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Color Correction Using a Still Camera for Images Projected onto a Light Colored Screen

Dae-Chul Kim, Tae-Hyoung Lee▲, Ho-Gun Ha and Yeong-Ho Ha▲
School of Electronics Engineering, Kyungpook National University,
1370 Sankyuk-dong, Buk-gu, Daegu 702-701, Korea
E-mail: E-mail: yha@ee.knu.ac.kr

Abstract. *Recently, projectors have become among the most common display devices not only for presentations at offices and in classes, but also for entertainment at home and in the theater. The use of mobile projectors expands applications to meetings in the field and presentation anywhere. Accordingly, projection is not always guaranteed to occur on a white screen, thereby introducing the possibility of some color distortion. In this article a general color correction method using a still camera as a convenient measuring device is proposed in order to match the colors between projections on white and light colored screens. The color correction is implemented using the proposed matrix which converts the input color to the resulting color appropriate for the colored screen. The proposed color correction matrix is estimated by linear regression using input digital values measured on the white and colored screens, thereby producing the same color on both the white and light colored screens. In addition, the calibration image contains information for nine steps in each color channel, enabling accurate construction of the transform matrix. In experimental results, the proposed method gives better color correction for both the objective and subjective evaluations than does a representative previous method. © 2011 Society for Imaging Science and Technology.*
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INTRODUCTION

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

Various algorithms have been proposed previously to reproduce compensated images on colored screens by changing the digital red-green-blue (*RGB*) values of original images.[1–7] Bimber and Emmerling proposed a color correction method that identifies the electro-optical transfer function for both the camera and projector and then divides the luminance values of the original image by those of the captured color screen.[1] Nayar et al.[2] and Grossberg et al.[3] proposed a color correction method using the radiometric model of a projector-camera system, where the radiometric model was represented using a single nonlinear monotonic response function. This means that the mapping function from input digital space to captured digital space can be created by displaying a set of 255 display images on a colored screen in quick succession and recording their corresponding camera images. Ashdown et al. proposed a color compensation method based on both a radiometric model and the content of the image.[4] Renani et al. presented the performance of screen compensation based on Nayar et al.[2] and Ashdown et al.[4] with five different camera characterization methods.[5] Tsukada and Tajima proposed a color correction method using a chromatic adaptation model or a color appearance model.[6] Input digital values for projection on a colored screen are estimated by a color appearance model. Son proposed a correction method using color constancy, varying the ratio of chromaticity values for each channel between a captured white patch on an arbitrary screen and on a white screen.[7] However, previous algorithms present limitations such as the possession of the measurement equipment and the necessity of precalibration between the projector and camera. In addition, the transform matrix of Son's method obtained only from a white patch yields inaccurate color reproduction on colored screens.

In this article, a color correction method using a generic still camera as a convenient measurement equipment is proposed. First, a test image containing a ramp of nine patches for each color channel is projected on white and light colored screens. Next, a camera captures the image containing the ramp of nine patches for each channel both on the white screen and then on the light colored screen, independently. After that, we estimate the color shift by verifying for each channel the correspondence of values taken from the white screen to those taken from the light colored surface. Finally, the color correction matrix is obtained by a regression method comparing each ramp value on the white screen and the corresponding value on the light colored screen.

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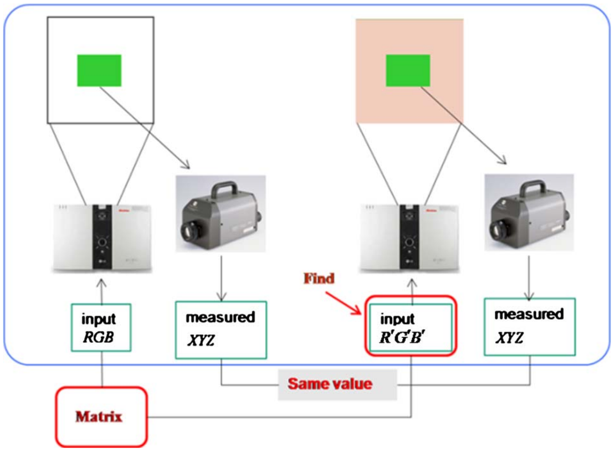

Figure 1. Color correction using characterization model.

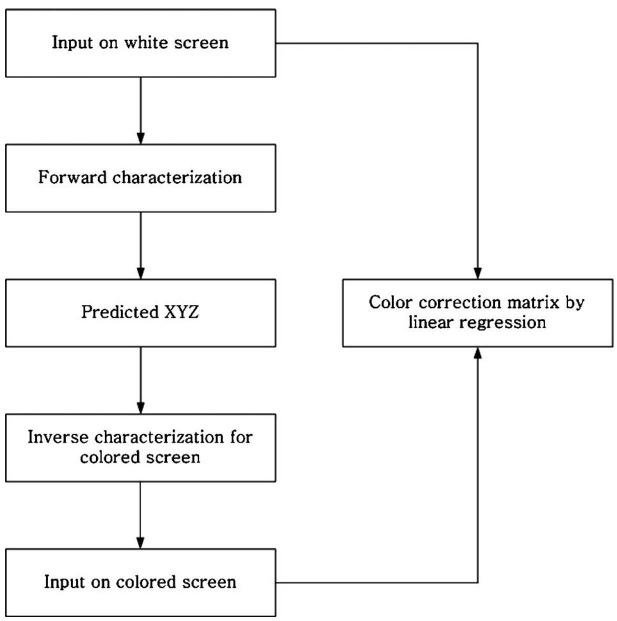

Figure 2. Workflow of color correction using characterization model.

PROPOSED COLOR CORRECTION METHOD

We have proposed a color correction method for a projected image using a digital camera as a measuring device. This method enables a projector to achieve color reproduction on a light colored screen close to that on a white screen. A new color correction matrix is used to relate input digital values on the white and light colored screens. This matrix represents the quantity of color shift between images projected on different surfaces. To verify the feasibility of the method we first arrange a more traditional setup, using a spectroradiometer and a projector characterization model. Then, to achieve our objective without a characterization process, we replace the measurement device with a camera.

