[*]*
[*]Dept. of Information and Image Sciences, Chiba University, Chiba, Japan
[**]PRESTO, Japan Science and Technology Corporation (JST)

Abstract

Recently, images of products are easily transferred to the customer in the E-commerce system, and are important information to decide to buy the products. The color of product is one of the important information. In this paper, spectral turn technique is proposed to achieve spectral based color reproduction in the e-commerce system with high lower compatibility to the conventional imaging technology.

Introduction

With the recent progress of broadband network such as ADSL, optical fiber, images of products are easily transferred to the customer, and are important information to decide to buy the products in the E-commerce system. This 21 century is thought as the age of 'personality' compared to the 'mass production' in the 20 century. In the E-commerce in this 21 century, people will hope to choose their favorite appearance of products. Color is one of the important factors of the favorite appearance. If the customer purchases a product in the e-commerce system, the product is physically send to the customer's office or home. Therefore, the customer can compare the color between original and reproduced color on display or hardcopy under the customer's environment. Device independent color repro-duction based on ICC-profile[1] or sRGB color space[2] are used for color reproduction in recent technology. However, the accurate color reproduction is guaranteed on the decided environment. This is not practical for the use of general customer. Viewing condition independent color reproduction based on color appearance model is expected to reproduce the color under different viewing condition. In this reproduction, however, the reproduced appearance of color is that of color under taken illuminants. The color of the object under the customer's viewing condition can not be reproduced by this technique.

Color reproduction techniques based on an estimation of reflectance spectra were proposed to reproduce correct color under an arbitrary environment.[4-11] The reflectance spectra are estimated from the multi-band images based on samples of reflectance spectra, which are measured previously. Using the estimated reflectance spectra and spectral characteristic of environmental illuminant, correct color is calculated and reproduced on a display or hardcopy by colorimetrical color reproduction.[6] Spectral based color reproduction had been proposed by many group and researcher in these 15 years. However, they are not used practically in the E-commerce. We think that this is cased by following aspects. Since there are many resources and devices of conventional imaging technology, it is difficult to change them into those of spectral imaging technologies.

In this paper, spectral turn technique is proposed to achieve spectral based color reproduction in the e-commerce system with high lower compatibility to the conventional imaging technology.

Spectral Based Color Reproduction

Total Flow of Spectral Based Color Reproduction

Figure 1 shows the total flow of spectral based color reproduction. The images of objects are captured under illuminant #1 by N-band camera. The obtained N-bands images are transformed into the spectral reflectance image. The spectral reflectance image is displayed or printed on various types of devices with consideration of viewing illuminant and color appearance transformations. In Figure 1, the color is reproduced on the conventional primaries display, multi-primaries (more than four primaries) display, conventional hardcopy, spectral based hardcopy. From the next sub-sections, the details of spectral based color reproduction are described.

Image Acquisition by N-band Camera and Estimation of Spectral Reflectance

The pixel value m_i at the N-band camera in Figure 2 can be written as

$$m_i = \int_{380\,nm}^{780\,nm} s_i(\lambda) r(\lambda) L_1(\lambda) d\lambda, \tag{1}$$

where $L_1(\lambda)$, $r(\lambda)$, $s_i(\lambda)$ indicates the spectral radiance of illuminant #1, and spectral reflectance of the object, spectral sensitivity for i-band, respectively. In the commercially available camera, the gamma correction is usually applied to the sensor signals. In this paper, it is assumed that the device profile that describes the input and output characterization of device should be obtained or measured, and the output signal should be transferred into the pixel value m_i in Eq. (1) based on the device profile.

