Projector Color Reproduction Adapted to the Colored Wall Projection

Masato Tsukada
Media and Information Research Laboratories, NEC Corporation, Kawasaki, Japan

Johji Tajima
Graduate School of Natural Sciences, Nagoya City University, Nagoya, Japan

Abstract

This paper proposes a projector color reproduction method that enables the true reproduction of colors when images are projected onto a colored wall rather than a white screen. In this method, a chromatic adaptation model or color appearance model is used as a color-matching algorithm. We apply six models to the color matching. Subjective experiments we performed show the color-matching performance of the six models. The color constancy model (CCM),[1] a chromatic adaptation model we previously proposed, produces the best performance in the experiments.

Introduction

The performance of image projectors has rapidly advanced in terms of miniaturization, brightness, and image quality. In addition, comparatively inexpensive projectors now provide large, high-quality screen images. As imaging devices, projectors are thus becoming increasingly popular.

As projectors become increasingly compact, users are more likely to use them in situations where a conventional screen is unavailable. However, when an image is projected onto a colored wall used as a temporary screen, the colors reproduced on the wall do not appear as they would on a white screen.

Conventional self-emission imaging devices such as LCD or CRT monitors can achieve comparatively good color reproduction by using an ICC profile and a color matching module (CMM). However, it is difficult for a projector to maintain an expected color appearance, even if the same strategy is applied as for monitors, because the colors reproduced by projectors are easily affected by external factors such as the screen color and ambient lighting. An improved technique for projector color reproduction is needed to solve these problems and enable higher quality images.

We have developed a projector color reproduction method to enable the true reproduction of colors when images are projected onto a colored wall, rather than a white screen, by remarking wall colors as external factors that strongly affect the projector color reproduction.

To develop this method, we considered use of a chromatic adaptation model or color appearance model as a color-matching algorithm. We applied six models to projector color matching and performed subjective experiments to evaluate the color-matching performance. Our results from these experiments have demonstrated the effectiveness of our method.

We have also implemented a wall-color correction function in a projector that is now on the market. Using hardware for color correction enables real-time processing for both still images and motion pictures.

Color Matching Algorithm

Color images reproduced by a projector generally consist of three primary colors, i.e. red (R), green (G) and blue (B). The spectral property $X(\lambda)$ at a pixel in an image is represented by Equation (1),

$$X(\lambda)=(r\cdot R(\lambda)+g\cdot G(\lambda)+b\cdot B(\lambda))\cdot S(\lambda) \quad ,(1)$$

where $R(\lambda)$, $G(\lambda)$, and $B(\lambda)$ are spectral power distributions of the R, G, and B phosphors, respectively. Constant coefficients r, g, and b represent the intensity of each color light, and $S(\lambda)$ is the surface reflectance of a screen.

Suppose that we use a wall in an office as a projection screen and the wall is not white. When an image is projected onto the wall, the reproduced color $X(\lambda)$ on the wall differs from what it would be on a white screen.

In such a case, though, we can make the colors reproduced on the wall close to those that would appear on a white screen by adjusting coefficients r, g, and b in Equation (1).

To achieve color matching that adapts to a wall color, color information must be obtained from the projection surface. One way to do this is to integrate a color image sensor with known color characteristics within the projector.

Source Color Space and Reference Color Space

A source color space and a reference color space are needed to resolve the color-matching problem. The source color space is the projector's color space that is formed on a standard white screen. This can be stored in the projector's memory in advance.

The reference color space should be calculated when a projector is used, because it varies depending on environmental conditions. This color space is a projector color space formed on a colored wall. Specifically, four colors (i.e., red, green, blue, and white) are projected onto a colored wall and a color image sensor integrated within a projector observes the four colors on the wall. The reference color space is calculated from measurement data regarding the four colors and the color characteristics of the color image sensor.

In our method, we use a 3x3 linear transformation model to transform RGB values that are device-dependent color to CIE 1931 XYZ values that are device-independent color. The source color space and the reference color space can be represented with a 3x3 matrix. Here, let S_x be the source color space and R_x denote the reference color space of a projector.

The reference color space R_x is calculated through the following steps.

(1) XYZ values for the four colors (red, green, blue, and white) are calculated from the RGB values of the four colors observed by the sensor and the 3x3 matrix C_{rx} from RGB to XYZ, which contains the color characteristics of the sensor. The chromaticities of the four colors are then calculated.

