Color Correction for Projected Image on Colored Screen Using Correction Matrix Based on Camera

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Abstract
Recently, projectors are one of the most common display device for using presentation at office and class, entertainment at home, and theater. The use of mobile projector expanded the applications such as meeting at field and presentation on the spot. The images are not always projected on white screen, causing color distortion. Various algorithms have been proposed to correct the projected color the same as that on white screen. However, previous algorithms have limitation such as real-time performance due to high computational complexity and use of measurement equipment as well as lack of accuracy due to the use of matrix obtained by simple linear method. Accordingly, color correction method using a camera is proposed to match the color between on white and colored-screen. This method has advantage at the accurate color reproduction on colored-screen by using ramp patches and regression method. It is differ from previous method using only two or three patches. In the proposed method, ramp patches for each channel are first projected on a white and colored screen, then captured by a camera, respectively. Next, each ramp patch on colored screen is related with that on white screen which have the same digital values obtained by the camera. This procedure provides quantity of color shift between on white and colored screen. After that, a color correction matrix is obtained by regression method using the relationship above. In our experimental results, modified images using proposed method on colored screen have better performance than previous methods focused on objective and subjective evaluation.

Introduction
Projectors are device to display images or videos onto a screen or wall. These are usually used at dark room because the images on screen are influenced a lot from exterior environment. For example, outdoor lights provide the deterioration of image perception. Therefore these devices are usually used for screening movies in a theater or presentation at dark office with white screen. However, miniaturization of projectors induces the production of mobile projectors, extending to lots of applications. Users can have meeting anywhere when they want, display blueprint at field, and enjoy movies at any places. In these utilization, images are not always projected on white screen, usually projected on light colored-screen, such as ivory or light blue wall. This condition allows color shift toward color on the wall, causing color distortion. Therefore, a color correction algorithm is necessary to get the image on colored wall which have the same color on white wall. Various color correction algorithms have already been introduced.[1]-[4] Bimber et al.[1] proposed a color correction method that identifies the electro-optical transfer function (EOTF) for both the camera and projector, then divided the luminance values of the original image by those of the captured color screen. Nayar et al.[2] proposed a radiometric model of the projector-camera system, where a color correction matrix is obtained by varying the RGB values for the captured arbitrary screen. Tsukada and Tajima[3] also proposed a color correction method using a chromatic adaptation model or color appearance model. Input digital value for projector on colored-screen is estimated by color appearance model. Son et al.[4] proposed method using color constancy varying the ratio of chromaticity values for each channel between the captured arbitrary screen and white screen images. However, previous algorithms have limitation such as real-time performance due to high computational complexity and use of measurement equipment as well as lack of accuracy due to the use of matrix obtained by simple linear method.

Accordingly, we propose color correction method for projected images on colored-screen. A camera is used to inter the color shift between white and colored screen. This method has advantage at the accurate color reproduction on colored-screen by using ramp patches and regression method. This is differ from previous method using only two or three patches. In the proposed method, ramp patches for each channel are first projected on a white and colored screen, then captured by a camera, respectively. Next, each ramp patch on colored screen by a camera is related with that on white screen which have the same digital values obtained by the camera. Then, through the relationship we find input digital values of ramps on colored-screen that is corresponding to input digital values of ramps on white screen. After that, a color correction matrix is obtained by regression method using input digital values on white and corresponded values on colored-screen.

Color Correction Method for Colored-screen
This paper proposed color correction method for projected image using color matching with camera. This
Color correction process based on projector characterization uses color correction matrix by regression using relationship between input digital values on white and colored screen. This relationship presents quantity of color shift between on white and colored screen. To verify color correction method using regression, we used characterization-based method for color correction.

**Color Correction Method Based on Characterization for Projector**

Color distortion is occurred when projectors may project an image on arbitrary surfaces, such as colored walls and papers, not only on a white screen. We solved this problem by estimating the tristimulus values of projected image on colored-screen. Color correction process based on projector characterization is shown in figure 1. First, projector characterization process onto white and colored-screens must be followed. Next, we estimate input digital values RGB on colored screen by using inverse-characterization onto colored-screen which have same CIEXYZ values with input signal RGB values on white screen. Then $3 \times 3$ color correction matrix is obtained by linear regression[5] using RGB and RGB values.