Color Correction Method Using the Characterization Model

In order to solve the color correction problem, our first approach was using a projector characterization model. In this case, the device characterization derives the relationship between device-dependent and device-independent color representations for a calibrated device. The problem is solved by obtaining the same tristimulus values for an image projected on different surfaces. This process is shown in Figure 1, and the workflow is shown in Figure 2. First, the projector characterization is performed for both white and light colored projection surfaces, where 16-step ramp patches are projected on both screens. The tristimulus values are then obtained for each ramp patch on each screen using a measurement device (CS-1000 spectroradiometer), resulting in different values for the same patch. Next, we estimate the linear tone curve corresponding to the *CIEXYZ* values from the Commission Internationale de l'Éclairage (CIE) using the S-curve model.[8] The forward model used to predict the *CIEXYZ* values projected on the white and colored screens is as follows:

$$\hat{R} = S_r(R),$$

$$\hat{G} = S_g(G),$$

$$\hat{B} = S_b(B), \tag{1}$$

where $S(\,)$ is a function for each digital *RGB* to luminance for each channel. $\hat{R}$, $\hat{G}$, and $\hat{B}$ are linear scalar values corresponding to R, G, and B. *CIEXYZ* values are estimated using the following equations:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = M \begin{bmatrix} \hat{R} \\ \hat{G} \\ \hat{B} \end{bmatrix}, \tag{2}$$

$$M = \begin{bmatrix} X_{\mathrm{RM}}^{C} & X_{\mathrm{GM}}^{C} & X_{\mathrm{BM}}^{C} \\ Y_{\mathrm{RM}}^{C} & Y_{\mathrm{GM}}^{C} & Y_{\mathrm{BM}}^{C} \\ Z_{\mathrm{RM}}^{C} & Z_{\mathrm{GM}}^{C} & Z_{\mathrm{BM}}^{C} \end{bmatrix}, \tag{3}$$

where $X_{\mathrm{RM}}, Y_{\mathrm{RM}}, Z_{\mathrm{RM}}$ are tristimulus values of the red channel at its maximum intensity, and likewise for green and blue. "C" indicates a black correction which is performed as per Eq. (3). For example, the calculation for dark corrected *XYZ* values is shown in Eq. (4) for the red channel. The same equation could be applied to green and blue. The subscript K indicates the measured black values,

$$\begin{bmatrix} X_R \\ Y_R \\ Z_R \end{bmatrix}^C = \begin{bmatrix} X_R - X_K \\ Y_R - X_K \\ Z_R - X_K \end{bmatrix}, \tag{4}$$

where the same equation could be applied to R, G, and B. The inverse characterization model is shown in the following equation:

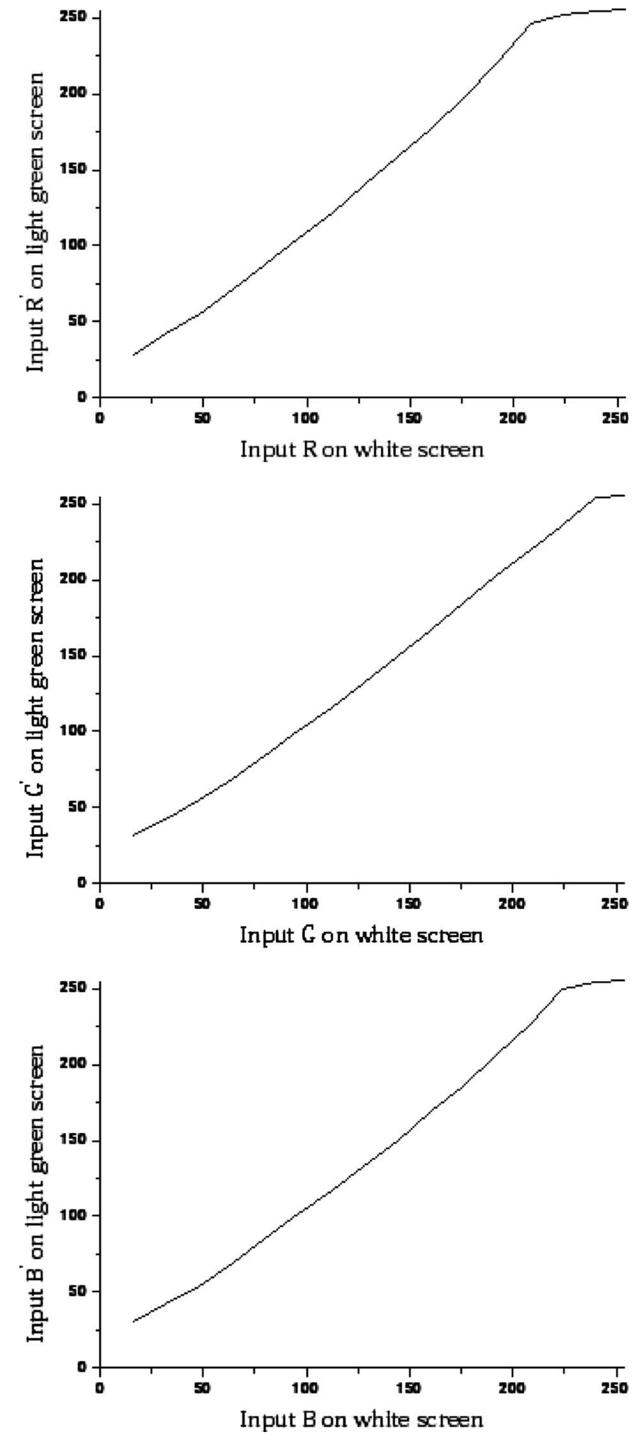

Figure 3. Relationship using characterization model between each channel input on white and light green screens.

