Improvement of Incomplete Chromatic Adaptation Model for Facial Pattern Images

Francisco Hideki Imai*‡, Norimichi Tsumura*, Hideaki Haneishi*, and Yoichi Miyake†

Department of Information and Computer Sciences, Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba-shi, 263 Japan

We improved the incomplete chromatic adaptation model proposed by Fairchild to reproduce facial pattern images under various illuminants. We introduced weighting coefficients in the modified fundamental chromaticities of the adapting stimulus used in the Fairchild model to improve the color reproduction. Psychophysical experiments using memory matching technique were performed to select the optimum weighting coefficients of adapting stimulus for facial pattern images. The improved model with the optimum coefficients was compared with other color appearance models, von Kries, RLAB, LLAB, and colorimetric color reproduction under three illuminants; illuminant A (2837 K), Daylight (6047 K) and Cool White (3957 K). As a result, it was shown that the improved model performed significantly well for facial pattern images if compared with other models.

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Introduction

Development of cosmetics and their sales promotion requires prediction of skin color images under various illuminants, because appearance of skin color depends on the illuminant in the environment. We have already proposed a colorimetric method to predict skin color images under various illuminants on a CRT display and hardcopy.[1] In this method, the spectral reflectance was estimated based on principal component analysis and the estimated spectral reflectance of human skin was used for computer simulation of colorimetric color reproduction.

One of the most significant factors affecting color appearance is the change of visual color sensitivities corresponding to changes of illumination. This phenomenon is known as chromatic adaptation. In the previous paper,[2] we studied a color reproduction system to predict the appearance of skin color images under various viewing illuminants. The chromatic adaptation model was applied to the colorimetric color reproduction method. Then, on a CRT display, we could achieve color appearance reproduction of printed skin color images under different viewing illuminants. The optimum color appearance model to predict color reproduction was estimated by psychophysical experiments based on a memory matching viewing technique and we found that the incomplete chromatic adaptation model proposed by Fairchild[3] was effective for a suitable prediction of color appearance in skin color patches. However, it was not always an optimum color appearance model to predict color reproduction of facial pattern images.

In this article[§] we improved Fairchild's chromatic adaptation model to reproduce facial pattern images well under various illuminants. We extended coefficients of incomplete chromatic adaptation in the Fairchild's model introducing weighting coefficients in the modified fundamental chromaticity equations. Psychophysical experiments were performed to select the optimum weighting coefficients of adapting stimulus for facial pattern images. The improved Fairchild model was compared with other models by psychophysical experiments.

Improved Fairchild Chromatic Adaptation Model for Facial Pattern Images

Fairchild Chromatic Adaptation Model and Its Extension. The Fairchild model shown in Eqs. 1 are based on a functional expression proposed by Hunt[4] for incomplete levels of adaptation.

$$L' = \rho_L L/L_N, \tag{1a}$$

$$M' = \rho_M M/M_N, \tag{1b}$$

$$S' = \rho_S S/S_N,, \tag{1c}$$

Where L, M, S and L', M', S' are cone excitations and cone values after adaptation, respectively; L_N, M_N, and S_N are the maximum cone excitations corresponding to the white point of the illuminant; and ρ_L, ρ_M, and ρ_S are parameters representing the degree of chromatic adaptation of each

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* IS&T Member

† IS&T Fellow

‡ Current address: Chester F. Carlson Center for Imaging Science, Rochester Institute of Technology,, 54 Lomb Memorial Drive, Rochester, NY 14623-5604 USA, Tel:(716)475-7842, e-mail: fhipci@rit.edu

