Improvement of Incomplete Chromatic Adaptation Model for Facial Pattern Images

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Abstract

We improved the incomplete chromatic adaptation model proposed by Fairchild to reproduce facial pattern images under various illuminants. The coefficients of color balance in Fairchild model were changed to improve the color reproduction. Psychophysical experiments using memory matching technique were performed to select the optimum coefficients of color balance 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(2837K), Daylight(6047K) and cool white(3957K). As a result, it was shown that the improved model is significant to reproduce facial pattern images than the other models.

1. 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 a 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 factor 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 image 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 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 by changing the color balance of the white point. Psychophysical experiments were performed to select the optimum color balance for facial pattern images. The improved Fairchild’s model was compared with other models by psychophysical experiments.

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2. Improved Fairchild’s Chromatic Adaptation Model for Facial Pattern Images

2.1 Fairchild’s chromatic adaptation model and its extension

The Fairchild's model shown in Eqs. 1 is based on a functional expression proposed by Hunt[4] for incomplete levels of adaptation.

$$L' = \rho_L L / L_N, \quad (1a)$$
$$M' = \rho_M M / M_N, \quad (1b)$$
$$S' = \rho_S S / S_N, \quad (1c)$$

where L, M, S and L', M', S' are cone fundamental values before and after adaptation respectively. L_N, M_N, and S_N are cone fundamental responses for the white point of the illuminant. ρ_L, ρ_M, and ρ_S are coefficients of incomplete adaptation calculated by the following equations;

$$\rho_L = \frac{\left(1 + Y_N^{\upsilon} + l_E\right)}{\left(1 + Y_N^{\upsilon} + 1/l_E\right)}, \quad (2a)$$
$$\rho_M = \frac{\left(1 + Y_N^{\upsilon} + m_E\right)}{\left(1 + Y_N^{\upsilon} + 1/m_E\right)}, \quad (2b)$$
$$\rho_S = \frac{\left(1 + Y_N^{\upsilon} + s_E\right)}{\left(1 + Y_N^{\upsilon} + 1/s_E\right)}, \quad (2c)$$

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

$$l_E = \frac{3L_N}{L_N + M_N + S_N}, \quad (3a)$$
$$m_E = \frac{3M_N}{L_N + M_N + S_N}, \quad (3b)$$

$$s_E = \frac{3S_N}{L_N + M_N + S_N}. \tag{3c}$$

We modified these fundamental chromaticity coordinates l_E, m_E, and s_E, namely the color balance coefficients K_L, K_M, and K_S were introduced into the l_E, m_E, and s_E as shown in the Eqs. 4;

$$l_E = \frac{K_L L_N}{L_N + M_N + S_N}, \tag{4a}$$

$$m_E = \frac{K_M M_N}{L_N + M_N + S_N}, \tag{4b}$$

$$s_E = \frac{K_S S_N}{L_N + M_N + S_N}. \tag{4c}$$

The coefficients are provided to adjust the degree of color balance of white point for facial pattern images instead of the constant value 3 in the Fairchild model.

2.2 Psychophysical experiments to tune color balance of white point for facial pattern image

The psychophysical experiments were performed to select the optimum coefficients of color balance 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 and Fairchild,[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^{o} 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”(2837K), “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), (b), (c), (d) show the number of selected times of the image reproduced by each combination of coefficients K_L , K_M, K_S . From the figures, we considered that the optimum color balance for facial pattern image are obtained when the coefficients K_L , K_M, K_S equal to 3.1, 2.9, 3.1 respectively.

3. Comparison of the improved Fairchild model with other color appearance models.

A) 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, by psychophysical experiments. The reproduced images under illuminant “A” are shown in Fig. 2.

Psychophysical experiments were performed using 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 provides 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 for various models using Thurstone’s law of comparative judgments[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 their 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 as 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), (b), and (c), where “Improved” indicates the improved Fairchild model for facial pattern image. The central horizontal bar in each plot of Figs. 3(a), (b), and (c) indicate 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 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 does not consider chromatic adaptation.

B) Experiment B (Improved Fairchild, von Kries, RLAB, LLAB)

XYZ and Fairchild reproductions were replaced by the RLAB refinement published in 1996,[10] and 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 ten observers. Figure 6 shows the percentage of skin color patch that was selected on CRT as the best one for 3 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 3 kinds of illuminants.

From Fig. 6, it is clear that the color appearance of patch by RLAB model was chosen as the best one. In this case the improved Fairchild’s model did not perform well as RLAB model. We considered that 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 LLAB model performed well for illuminant “A” but it could not predict well for other illuminants used in the experiment. On the other hand, von Kries model performed well for “Day Light“ and “Cool White” but it 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 imges of three Japanese young women were added to the psychophysical experiments and the result was analyzed statistically. Figures 8(a), (b), and (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 same in statistical values for facial pattern reproduction under “Day Light” illuminant. From Fig. 8(c) it can be also found that von Kries and LLAB models are approximately same in statistical values for reproduction under “Cool White” illuminant. It is also possible to see from Fig. 8(c) that RLAB and the extended Fairchild’s model are approximately same in statistical values for reproduction under “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.

4) 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 proposed model was less dependent on illuminants than the other tested models for facial pattern image reproduction. We conclude that the adjustment of the coefficients of color balance customizes the Fairchild’s model for the reproduction of facial pattern images under various illuminants. We believe that this technique of fine tuning of Fairchild’s model could be used for other kinds of images.

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