Figure 4. Resulting image using characterization model; (a) original image on white screen, (b) original image on light green screen, and (c) corrected image on light green screen.

$$\begin{bmatrix} \hat{R} \\ \hat{G} \\ \hat{B} \end{bmatrix} = M^{-1} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}. \quad (5)$$

After characterization, tristimulus values are obtained using the same ramp patches of each screen. Then, we check those patches between the white and colored screens which have the same tristimulus values. Accordingly, we can obtain input digital values ($R'G'B'$), corresponding to input digital values (RGB) on a white screen, for the colored screen using inverse characterization. Figure 3 shows the relationship between input digital values for white and light green surfaces. At the final stage, a 3×3 color correction matrix is obtained using the relationship between RGB on the white screen and $R'G'B'$ on the colored screen. The regression equation as expanded into a quadratic or a cubic form can be used to obtain the color correction matrix. We used a quadratic or cubic equation polynomial regression; however, the coefficients are almost zero, except for the first order coefficient. Thus, during our investigation the input digital value on the light colored screen and the input digital value on the white screen were found to have a linear relationship. Therefore, a linear regression model was adopted,[9]

Table I. Evaluation of characterization-based method for light green screen.

	Average digital value of *R* channel	Average digital value of *G* channel	Average digital value of *B* channel	*r* chromaticity	*g* chromaticity	*b* chromaticity	Chromaticity error
Projected image on white	121.7538	119.9674	117.5218	0.3389	0.3339	0.3271	0
Projected image on light green	106.3192	113.7949	130.0735	0.3216	0.3443	0.3341	0.0347
Characterization-based method on light green	117.5218	110.4443	125.9337	0.3330	0.3389	0.3281	0.0118

$$P = V^T\alpha, \tag{6}$$

where

$$V = \begin{bmatrix} R_1 & \cdots & R_n \\ G_1 & \cdots & G_n \\ B_1 & \cdots & B_n \end{bmatrix}, \tag{7}$$

$$\alpha = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{bmatrix}, \tag{8}$$

$$P = \begin{bmatrix} R_1' & G_1' & B_1' \\ \vdots & \vdots & \vdots \\ R_n' & G_n' & B_n' \end{bmatrix}, \tag{9}$$

where $(R_1, R_2, \ldots, R_n)$ are the experimental input digital values for the R channel on the white screen and $(R_1', R_2', \ldots, R_n')$ are the estimated input digital values having the same *CIEXYZ* values on the white screen for the R channel on the light colored screen; n is the number of samples used. The coefficients for the computed matrix are as follows:

$$\alpha = (VV^T)^{-1}VP. \tag{10}$$

The resulting images are obtained by applying the inverse 3×3 color correction matrix. Figure 4 shows the results of color correction for a uniform light green color paper using this characterization method. Fig. 4(b) shows that the overall image appears greenish under the influence of the surface color when the original image is projected onto a colored screen. Fig. 4(c) shows that an image, processed with color correction based on the characterization, does not acquire much influence from the surface color. This image clearly shows a color reproduction on light green screen close to that obtained on a white screen. Table I shows an evaluation of the color compensation for Fig. 4. For the images projected onto the colored screens, the chromaticity errors for the corrected images using the characterization model were reduced when compared to those for the uncorrected images.

Color Correction Using a Camera

Projector characterization, and subsequent calibration, usually cannot be performed by the average user due to time, location, and equipment constraints. To mitigate this problem, we propose a color correction method using a digital camera. The camera is used to estimate the color shift between a reference white screen and a colored projection surface. The workflow is shown in Figure 5. First, a test image containing a ramp of nine patches for each color channel is projected onto a white screen and then onto a light colored screen. Next, the camera is used to capture images of the ramp of nine patches for each channel on both the white and light colored screens. The test image is shown in Figure 6. In the case of the projector characterization-based method, a ramp with 16 steps for each channel was used to derive the tone characteristics of the projector. However, a ramp of nine patches for each channel is used for the camera-based method; insofar as when a ramp with 16 or more steps is used with a generic still camera, it is hard to confirm the specific tones in the resulting camera images. The digital value interval between the patches in the ramps is empirically set at 20 for the range [48, 208]. For example, the

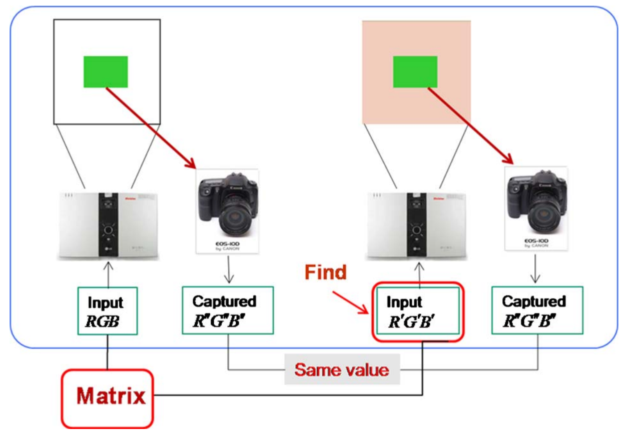

Figure 5. Workflow of camera-based color correction.

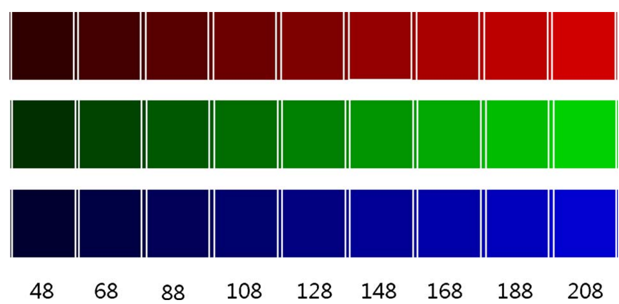

Figure 6. Test image comprising ramps of nine patches for each channel.

digital values for the ramp of nine patches for the R channel are (48,0,0),(68,0,0),…,(208,0,0). The same notation is applied to the G and B channels. Next, digital values are obtained by the camera for each ramp patch on both screens, resulting in different values for the same patch. Table II shows the RGB digital values obtained using a camera on white and light green screens. Then, the input digital values $R'G'B'$ of the ramps on the light colored screen corresponding to the input digital values RGB of the ramps on the white screen are checked. The problem of quantization is not considered, as difference values less than integer numbers are hardly perceivable by human vision. The 3×3 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 [Eqs. (6)–(10)]. The results for the light green screen are shown in Figure 7(a), while Figs. 7(b)–7(d) show the results for the pink, green, and sky blue screens, respectively.