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cone mechanism. They are calculated by the following equations:

$$\rho_L = \frac{\left(1 + Y_N^v + \ell_E\right)}{\left(1 + Y_N^v + 1/\ell_E\right)}, \tag{2a}$$

$$\rho_M = \frac{\left(1 + Y_N^v + m_E\right)}{\left(1 + Y_N^v + 1/m_E\right)}, \tag{2b}$$

$$\rho_S = \frac{\left(1 + Y_N^v + s_E\right)}{\left(1 + Y_N^v + 1/s_E\right)}, \tag{2c}$$

where Y_N is the luminance of the adapting stimulus; ν is an exponent that defines the shape of the degree of the adaptation; and ℓ_E, m_E, and s_E are the modified fundamental chromaticity coordinates of the adapting stimulus given by

$$\ell_E = \frac{3(L_N/L_E)}{L_N/L_E + M_N/M_E + S_N/S_E}, \tag{3a}$$

$$m_E = \frac{3(M_N/M_E)}{L_N/L_E + M_N/M_E + S_N/S_E}, \tag{3b}$$

$$s_E = \frac{3(S_N/S_E)}{L_N/L_E + M_N/M_E + S_N/S_E}, \tag{3c}$$

where L_E, M_E, and S_E are the fundamental tristimulus values of an equal energy source.

We changed these modified fundamental chromaticity coordinates of adapting illuminant ℓ_E, m_E, and s_E, namely, the weighting coefficients of adapting stimulus K_L, K_M, and K_S were introduced into the ℓ_E, m_E, and s_E as shown in Eqs. 4:

$$\ell_E = \frac{K_L(L_N/L_E)}{L_N/L_E + M_N/M_E + S_N/S_E}, \tag{4a}$$

$$m_E = \frac{K_M(M_N/M_E)}{L_N/L_E + M_N/M_E + S_N/S_E}, \tag{4b}$$

$$s_E = \frac{K_S(S_N/S_E)}{L_N/L_E + M_N/M_E + S_N/S_E}, \tag{4c}$$

The coefficients are provided to adjust the weight of each modified fundamental chromaticities coordinates for facial pattern images instead of the constant value 3 in the Fairchild model. In our experiments we used the simplified fundamental chromaticity coordinates given by Eqs. 5 because we incorporated the normalization of fundamental chromaticity coordinates relative to an equal-energy illuminant into the matrix used for the conversion from *X, Y, Z* tristimulus values to *L, M, S* cone fundamental values.