(2) 3x3 matrix M and 3x3 matrix A are created.

$$M = \begin{pmatrix} rx & gx & zx \\ ry & gy & zy \\ 1-rx-ry & 1-gx-gy & 1-zx-zy \end{pmatrix} \quad , (2)$$

$$A = \begin{pmatrix} \frac{wx}{wy} & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & \frac{1-wx-wy}{wy} \end{pmatrix} \quad , \quad (3)$$

where rx, ry, gx, gy, bx, by, wx, and wy represent, respectively, the chromaticities of R,G,B, and W projected onto the wall.

(3) 3x3 matrix B is obtained by multiplying A with M^{-1}.

$$B = A\, M^{-1} \quad (4)$$

(4) The reference color space R_x is obtained by multiplying B with M.

$$R_x = MB \quad (5)$$

Color-Matching Processing

When observers see an image projected onto a screen, they perceive the colors of the image while their eyes adapt to the colors on the screen to some degree. Based on this concept, the color-matching problem between different color imaging devices, such as a display and a printer, can be applied to the color-matching problem that occurs when images are projected onto a colored wall by projectors. That is, color appearance models or chromatic adaptation models can be used to bring the color appearance reproduced on a colored wall close to that on a standard white screen.

Figure 1 represents a general color-matching process by using a chromatic adaptation model or a color appearance model (CAM).

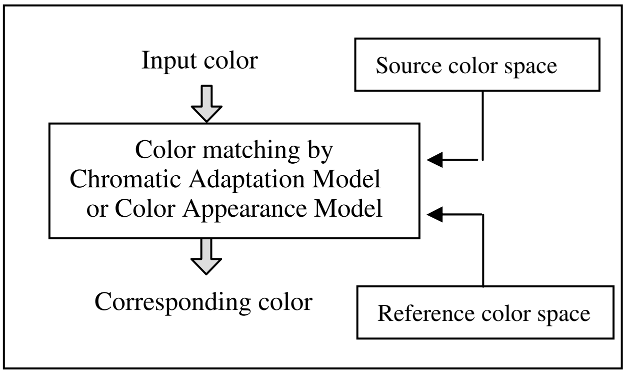

Figure 1. Color matching

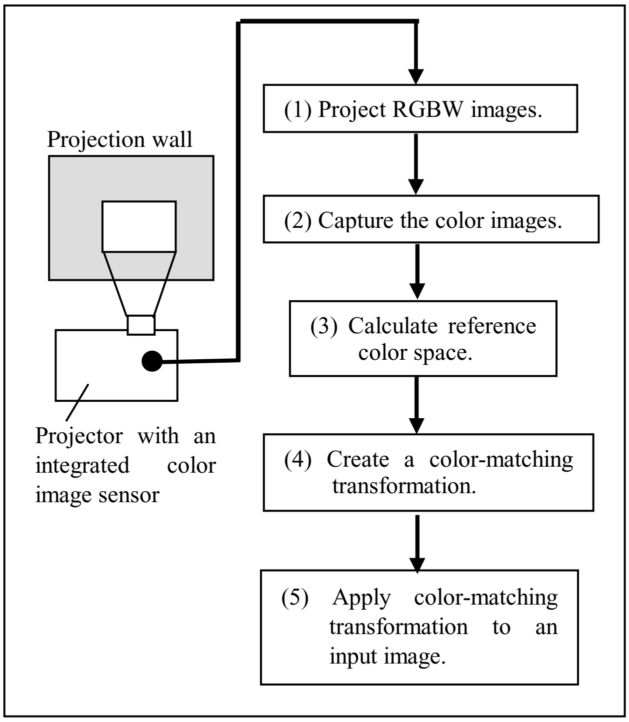

Figure 2. Color-matching process in projector

Figure 2 illustrates our proposed projector color-matching process that consists of the following five steps.

(1) Project four colors (i.e., R, G, B, and W) onto a wall.
(2) Observe the four colors with the color image sensor integrated into a projector.
(3) Obtain the reference color space from color information regarding the four colors on the wall.
(4) Create a color-matching transformation from the source color space to the reference color space.
(5) Apply the color-matching transformation to an input image.

Figure 3 summarizes the color data flow in a color-matching process for a projector color reproduction. RGB values ($\gamma = 1.0$) are transformed to XYZ values under the source color space by a linear transformation using 3x3 matrix S_x. X'Y'Z' values of the corresponding color under the reference color space are calculated by using a chromatic adaptation model or a color appearance model. X'Y'Z' values are converted to R'G'B' values ($\gamma = 1.0$) that are dependent color values for a projector by a linear transformation using 3x3 matirx R_x.

