Image-Based Skin Color Synthesis for Mobile Phones with Camera

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Abstract

In this paper, we propose practical algorithms for the pigment color separation and synthesis of the human skin color to be used on mobile phone with camera. These algorithms overcome the limitation of the conventional algorithm such as using polarizing filters. The pigment colors are separated based on the proposed empirical pigment vector. The empirical vectors are extracted from skin color database. We evaluated the proposed algorithms for 45 images (5 persons, 3 cameras, 3 illuminants). The evaluated results showed that the proposed algorithms performed well on most of skin images.

Introduction

Skin color reproduction may be considered the most important problem for color reproduction. The slight changes of the structure and pigment construction produce rich skin color variation. Skin color correction is required for image communications based on mobile phones with camera, since the characteristics of camera are different from each other (see Figs. 5 and 6).

In 1999, Tsumura et al. have proposed the method to separate pigments from skin images and reproduce the various facial color images by changing the quantities of the separated two pigments. This method can be used for realistic skin color correction. However, this method requires a polarizing filter and strictly given geometry to obtain the body reflection of the human skin, and it requires that the camera has ideal tone characteristics. These requirements can not be applied to the mobile phone with camera under the practical situation.

In this research, we propose two algorithms for the pigment separation and synthesis of the human skin using the mobile phone with camera. Figure 1 shows the schematic flow of the proposed image-based skin color synthesis. Upper flow shows the proposed algorithm #1, (b) is a body reflection image obtained by removing surface reflection from the original image (a), (c) is a linear image after gamma correction, (d) are the melanin and the hemoglobin images, (e) are the images changing quantities of two pigments, (f) is the nonlinear image obtained by synthesizing the melanin and hemoglobin images and multiplying gamma curve, (g) is the resultant image obtained by adding surface reflection. This method is expected to keep the accuracy of separation and synthesis. Lower flow shows the proposed algorithm #2 which algorithm has no necessity of processes (b), (c) and (f). Therefore, this algorithm is expected to be used for practical use because it does not require the separation of body and surface reflection and gamma correction.

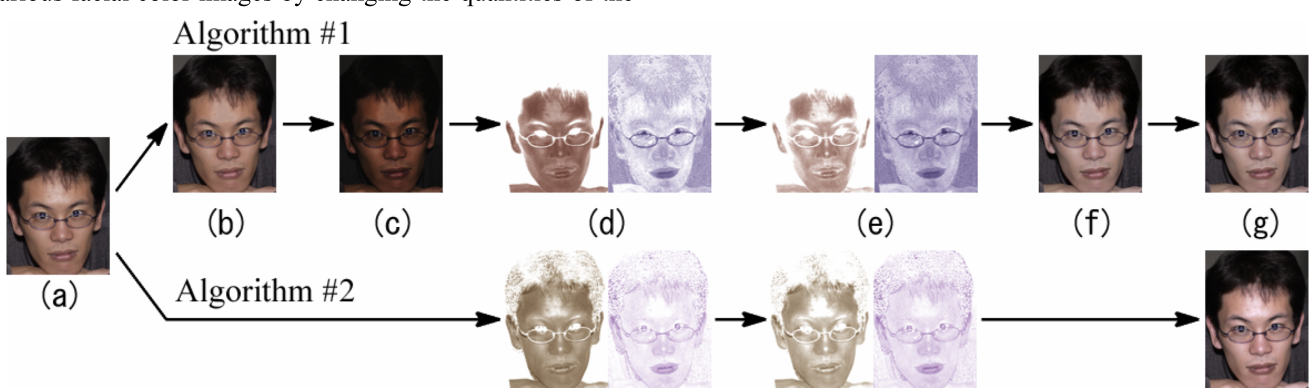


Figure 1. Flow of the process for two proposed algorithms: (a) Original image (b) Without surface reflection (c) Gamma corrected image (d) Melanin and hemoglobin components (e) Changing melanin and hemoglobin components (f) Inverse-Gamma corrected image (g) Resultant image

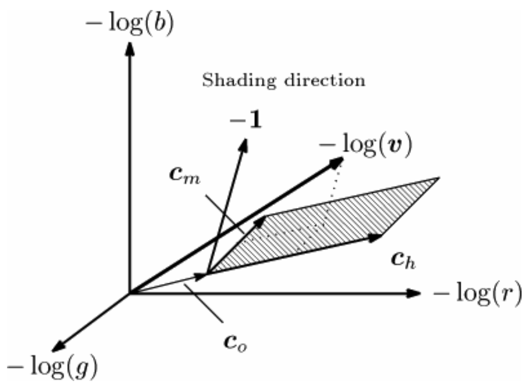


Figure 2. Observed signal of skin color

Human Skin Color Model

Human skin consists of plane parallel epidermal and dermal layers. Various pigments are contained in the layers; especially melanin and hemoglobin are dominantly contained in the epidermal and dermal layer, respectively. According to the skin color model shown in Fig. 2, skin color vector v can be expressed by