Characterization for projector process is as follows. After, input 16 steps RGB patches for each channel are projected on white and arbitrary colored-screen. Then we estimate linear tone curve corresponding to CIEXYZ values using s-curve model to correct non-linear characteristic between RGB and CIEXYZ values. The forward model accepts RGB digital value and predicts CIEXYZ value projected onto white and arbitrary screen. The forward model is presented in Eq. (1)[6].

$$
\begin{align*}
R & = rLUT(R) \\
G & = gLUT(G) \\
B & = bLUT(B)
\end{align*}
$$

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$$
\begin{align*}
R & = rLUT(R) \\
G & = gLUT(G) \\
B & = bLUT(B)
\end{align*}
$$

Where $X,Y,$ and $Z$ are measured tristimulus values and subscripts $RG$ and $B$ are full red, full green, and full blue. $R,G,$, and $B$ is linear scalar values corresponding to $R,G,$ and $B$ . ’’C’’ indicates that black correction has been applied. For example, the calculation for black corrected $XYZ$ values is shown in Eq. (4). And the inverse model accepted by inverting matrix $M$.

$$
X' \begin{bmatrix}
X' \\
Y' \\
Z'
\end{bmatrix} = M \begin{bmatrix}
R' \\
G' \\
B'
\end{bmatrix}
$$

$$
M = \begin{bmatrix}
X_e^C & X_g^C & X_b^C \\
Y_e^C & Y_g^C & Y_b^C \\
Z_e^C & Z_g^C & Z_b^C
\end{bmatrix}
$$

$$
\begin{bmatrix}
X_e' \\
Y_e' \\
Z_e'
\end{bmatrix} = \begin{bmatrix}
X_e - X_k \\
Y_e - Y_k \\
Z_e - Z_k
\end{bmatrix}
$$

$R,G,$, and $B$ are pushed through the inverse of Eq.(1) to return RGB values. As a result, we estimate $RG,B$ values screen using inverse-characterization onto colored-screen which are input signals for projector on colored-screen that have same CIEXYZ values with input signal RGB values on white screen. Figure 2 shows the relationship between $R$ and $R_e$. Where and $R_e$ are $R$ channel input on white screen and light green screen. Therefore, $3 \times 3$ color-correction matrix is obtained using linear regression by using RGB and $RG,B_i$. 

$$
P = V^T \alpha
$$
Figure 3. Workflow of camera-based color correction

![Diagram showing workflow of camera-based color correction](image)

Where \((R_1, R_2, ..., R_n)\) is \(R\) channel input digital value of projected image on white screen and \((R_1, R_2, ..., R_n)\) present \(R\) channel input digital value of projected image on colored-screen which have same \(CIE\, XYZ\) values onto input signal \(RGB\) values on white screen. \(n\) is number of used samples. Coefficients of linear regression is calculated by Eq.(10).

\[
\alpha = \left(VV^T\right)^{-1}VP \tag{6}
\]

In this process, we obtained a \(3 \times 3\) color correction matrix about a colored-screen. Then color corrected image on colored-screen is obtained by applying inverse \(3 \times 3\) color correction matrix to original image.

Color Correction Method based on Color Matching with Camera

Color correction method based on characterization for projector is explained. However, this method cannot use without characterization onto arbitrary screen. Thus, it is difficult to use in real time process. Accordingly, we propose color correction method for projected images on colored-screen. A camera is used to inter the color shift between white and colored screen. Figure 3 shows workflow the proposed method. This method consists of following steps. First, 9 ramp patches for each channel are projected on white and arbitrary colored-screen, then captured by a camera, respectively. After that, we calculate average digital value for captured each patch by a camera. Next, we find patch which is same digital value \(RGB\) on white and colored-screen. Then, we find input digital values \(RGB\) of ramps on colored-screen that is corresponding to input digital values \(RGB\) of ramps on white screen. After then, \(3 \times 3\) color-correction matrix is obtained by linear regression by using input digital values which are \(RGB\) and \(RGB\). This procedure is same with eq(6)-eq(10). Figure 4 shows the relationship between \(R\) and \(R\). Where \(R\) and \(R\) are \(R\) channel input on white and light green screen. Finally, corrected image on colored-screen is obtained by applying inverse \(3 \times 3\) color correction matrix to original image.