Fig. 3 shows the relationship between R and R', where R is the experimental input and R' is estimated via an inverse characterization model of the projection surface. The estimation is constrained so that R projected on the white screen and R' projected on the light colored screen induce the same tristimulus value. Meanwhile, Fig. 7 shows the relationship between R and R', where R is the experimental input and R' is estimated using the value captured by the camera. The estimation is constrained so that R projected on the white screen and R' projected on the light colored screen induce the same RGB values. Finally, the resulting images are obtained by applying the inverse color correction matrix. As a result, it is possible to apply the proposed method to current devices as a real time process.

Table II. *RGB* digital values by camera on white and light green screens.

Input digital value			Digital value of captured image on white screen by Canon camera			Digital value of captured image on light green screen by Canon camera		
R	*G*	*B*	*R*	*G*	*B*	*R*	*G*	*B*
48	0	0	9	0	0	3	0	0
68	0	0	26	0	0	21	0	0
88	0	0	42	0	0	34	0	0
108	0	0	64	0	0	54	0	0
128	0	0	93	0	0	78	0	0
148	0	0	119	0	0	101	0	0
168	0	0	147	0	0	126	0	0
188	0	0	178	0	0	154	0	0
208	0	0	197	0	0	174	0	0
0	48	0	16	24	31	10	22	29
0	68	0	25	40	33	22	38	31
0	88	0	38	63	35	32	59	32
0	108	0	54	86	2	50	83	1
0	128	0	77	120	5	70	116	5
0	148	0	100	154	9	90	146	9
0	168	0	116	178	23	107	173	20
0	188	0	136	204	37	126	199	36
0	208	0	148	218	50	138	213	46
0	0	48	0	0	20	0	0	19
0	0	68	0	0	38	0	0	35
0	0	88	0	0	63	0	0	59
0	0	108	0	2	91	0	2	85
0	0	128	0	11	127	0	12	118
0	0	148	0	19	160	0	20	150
0	0	168	0	27	186	0	27	178
0	0	188	0	40	210	0	39	203
0	0	208	0	49	223	0	48	217

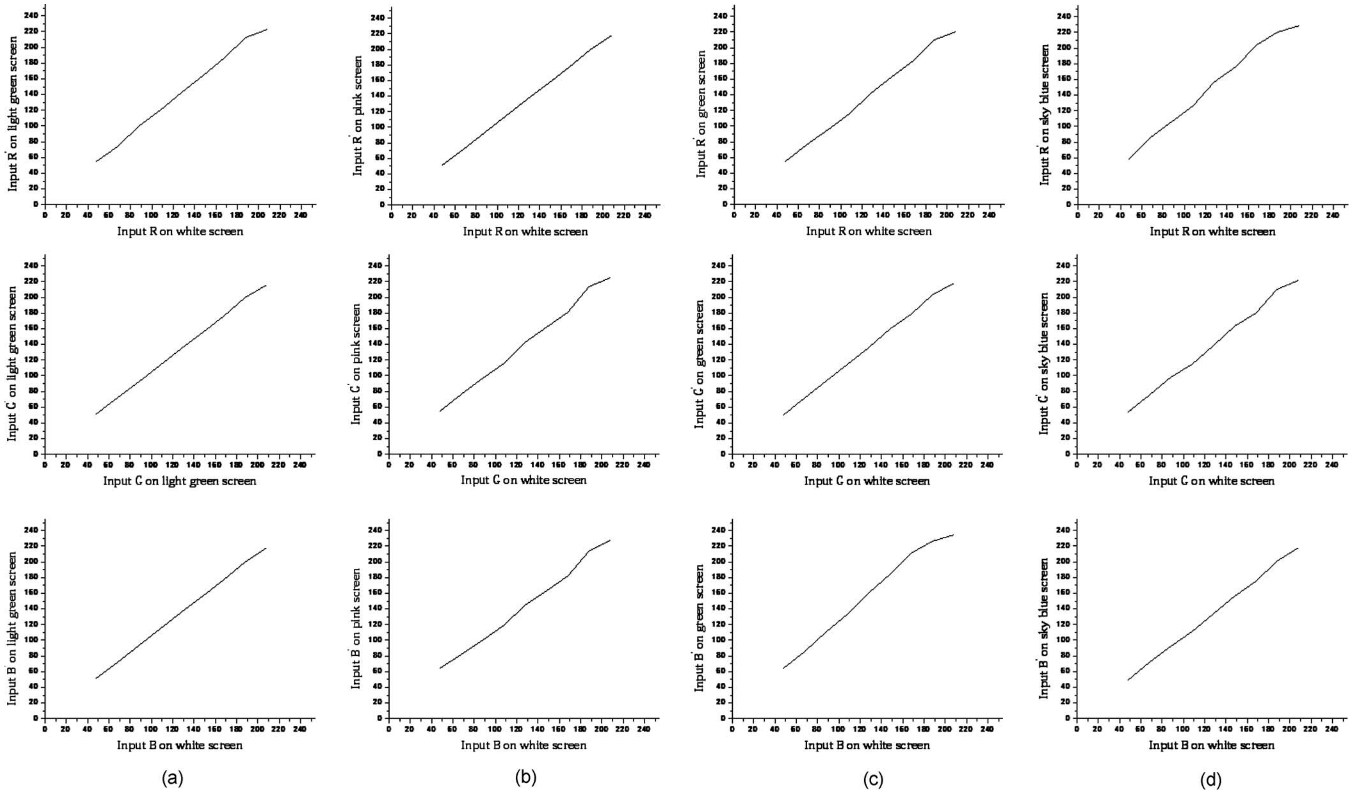

Figure 7. Relationship using proposed method between each channel input on white and light colored screens. (a) Light green screen, (b) pink screen, (c) green screen, and (d) sky blue screen.

RESULTS

Methods

For an experimental evaluation of the proposed algorithm, an LG RD-JT90 DLP projector, a Canon 10D camera, and a Fuji F810 camera were used. Four kinds of light colored papers (light green, pink, green, and sky blue) were used as the projection surfaces. The various screen colors captured by camera are shown in Figure 8. Tristimulus values of light colored screens are presented in Table III.

