Compensation for projected image under dim illumination with CIECAM02

Sayuri Kamimigaki [a], *Keisuke Taki* [b], *Keita Hirai* [b], *Shoji Yamamoto* [c], *Norimichi Tsumura* [a,b], *Toshiya Nakaguchi* [a,b], *and Yoichi Miyake* [a,b,d]

[a] Department of Information and Image Sciences, Chiba University; Chiba/ Japan
[b] Graduate School of Advanced Integration Science, Chiba University; Chiba/Japan
[c] Tokyo Metropolitan College of Industrial Technology; Tokyo/Japan
[d] Research Center for Frontier Medical Engineering, Chiba University; Chiba/Japan

Abstract

*In our previous paper, we have developed a projector-Based color matching system for print industry. In this system, a color of print can be matched to the desired color to minimize the color difference between print and projected images. However, in this color matching, it is necessary to observe and measure the projector image under the dark room. In this paper, we proposed a new color correction method for projector image under dim illumination based on the CIECAM02. As well known, in the dim room, the color gamut of reproduced image becomes narrow compared with the gamut in the darkroom. M.Ashdown et al. proposed a method to compress the color gamut in the CIEL*u*v* color space. However, the chromatic adaptation according to the change of white point of the illumination is not considered in this method. Therefore we introduce CIECAM02 for color matching under the dim viewing condition. Chromatic and achromatic channels in CIECAM02 space are calculated from an input image and the chromatic channels are compressed to match the possible projection range of output under the illumination. The images obtained by conventional and proposed algorithms are evaluated by the psychophysical experiment used memory matching. As a result, it was shown that the proposed method can improve the color appearance under dim illumination.*

Introduction

In the manufacturing industry, computer aided design system have been widely used to simulate appearance of a product at low cost. However, it is not easy to match the appearance between a real object and a simulated object on the conventional display such as CRT and LCD due to the difference of perceptual mechanism (visual mode) in observing the color (Fig.1). Observers perceive real object color as reflection. The conventional display's color is self-luminescence.

Yamamoto et al. have proposed a method for real-time control of appearance on an object using a projector [1]. In the projection-based display systems, the color of projection is natural because observers can perceive reflected colors that are the same as a real object.

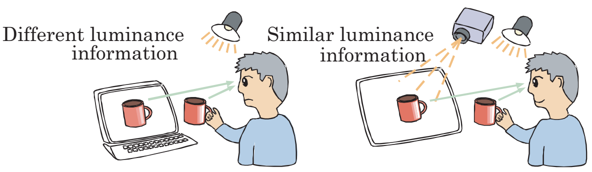

Figure 1. Difference of visual modes

The practical problems of the system is that the projection image is un-saturated in a dim illuminated room. Because the available color gamut is narrowed in color of projected image by illumination. For overcoming the problem, M. Ashdown et al. proposed a method to compress color gamut in the CIEL*u*v* color space for minimization of color difference[2]. However, this method does not consider two problems. One problem is the chromatic adaptation which accompany with the change of the white point of the illumination. The another problem is the lost details in dark regions which is caused from excluding local luminance.

In this paper, we propose the method that uses CIECAM02 [3] and enhances the detail by adaptation degree to overcome the problems of chromatic adaptation and the lost details. CIECAM02 is usually used for color appearance matching between hardcopy and CRT. Enhancement of low contrast region is calculated by the adaptation luminance L_A and the adaptation degree D that varies locally in the image(Fig.2). We use CIECAM02 and locally adaptation luminance for compensating the color of projected image under dim illumination(Fig.3).

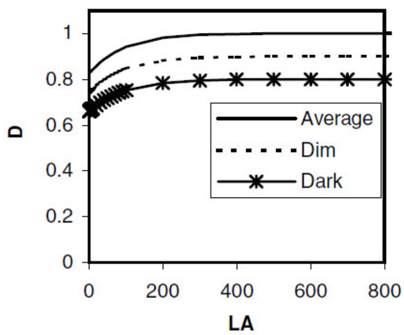

Figure 2. Degree of adaptation computed using L_A and surround[3]