$$\log(\boldsymbol{v}) = q_m \boldsymbol{c}_m + q_h \boldsymbol{c}_h + \boldsymbol{c}_o , \qquad (1)$$

where $\boldsymbol{c}_m$ and $\boldsymbol{c}_h$ are pure density vectors of melanin and hemoglobin, q_m and q_h are relative quantities of the pigments respectively, $\boldsymbol{c}_o$ is spatially stationary vector caused by other pigments and skin structure[2]. As shown in Eq. (1), the skin color can be expressed with simple vector operation. The density vectors $\boldsymbol{c}_m$ and $\boldsymbol{c}_h$ can be estimated from a skin image using ICA (Independent component analysis).

Algorithms for Skin Color Correction

In estimating melanin and hemoglobin density vectors using ICA, two preprocesses are required for realistic color correction;

Preprocess #1 Gamma correction, the image is corrected to have an ideal tone characteristic ($\gamma = 1$).
Preprocess #2 Surface reflection removal. The image is separated into the body reflection image and the surface reflection image.

Since a usual camera rarely has the ideal tone characteristic ($\gamma = 1$) for our process. We have to perform gamma correction of the system by using reference color patches taken with the subject simultaneously. However, when we use a mobile phone with camera, it is not practical to take the reference color patches simultaneously. We have to remove surface reflection for the preprocess #2 from the original image. Although we can easily remove surface reflection by using polarizing filters, it is not practical to use polarizing filters in the case of situation where a mobile phone with camera is used.

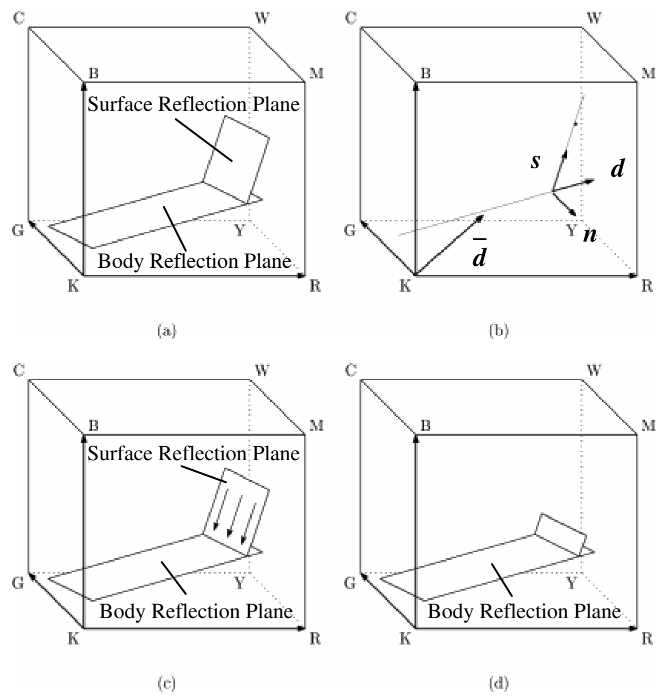


Figure 3. Color histogram in color cube space: (a) Cluster shape (b) Direction vectors (c) Reducing surface reflection (d) Cluster shape after reducing surface reflection

In this paper, we propose following two modified algorithms in order to overcome the above problems as possible as we can.

Algorithm ♯1: Without Polarizing Filters

This method is expected to keep the accuracy of separation and synthesis. If we take an image of object which is uniform color and diffuse reflectance, such as a ceramic cup, and plots color histogram in the color cube space, the histogram make two planes as is shown in Fig. 3(a). Pixels caused in highlight region by surface reflection and pixels in diffused region caused by body reflection are placed on the surface reflection plane and body reflection plane, respectively. The algorithm employs PCA (principal component analysis) to discriminate the pixels placed each plane. Let $\boldsymbol{s}$ and $\boldsymbol{d}$ be the first principal component vectors of surface and body reflection plane respectively and $\boldsymbol{n}$ be their cross product, $\bar{\boldsymbol{d}}$ be the mean vector of body reflection plane. Arbitrary point $\boldsymbol{p}=[r,g,b]^t$ in color cube space can be expressed by the following equation.

$$\boldsymbol{p} = \begin{bmatrix} r \\ g \\ b \end{bmatrix} = \begin{bmatrix} \boldsymbol{d} & \boldsymbol{n} & \boldsymbol{s} \end{bmatrix} \begin{bmatrix} c_d \\ c_n \\ c_s \end{bmatrix} + \bar{\boldsymbol{d}} , \qquad (2)$$

where

$$\boldsymbol{d} = [d_r, d_g, d_b]^T , \quad \boldsymbol{n} = [n_r, n_g, n_b]^T ,$$
$$\boldsymbol{s} = [s_r, s_g, s_b]^T , \quad \bar{\boldsymbol{d}} = [\bar{d}_r, \bar{d}_g, \bar{d}_b]^T .$$