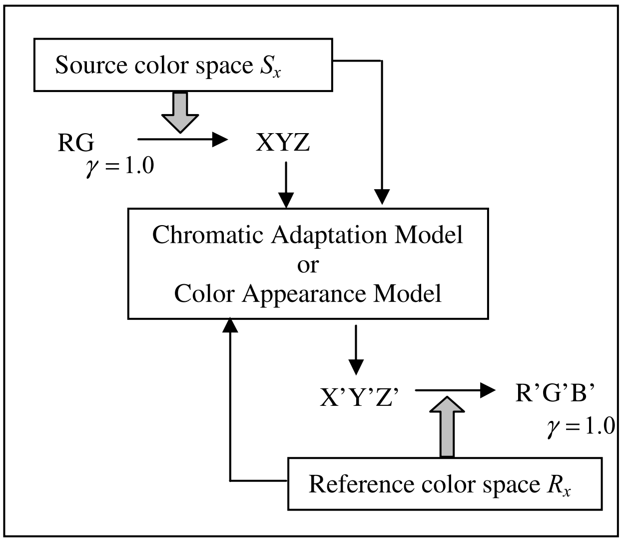

Figure 3. Color data flow in the color-matching process.

Experiments

For color matching when images are projected onto a colored wall, our method uses a color appearance model or a chromatic adaptation model. The color-matching performance of several models has been evaluated for color appearance matching between two CRT monitors whose whites are different and between a CRT monitor and a printer.[1-3] Here, we have carried out subjective experiments to evaluate the color-matching performance of these models for a projector in a dark room.

Evaluation of Color-Matching Performance

We evaluated the color-matching performance of six models (i.e., von Kries, CIELAB, Nayatani,[4] RLAB,[5] CIECAM97s,[6] and CCM[1]) by using them for color matching between two projectors whose whites differed.

Figure 4 shows the experimental viewing conditions. We used DA-LITE Fast-Fold SCREEN in our experiments. The white of the projector projected onto the screen on the test side was set to the default white, which was a bluish white ((x, y) = (0.298, 0.347)), and that of the projector on the reference side was adjusted to the same chromaticity as D50. The projectors' luminance level was set to 334 cd/m^2. In the experiments, we simulated a colored-wall projection by using two projectors whose whites differed and a standard white screen.

Four kinds of natural images were prepared because subjects could be influenced by the image. The N1 (Portrait), N2 (Cafeteria), N3 (Fruit Basket), and N7 (Musician) images from ISO/JIS-CMYK SCID were used for this evaluation. Images used as test stimuli were appropriately converted to RGB images because SCID images are supplied as CMYK ones. These images were hemmed with a reference white. Reference images were created by applying the above six models to the test images.

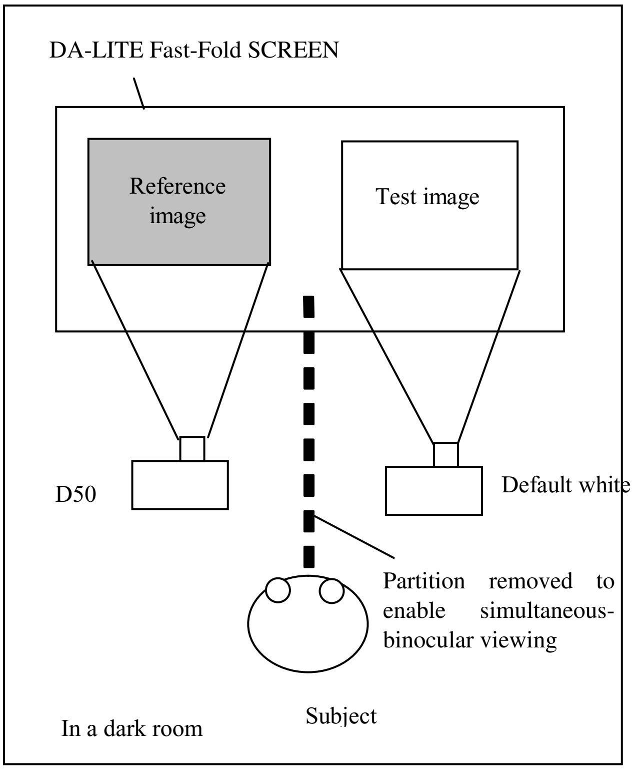

Figure 4. Viewing conditions in the color-matching evaluation experiments

Two types of viewing condition were examined. We tried color-matching evaluation with successive-haploscopic viewing technique at first.[7] The partition was removed to allow simultaneous-binocular viewing technique, because we want to know the difference of the color-matching performance via viewing techniques.