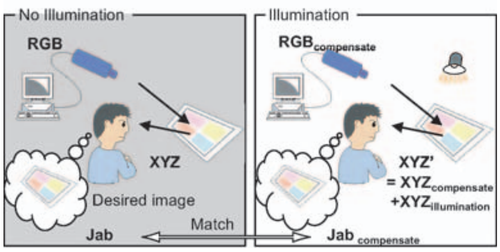

Figure 3. Color Compensation under dim illumination

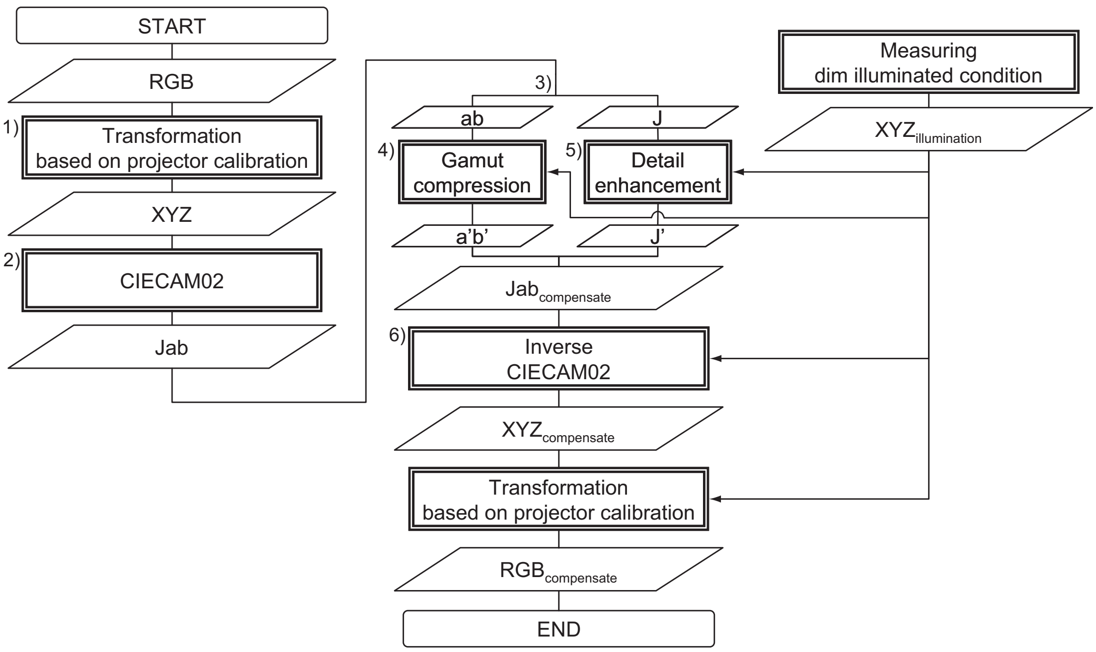

Figure 4. *Flowchart of Compensation*

The proposed algorithm

In our color correction algorithm based on the CIECAM02, it is necessary to know the tri-stimulus values XYZ of input data without illumination. Therefore, it is necessary to have projector's response function that the relationship between projector's input RGB and output XYZ. Reflected XYZ illuminated by projector on the white paper can be measured. We used the PCA-Spline model for projector calibration, since this model is effective for three primary colors type of display [1]. The compensation algorithm is composed of sixth steps as shown in Figs.3, 4.

1) For calculating the appearance of an original image in a dark room, at first, original RGB image is transformed to XYZ image based on the projector's response function and the calibration data.

2) Converting XYZ image to Jab color space in CIECAM02. CIECAM02 requires white point as input data. The white point for calculating Jab is projected white.

3) The Jab is separated into achromatic (J) and chromatic (ab) channels.

4) Chromatic channels are transformed to match the possible projection range (a'b') under dim illumination for minimization of color difference(Fig.5)[2].The range can be precomputed by measuring the dim illuminated condition.

5) Achromatic channels are transformed to match the possible projection range (J') under dim illumination for enhancement of low contrast region. The detail information can be precomputed by brightness image divided by birateral filtered image as local adaptation luminance in CAT02 transformed RGB space.

6) In the inverse transformation, the compensated RGB image ($RGB_{compensate}$) is calculated from changed achromatic (J') and chromatic (a'b') channels (J'a'b' = $Jab_{compensate}$). The white point in inverse transformation is white of projector + illumination, and the $RGB_{compensate}$ image is the final output under dim illumination.

Gamut compression

Gamut compression is to match the possible projection range under dim illumination with preserving the distribution(Fig.5). The possible projection range is in by the polygon Y-R-M-B-C-G chromatic channels computed by Equation 1-3. With the gray world assamption, white point was projection white, and luminance for adaptation degree was 20 % of White point luminance under dim illumination in this research.