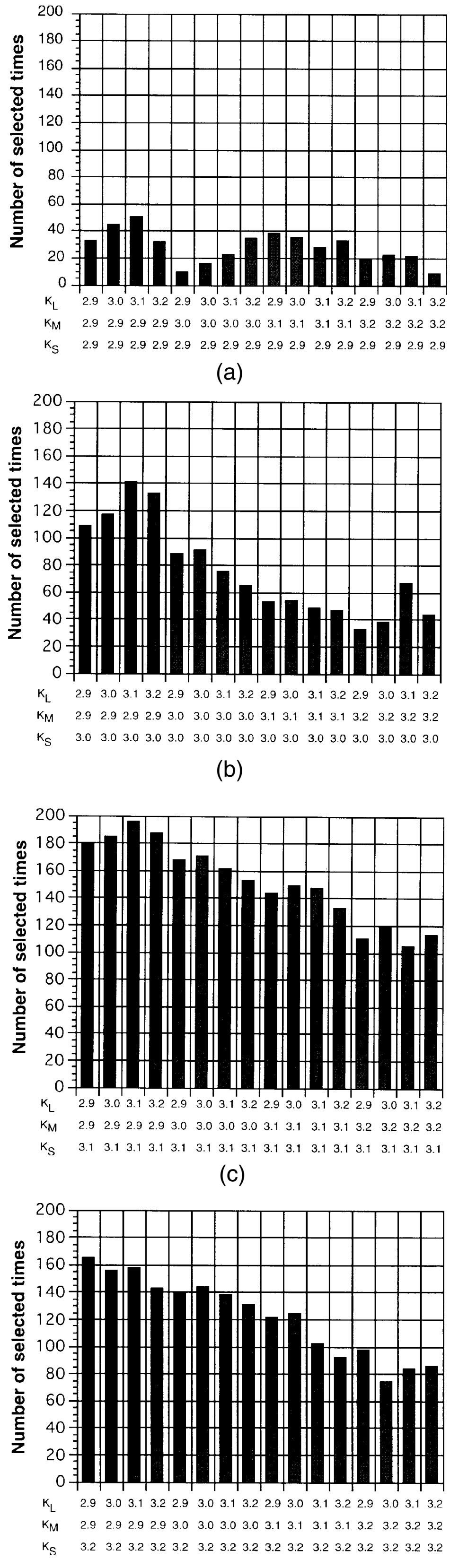

Figure 1. (a) Number of selected times when K_L, K_M are changed from 2.9 to 3.2 and K_S = 2.9; (b) number of selected times when K_L, K_M are changed from 2.9 to 3.2 and K_S = 3.0; (c) number of selected times when K_L, K_M are changed from 2.9 to 3.2 and K_S = 3.1; (d) number of selected times when K_L, K_M are changed from 2.9 to 3.2 and K_S = 3.2.

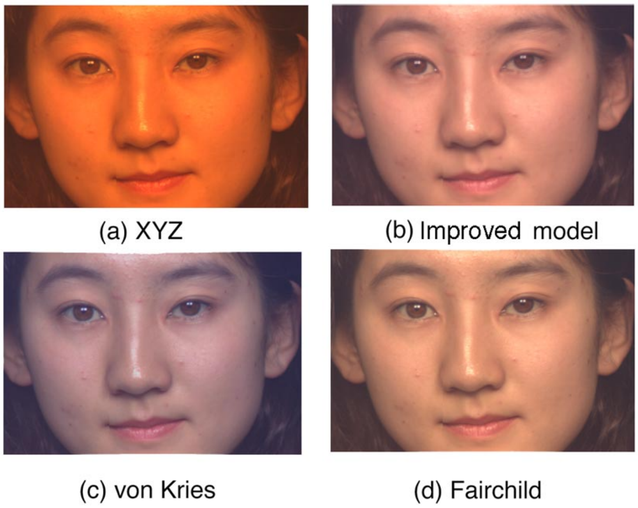

Figure 2. A facial pattern image reproduced on a CRT for illuminant "A": (a) XYZ, (b) improved model, (c) von Kries, and (d) Fairchild.

$$\ell_E = \frac{K_L L_N}{L_N + M_N + S_N}, \tag{5a}$$

$$m_E = \frac{K_M M_N}{L_N + M_N + S_N}, \tag{5b}$$

$$s_E = \frac{K_S S_N}{L_N + M_N + S_N}. \tag{5c}$$

Psychophysical Experiments to Tune the Proposed Weighting Coefficients for Facial Pattern Image. The psychophysical experiments were performed to select the optimum weighting coefficients of adapting stimulus for a facial pattern image of a Japanese young woman. The images were taken by a HDTV camera and digitized with 8 bits to get an image of 1920 by 1035 pixels.

Memory matching viewing technique, recommended by Braun, Fairchild, and Alessi[5] was adopted for the psychophysical experiments that were conducted following the guidelines of the CIE Technical Committee 1-27 on "Specification of colour appearance for reflective media and self-luminous display comparisons."[6] In this viewing technique, the CRT display and the standard illumination booth were angularly positioned at 90° such that the observers can only see one of them at a time. The experiments were performed in a dark environment. Three kinds of illuminants; "A" (2837 K), "Day Light" (6047 K), and "Cool White" (3957 K) were considered.[1,2]

At first, we prepared the 64 images where the coefficients K_L, K_M, and K_S were varied from 2.9 to 3.2 under each illuminant. The images were displayed in pairs on CRT display. The observer, F.H.I., was asked to select on CRT the most similar image to the original hardcopy. Figures 1(a) through 1(d) show the number of selected times of the image reproduced by each combination of coefficients K_L, K_M, and K_S. From the figures, we considered that the optimum weighting coefficients of adapting stimulus for facial pattern image are obtained when the coefficients K_L, K_M, and K_S equal to 3.1, 2.9, and 3.1, respectively.

Comparison of the Improved Fairchild Model with Other Color Appearance Models. ***Experiment A (Improved Fairchild, XYZ, von Kries, Fairchild).*** The performance of the modified Fairchild's incomplete chromatic adaptation model was compared with colorimetric color reproduction and other color appearance models, von Kries,[7] Fairchild, and by psychophysical experiments. The reproduced images under illuminant "A" are shown in Fig. 2.

