Color Correction for Projected Image on Colored-screen
Based on a Camera

Dae-Chul Kim, Tae-Hyoung Lee, Myong-Hui Choi, and Yeong-Ho Ha

School of Electronics Engineering, Kyungpook Natl. Univ.,
1370, Sankyuk-dong, Buk-gu, Taegu 702-701, South Korea;
Department of Multimedia, Daegu Polytechnic College Univ.,
42 Jinri-2gil, Suseong-gu, Taegu 706-711, South Korea

ABSTRACT

Recently, projector is one of the most common display devices not only for presentation at offices and classes, but for entertainment at home and theater. The use of mobile projector expands applications to meeting at fields and presentation on any spots. Accordingly, the projection is not always guaranteed on white screen, causing some color distortion. Several algorithms have been suggested to correct the projected color on the light colored screen. These have limitation on the use of measurement equipment which can’t bring always, also lack of accuracy due to transform matrix obtained by using small number of patches. In this paper, color correction method using general still camera as convenient measurement equipment is proposed to match the colors between on white and colored screens. A patch containing 9 ramps of each channel are firstly projected on white and light colored screens, then captured by the camera, respectively. Next, digital values are obtained by the captured image for each ramp patch on both screens, resulting in different values to the same patch. After that, we check which ramp patch on colored screen has the same digital value on white screen, repeating this procedure for all ramp patches. The difference between corresponding ramp patches reveals the quantity of color shift. Then, color correction matrix is obtained by regression method using matched values. Differently from previous methods, the use of general still camera allows to measure regardless of places. In addition, two captured images on white and colored screen with ramp patches inform the color shift for 9 steps of each channel, enabling accurate construction of transform matrix. Nonlinearity of camera characteristics is also considered by using regression method to construct transform matrix. In the experimental results, the proposed method gives better color correction on the objective and subjective evaluation than the previous methods.

Keywords: Projector, color correction, colored-screen

1. INTRODUCTION

Projection display technology has undergone a revolution in terms of resolution, brightness, and miniaturization. Such elements brought to the development of portable projectors and even phone embedded ones. These devices allow the consumer to always carry and use projectors: anytime, anywhere. However, during use, color fidelity of the projector relies on the surrounding environments characteristics, such as ambient illuminant and projection surface. In particular images are not always projected on a white screen, instead the projection unusually happens on light colored surfaces such as an ivory or light blue wall. Therefore, portable or mobile beam projectors are being confronted with incorrect color reproduction due to the influence of the colored surface. Therefore, this paper presents a color correction method for projection on colored surfaces.

Various algorithms have been proposed previously reproducing compensated images on colored screens by changing the pixel values of original images[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 a correction 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 present limitations such as the possession of the measurement equipment. Also, the number of measurement is performed with the same number of patches. In addition, use of transform matrix obtained by two or three patches for each channel induces inaccurate color reproduction on colored screen compared with image on white screen.

In this paper, a color correction method using general still camera for projected images on colored-screen is proposed. Initially, a patch containing ramps of each channel is projected both on a white and colored screen, then captured by camera. Next, digital values are obtained by the camera for each ramp patch on both screens, resulting in different values for the same patches. After that, we check which ramp patch on colored screen has the same digital value on white screen, repeating this procedure for all ramp patches. Difference between checked ramp patches reveals the quantity of color shift. Finally, color correction matrix is obtained by regression method using each ramp value on white and corresponded ramp on colored-screen.

2. PROPOSED COLOR CORRECTION METHOD

We proposed color correction method for projected image using a camera. This method enables a projector to achieve color reproduction on a colored screen close to that on white screen. A new color correction matrix is used to relate between input digital values on white and colored screen. This matrix represents the quantity of color shift between images projected on different surfaces. Proposed method is performed using a specral-radiometer first to have the confidence in the procedure. Then, to achieve our object without characterization process, we replace measurement device for characterization with a camera.

2.1 Color correction method using characterization model

In order to solve the color correction problem we first approach it by using a projector characterization model. The problem is solved by obtaining the same tristimulus values for an image projected on different surfaces. The process is shown in figure 1.

