Spectrum based Color representation on Augmented Reality

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Abstract: As mobile devices have improved, many people have experienced augmented reality. However, an augmented object seems to be floated on real object because of color difference, shadow effect, and so on, and a lot of studies are conducted to overcome the problem. In this paper, we suggest augmented reality based on spectrum in a robust illumination. To display a spectral object on a RGB color display device, power spectrum of illumination and sensitivity of camera are obtained using an expanded marker which contains many colors. Evaluations are conducted by comparing relit color accuracy between conventional color correction and suggested method because the suggested method shows high accuracy and well color adaptation in illumination, it is expected to be used in various illumination condition.

1. Introduction

Augmented reality is to display the virtual object within real object on display devices, and we can easily access to augmented reality as development of mobile devices. However, the augmented object looks floating on the air due to difference of illumination, shadow, and so on. To overcome the problem, relighting the augmented object for appropriate color can be a solution. One of the conventional method for color correction uses a 3x3 color correction matrix mapping RGB to RGB. Since using the matrix for color correction is appropriate way, virtual objects with more information can give possibility for better color correction.

In this paper, we suggest augmented reality based on spectrum to adapt in robust to varying illumination. For spectrum-based relighting of the virtual object, environmental characteristics which contains power spectrum of illumination and spectral sensitivity of camera are obtained by using a color marker and its spectral reflectance. With obtained environmental characteristics, a virtual object which changes the color according to the color of light can be augmented.

We have performed experiments for a variety of purposes. Every experiment is conducted under the illumination which is created by 5-colors LEDs. For finding optimal condition of the suggested method, we compare color accuracy by the number of channels and color accuracy with suggested method and conventional method. By the comparison, the suggested method shows better color accuracy of the augmented object.

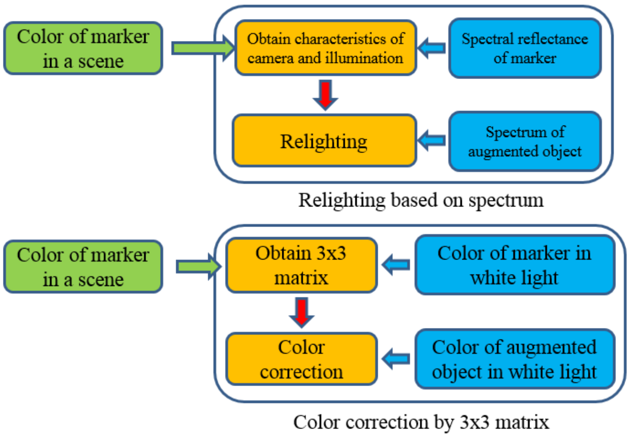

Figure 1. Flow chart of color correction method (up) and color suggested method (down).

2. Color correction

For relighting a virtual objects in varying illumination, color correction is used on the color of object. In this chapter, we will see how conventional color correction method and suggested method work. Flow charts of the methods can be seen in Figure 1.

2. 1 Color correction matrix

The color correction based on 3x3 matrix is shown in Equation 1. It uses RGB 3-channel input and RGB 3-channel output, so it makes up 3x3 correction matrix. By using the correction matrix, ratios between colors are adjusted, and colors are corrected.

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$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}, = \mathrm{A} \begin{bmatrix} R \\ G \\ B \end{bmatrix}. \qquad (1)$$

The correction matrix can be obtained through more than 3 RGB input and output values. For color correction, input values are obtained in white illumination, and output values are obtained in other illumination. With RGB values, the correction matrix A can be obtained by solving least square. With the matrix and other RGB values in white illumination, corrected RGB colors are obtained by simple matrix multiplication, so the corrected colors seems to be relighten.

2. 2 Relighting using spectral reflectance

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RGB images obtained by a camera can be simply expressed using a linear digital camera model.

$$I = \int c(\lambda)p(\lambda)s(\lambda)d\lambda. \qquad (2)$$

In this Equation, *I* is RGB values, *p* is power spectrum of illumination, *s* is spectral reflectance of object, and *c* is spectral sensitivity of camera. According to Equation 2, we can get RGB values by spectrum of illumination, spectral reflectance, and camera sensitivity. Although the spectral reflectance is invariable, illumination and camera spectrum is variable according to surrounding; illumination is changed by position and type of the light source, and camera sensitivity is changed by type of camera models, exposure time, white balance, and so on.