The proposed method was evaluated using a quantitative analysis and by an observer's preference test. The subjective evaluation test involved 20 observers, four females and 16 males, aged 24–34. The eyesight of the observers was either normal or corrected with glasses, and the test was conducted in a darkened room (0.04 lx). A combination of white and light colored paper was used as the projection surface. For the subjective evaluation, the resulting images were compared using Son's method and the proposed algorithm. In the experiment, four images were projected onto the white and light colored screens where the input images were projected onto the white screen in the first row and first column as the reference, while the corresponding pair of corrected images (using Son's method and the proposed algorithm) was projected onto the light colored screen in the second column. The observers were then asked to rank the corrected images according to their preference. Each observer judged each pair of corrected images and assigned 1 to the selected image and 0 to the rejected image. In the case of a tie, 0.5 was assigned to each image. The scores were then totaled and converted to a Z-score.[10]

Meanwhile, quantitative evaluation was performed based on the average difference of the *RGB* chromaticity between the images captured from the white screen and those from the light colored screens.[7] As the images projected on the light colored screen were affected by the surface color tone, quantitative evaluation was performed based on comparing the *RGB* chromaticity errors between the white and four light colored surfaces. First, the projected images were captured using a camera, and the average chromaticity values were calculated for each channel. The chromaticity errors were then calculated based on the values for the white screen and those for the light colored screens. The proposed method was first compared with the previous method in a darkened room. Next, to verify the generality of the proposed method, the proposed method was again carried out using another camera. Finally, the proposed method was used for the case of a different luminance.

Comparison between the Proposed Method and a Previous Method

The test image and corrected images are first projected on white and light colored screens (light green, pink, green, and sky blue) in a dark room, and then captured using a Canon 10D camera and compared. Figures 9(a), 10(a), 11(a), and 12(a) show the test images projected onto the white screen. Figures 9–12 show a comparison of Son's method and the proposed method when using the light colored (light green,

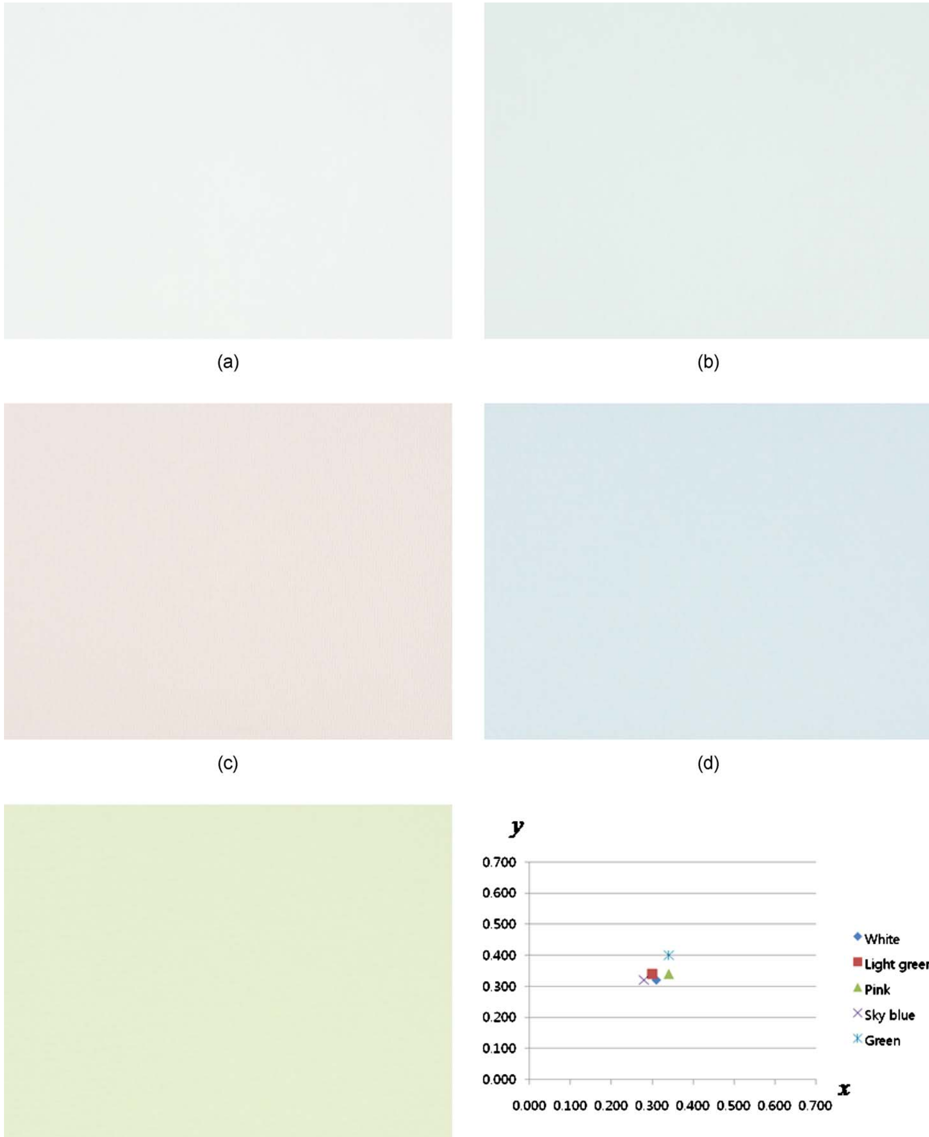

Figure 8. Various screens captured by camera: (a) white, (b) light green, (c) pink, (d) sky blue, (e) green, and (f) color coordinates of screens.

pink, green, and sky blue) screens. Figs. 9(b), 10(b), 11(b), and 12(b) show that the images projected on the light green colored screen predominantly included the surface color tone. Figs. 9(c), 10(c), 11(c), and 12(c) show the corrected images on the light colored screens when using Son's method, while the corrected images on the light colored screens when using the proposed method are shown in Figs. 9(d), 10(d), 11(c), and 12(d). The corrected images when using the proposed method were more similar to the original images on the white screen than those obtained using

Table III. Tristimulus values of various screens.

	X	Y	Z	CIE_{xy_x}	CIE_{xy_y}
White	87.41	91.04	104.23	0.31	0.32
Light green	68.73	77.2	82.75	0.3	0.34
Pink	76.31	75.97	69.46	0.34	0.34
Sky blue	61.23	69.79	86.39	0.28	0.32
Green	63.17	73.76	47.36	0.34	0.4

Figure 9. Resulting images using color correction algorithm; (a) original image on white screen, (b) original image on light green screen, (c) corrected image on light green screen by Son's method, and (d) corrected image on green by proposed method.