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \mathbf{M}_{CAT02} \begin{bmatrix} X \\ Y \\ G \end{bmatrix} \tag{1}$$

$$\mathbf{M}_{CAT02} = \begin{bmatrix} 0.7328 & 0.4296 & -0.1624 \\ -0.7036 & 1.6975 & 0.0061 \\ 0.0030 & 0.0136 & 0.9834 \end{bmatrix} \tag{2}$$

$$RGB_c = \left[Y_w \frac{D}{RGB_w} + (1-D) \right] RGB \tag{3}$$

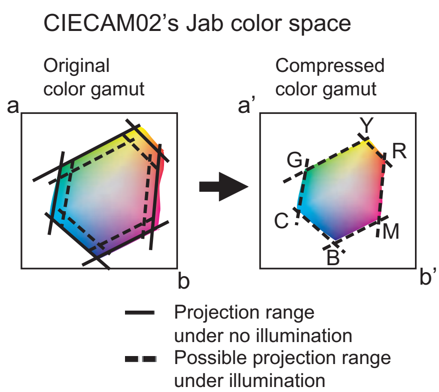

Figure 5. *Compression of chromatic channels*

Detail Enhancement

Detail enhancement is composed of the two steps. First, average of pixel surround and pixel value in CAT02 is required for detail image:

$$RGB_{detail} = \frac{RGB_{CAT02}}{RGB_{local,CAT02}} \tag{4}$$

Average of pixel surround as local image Y_{local} is computed by bilateral filter[7]:

$$Y_{local}(\mathbf{x}) = (G * Y)(\mathbf{x}) \tag{5}$$

$$G(\mathbf{x}) = k^{-1} \exp^{-\frac{1}{2}\left(\frac{\delta(\phi,\mathbf{f})}{\sigma_r}\right)^2} \exp^{-\frac{1}{2}\left(\frac{d(\xi,\mathbf{x})}{\sigma_d}\right)^2} \tag{6}$$

$$k(\mathbf{x}) = \iint \exp^{-\frac{1}{2}\left(\frac{\delta(\phi,\mathbf{f})}{\sigma_r}\right)^2} \exp^{-\frac{1}{2}\left(\frac{d(\xi,\mathbf{x})}{\sigma_d}\right)^2} d\xi \tag{7}$$

$$\delta(\phi,\mathbf{f}) = \delta(\phi - \mathbf{f}) = \|\phi - \mathbf{f}\| \tag{8}$$

As bilateral filter is edge preserved low-pass filter, processed image is prevented from artifact such as halo. Edge information is recognized:

$$g(\mathbf{x}) = \begin{cases} 1 - \frac{\delta(\mathbf{x})}{\sigma_s} & \delta(\mathbf{x}) \leq \sigma_s = 37 \\ 0 & \text{otherwise} \end{cases} \tag{9}$$

σ_s is 37 in Image quality map of the Statistical Image Evaluation by Jobson(Fig.6)[6]. σ_r is 17 by gaussian approximation of Eq.9. σ_d is 18 in 151 pixel of window size by field of view in 10 degrees. Finally, original image and detail image are adaptively-weighted in CAT02:

$$J' = \left[\left[D \times Y_w \times RGB_{detail} + (1-D) \times RGB_{CAT02} + RGB_{Illumination,CAT02}\right]_{CAT02^{-1}}\right]_{XYZtoJ} \tag{10}$$

$$Y_w = Y_{local} + Y_{illumination} \tag{11}$$

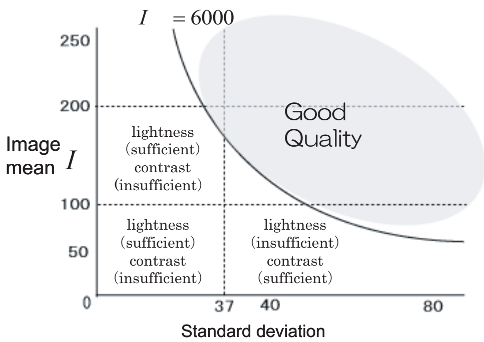

Figure 6. *Image quality map[5]*

(a)Original image under no illumination

(b)Original image under illumination

(c)Compensated image by proposed method

(d)Compensated image by conventional method

Figure 7. *Output under experimentation environment (Image2)*

Psychophysical Experiment

The psychophysical experiment was preformed using the memory matching technique to evaluate the images produced by different algorithms. Figure 8 shows the experimental setup. The observer was instructed to remember the appearance of the projection image under no illumination. Then the observer has at least 1 minute for adapting dim illumination (10cd/m^2). After that, images compensated by conventional [2] and proposed method are presented one by one. The observers evaluated each image and the rating scale is from 1 to 5 as shown in Fig.9. Fifteen observers evaluated 3 images shown in Fig.10.