The coordinate systems $[r,g,b]$ and $[c_d,c_n,c_s]$ can be transformed each other. The pixels on the surface plane have large value of s compared to other regions. The algorithm transforms $[r,g,b]$ into $[c_d,c_n,c_s]$ by using inverse transform of Eq. (2) and reduces the value as shown in Fig. 3(c). Finally, the algorithm transforms $[c_d,c_n,c_s]$ into $[r,g,b]$ by using Eq. (2) (see Fig. 3(d)).

Although it is impractical to use reference color patches for gamma correction, the high accuracy of estimation can be obtained as well as the conventional algorithm.

Algorithm #2: Without Polarizing Filters and Reference Color Patches

This algorithm estimates the density vector $\boldsymbol{c}_m$ and $\boldsymbol{c}_h$ without using polarizing filters and color patches. Mean density vectors estimated from many skin images is used as the vectors of melanin and hemoglobin vector for each image. As shown in Fig. 1, this algorithm does not apply the process (b); separation of body reflection and surface reflection, the process (g); adding surface reflection and the process (c); gamma correction, the process (f); multiplying gamma curve. The accuracy of color collection tends to be less than the conventional technique. However, this algorithm is used for practical use because this algorithm can be used without polarizing filters and reference color patches.

Results

Evaluating the Accuracy of Color Correction Compared to the Conventional Method

We evaluated the accuracy of color correction for the proposed algorithms by calculating ΔE_{94} color difference compared with the conventional algorithms. Figure 4 shows examples of a realistic synthesis of male's face by uniformly decreasing or increasing the melanin and hemoglobin components by using each algorithm. Figures 4(a), (b) and (c) are the results of skin color reproduction by using the conventional algorithm, the proposed algorithm #1 and the proposed algorithm #2, respectively. Each row of images indicates an increase or decrease in the amount of melanin. From left to right, the amount of melanin is decreased or increased by adding a relative value of -0.4, 0, +0.4 to the melanin amount. Each column of images indicates an increase or decrease in the amount of hemoglobin. From bottom to top, the amount of hemoglobin is decreased or increased by adding a relative value of -0.2, 0, +0.2.

The maximum and the average color difference between the conventional algorithm and the proposed algorithm #1 were 1.50 and 1.15. Since they can be hardly distinguished if color difference is less than 3, it can be said that the accuracy of color correction by using the proposed algorithm #1 is close to the conventional algorithm. On the other hand, the maximum and the average color difference between the conventional algorithm and the proposed algorithm #2 were 19.05 and 11.84. Although the accuracy of color correction by using the proposed algorithm #2 is quite low, we can see realistic changes of facial color as shown in Fig. 4(c).

Influence of the Environmental Illuminants

We used three kinds of mobile phones with camera for taking skin images. Figure 5 shows examples of images taken by using each camera. These images are taken for the same subject at the same place. Figure 6 shows the CDF (cumulative distribution function) of pixel values in these images. These results show that Camera B reproduces relatively reddish in comparison with two cameras.

In order to reproduce white skin color, we found empirically that the amount of melanin is decreased with a value of -0.4, and the amount of hemoglobin is decrease with a value of -0.2. Figure 7 shows results of skin color reproduction. Since the original image taken by Camera B is reproduced relatively reddish, the white skin is reproduced by reducing hemoglobin component. On the other hand, the original image taken by Camera C looks pale, unnatural skin color is reproduced by reducing hemoglobin component. Since the optimal parameters depend on photography environment, we have to consider dependability of photography environment in the future. The original images and examples of skin color reproduction are shown in Figs. 8 and 9. We can see both natural and unnatural skin color changes.

Conclusions and Discussions

The skin color image was separated into two images, the melanin image and the hemoglobin image, by using ICA in the optical density domain of three color channels. The separated components were synthesized to simulate the various facial color images by changing the quantities of the separated two pigments. The conventional algorithm can not be applied to the images taken by mobile phones with camera since polarizing filters and reference color patches are required. Therefore, we proposed two algorithms which can be applied to the image taken by mobile phones with camera.

The proposed algorithm #1 can achieve realistic color correction. We can use this algorithm by determining gamma curve of the camera. By using proposed algorithm #2, we can reproduce natural skin color without prior information. However, the optimal quantities of melanin and hemoglobin depend on images in order to reproduce preferred skin color. It is necessary to find the optimal changes of quantities for melanin and hemoglobin in reproducing better skin color for various images.