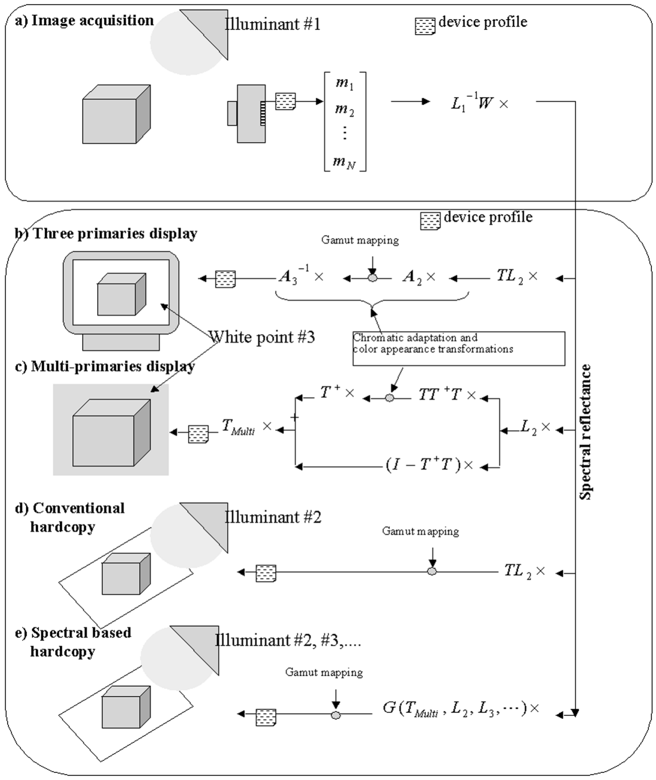


Figure 1. Flow of total process in spectral based color reproduction

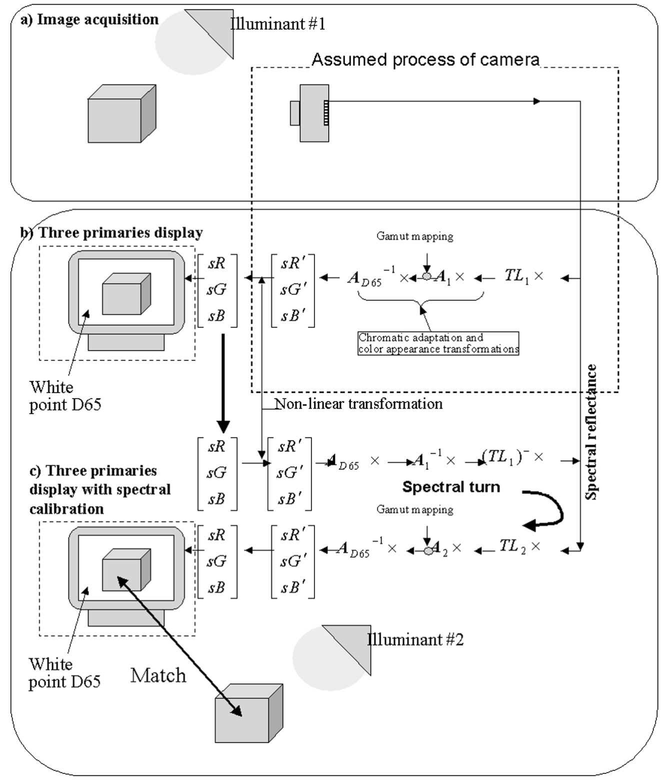


Figure 2. Process of spectral based processing for sRGB system

The spectral reflectance image is estimated from the multi-band image based on the statistical characteristic of reflectance spectra. The principal component analysis, Wiener estimation method, or multiple regression method are often used for this estimation. Let W be the estimation matrix from vector of pixel values $\boldsymbol{m} = [\boldsymbol{m}_1, \boldsymbol{m}_2, \cdots, \boldsymbol{m}_N]^t$ to spectral radiance vector. The reflectance vector $\boldsymbol{r} = [\boldsymbol{r}(\lambda_{380}, \lambda_{390}, \cdots, \lambda_{780}]^t$ can be written as,

$$\boldsymbol{r} = L_1^{-1} W \boldsymbol{m}\,,, \tag{2}$$

where L_1 is diagonal matrix with spectral radiance of illuminant #1. Although the matrix $L_1^{-1}W$ can be directly obtained by the estimation method, the inverse lighting matrix L_1^{-1} is explicitly shown in Eq.(2).

Softcopy of N-band images

The estimated spectral reflectance is converted into the tristimulus values under the illuminant #2. It is assumed the real object is observed under this illuminant #2. The vector of tristimulus values $\boldsymbol{x} = [X, Y, Z]$ can be written as,

$$x = TL_2 \mathbf{r}\,, \tag{3}$$

where L_2 is the diagonal matrix with spectral radiance of illuminant #2, T is the matrix of color matching function.

If the response of observer's vision is the same at real object and display, tristimulus values give a appropriate color to reproduce on display. We may call this as spectral based colorimetrical color reproduction. However, practically, it is impossible to set the same response of observer's visions, since the human visions are adapted to the white point #3 on the display. Chromatic adaptation and color appearance should be considered to match the color appropriately. The vector of tristimulus values $\boldsymbol{x} = [X', Y', Z']^t$ with the consideration of this adaptation can be written as,

$$\mathbf{x}' = \mathbf{A}_3^{-1} \mathbf{A}_2 \mathbf{x} \tag{4}$$

where $\boldsymbol{A}_2$, $\boldsymbol{A}_3$ are operator of chromatic adaptation and color appearance transformations for illuminant #2 and #3, respectively. The gamut mapping will be applied at the viewing independent color space in Eq. (4) as shown in Fig. 2. The operator $\boldsymbol{A}$ depends on the color appearance model used. In this paper, for the simplicity to explain, chromatic adaptation model in RLAB model[3] is described and used in the experiments.

