Measurements of Skin Chromophores by Independent Component Analysis and the Application to Cosmetics

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Abstract

The spatial distributions of melanin and hemoglobin in human skin can be determined by independent component analysis (ICA) of a skin color image. The separation is based on the skin color model in the optical density domain to quantify the change in the chromophores. In this paper the analysis was applied to many skin images, and the distribution of skin chromophores, such as melanin and hemoglobin, agreed well with the physiological knowledge. The effectiveness of cosmetics products were also quantitatively evaluated by observing the changes in the amount of each chromophore. Finally a simulation system to synthesize the changes in skin chromophores was proposed to demonstrate its validity.

1. Introduction

With the recent progress of various imaging systems such as multi-media, computer graphics and telemedicine systems, the skin color has become increasingly important for communication, image reproduction on hardcopy and softcopy, medical diagnosis and so on.[5-7] In cosmetics industry[12] also, skin color is very important to evaluate the effectiveness of cosmetic products. But it is very difficult to evaluate the effectiveness for each chromophore only by colorimetric values, because the values contain the information of various skin chromophores such as melanin and hemoglobin at the same time. Therefore it is necessary to extract the information of each skin chromophore independently.

In this paper the spatial distributions of melanin and hemoglobin in skin were separated by independent component analysis (ICA[1]) from a skin color image. ICA is a technique that extracts the original signals from mixtures of many independent sources without ***a priori*** information on the sources, and is briefly reviewed in section 2. Separation results which agreed well with the physiological knowledge are shown in Section 3. The effectiveness of cosmetics products were also quantitatively evaluated by the amount of separated melanin component.

The schematic flow in the proposed image-based skin color analysis is shown in Figure 1. The original photo was separated into the images of surface and body reflection[4] by using polarized light.[2] The body reflection image was analyzed by the ICA technique to isolate both melanin and hemoglobin component images. By using these images, the relative density of each chromophore component was measured to evaluate the efficacy of cosmetics products.

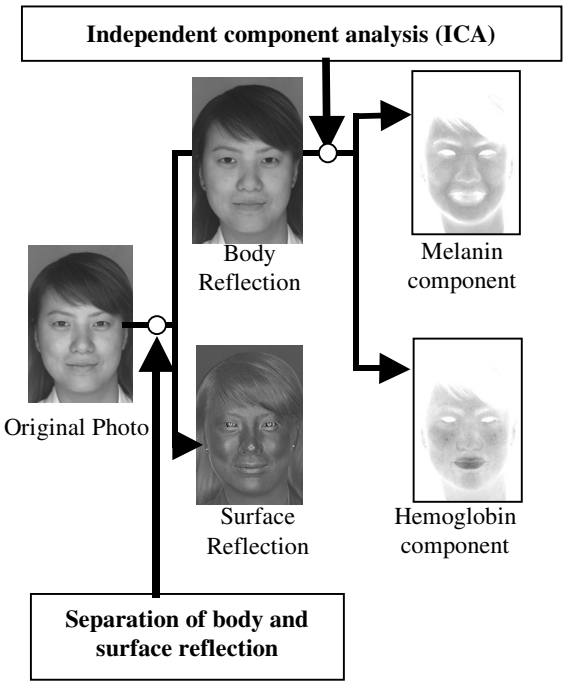

Figure 1. Schematic flow of imaging process in the proposed image-based skin color analysis.

2. Modeling of Skin Color for ICA

ICA is a technique that extracts the original signals from mixtures of many independent sources without *a priori*

information on the sources and the process of the mixture. Observed vector $\boldsymbol{v}_{l,m}$ is shown as follows:

$$\mathbf{v}_{l,m} = \mathbf{A}\mathbf{x}_{l,m} \quad (1)$$

where $\boldsymbol{x}_{l,m}$ is the source signal vector, and **A** is a 2x2· mixing matrix. By applying the ICA to the observed vector, the relative source signals are extracted without ***a priori*** information on these items, by assuming that original source signals are mutually independent. In performing ICA, following equation was defined by using a separating matrix **H** and an extracted independent vector $\boldsymbol{s}_{l,m}$: as follows;

$$\mathbf{s}_{l,m} = \mathbf{H}\,\mathbf{v}_{l,m} \quad (2)$$

The fixed point algorithm[3,8-10] was used to estimate the separating matrix **H**, and the extracted independent vector $\boldsymbol{s}_{l,m}$ which corresponds to $\boldsymbol{x}_{l,m}$ was obtained. Tsumura et al. described the details of the theory in previous papers.[2]