References

1. N. Tsumura, N. Ojima, K. Sato, M. Shiraishi, H. Shimizu, H. Nabeshima, S. Akazaki, K. Hori, Y. Miyake, Image-based skin color and texture analysis/synthesis by extracting hemoglobin and melanin information in the skin, acm Transaction on Graphics, Vol. 22, No. 3. pp. 770-779 (2003).
2. N. Tsumura, H. Haneishi, Y. Miyake, Independent component analysis of skin color image, Journal of Optical Society of America A Vol. 16 No.9, pp. 2169-2176 (1999).

3. G. J. Klinker, A Physical Approach to Color Image Understanding, A K Peters, Ltd., 1993

Biography

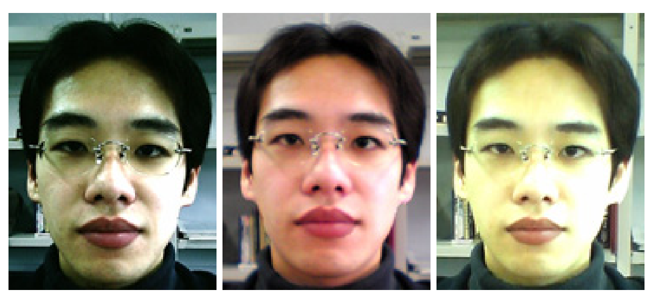
Shinji Nakagawa was born in Osaka, Japan, on January 8, 1982. He received his B.E. degrees in department of information and computer science from Chiba University in 2004. Now he is a master course student in Chiba University. His research interests include image processing and video image evaluation.

(a) Conventional Algorithm *(b Proposal Algorithm #1* *(c) Proposal Algorithm #2*

Figure 4. Results of skin color reproduction varying melanin and hemoglobin: (a) The conventional algorithm (b) The proposed algorithm #1 (c) The proposed algorithm #2

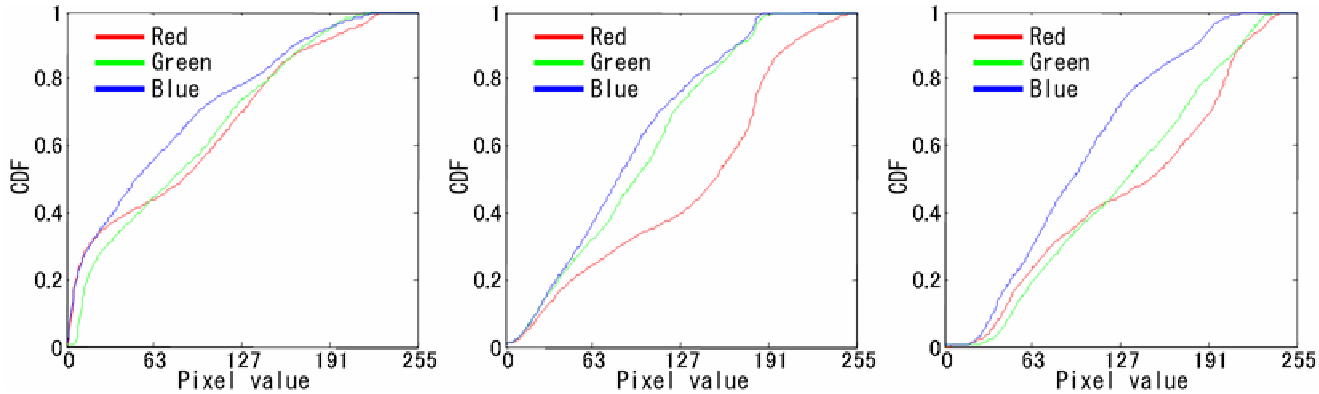
Camera A *Camera B* *Camera C*

Figure 5. Influence of camera characteristics



Camera A *Camera B* *Camera C*

Figure 7. Results of white skin color reproduction



Camera A *Camera B* *Camera C*

Figure 6. The CDF of the skin color image

Person #1

Person #2

Person #3

Person #4

Person #5

Illum. #1 *Illum. #2* *Illum. #3* *Illum. #1* *Illum. #2* *Illum #3* *Illum. #1* *Illum. #2* *Illum #3*

Camera A *Camera B* *Camera C*

Figure 8. The original images (taken 5 persons, 3 cameras, 3 illuminants)

(a) With melanin -0.4,hemoglobin -0.2

(b) With melanin -0.4,hemoglobin +0.2

(c) With melanin +0.4,hemoglobin -0.2

(d) With melanin +0.4,hemoglobin +0.2

Figure 9 The result of skin color reproduction: (a)With melanin -0.4,hemoglobin -0.2 (b) With melanin -0.4,hemoglobin +0.2 (c) With melanin +0.4,hemoglobin -0.2 (d) With melanin +0.4,hemoglobin +0.2