At the chromatic adaptation model in RLAB model, the operator ***A*** under illuminant #2 can be written as,

$$\mathbf{A}_2 = \mathrm{RA}_2\mathrm{M} \tag{5}$$

where matrix M is the transformation to cone responses, matrix A is chromatic-adaptation transformation, matrix R is transformation to the reference viewing conditions. At the chromatic adaptation model in RLAB model, the incomplete adaptation is considered. The operator ***A*** for white point #3 is also calculated as,

$$\mathbf{A}_3 = \mathrm{RA}_3\mathrm{M} \tag{7}$$

Therefore, the Eq. (4) can be rewritten as

$$\mathbf{x}' = (\mathrm{RA}_3\mathrm{M})^{-1}\mathrm{RA}_2\mathrm{M}\mathbf{x} \tag{8}$$

These tristimulus values are converted into the digital counts for display based on the device profile that should be obtained or measured. The reproduced color on the display will match with the color of the real object under illuminant #2. We may call this as spectral based corresponding color reproduction.

Recently, to suppress the individual variation of color matching function, multi-primaries display technology is proposed by Hill at al. and Osawa et al.[13] For example,[13] using a 6-primary display and 2 sets of tristimulus values (i.e. 6-stimulus values) corresponding to the CIE 1931 and the CIE 1964 color mating functions, the reproduced color is matched for CIE 1931 and the CIE 1964 standard observers. The digital counts of the 6-primary display to reproduce a given set of 6-stimulus values of the object are uniquely determined by using a 6 by 6 matrix. The chromatic adaptation and color appearance transformations for this system are not developed at all, and will not be developed in near future. In this paper, the chromatic adaptation and color appearance transformations is applied to a part of color which is represented on conventional CIE 1931 color matching functions. The estimated spectral reflectance is divided into two parts that are sensed or not by the color matching functions as follows.

$$\mathbf{r} = T^{+}T\mathbf{r} + (I - T^{+}T)\mathbf{r} \tag{9}$$

where T^+ is the Moor-Penrose's generalized inverse of T. The first term on right hand side of Eq. (9) is the term sensed by the CIE 1931color matching functions. The term is again transformed into the tristimulus values. The chromatic adaptation and color appearance transformation is applied to the values, and transformed back into the spectral reflectance. The second term is not processed. The divided parts are combined, and transformed into the N-stimulus values. The N-stimulus values are converted into the digital counts for display based on the device profile.

Compatibility with sRGB System: Spectral Turn

Since there are many resources and devices of conventional RGB or CMYK imaging technology, it is difficult to change them into those of spectral imaging technologies. In this paper, we assumed the process of the camera system based on the sRGB system, and tried to apply the spectral based technique into the conventional system.

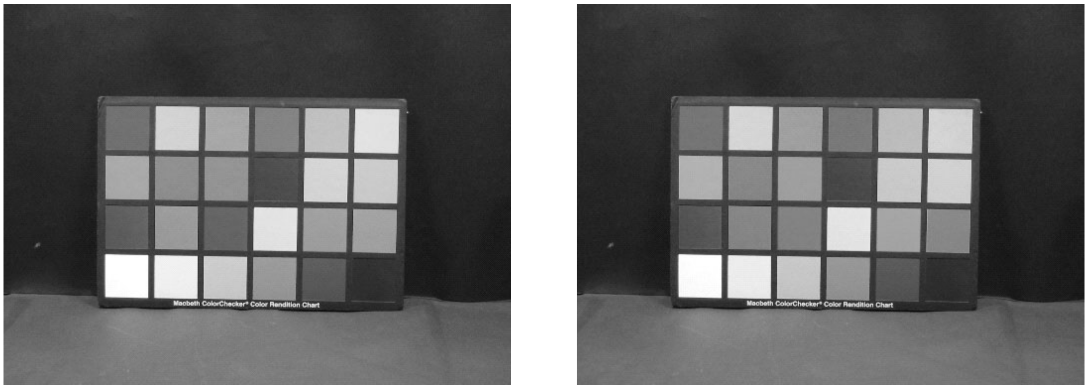
Figure 2 shows that process of spectral based processing for sRGB system. In this paper, the sRGB system is assumed to be designed to reproduce the appearance of color under the taken illuminant on the sRGB display with sRGB viewing conditions. Based on the process on spectral based color reproduction in Fig. 1, the process in the camera is assumed as the process surrounded by broken lines in Fig.2. From the camera, we just get the sRGB values, however, to reproduce the appearance of color under illuminant #1 on sRGB display, the process will be able to be divided into the colorimetrical part and part of chromatic adaptation and color appearance transformation, virtually.

