Spectral Reflectance of Skin Color and its Applications to Color Appearance Modeling

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Abstract

Fifty-four spectral reflectances of skin colors (facial pattern of Japanese women) were measured and analyzed by the principal component analysis. The results indicate that the reflectance spectra can be estimated approximately 99% by only three principal components. Based on the experimental results, it is shown that the spectral reflectance of all pixels in skin can be calculated from the R, G, B signals of HDTV (High Definition Television) camera.

Computer simulations of color reproduction in skin color have been developed in both colorimetric color reproduction and color appearance models by von Kries, LAB and Fairchild. The obtained color reproduction in facial pattern and skin color patch under different illuminants are analyzed. Those reproduced color images were compared by memory matching method. The difference of appearance models is described and the difference of appearance between skin color patch and facial pattern is also discussed and analyzed.

Introduction

In desktop publishing of digital photography, cross-media corresponding color reproduction of portrait under various illuminants is desirable. To achieve color appearance matches across media, the traditional colorimetric method must be enhanced using color appearance models.

A previous work shows that the spectral reflectance of human skin can be represented by three basis functions based on the principal component analysis.[1] Then, the two dimensional distribution of spectral reflectance of the skin can be estimated using the values of three color channels and the spectral radiance of the illuminant, as is performed in electronic endoscope images.[2] The colorimetric color reproduction under various illuminants[3] can be achieved using both the estimated spectral reflectance of the object and the spectral radiance of the illuminant.

In this paper, we propose a color reproduction method to predict the appearance of skin color image under various viewing illuminants[4] using the colorimetric information of skin color images taken by HDTV camera. In this method chromatic adaptation transformations proposed by von Kries[5] and Fairchild[6], and LAB[7] color space is applied to the colorimetric color reproduction obtained by principal components of human skin reflectance.[3] By this method we can achieve the corresponding color reproduction on a CRT display of printed skin color images under various viewing illuminants. Optimum color appearance model to predict color reproduction is selected by psychophysical experiments based on the memory matching method. The difference of appearance between skin color patch and facial pattern is also discussed and analyzed.

Principal Component Analysis of Spectral Reflectance of Human Skin

Ojima et al.[1] measured one hundred eight spectral reflectances of skin in human face for 54 Mongolians (Japanese women) who are between 20 and 50 years old. The spectral reflectance was measured at intervals of 5 nm between 400 nm and 700 nm. Therefore, the spectral reflectance is described as vectors $\boldsymbol{o}$ in 61-dimensional vector space. The covariance matrix of the spectral reflectance was calculated for the principal component analysis. Then, the spectral reflectance of human skin can be expressed as a linear combination of the principle component vectors as follows:

$$o = \bar{o} + \sum_{i=1}^{61} \alpha_i \boldsymbol{u}_i , \qquad (1)$$

where $\bar{o}$ is the averaged spectral reflectance, $\boldsymbol{u}_i$ (i = 1...61) are the eigenvectors and α_i (i = 1...61) are the eigenvalues. The eigenvectors are combined in order of the eigenvalues.

The cumulative proportion ratio of these principle components shows that the spectral reflectance of human skin can be represented approximately 99.5% by using linear combination of three principal components.[1] Therefore the Equation (1) can be represented approximately as follows:

$$\boldsymbol{o} \cong \bar{\boldsymbol{o}} + \sum_{i=1}^{3} \alpha_i \boldsymbol{u}_i = \bar{\boldsymbol{o}} + \begin{pmatrix} u_1 & u_2 & u_3 \end{pmatrix} \begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{pmatrix} \qquad (2)$$

Colorimetric Color Reproduction of Skin

Figure 1 shows schematic diagram of color reproduction from an image taken by HDTV camera to CRT or hardcopy of skin color under various illuminants. A skin color image taken by HDTV camera was transformed from the original *RGB* data to *X, Y,* and *Z* tristimulus values by matrix $\boldsymbol{M}_1$ obtained by multiple regression analysis of skin color patch. A two dimensional distribution of spectral reflectances of skin $\boldsymbol{O}(i, j, \lambda)$, where i, j are the coordinates of the image, is estimated using three principal components of the reflectance of the skin. The tristimulus values X', Y', Z' of skin color under a selected illuminant are easily calculated from $\boldsymbol{O}(i, j, \lambda)$ and the spectral radiance $E(\lambda)$ of the illuminant.