![Figure 1. Color correction using characterization model.](image_url)
First, projector characterization is performed for both white and colored projection surfaces. Tristimulus values are obtained by the measurement device (a CS-1000 spectro-radiometer) for each ramp patch on each of the surfaces, resulting in different values for the same patch. After that, we check patch on colored screen which has the same tristimulus value on white screen, repeating this procedure for all ramp patches. Then, we check input digital values \((R,G,B)\) on colored screen by using inverse-characterization onto colored-screen which are corresponding to input digital values \((RGB)\) on white screen. Then 3×3 color correction matrix is obtained by linear regression using \(RGB\) and \(R,G,B\) values[5]. A distinct characterization model is computed for each of the two projection surfaces in the following way. Input 16 steps ramp patches for each channel are first measured for each screen. Then we estimate linear tone curve corresponding to \(CIEXYZ\) values by using the s-curve model. The forward model to predict \(CIEXYZ\) values projected onto white and colored screen is presented as follows[6].

\[
\begin{align*}
R &= S_R(R) \\
G &= S_G(G) \\
B &= S_B(B)
\end{align*}
\]

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

\[
M = \begin{bmatrix}
X_R^C & X_G^C & X_B^C \\
Y_R^C & Y_G^C & Y_B^C \\
Z_R^C & Z_G^C & Z_B^C
\end{bmatrix}
\]

\[
\begin{bmatrix}
X_R \\
Y_R \\
Z_R
\end{bmatrix}^C = \begin{bmatrix}
X_R - X_K \\
Y_R - Y_K \\
Z_R - Z_K
\end{bmatrix}
\]

where subscripts \(R, G,\) and \(B\) are maximum red, maximum green, and maximum blue. \(R', G',\) and \(B'\) are linear scalar values corresponding to \(R, G,\) and \(B\). \(C\) indicates black correction which is performed as per Eq. (4). The inverse characterization model is shown in the following equation.

\[
\begin{bmatrix}
R' \\
G' \\
B'
\end{bmatrix} = M^{-1} \begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix}
\]

After characterization, tristimulus values are obtained using the same ramp patches on each screen. Then, we check to patches between on white and colored screen which have the same tristimulus values. Accordingly, we can obtain input digital values \((R,G,B)\) on colored screen by using inverse-characterization which are corresponding to input digital values \((RGB)\) on white screen. Figure 2 explains the relationship between input digital values on for white and colored surfaces.
At the final stage, a $3 \times 3$ color-correction matrix is obtained by using the relationship between $RGB$ on white and $R_iG_iB_i$ on colored screen. Regression is used to estimate the matrix as per the following equation.

\[ P = V^T \alpha \]  \hspace{1cm} (6)

where

\[ V = \begin{bmatrix} R_1 & \cdots & R_s \\ G_1 & \cdots & G_s \\ B_1 & \cdots & B_s \end{bmatrix} \]  \hspace{1cm} (7)

\[ \alpha = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{bmatrix} \]  \hspace{1cm} (8)

\[ P = \begin{bmatrix} R_1 & G_1 & B_1 \\ \vdots & \vdots & \vdots \\ R_n & G_n & B_n \end{bmatrix} \]  \hspace{1cm} (9)

where $(R_1, R_2, \ldots, R_s)$ are the input digital values for $R$ on white screen and $(R_1, R_2, \ldots, R_n)$ are the input digital values for $R_i$ on colored-screen having the same $CiEXYZ$ values on white screen. $n$ is the number of used samples. The coefficients for the computed matrix are as follows.

\[ \alpha = (V V^T)^{-1} V P \]  \hspace{1cm} (10)

The resulting images are obtained by applying the inverse $3 \times 3$ color correction matrix. Figure 3 shows the results of color correction for uniform light green color paper using characterization method. This image clearly shows a color reproduction close to that obtained by using a white screen.
2.2 Color correction by using camera

Projector characterization, and the subsequent calibration, usually cannot be performed by the average user due to time, location and equipment constraints. To overcome the problem, we propose color correction method using a digital camera. The camera is used to estimate the color shift between a reference white screen and colored projection surface. Workflow is shown in Figure 4.