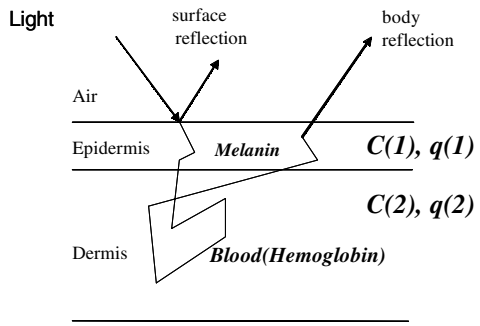

Figure 2. Schematic expression of a two-layered skin model.

On the other hand, we made four assumptions to analyze skin color: the skin color can be described by Lambert-Beer law, the spectral distribution of skin color is not abrupt in the range of each channel in the imaging system, the spatial variations of skin color are caused by two dominant chromophores, such as melanin and hemoglobin (Figure 2),[2,11] and the chromophore density are mutually independent. The assumptions ensure linearity between the observed color signals and pure color signals of the skin chromopores in the density domain of three channels. We denoted by $\boldsymbol{v}_{l,m}$ the observed color density vector on the image coordinates(l,m):

$$\mathbf{v}_{l,m} = [-\log(r_{l,m}), -\log(g_{l,m}), -\log(b_{l,m})] \quad (3)$$

where r,g,b are pixel values for R,G,B channels.

According to the skin color model,[2] the observed color density vector can be expressed by the following equation:

$$\mathbf{v}_{l,m} = q_{l,m}(1)\,\mathbf{c}(1) + q_{l,m}(2)\,\mathbf{c}(2) + \mathbf{c}(3) \quad (4)$$

where c(1) and c(2) are pure chromophore vectors of melanin and hemoglobin respectively, and c(3) is a bias vector. ql,m(1) and ql,m(2) are relative quantities of melanin and hemoglobin respectively. The skin color distribution in the skin image is schematically described in Figure 3. It shows that the plots of skin color are distributed on the two-dimensional plane spanned by pure chromophore vectors of melanin and hemoglobin.

Finally, the observed color density vector of skin vl,m is analyzed by ICA to search for independent pure chromophore vectors of melanin and hemoglobin (c(1), c(2)).

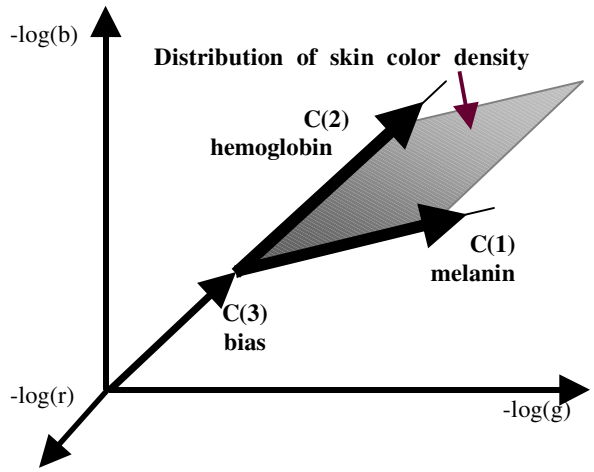

Figure 3. Schematic expression of skin color distribution in the optical density domain of three channels.

3. Experimental Results

3.1 Analysis of Artificially Generated Chromophores

The physiological validity of the proposed analysis was confirmed by practical experiments. The arm of a subject was irradiated by UV-B for the melanin component, and methyl nicotinate which is known to increase hemoglobin is applied to the other arm for the hemoglobin component. An image of the arm, where UV-B (1.5 Minimum Erythema Dose) was irradiated in local rectangular areas, was taken after two weeks by a digital camera (Nikon D1, 2,000 by 1,312 pixels). An image of the arm, where methyl nicotinate (1 mg/ml solution) was also applied in local round areas, was also taken by a digital camera after 30 minutes of application. These images were analyzed by the proposed method. Figures 4(a), (b), and (c) show the original skin image and the images of the densities for the melanin and hemoglobin components, respectively. On the other hand, Figures 4(d), (e), and (f) show the original skin image for methyl nicotinate and the images of the densities for the melanin and hemoglobin components, respectively. Figure 4(b) shows the square patterns caused the by melanin component ,but the patterns did not appear in the hemoglobin component in Figure 4(c). Figure 4(f) also shows the round patterns, which indicate the biological response of hemoglobin to methyl nicotinate, but there was not any response of melanin component in Figure 4(e).