The predicted tristimulus values are displayed on CRT and printed by color transform matrix for calibration. Then, the skin color image is reproduced colorimetrically both on CRT display and hardcopy.

Corresponding Color Reproduction of Skin Color

Figure 2 shows a schematic diagram of the proposed corresponding color reproduction method for skin color. By using color appearance models, the tristimulus values X_a, Y_a, and Z_a after the chromatic adaptation can be calculated from the tristimulus values X', Y', and Z' obtained by colorimetric color reproduction. The first step is a transformation from tristimulus values, X', Y', and Z' to cone fundamental tristimulus values L, M, and S using the Hunt-Pointer-Estévez transformation normalized to CIE Illuminant D65. The values L_a, M_a, and S_a which are the cone responses after the chromatic adaptation were predicted from the L, M, S values using von Kries, LAB, and Fairchild models. Then, the tristimulus values X_a, Y_a, and Z_a, considering chromatic adaptation, are calculated by the inverse of matrix $\boldsymbol{M}_2$. Finally, the predicted image with tristimulus values X_a, Y_a, and Z_a is reproduced on CRT display by color transform matrix.

Psychophysical Experiment to Select an Optimum Color Appearance Model for Proposed Method

Color appearance models to predict color reproduction was estimated by psychophysical experiments. The images on CRT display surrounded by a dark environment were compared with a hardcopy illuminated in the standard illumination booth (Macbeth Spectralight II). The booth has four illuminants; “Day light” (CIE D65), “A” (2,856 K), “Cool white” (4,150 K), and “Horizon” (2,300 K).

Five facial images of a Japanese young women were taken by a HDTV camera and digitized with 8 bits to get an image of 1920 by 1035 pixels. Six skin color patches with same color in facial pattern are also prepared. The predicted color reproduction for skin color patches and facial images in the viewing booth were displayed on CRT. Three images, predicted using von Kries, Fairchild, CIELAB models, and XYZ image without considering chromatic adaptation were calculated for each viewing illuminant.

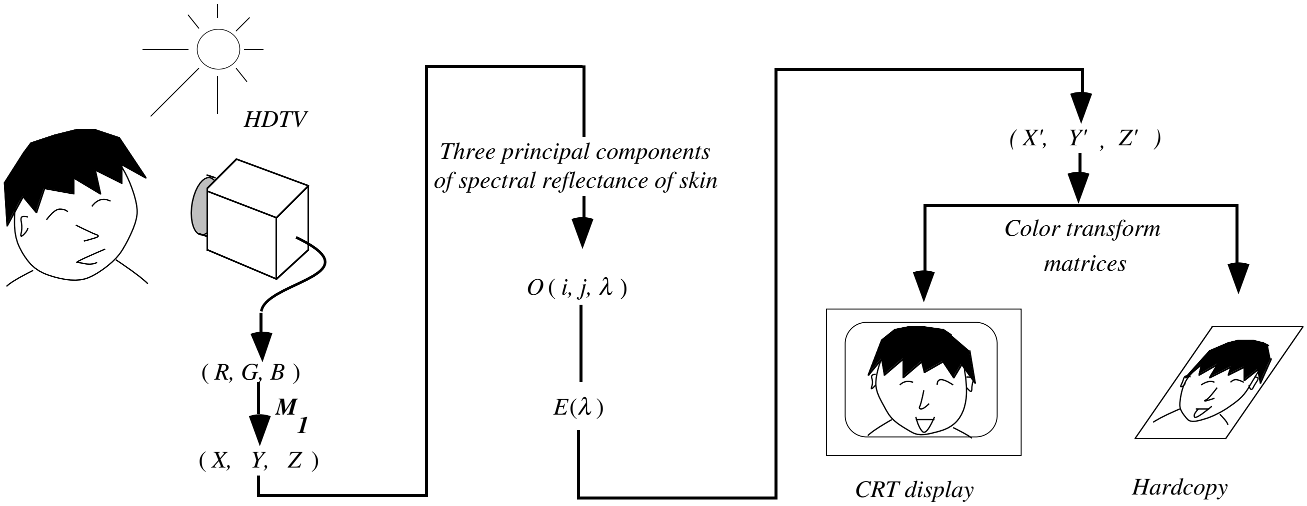


Figure 1. Diagram of colorimetric color reproduction of skin color image under various illuminants.