First, a patch containing 9 ramps of each channel are projected on white and arbitrary colored-screen, then captured by a camera, respectively. Next, digital values are obtained by the camera for each ramp patch on both screens, resulting in different values to the same patch. After that, we check ramp patch on colored screen using linear interpolation which has the same digital value on white screen, repeating this procedure for all ramp patches. Table 1 shows RGB digital values by camera on white and green screen. Then, we check input digital values $R, G, B$ of ramps on colored-screen that is corresponding to input digital values $RGB$ of ramps on white screen. The $3 \times 3$ color-correction matrix is then obtained by linear regression using $RGB$ and $R, G, B$. Regression is performed as described for the characterization based method, Eq. (6)-(10). Check-up results are shown in Figure 5. Finally, the resulting images are obtained by applying the inverse color correction matrix. As a result, real time process is possible to apply current devices.
Table 1. RGB digital values for R channel ramps by camera on white and green screen.

<table>
<thead>
<tr>
<th>Input digital value on white</th>
<th>Captured values on white by camera</th>
<th>Captured values on green by camera</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>G</td>
<td>B</td>
</tr>
<tr>
<td>48</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>68</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>88</td>
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<tr>
<td>148</td>
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<td>0</td>
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<tr>
<td>168</td>
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<td>0</td>
</tr>
<tr>
<td>188</td>
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<td>0</td>
</tr>
<tr>
<td>208</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 5. Relationship between each channel input on white and green screen.

3. EXPERIMENTAL RESULTS

To carry out an experimental evaluation for the proposed algorithm, LG RD-JT90 DLP projector was used. Four light colored papers have been used as projection surfaces. Evaluation of the proposed method is performed by quantitative analysis and observer’s preference test. Figure 6 shows the comparison of Son’s and proposed method using light green screen. Figure 6(a) is the original image on white screen, Figure 6(b) is the same image on the green colored screen.
Figure 6(c) and (d) shows the result of Son’s method compared to the proposed one. Corrected image using proposed method on green screen is more similar to original image on white screen than Son’s method. Quantitative evaluation is performed by comparing chromaticity errors in Table 2. Chromaticity errors for the proposed method are less than for Son’s method. Also in subjective evaluation using observer’s preference test, the proposed method shows better performance than others.

Table 2. Evaluation of color compensation for green screen.

<table>
<thead>
<tr>
<th></th>
<th>Original (white)</th>
<th>Original (green)</th>
<th>Son’s method</th>
<th>Proposed method</th>
</tr>
</thead>
<tbody>
<tr>
<td>r chromaticity</td>
<td>0.3389</td>
<td>0.3573</td>
<td>0.3376</td>
<td>0.3436</td>
</tr>
<tr>
<td>g chromaticity</td>
<td>0.3339</td>
<td>0.3694</td>
<td>0.3633</td>
<td>0.3535</td>
</tr>
<tr>
<td>b chromaticity</td>
<td>0.3271</td>
<td>0.2733</td>
<td>0.2991</td>
<td>0.3029</td>
</tr>
<tr>
<td>Chromaticity error</td>
<td>0</td>
<td>0.1076</td>
<td>0.0587</td>
<td>0.0486</td>
</tr>
</tbody>
</table>

4. CONCLUSION

This paper proposes a color correction method for images projected on colored surfaces. To achieve our object without characterization process, we replace measurement device for characterization with a digital camera. We estimate a $3 \times 3$ color correction matrix by linear regression using input digital values which produce the same color on both white and colored screen. Differently from previous methods, the use of general still camera allows to measure regardless of places. In addition, two captured images on white and colored screen with ramp patches inform the color shift for 9 steps of each channel, enabling accurate construction of the transform matrix. Nonlinearity of camera characteristics is also considered by using regression method to construct a transform matrix. In the experimental results, corrected image using the proposed method on colored screen have shown better performance than previous methods in both objective and subjective evaluations.
ACKNOWLEDGEMENT

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 2009

REFERENCES