These results are valid physiologically, and show the effectiveness of the proposed method of skin color image analysis. We can also indirectly conclude that the approximation for the imaging model in Section 2 is also valid in our applications.

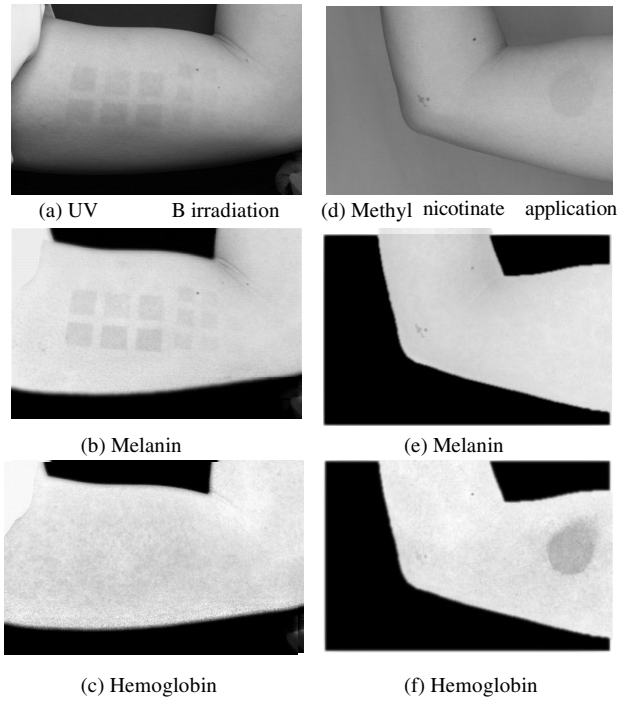

Figure 4. Analysis of chromophore patterns generated by artificial treatments. UV-B irradiation:(a)original, (b)melanin component, (c)hemoglobin component. Application of methyl nicotinate: (d)original, (e)melanin component, (f)hemoglobin component.

3.2 Analysis of Facial Skin

The proposed analysis was applied to actual facial images. As an example, an image of facial skin with acnes was taken and analyzed (Figure 5). Both square areas and circular areas in Figure 5 indicate acnes. In figure 5(a), both acnes are similar to each other. The extracted hemoglobin component image (Figure 5(c)) shows there are rashs in both areas, but melanin pigmentation was only in square areas (Figure 5(b)). These results show that acnes which are similar in the original image can be separated by comparing the chromophore component, especially the melanin component in this case.

3.3 Evaluation of Cosmetic Products

In order to evaluate the effectiveness of cosmetic products such as lightening essence, facial skin color images of 39 female subjects were captured periodically and analyzed. The cosmetic product which is useful for lightening was applied to their faces everyday for 9 weeks. Fig. 6 shows the change of melanin densities as compared with the beginning (0 week). As a result, the change in melanin density, which was the averaged value of the 39 subjects, decreased during the 9 weeks, down to minus 0.1. The relationship between the changes and melanin and color will be discussed.

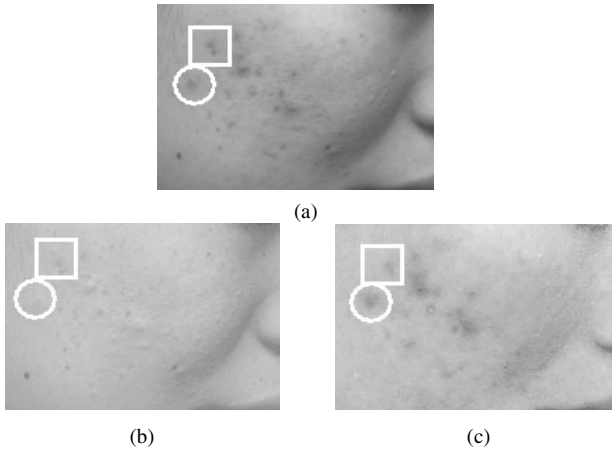

Figure 5. Analysis of an actual facial skin image. (a)original, (b)melanin component, (c)hemoglobin component.