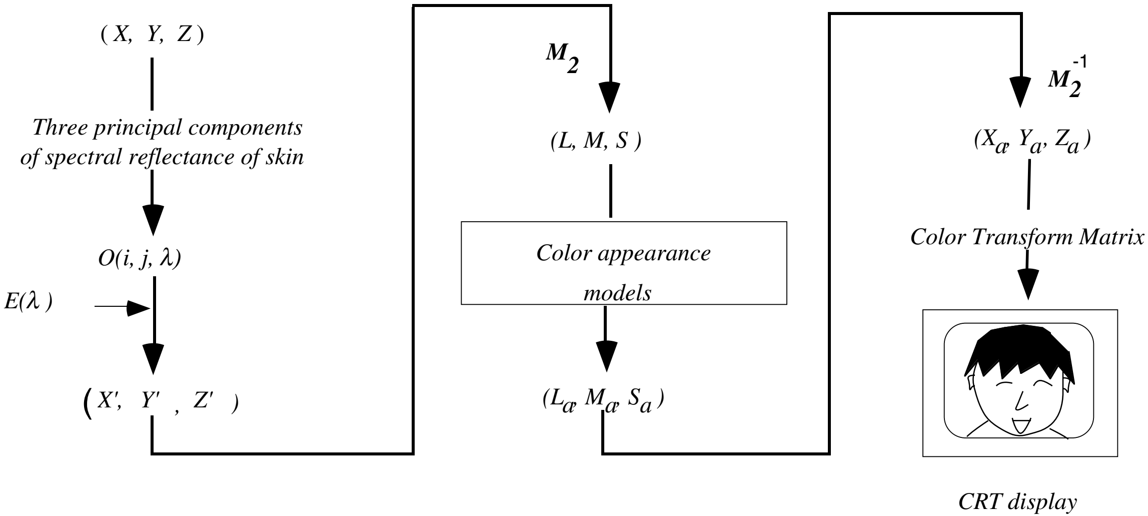


Figure 2. Diagram of corresponding color reproduction of skin color image under various illuminants.

A memory matching method, recommended by Braun and Fairchild,[8] was used to select an optimum color appearance model for skin color images displayed on a CRT. 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.

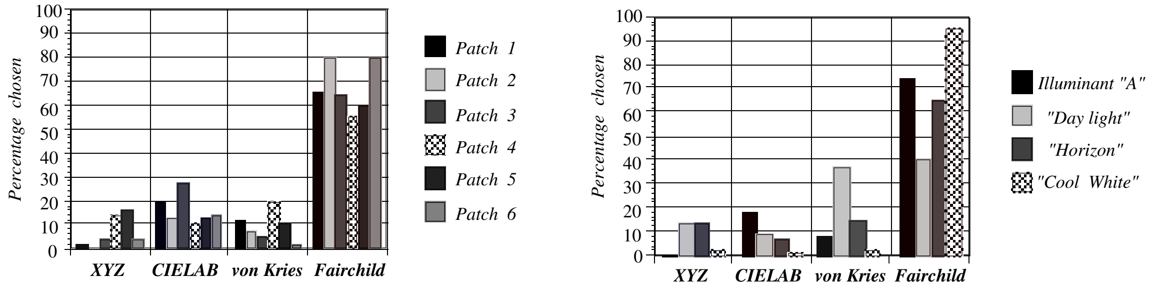
Ten observers (students involved in image processing) viewed the images in the illumination booth for a minute to stabilize the perception of the color. Then, they would view the CRT display where four predicted images, XYZ, von Kries, Fairchild, CIELAB images are displayed. Observers were instructed to choose the best prediction in the four images on CRT display. The psychophysical experiment was performed for both skin color patch and facial images.