With known spectral reflectance that does not change, we can get RGB values in different lighting environments if we know the illumination and camera characteristics changed by each environment. To obtain the spectral characteristics, obtaining both of them at once is better than obtaining each of them separately, and it can be represented as Equation 3.

$$\mathrm{I} = \mathrm{S}(\mathrm{CP}). \qquad (3)$$

In this Equation, rows of CP and columns of S are the number of channels of spectrum, rows of I is the number of colors, and columns of CP are channels of camera. Equation 3 is the same form with Ax=b, and it is general form of optimization. To solve Equation with minimum squared error, least square is one of the typical way to solve this Equation. If the number of colors are larger than rank of CP, CP can be obtained by least squares as shown in Equation 4.

$$\mathrm{CP} = (\mathrm{S}^{\mathrm{T}}\mathrm{S})^{-1}\mathrm{S}^{\mathrm{T}}\mathrm{I}\,. \qquad (4)$$

By using the matrix CP, an object with known spectral reflectance can be relit by simple matrix multiplication.

3. Marker building

While experiments are conducted for relighting a virtual object, illumination is changed variously, and tracked marker must be found for coordinates and space for augmented object. In significant changes in lighting condition, tracking a colored marker will not work because predicting color difference and shape in those illuminations is impossible although colors are need for relighting. On the other hand, using a white and black marker always offers maximum and minimum values by camera in any illumination, so the marker allows tracking in a variety of lighting.

For non-trackable color marker, using the white and black marker for tracking, and access to color marker by geometric relation between them. For our test, we chose 20 colors, and it surrounds the black and white markers as it shows in Figure 2. With the printed marker, we can get spectral reflectance of 20 colors and we can find the multiplication of camera sensitivity and power spectrum of illumination by Equation 4.

Figure 2. Black-and-white marker with 20 colors.

Choosing 20 colors and geometric positional relationship with an achromatic color marker,
However, white and black can provide

4. Illumination and camera

In our experiments, we change illumination for evaluate relighting of virtual object. We use LEDs with five kinds of color, and each of them is white, blue, red, green, and amber. For general augmented reality, position of light source is not limited, so the marker is not exposed uniformed by illumination. However, we restricted partial shadow and specular components because it gave unexpected results.

For video capturing, we use general webcam Logitech C910, but fix white balance and exposure time.

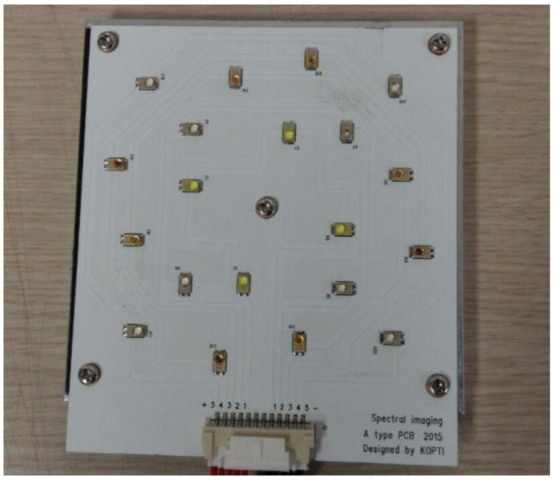

Figure 3. Illumination source consists of 20 LEDs with five kinds of color

5. Experimental results

Experiments are conducted for color correction by correction matrix and relighting with spectral reflectance. To get power spectrum of illumination and camera sensitivity, least square is chosen to optimization, and the number of spectrum channels are 9, 12, and 18 along 380nm-730nm. Each steps of channel is 40nm, 30nm, and 20nm.

For relighting an augmented object, standard color of the object must be chosen, and correction matrix method and suggested method need different type of color data. To make correction matrix, twenty input colors are selected in white light, and color of augmented object is the same with a white paper. Unlike the correction matrix, suggested method uses spectrum of white paper.

We evaluate relighting methods in two ways. One finds color difference of augmented object between previous and current frames for checking whether the proposed method is robust to noise or not. If the color difference is larger, relit color is weak from the noise, and it is not appropriate for relighting. Table 1 shows color variations of the marker and augmented object which is made by correction matrix and by suggested method, between the frames. As shown in Table 1, color of marker has the minimum color difference, and the color difference of augmented object is larger than it. When the difference of color is under 1.0 value, the observation cannot distinguish color variation, and suggested method with nine channels is better than 12, 18 channels.