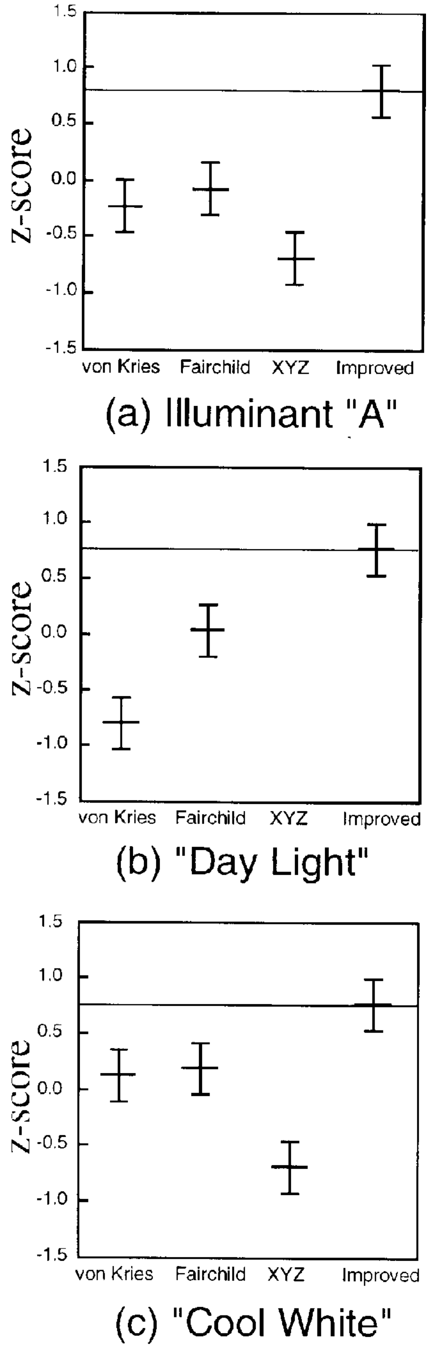

Figure 3. Averaged interval scale of the performance of each model to reproduced a facial pattern image for 3 kinds of

Psychophysical experiments were performed using a memory matching viewing technique. A hardcopy in a standard illuminant booth was compared with a pair of reproductions on CRT in a dark environment. Ten observers were asked to select the reproduction on CRT which provided the best match in color appearance with the hardcopy. The choices of reproduction on CRT were converted into an interval scale of color reproduction quality

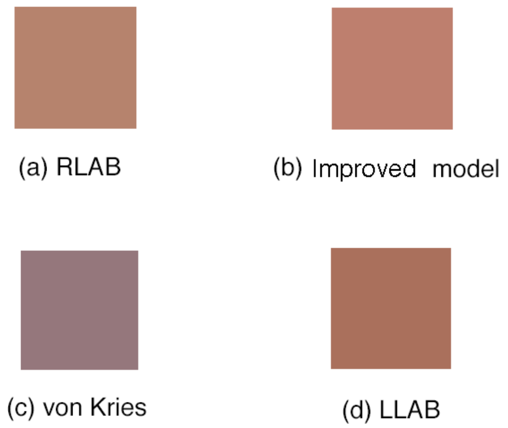

Figure 4. A skin color patch reproduced on CRT display for illuminant “A”: (a) RLAB, (b) improved model, (c) von Kries, and (d) LLAB.