We followed the paired-comparison method to determine the order of the models' color-matching performance. Two subjects with normal color vision evaluated the color appearance of four kinds of natural image projected by the two projectors. A test image was projected on the right side and showed the original color appearance as a test stimulus. The reference images reproduced using the six models were projected on the left side as reference stimuli. Two images were randomly selected from these six images and were alternately (not simultaneously) projected by the subjects' clicking a mouse. Subjects judged the superiority or inferiority in the color matching of the reference images. The experiments were repeated twice.

Table 1 shows the results from the evaluation experiments for successive-haploscopic viewing. In the table, NM and CIECAM stand for Nayatani model and CIECAM97, respectively. The color-matching performance ranking, from high to low, was CCM, Nayatani, RLAB, CIECAM97s, von Kries, and CIELAB.

The color-matching performance ranking for simultaneous-binocular viewing was the same as that for successive-haploscopic viewing in our experiments.

The experiments were a simulation of a colored-wall projection, as in our earlier experiments.

Table 1. Results from color matching between two projectors whose whites differed

	Musician	Cafeteria	Portrait	Fruit
1	CCM	CCM/NM	CCM	CCM
2	NM	------------	NM	RLAB/NM
3	RLAB	RLAB	RLAB	-----------
4	CIECAM	CIECAM	CIECAM	CIECAM
5	von Kries	von Kries	von Kries	von Kries
6	CIELAB	CIELAB	CIELAB	CIELAB

NM

Evaluation of Color-Matching Performance for Colored-Wall Projection

We then conducted more practical experiments by using actual colored walls. We evaluated the color matching between test images projected onto a white screen and reference images calculated using three models (i.e., CCM, CIECAM97s and von Kries) projected onto colored walls.

We used three types of colored wall in the experiments. Table 2 shows the chromaticities of the projector's white when projected onto the white screen and the three colored walls. The experimental conditions, such as the viewing conditions, were otherwise the same as in our earlier experiments.

The color-matching performance ranking, from high to low, in this case was CCM, CIECAM97s, and von Kries.

Table 2. The xy chromaticity of projector whites on a white screen and colored walls

Screen type	x	y
Standard white screen	0.2958	0.3420
Yellow	0.3267	0.3905
Pale blue	0.2507	0.3052
Pink	0.3239	0.3347

Projector Wall-Color Correction

NEC Viewtechnology Ltd. developed projectors with a new color reproduction function (which we developed) to enable the true reproduction of colors when images are projected onto a colored wall rather than a white screen. Figure 5 shows the projector (MT1060 / MT1065), within which a color camera is integrated. The color camera is used as a color sensor to obtain color information from images projected onto a colored wall.

We adopted CCM because it performs well as color-matching algorithm in the wall-color correction. CCM is a chromatic adaptation model we previously proposed that is based on the basic concept of color constancy in human vision.

In this model, hypothetical spectral properties of objects and the illumination in an image are recovered by introducing certain assumptions concerning human color vision. The model applies to both incomplete and complete chromatic adaptation.

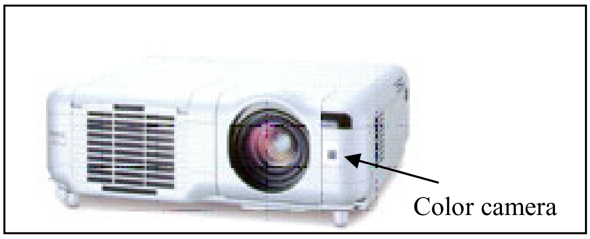

Figure 5. Projector with an integrated color image sensor(MT1065/MT1060)

To implement the wall-color correction in a projector, we have to realize real-time processing for both still images and motion pictures. We achieved fast color correction processing by introducing CCM with a low computational cost.

Figure 6 is a block diagram of the processing part for the wall-color correction integrated into our projector. The projector obtains the reference color space on a projection screen with a color camera installed in the projector. The processing part of the wall-color correction creates a color-matching transformation from the source color space stored in advance in the projector memory and the reference color space. An input color RGB is then converted to the output color R'G'B' at a high speed.