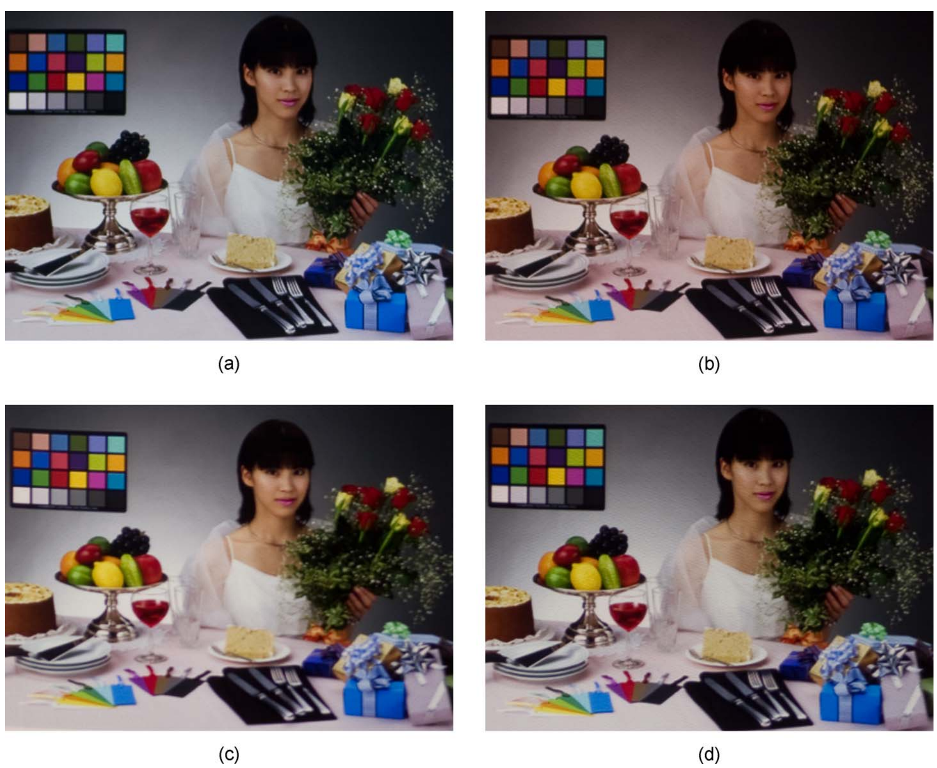

Figure 10. Resulting images using color correction algorithm; (a) original image on white screen, (b) original image on pink screen, (c) corrected image on pink screen by Son's method, and (d) corrected image on green by proposed method.

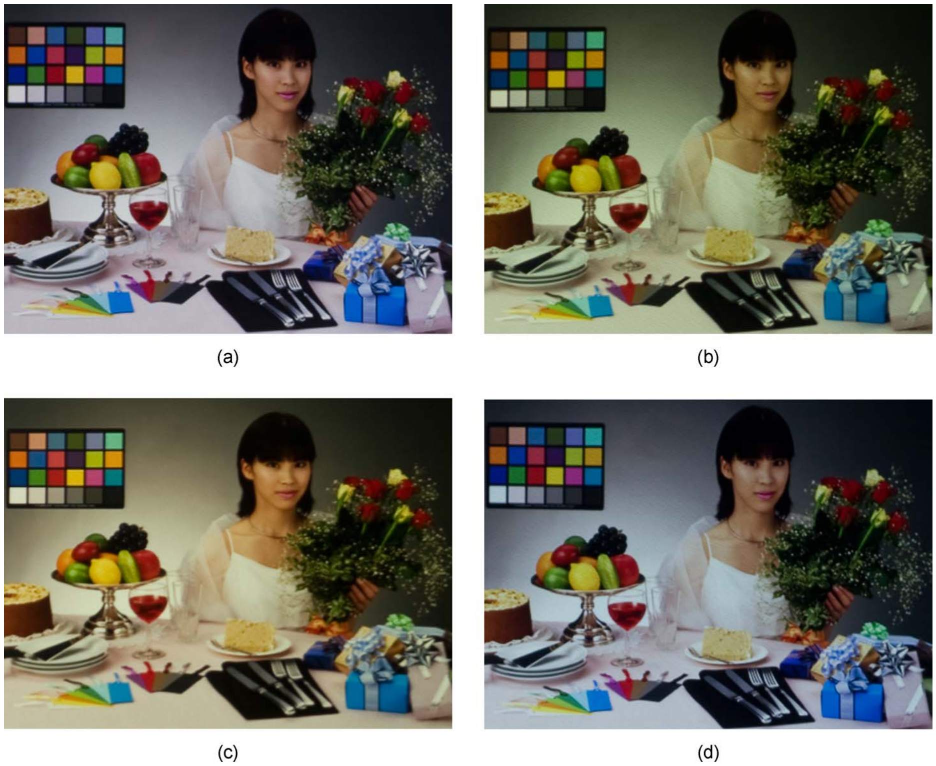

Figure 11. Resulting images using color correction algorithm; (a) original image on white screen, (b) original image on green screen, (c) corrected image on green screen by Son's method, and (d) corrected image on green by proposed method.

Figure 12. Resulting images using color correction algorithm; (a) original image on white screen, (b) original image on sky blue screen, (c) corrected image on sky blue screen by Son's method, and (d) corrected image on green by proposed method.

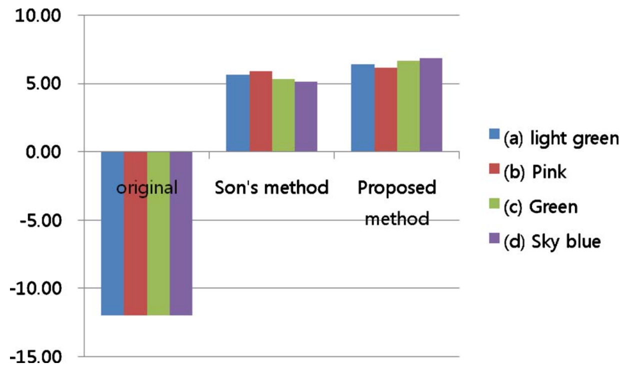

Figure 13. Z-scores for test images as a result of subjective evaluation.