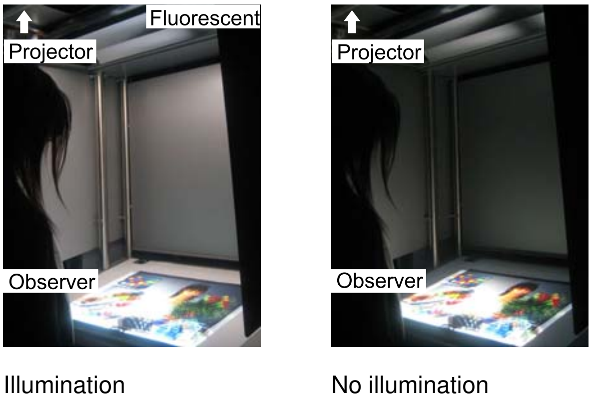

Figure 8. Experimental setup

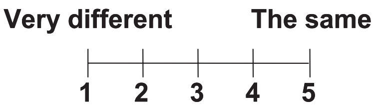

Figure 9. Rating scale for experiment of image accuracy

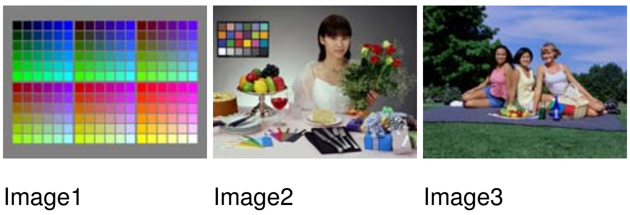

Figure 10. Thumbnails of experimental images

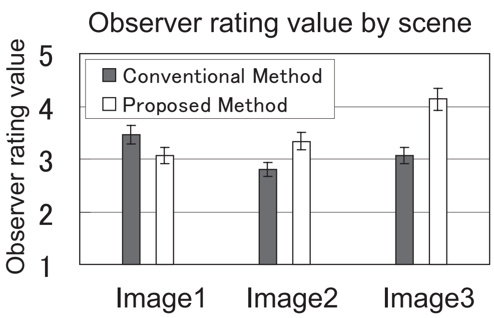

Figure 11. Preference scores by scene

Results and Discussion

Figure 11 shows the experimental results. In Image 1, 2 and 3, the rating value of proposed method (compensation in CIECAM02 space) were 3.33, 3.07, 4.13 and the average was 3.5, and that of conventional method (compensation in CIEL*u*v* space) were 2.8, 3.47, 3.07 and the average was 3.1 respectively. In the overall results, the proposed method is better than conventional method. In the both methods, the chromatic channels are optimized in each color space. In inverse transform, our proposed method uses the white point for the observers' adaptation. Additionally, the achromatic channel is considered as the local detail information. The observer rating value of proposed method is higher than conventional method except Image 1. As the compensation degree is different locally, high frequency component in the images is changed. Image 2, 3 has more high frequency component than the spatial periodically-patterned image as Image 1. Due to this, Image 1 is more unnaturally affected than others. Therefore, in Image 2 and 3, our proposed method achieved more improvement of appearance than the conventional method.

Conclusions

We proposed color correction method of projection display that based on the CIECAM02 with local luminance. From the experimental results, our proposed method improves the color appearance under dim illuminated condition as compared with conventional method. As the future work, we are planning to develop the color correction algorithm under non uniform illumination and which is dependent on the image content. In addition, we'll reexamine the psychophysical evaluation method for projected images.

References

[1] S. Yamamoto, K. Ueda, N. Tsumura, T. Nakaguchi, Y. Miyake, Projector-based color simulator for print industry, IEICE trans. on Fundamentals of Electronics, Communications and Computer Sciences, Vol.E89-A, No.11, pp.2962-2969, (2006).

[2] M. Ashdown, T. Okabe, I. Sato, and Y. Sato, Robust Content-Dependent Photometric Projector Compensation, In IEEE International Workshop on Projector-Camera Systems (ProCams), pp 61-67, (2006).

[3] N. Moroney, M. D. Fairchild, R. W. G. Hunt, C. Li, M. R. Luo, and T. Newman, The CIECAM02 Color Appearance Model, 10th Color Imaging Conference Scottsdale, pp.23-27, (2002).

[4] F. Durand and J. Dorsey, Fast Bilateral Filtering for the Display of High-Dynamic-Range Images, In Proceedings of ACM SIGGRAPH 2002, pp.257-266, (2002).

[5] Y. Takematsu, T. Nakaguchi, N. Tsumura, and Y. Miyake, Improvement of image quality using Retinex theory based on the statistical image evaluation, J. Society of Photographic Science and Technology of Japan, vol.60, no.4, pp.410-416, (2004).

[6] Jobson, D. J., Rahman, Z., and Woodell, G. A. The Statistics of Visual Representation,Proceedings of Visual Information Processing XI, SPIE, 4736. (Invited paper), (2002).

[7] TOMASI, C., AND MANDUCHI, R. Bilateral filtering for gray and color images, In Proc. IEEE Int. Conf. on Computer Vision, pp. 836-846, (1998).

Author Biography

Sayuri Kamimigaki received the B.E. degree in Information and Image Sciences from Chiba University, Chiba, Japan, in 2008. She is currently a master course student in Graduate School of Advanced Integration Science, Chiba University. Her research interests are projector - camera systems and color image processing.