Experimental Results and Discussion

Figure 3(a) shows the percentage of trials for which each reproduced model on CRT display was selected as the most similar color reproduction to an hardcopy illuminated by various illuminants. As a result, in an average of 68% of the trials the observers selected Fairchild model. Figure 3(b) shows the percentage of trials for the selected color reproduction on CRT as the most similar one to an hardcopy illuminated by each illuminant in the booth. We can see that the incomplete adaptation proposed by Fairchild, was effective under "Cool White", "Horizon", and Illuminant "A". However, under "Day Light" the Fairchild model was not as effective as other illuminants, because under this illuminant there is no significant degree of adaptation, and there is no perceptible differences between the images predicted by von Kries and Fairchild models.

On the other hand, Figure 4(a) shows the percentage of selected facial pattern image reproductions on CRT according to the criterion of similarity to a hardcopy under various illuminants in the illuminant booth. Fairchild model was well selected as in the previous experiment with skin color patches. As a result, an average of 43% of the trials the observers selected Fairchild model. Figure 4(b) shows the percentage of selected facial pattern images on CRT according to the criterion of similarity to a hardcopy illuminated by each illuminant in the booth. In the case of facial image, there is no significant difference of experimental results among illuminants for each model.

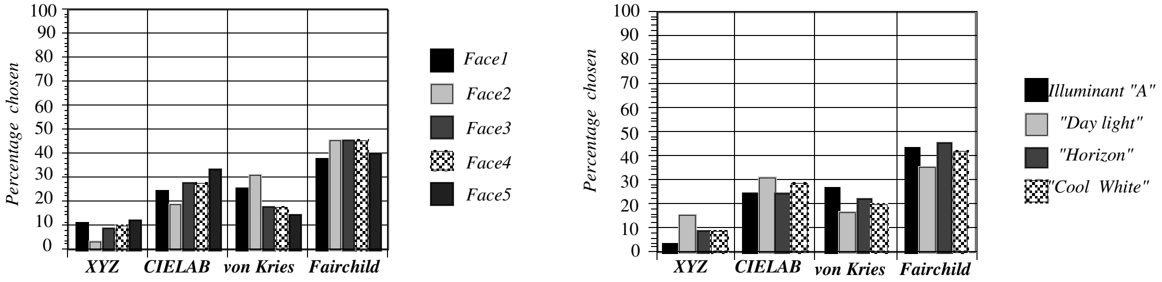
Comparing Figure 3 and Figure 4 we can find that there is a difference in the percentage of selected image for the Fairchild model between the color patches and facial pattern. In the case of facial pattern, other color appearance models were selected more times than the experiment with color patches. Perhaps there is a fundamental difference between matching colored patches and matching facial images, as suggested by Braun et al.[9] It is known that the facial skin color is one of the human memorized colors. We believe that the difference in the result is due to the highly dependence of color appearance of facial skin colors on the individual memorization. We can conclude that the Fairchild model is significant in our proposing method for prediction of skin color patches, however this model cannot be completely applied for facial pattern images.



(a) Selected model in the prediction of the color appearance for each skin color patch under various illuminants.

(b) Selected model in the prediction of the color appearance of six skin color patches under four illuminants.

Figure 3. Percentage of trials on which each reproduced skin color was selected on a CRT display as the most similar color reproduction to an illuminated hardcopy.



(a) Selected model in the prediction of the color appearance for each facial pattern image under various illuminants.

(b) Selected model in the prediction of the color appearance of five facial pattern images under four illuminants.

Figure 4. Percentage of trials on which each reproduced facial pattern image was selected on a CRT display as the most similar reproduction to an illuminated hardcopy.

Conclusion

On the basis of the principal component analysis of the spectral reflectance of human skin, a corresponding color reproduction method was proposed for skin color images under various illuminants using color appearance models. By subjective experiments we found that the incomplete chromatic adaptation model proposed by Fairchild 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. Furthermore studies are necessary to consider the influence of memorized facial skin color in the cognitive mechanisms of chromatic adaptation.

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