To match the color under illuminant #2, it is necessary to process inversely into the spectral reflectance, and return to the sRGB value after the exchange of the illuminants. Figure 2 shows this process in detail, and we named this technique as spectral turn. Using appropriate samples to estimate the spectral estimation is a key technology to go beyond the conventional color correction techniques.

We performed preliminary experiment to confirm the effectiveness of the proposed technique. The Macbeth-Gretag color checker was taken under illuminant D65 by commercially available digital camera. The image taken is reproduced on sRGB display under sRGB environment, and confirmed that the color is reproduced correctly on sRGB display by haploscopic method. The image is transformed by spectral turn into the image which was assumed to be taken under illuminant A. Figure 3(a)(b) shows the image that are originally taken under illuminant D65 and are processed to match the object under illuminat A, respectively. By three subjects, we performed the subjective experiments to evaluate the processed images based on haploscopic method, where the color checker is illuminated by illuminant A. The results of subjective experiments showed that the most of the color is reproduced well by the proposed method. Unfortunately, blue in Macbeth color was not reproduced well in this experiment.

Conclusion

The proposed spectral tune technique has high lower compatibility to the conventional imaging technology, and could implement spectral based color reproduction.



(a) Original image taken under illuminant D65 *(b) Processed image to match the color under illuminant A*

Figure 3. An example of spectral turn by spectral based color reproduction for sRGB system

References

1. ICC (International Color Conortium), "Spec ICC.1:1998-09, File Format for Color Profiles," (1998)
2. IEC 61966-2-1 "Multimedia systems and equipment - Colour measurement and management - Part 2-1: Colour management - Default RGB colour space -sRGB" (1999).
3. M. D. Fairchild, Color Appearance Models, Addison-Wesley (1997).
4. B. A. Wandell, "The Synthesis and Analysis of Color Images," *IEEE Trans. PAMI PAMI-9*, pp.2-13 (1987).
5. M.J. Vrhel and H.J. Trussell, "Color Correction Using Principal Components," *Color Res. Appl.* **17** , p.328 (1992).
6. T. Shiobara, S. Zhou, H. Haneishi, N. Tsumura and Y. Miyake, "Improved color reproduction of electronic endoscopes" *J. Imag. Sci. and Tech*. **40**, pp.494-501 (1996).
7. H. Maitre, F. Schmitt, J.-P. Crettez, Y. Wu and J.Y. Hardeberg: *IS&T/CIC 4th Color Imaging Conference*, p.50 (1996).
8. F. H. Imai, N. Tsumura, H. Haneishi, and Y. Miyake, "Prediction of color reproduction for skin color under different illuminants based on the color appearance models", *J. Image Science and Technology* **41**, 2, pp.166-173(1997).
9. Y. Yokoyama, N. Tsumura, H. Haneishi, and Y. Miyake, J.. Hayashi, and M. Saito, "A new color management system based on human perception and its application to recording and reproduction of art printing," *IS&T/SID's 5th Color Imaging Conference*, pp.169-172(1997).
10. M. Yamaguchi, R. Iwama, Y. Ohya, T. Ohyama, Y. Komiya, "Natural color reproduction in the television system for telemedicine," *Proc. SPIE* **3031**, pp.482-489 (1997).
11. F. H. Imai and R. S. Berns, High-Resolution Multi-Spectral Image Archives: *IS&T/SID's 6th Color Imaging Conference*, pp.224-227(1998).
12. D. Nakao, N. Tsumura et al,. "Developing Java SDK for spectral image delivering based on generalized color matching, " *ICIS01* (Tokyo, 2002).
13. K. Ohsaw, F. Konig, M. Yamaguchi and N.Ohyama, "Multi-primary display optimized for CIE1931 and CIE1964 colormatching functions, " *Proceeding of AIC* (2001).
14. T. Kawaguchi, N. Tsumura, H. Haneishi, M. Kouzaki and Y. Miyake, "Vector Error Diffusion Method for Spectral Color Reproduction," *Proc. IS&T PICS99* pp.394-397 (1999)
15. D. Tzeng, Spectral-Based Color Separation Algorithm Development for Multiple-Ink Color Reproduction, Ph. D. dissertation, R. I. T., Rochester, N. Y. (1999)
16. L. A. Taplin and R. S. Berns, "Spectral color reproduction based on a six-color inkjet output system," *IS&T/SID's 9th Color Imaging Conference*, pp.209-213(2001).
17. Th. Keusen,"Multispectral color system with an Encoding Format Compatible with the conventional tristimulus model," *JIST* pp.510-515 (1996).

Biography

Dr. N. Tsumura is an associate professor of Chiba University. **Miss. K. Cherdhirunkorn and Mr. T. Ikeda** are master course students at Chiba University. **Dr. Y. Miyake** is a professor of Chiba University.