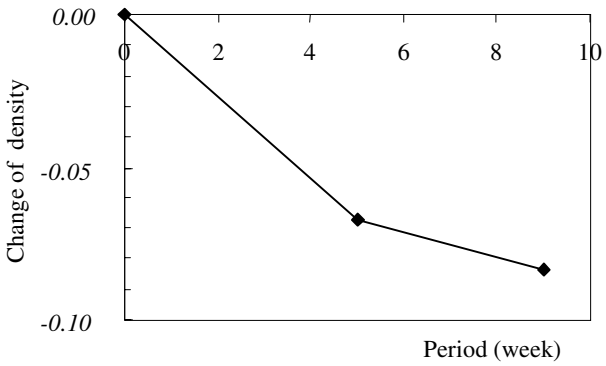

Figure 6. Relative changes in melanin density during the 9 weeks the lightening essence was applied.

3.4 Skin Color Synthesis

In order to understand and experience the changes of each chromophore component, we made a simulator to synthesize the various facial skin color images by changing the extracted chromophore components. The simulation was performed by reversing the analyzing process shown in Figure 1. As examples, synthesized images of a woman's face were made by changing the hemoglobin and melanin components, shown in Figure 7. The center image is of the original skin color. The left and right images in the middle row were synthesized by respectively decreasing and increasing the amount of hemoglobin. The upper and lower images in the middle column were synthesized by respectively increasing and decreasing the amount of melanin. The images in the upper right and left, lower right and left were synthesized by changing the amounts of both hemoglobin and melanin. The change in melanin densities

are set at twice the average amount mentioned in section 3.3. We could see very realistic changes of facial color. We also made the simulator with a graphical user interface (GUI) to demonstrate the performance.

Figure 7. Skin color synthesis with changes in melanin and hemoglobin densities (color images).

4. Conclusions

The proposed technique worked very well to separate skin chromophore components from a skin image. It was indicated that the chromophore component images were very useful to understand the skin condition, such as acnes. The effectiveness of a cosmetic product was quantitatively evaluated by observing the changes in the amount of each chromophore extracted by the proposed method.

It is necessary to determine the relationship between the relative densities and chromatic values. In the future, the performance of the technique in medical diagnoses will be tested.

References

1. N. Tsumura, H. Haneishi, and Y. Miyake, Independent component analysis of skin color image. Journal of Optical Society of America A 16(9), 2169-2176(1999).
2. N. Ojima, T. Minami, and M. Kawai, Transmittance measurement of cosmetic layer applied on skin by using image processing. In Proceeding of The 3rd Scientific Conference of the Asian Societies of Cosmetic Scientists, 114 (1997).
3. A. Hyvarinen and E. Oja, Neural computation, 9, 1483-1492 (1997).
4. S. Shafer, Using color to separate reflection components. Color Research Applications 10,(4), 210-218 (1985).
5. F. H. Imai, N. Tsumura , H. Haneishi and Y. Miyake, J. Image Sci. Thechnol., 40, 422 (1996).
6. Y. Yokoyama, N. Tsumura, H. Haneishi, Y. Miyake, J. Hayashi, M. Saitoh, Proceedings of IS&T/SID's 5th Color Imaging Conference, Color Science, Systems and Application (Society for Imageing Science & Thechnology, Springfield, VA, 1997), 169 (1997).
7. M. Yamaguchi, R. Iwama, Y. Ohya, T. Obi, N. Ohyama and Y. Komiya, Proceedings of Soc. Photo-Opt. Instrum. Eng., 3031, 482 (1997).
8. G. Burel, Neural Networks, 5,937 (1992).
9. J. Keahunen, E. Oji, L. Wang, R. Vigario and J. Joutensalo, IEEE Trans. Neural Network 8, 486 (1997).
10. C. Jutten, J. Hearult, Signal Process., 24, 1 (1991).
11. N. Tsumura, H. Haneishi, and Y. Miyake, Independent component analysis of spectral absorbance image in human skin. Optical Review 7(6) 479-482 (2000).
12. N. Ojima, Hideto Shimizu, N. Tsumura, S. Akazaki, K. Hori, Y. Miyake, Measurements of skin chromophores by independent component analysis and the application to evaluation of cosmetics., Proc. Asian Symposium on Biomedical Optics and Photomedicine, 242-243 (2002).

Biography

Nobutoshi Ojima received his B.E. and M.E. degree in Chemistry from Tohoku University in 1986, 1988, respectively, and a Ph.D. degree from Chiba University in 1994. Since 1988, he has worked in Institute of Beauty Sciences & Intelligence at Kao Corporation in Tokyo Japan. His major research subjects are skin color and skin image processing.