Table 1. Color difference of augmented object per frame rate

		Difference of color between the frames
Color of the marker		0.28613
Correction matrix		0.32592
Suggested method	9 channels	0.99070
	12 channels	3.22270
	18 channels	29.29240

For evaluation relighting methods, the other finds color accuracy between the suggested method and the conventional color correction method. In order to measure the error, we set color of white paper as reference. The error can be calculated by the color difference between the white paper and the corrected color of virtual object. We conduct an experiment with five illumination, and Table 2 shows the CIE Lab errors under each illumination. Equation 5 shows CIE Lab errors.

$$\Delta E_{ab}^{*} = \sqrt{(L_2 - L_1)^2 + (a_2 - a_1)^2 + (b_2 - b_1)^2}. \quad (5)$$

Table 2. Comparison between Lab errors of 5 illuminations.

Illumination	Correction matrix	suggested
Blue	15.3253	5.6361
Amber	1.2653	2.7724
Green	21.2281	5.8403
Red	9.8586	4.3194
White	18.2580	3.1832
average	13.1871	4.3503

Comparison of the color error shows that suggested method is better in color expression than conventional correction. Figure 4, 5 show the results of color correction and suggested method, respectively.

14. Conclusion

In this paper, we showed augmented reality whose color is changed according to the lighting. By using spectrum information and color marker, we proposed accurate color representation method and compared color accuracy. In the experimental results, we verified that the proposed method can help users can realistically feel the augmented reality in various illumination changes.

Figure 4. Color correction by correction matrix in red, green blue, and amber light.

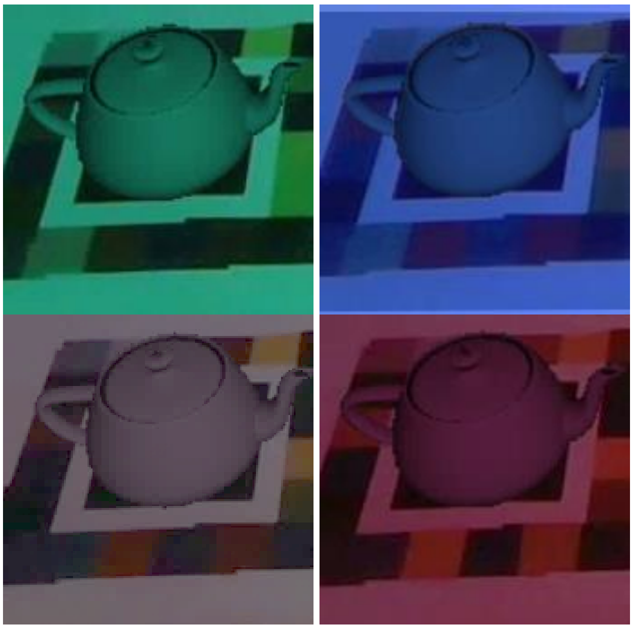

Figure 5. Relighting by suggested method in red, green, blue, and amber light.

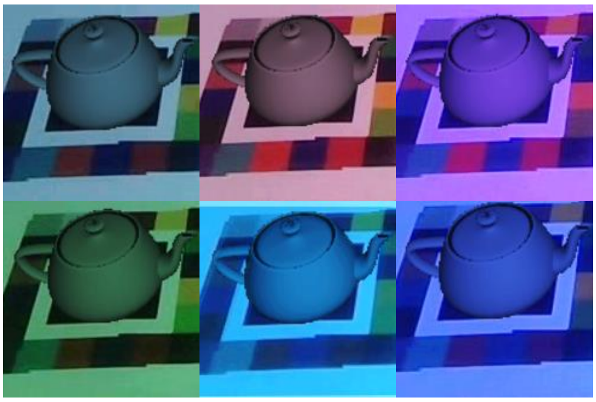

Figure 6. Relighting by suggested method in various lights

Acknowledgements

This research is supported by Ministry of Culture, Sports and Tourism (MCST) and Korea Creative Content Agency (KOCCA) in the Culture Technology (CT) Research & Development Program

References

[1] J. Jiang and J. Gu, “Recovering spectral reflectance undercommonly available lighting condition,” IEEE Computer Society Conference, pp. 1-8, 2012.
[2] J. PS. Parkkinen, J. Hallikainen, and T. Jaaskelainen, “Characteristic spectra of Munsell colors,” Journal of the Optical Society of America A, Vol. 6, Iss. 2, pp. 318-322, 1989.
[3] C.L. Lawson and R.J. Hanson, “Solving least squares problem, Prentice-hall, NewJersey, Englewood Cliffs. 1974