Son's method. Figure 13 and Table IV show the Z-scores of each algorithm for the test images. For the preference test, the Z-scores for the proposed method were generally higher than those for Son's method. Most observers preferred the images resulting from the proposed method. The quantitative evaluation was performed by comparing the *RGB* chromaticity errors on the four light colored surfaces. Table V shows an evaluation of the color compensation for Figs. 9–12. For the images projected onto the light colored screens, the chromaticity errors for the corrected images using the proposed method were reduced compared to those for the uncorrected images and the images corrected using Son's method.

Color Correction by the Proposed Method Using a Different Camera

To verify the feasibility of the proposed method using a generic still camera, the proposed method was again carried out using a Fuji F810 camera. Figure 14 shows the corrected images on the light colored screens using the proposed method with this camera. Figure 14(a) shows the image projected on the white screen, while Figs. 14(b)–14(e) show the resulting images projected on the light colored (light green, pink, green, and sky blue) screens using the proposed method. Quantitative evaluation was performed by comparing the *RGB* chromaticity errors for images on the four light colored surfaces. Table VI presents the chromaticity errors on the light green, pink, green, and sky blue surfaces. The chromaticity errors for the corrected images were reduced when compared to those for the uncorrected images on the light colored screens, confirming the generality of the proposed method with respect to the still camera employed.

Color Correction for Surround Luminance

To verify the feasibility of the proposed method with a change of luminance, the proposed method was evaluated using both 0.04 and 13.4 lx. The experiment was conducted in a darkened room with and without a lamp stand to estimate the correction performance with respect to the intensity of the illumination. Here, 0.04 lx represents the luminance level in the darkened room; 13.4 lx was the luminance level in the room with the lamp turned on, and it was chosen as the proper luminance level for watching an image on a screen. We used reference data obtained with the Cannon 10D camera for the ramps of nine patches for each channel on the white screen in darkened room (0.04 lx). The data for ramp patches on the colored screen were obtained using the

Table IV. Z-score for test images.

Screen	Original	Son's method	Proposed method
Light green	−12.00	5.62	6.38
Pink	−12.00	5.88	6.12
Green	−12.00	5.33	6.67
Sky blue	−12.00	5.16	6.84

Table V. Evaluation of color compensation for Figs. 9–12.

	Average digital value of *R* channel	Average digital value of *G* channel	Average digital value of *B* channel	*r* chromaticity	*g* chromaticity	*b* chromaticity	Chromaticity error
Projected image on white	98.2997	93.1173	95.0351	0.3431	0.3250	0.3317	0
Projected image on light green	80.0254	86.5923	87.4580	0.3149	0.3408	0.3442	0.0563
Son's method on light green	99.5242	100.2594	101.9339	0.3298	0.3322	0.3378	0.0266
Proposed method on light green	100.9999	98.2147	101.8426	0.3339	0.3374	0.3287	0.0101
Projected image on pink	98.6194	81.8562	78.1343	0.3813	0.3165	0.3021	0.0763
Son's method on pink	109.8857	98.5297	95.4099	0.3616	0.3242	0.3140	0.0370
Proposed method on pink	110.5997	100.0431	96.1985	0.3604	0.3260	0.3135	0.0365
Projected image on green	84.7036	88.4246	62.0242	0.3602	0.3760	0.2637	0.1360
Son's method on green	106.3856	98.71594	80.6305	0.3723	0.3454	0.2821	0.0991
Proposed method on green	99.1284	100.1185	106.2141	0.3432	0.3546	0.3021	0.0592
Projected image on sky blue	67.7522	80.5424	90.2654	0.2840	0.3376	0.3783	0.1183
Son's method on sky blue	93.8730	98.4849	104.5777	0.3161	0.3316	0.3521	0.0540
Proposed method on sky blue	99.1284	100.1185	106.2141	0.3245	0.3277	0.3477	0.0372

(a) (b) (c) (d) (e)

Figure 14. Corrected images by proposed method using Fuji F810 camera on light colored screens; (a) original image on white screen, (b) corrected images on light green screen (c) corrected images on pink screen, (d) corrected images on green screen, and (e) corrected images on sky blue screen.

Table VI. Evaluation of proposed method using Fuji camera.

	Average digital value of *R* channel	Average digital value of *G* channel	Average digital value of *B* channel	*r* chromaticity	*g* chromaticity	*b* chromaticity	Chromaticity error
Projected image on white	97.7402	94.8515	87.2862	0.3492	0.3389	0.3118	0
Projected image on light green	86.5184	91.4941	82.7810	0.3317	0.3508	0.3174	0.0349
Proposed method on light green	100.7615	100.0134	91.6048	0.3446	0.3420	0.3133	0.0092
Projected image on pink	94.1986	85.0045	74.2309	0.3716	0.3354	0.2929	0.0597
Proposed method on pink	102.6495	99.7101	91.4067	0.3494	0.3394	0.3111	0.0152
Projected image on green	88.4987	93.0034	61.8413	0.3636	0.3821	0.2541	0.1339
Proposed method on green	101.5238	106.8033	87.3914	0.3433	0.3611	0.2955	0.0511
Projected image on sky blue	78.2654	88.2304	86.5012	0.2840	0.3376	0.3783	0.0789
Proposed method on sky blue	97.5184	100.8896	95.5854	0.3245	0.3277	0.3477	0.0342