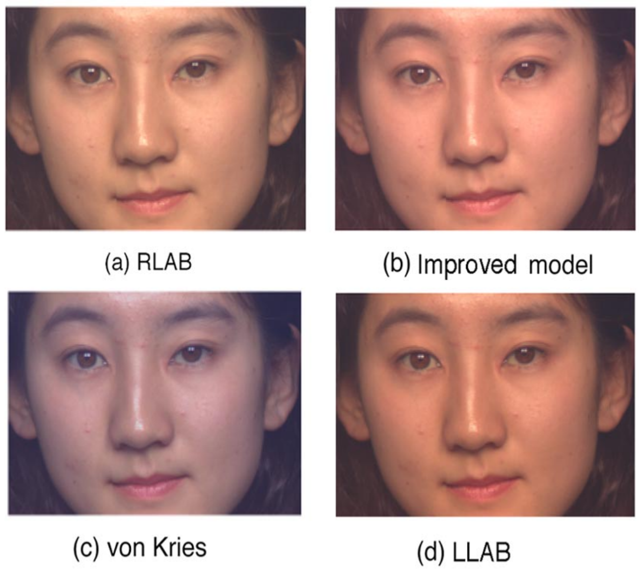

Figure 5. A portrait image reproduced on CRT display for illuminant “A”; (a) RLAB, (b) improved model, (c) von Kries and (d) LLAB.

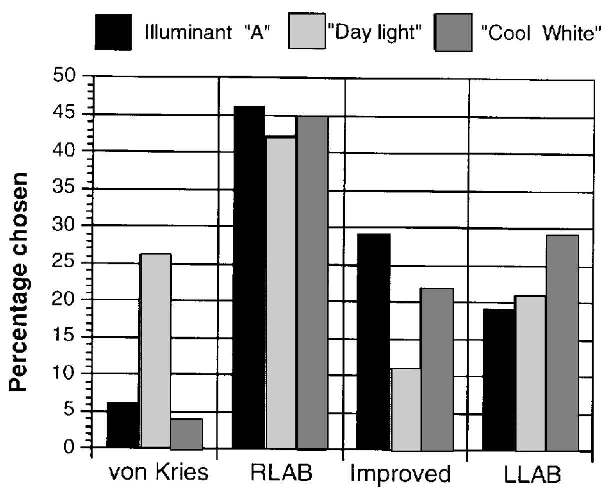

Figure 6. Percentage of reproduction selected on CRT display as the best for skin color patches under three kinds of illuminants.

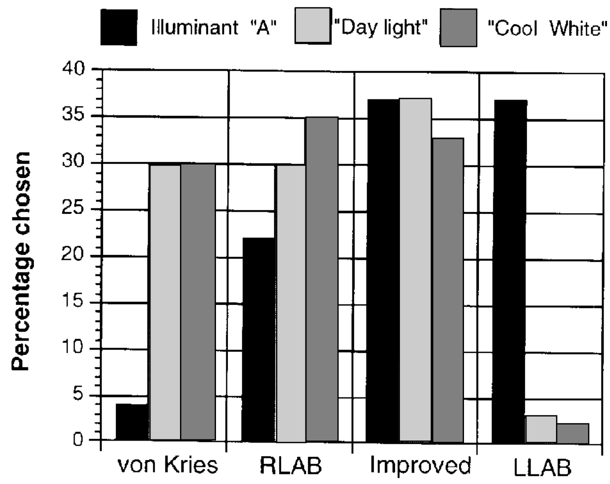

Figure 7. Percentage of reproduction selected on CRT display as best for facial pattern image under three kinds of illuminants.

for various models using Thurstone’s law of comparative judgment.[8] Using statistical procedures described by Torgeson[9] the averaged z-scores for each model were calculated. These z-scores give interval scale values indicating performance in the reproduction of the original hardcopy. A confidence interval of 95% for the averaged value was considered. The performances of two models are considered equivalent if the average of one model falls within the confidence interval of another model .

The results of these experiments are shown in Figs. 3(a) through 3(c), where “improved” indicates the improved Fairchild model for facial pattern image. The central horizontal bar in each plot of Figs. 3(a) through (c) indicates the averaged interval scale value and the horizontal bars in the extremities indicate the error in 95% confidence interval. In the case of the XYZ image under “Day Light” illuminant, it was not possible to calculate the z-score because the image reproduced by XYZ was not selected at all.

The statistical result of these comparisons showed that the improved Fairchild’s model had the best averaged z-scores for all kinds of illuminants. The XYZ image showed the worst results because this reproduction did not consider chromatic adaptation.