Experiments

To carry out an experimental evaluation for the proposed algorithm, LG RD-JT90 DLP projector was used as a testing device. Colored paper are replaced the colored screens, where single color surfaces. Evaluation of proposed method is performed by observer’s preference test and quantitative analysis. Figure 5 shows the results of corrected image on uniform sky color paper using Son’s and proposed method. The projected image on green colored paper included green color, as shown in Figure 5(b), and its image compared with projected image on white paper in Figure 5(a). Figure 5(c) shows the result of corrected image using Son’s method and Figure 5(d) shows the result of corrected image using proposed method. For quantitative evaluation, table 1 shows comparison of chromaticity error between previous method and proposed method. Therefore, the image quality of the projected image can be improved, compared to that of the projected image on a white screen. In our experimental results our proposed method shows the better performance than previous methods focused on objective and subjective evaluation.

Conclusion

This paper proposes color correction method for projected images on colored-screen. A camera is used to find the color shift between white and colored screen. We use 9 ramp patches for each channel. Each ramp
patch on colored screen by a camera is related with that on white

![Image](a)

![Image](b)

![Image](c)

![Image](d)

Figure 5. Resulting images using color correction algorithm; (a) Original image on white screen, (b) original image on green screen, (c) corrected image on green screen by Son’s method, (d) corrected image on green by proposed method.

screen which have the same digital values obtained by the camera. Then, through the relationship we find input digital values of ramps on colored-screen that is corresponding to input digital values of ramps on white screen. After that, a color correction matrix is obtained by regression method using input digital values on white and corresponded values on colored-screen. In our experimental results, modified images using proposed method on colored screen have better performance than previous methods focused on objective and subjective evaluation.

<table>
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<tr>
<th>Table 1. Evaluation of color compensation for green screen</th>
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<td>r chromaticity</td>
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<tr>
<td>Original (white)</td>
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<tr>
<td>Original (green)</td>
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<tr>
<td>Son’s method</td>
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<td>Proposed method</td>
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<td>g chromaticity</td>
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<tr>
<td>Original (white)</td>
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<td>b chromaticity</td>
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<td>Original (white)</td>
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<td>Original (green)</td>
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<td>Son’s method</td>
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<td>Proposed method</td>
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<td>Chromaticity error</td>
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Acknowledgement

This research is supported by Ministry of Culture, Sports and Tourism (MCST) and Korea Content Agency (KOCA) in the Culture Technology (CT) Research and Development Program 2010 this work was supported by the fourth phase of the Brain Korea 21 Program in 2010.

References


Biography

Dae-Chul Kim B. S. and M. S. degrees in Electronic Engineering from Kyungpook National University, Taegu, Korea, in 2007 and 2010, respectively, and now is Ph. D. degree student in Electronic Engineering from Kyungpook National University. His main research interests are in color image processing and image processing.

Yeong-Ho Ha received the B. S. and M. S. degrees in Electronic Engineering from Kyungpook National University, Taegu, Korea, in 1976 and 1978, respectively, and Ph. D. degree in Electrical and Computer Engineering from the University of Texas at Austin, Texas, 1985. In March 1986, he joined the Department of Electronics Engineering of Kyungpook National University and is currently a professor. He served as TPC chair, committee member, and organizing committee chair of many international conferences held in IEEE, SPIE, and IS&T and domestic conferences. He served as president and vice president in Korea Society for Imaging Science and Technology (KSIST), and vice president of the Institute of Electronics Engineering of Korea (IEEK). He is a senior member of IEEE and a member of Pattern Recognition Society and Society for IS&T and SPIE, as well as a fellow of IS&T in 2009. His main research interests are in color image processing, computer vision, and digital signal and image processing.