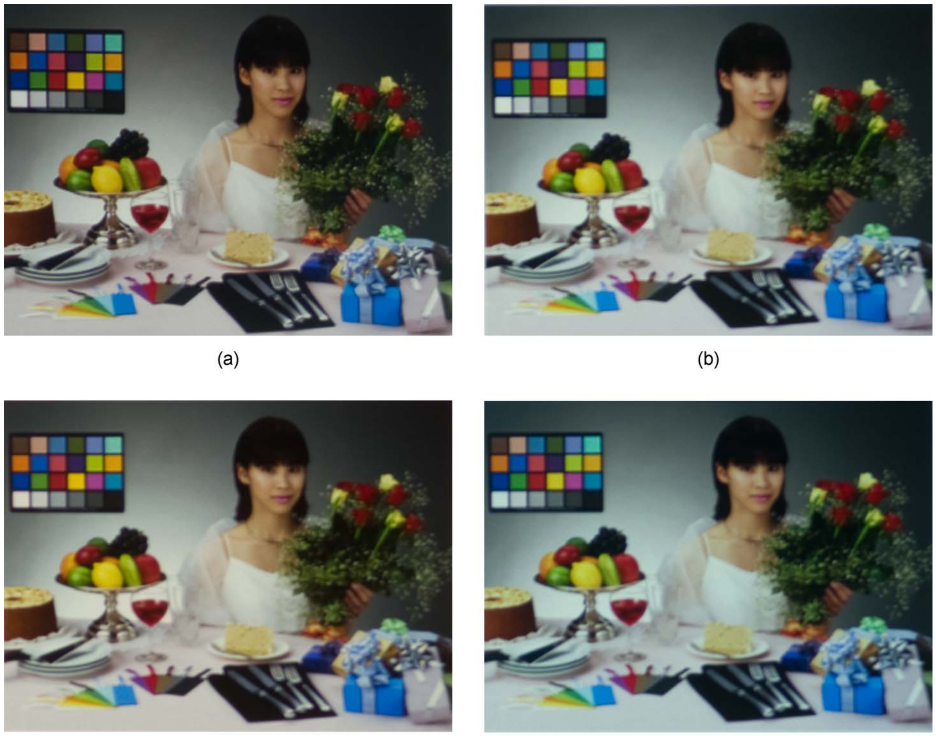

Figure 15. Corrected images by proposed method on light colored screens in 13.4 lx around luminance; (a) original image on white screen, (b) corrected images on light green screen, (c) corrected images on pink screen, and (d) corrected images on sky blue screen.

Table VII. Evaluation of proposed method for higher surround luminance level.

	Average digital value of *R* channel	Average digital value of *G* channel	Average digital value of *B* channel	*r* chromaticity	*g* chromaticity	*b* chromaticity	Chromaticity error
Projected image on white	121.7538	119.9674	117.5218	0.3389	0.3339	0.3271	0
Projected image on light green	78.3567	89.4343	80.641	0.3150	0.3601	0.3247	0.0524
Proposed method on light green	98.1961	104.0818	99.9035	0.3249	0.3444	0.3306	0.0279
Projected image on pink	98.5772	83.5863	70.9113	0.3895	0.3302	0.2801	0.1012
Proposed method on pink	102.6495	99.7101	91.4067	0.3470	0.3433	0.3096	0.0349
Projected image on sky blue	65.1947	85.2860	84.3943	0.2775	0.3631	0.3593	0.1226
Proposed method on sky blue	92.3414	105.5592	101.4364	0.3086	0.3526	0.3388	0.0608

Cannon 10D camera in 13.4 lx surround luminance. The correction matrix was then obtained using these data from the Cannon 10D camera with the 13.4 lx surround luminance and the reference data. Figure 15 shows the corrected images on the light colored screens when using the proposed method and 13.4 lx luminance. Fig. 15(a) shows the original image on the white screen, while Figs. 15(b)–15(d) show the images reproduced on the light colored (light green, pink, green, and sky blue) screens when using the proposed method. The quantitative evaluation was performed based on comparing the *RGB* chromaticity errors on the light colored surfaces. Chromaticity errors on the light colored surfaces are shown in Table VII. The chromaticity errors for the corrected images were reduced compared to those for the uncorrected images on the light colored screens, confirming the correction ability of the proposed method under higher luminance levels.

CONCLUSIONS

This article proposes a color correction method for images projected on colored surfaces using a generic still camera as a convenient measurement device for characterization. A 3×3 color correction matrix is estimated by linear regression using input digital values, thereby producing the same color on both white and light colored screens. As distinct from previous methods, the use of a generic still camera allows measurements to be taken, regardless of the location. In addition, the calibration image contains information on nine steps for each color channel, enabling an accurate construction of the transform matrix. Experimental results based on objective and subjective evaluations confirmed that the corrected images on the colored screens were better with the proposed method than with a representative previous method.

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REFERENCES

1. O. Bimber and A. Emmerling, "Embedded entertainment with smart projectors", IEEE Computer **38**, 56–63 (2005).
2. S. K. Nayar, H. Peri, M. D. Grossberg, and P. N. Belhumeur, "A projection system with radiometric compensation for screen imperfection", *Proc. IEEE International Workshop on Projector-Camera Systems* (IEEE, Piscataway, NJ, 2003) pp. 1–8.
3. M. D. Grossberg, H. Peri, S. K. Nayar, and P. N. Belhumeur, "Making one object look like another: Controlling appearance using a projector-camera system", *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'04)* (IEEE Computer Society, Los Alamitos, CA, 2004) Vol. **1**, pp. 452–459.
4. M. Ashdown, T. Okabe, I. Sato, and Y. Sato, "Robust content-dependent photometric projector compensation", *Proc. 2006 Conference on Computer Vision and Pattern Recognition Workshop* (IEEE Computer Society, New York, 2006) pp. 6–13.
5. S. A. Renani, M. Tsukada, and J. Y. Hardeberg, "Compensating for non-uniform screens in projection display systems", Proc. SPIE **7241**, 72410F (2009).
6. M. Tsukada and T. Tajima, "Projector color reproduction adapted to the colored wall projector", *Proc. IS&T's CGIV2004* (IS&T, Springfield, VA, 2004) pp. 449–453.
7. C. H. Son and Y. H. Ha, "Color correction of images projected on a colored screen for mobile beam projector", J. Imaging Sci. Technol. **52**, 030505 (2008).
8. Y. Kwak, C. Li, and L. MacDonald, "Controlling color of liquid-crystal displays", J. Soc. Information Display **11**(2), 341–348 (2003).
9. S. Westland and C. Ripanmonti, *Computational Colour Science Using Matlab* (Wiley, New York, 2004).
10. J. Morovic, *Color Gamut Mapping* (Wiley, New York, 2008).