Experiment B (Improved Fairchild, von Kries, RLAB, LLAB). XYZ and Fairchild reproductions were replaced by the RLAB refinement[10] published in 1996, and the LLAB model[11] to refine and update the psychophysical experiments. We tested these models for both skin color patches and facial pattern images. Figure 4 shows a reproduced skin color patch under illuminant “A.” Figure 5 shows the reproduced facial pattern image under illuminant “A.”

Six color patches were examined by two observers and a facial pattern image was observed by 10 observers. Figure 6 shows the percentage of skin color patch selected on CRT as the best for three kinds of illuminants, and Fig. 7 shows the percentage of selection for the facial pattern image chosen as the best one on CRT display for three kinds of illuminants.

From Fig. 6, it is clear that the color appearance of the patch by RLAB model was chosen as the best. In this case the improved Fairchild’s model did not perform as well as the RLAB model. We believe this is because the coefficients of color balance were adjusted for facial pattern not for skin color patches. From Fig. 7, it is apparent that the LLAB

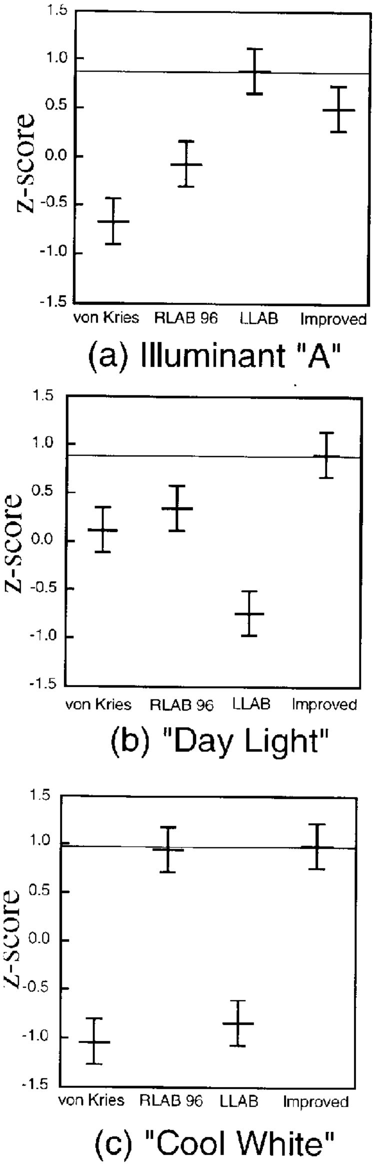

Figure 8. Averaged interval scale of the performance of each model to reproduce four facial pattern images for three kinds of illuminants: (a) illuminant "A," (b) "day light," and (c) cool white.

model performed well for illuminant A but it could not predict well for other illuminants used in the experiment. On the other hand, the von Kries model performed well for "Day Light" and "Cool White" but gave poor results for illuminant "A." The improved Fairchild's model presented the overall best result under all kinds of illuminants.

The reproduction of facial pattern images of three Japanese young women were added to the psychophysical experiments and the result was analyzed statistically. Figures 8(a) through 8(c) show the averaged interval scale values for the reproduced facial pattern images under various illuminants. From Fig. 8(b) it is clear that von Kries and RLAB models are approximately the same in statistical values for facial pattern reproduction under "Day Light" illuminant. From Fig. 8(c) it also can be found that von Kries and LLAB models are approximately the same in statistical values for reproduction under the "Cool White" illuminant. It is also possible to see from Fig. 8(c) that RLAB and the extended Fairchild's model are approximately the same in statistical values for reproduction under the "Cool White" illuminant. The statistical result of these comparisons showed that the improved Fairchild's model had the best averaged z-scores for all kinds of illuminants and it is the same as the result obtained in the previous psychophysical experiments.

Conclusion

We improved Fairchild's chromatic adaptation model and compared it with other color appearance models and colorimetric color reproduction by psychophysical experiments. As a result, we found that the performance of the improved model was less dependent on illuminants than the other tested models for facial pattern image reproduction. We conclude that the adjustment of the introduced weighting coefficients of adapting stimulus in the modified fundamental chromaticity coordinates customizes the Fairchild's model for the reproduction of facial pattern images under various illuminants. We believe this technique of fine tuning of Fairchild's model could be used for other kinds of images.

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