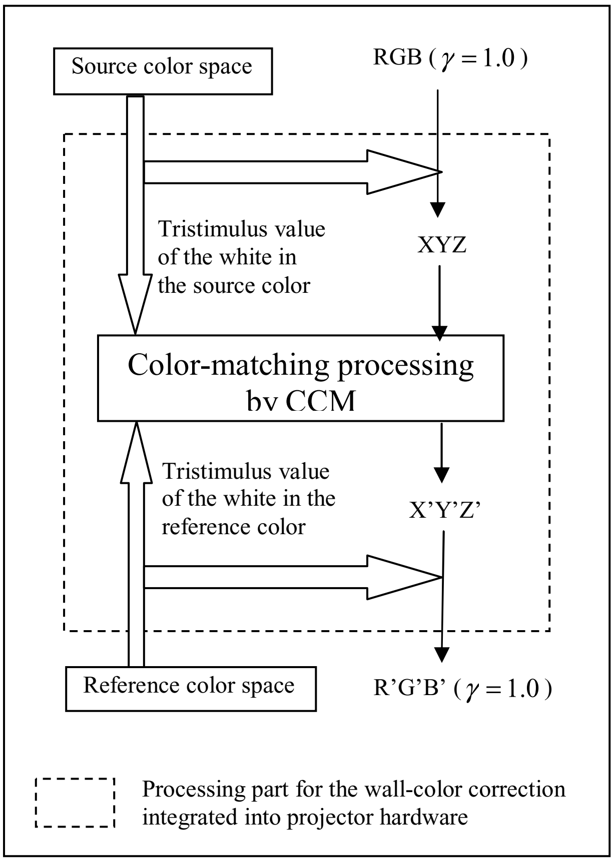

Figure 6. Wall-color correction integrated into projector hardware

Conclusion

We have developed a color reproduction method that enables a projector to achieve a color appearance on a colored wall close to that on a standard white screen. Color appearance models or chromatic adaptation models can be used in our method.

We performed subjective experiments to evaluate the color-matching performance of six models when we applied these models to color matching for colored-wall projection. The results indicated that CCM (which we earlier developed) provides better color matching than the five other models. Moreover, the experimental results confirmed that the color reproduction method we have proposed is an effective function for projector.

NEC Viewtechnology, Ltd. put a projector integrating a color image sensor on the market in 2002. The projector is capable of wall color correction, which we developed as a new function.

As projectors continue to become lighter and more compact, we expect wall color correction to become increasingly important to extend projector use since it means that availability of an appropriately colored screen will become less of a restriction.

References

1. Tsukada M., Tajima J., Yoshikawa H. and Yaguchi H.: "Color Appearance Matching Based on Color Constancy Theory", Proc. IS&T 1999 PICS, pp.348-353 (1999).
2. Tsukada M., Tajima J.: "Chromatic Adaptation Model Based on Spectral Property Estimation and Its Color Matching Performance", Proc. IS&T 1st CGIV, pp.11-15 (2002).
3. Tsukada M., Tajima J. and Yaguchi H.: "Evaluation of Color Matching Performances for SPEM and other Models", Color Res. and Appl, 28, 6, pp.445-453 (2003).
4. Nayatani Y.: "Simple Estimation Method for Effective Adaptation Coefficient", Color Res. and Appl, 22, 4, pp.259-268 (1997).
5. Fairchild M.D.: "Refinement of the RLAB Color Space", Color Res. Appl., 21, 5, pp.338-346 (1996).
6. Luo M.R. and Hunt R.W.: "The Structure of the CIE 1997 Colour Appearance Model (CIECAM97s) ", Color Res. and Appl., 23, 3, pp138-146 (1998).
7. Braun K.M., Fairchild M.D. and Alessi P.J.: "Viewing Techniques for Cross-Media Image Comparisons", Color Res. and Appl., 21, 1, pp6-17 (1996).

Biographies

Masato Tsukada is a research scientist in the Media and Information Research Laboratories, NEC Corporation. He received the BS degree and MS degree in computer science from Tsukuba University in 1989 and 1991, respectively. Since joining NEC Corporation in 1991, he has been engaged in research on color vision, color image processing, and color reproduction. He was awarded the best paper award by the Institute of Image Electronics Engineers of Japan (IIEEJ) in 1998. He is a member of the Information Processing Society of Japan (IPSJ).

Johji Tajima graduated from the Faculty of Science, the University of Tokyo, in 1971 and received a doctorate in 1990. From 1971 to 2003, he was a research member of NEC Corporation and was engaged in research on image processing and pattern analysis, especially color image processing and 3D vision. In 2003, he became a professor of the Graduate School of Natural Sciences, Nagoya City University. Prof. Tajima is a member of the IEICE, IIEEJ, and the Information Processing Society of Japan (IPSJ). He is a fellow of IAPR.