Accurate Mapping Pigmentations in Human Skin by Spatio-Temporal Modulation of Light Source in the Multi-Spectral Imaging

Masahiro Okuyama, Naohiro Yokoyama, Daisuke Nakao,
Norimichi Tsumura, and Yoichi Miyake
Department of Information and Imaging Sciences
Chiba, Japan

Abstract

Recently, it is expected to monitor a health condition of elder people at their home. Skin color has a lot of information to monitor the health condition. A monitoring system of the pigmentation in human skin will be effective to detect a sudden change of the health condition. A prototype monitoring system was proposed in our previous paper. In that system, an integrated sphere was used to illuminate the skin surface uniformly. However, it was not practical for daily life to use the integrated sphere. In this paper, we constructed a daily monitoring system for skin pigmentation by using spatio-temporal modulation of light source to cancel the shading on the skin surface. We performed experiments to show the effectiveness of our system.

Introduction

In recent years, it is required to monitor the state of condition for elder people at their home since the population of them is increasing rapidly particularly in Japan. Skin color has very useful information to monitor the health condition and to diagnose various diseases. Therefore we consider that it is important to develop a system for monitoring the pigmentation of human skin. In our previous paper, we have reported a prototype monitoring system to estimate the pigmentation map of human skin.[1] In that system, the human skin was recorded by a RGB digital video camera under an integrated sphere to remove the shading on the skin surface. Furthermore the pigmentation map of skin was calculated using the inverse Monte Carlo simulation of photon migration. Experimental results of that prototype system have shown that the RGB image was not enough to estimate the accurate skin pigmentation.[2] It was also not practical to use the integrated sphere for the daily monitoring.

In this paper, we constructed a daily system for monitoring skin pigmentation by using spatio-temporal modulation of light source to cancel the shading on the skin surface. We use the photometric stereo technique[3] to remove the influence of shading caused by unidirectional illumination. In this system, we also use a 4-bands digital video camera system that is developed to increase the accuracy of the estimation for pigmentation.

In the next section, the photometric stereo is briefly introduced. After that, the proposed monitoring system for skin pigmentation is described.

Photometric Stereo Technique

The photometric stereo technique is used to obtain the absolute reflectance image where influence of shading is removed.[4] In the photometric stereo technique, at least 3 illuminants are used, and an image is taken by each illuminant. We assume that reflectance property of skin surface is Lambertian, illuminants are point sources and located at infinity distant from the surface. As is shown in Figure 1, let us define $\boldsymbol{l} = (l_x, l_y, l_z)^t$ as illuminant vector that directs to the light source and whose length $\|\boldsymbol{l}\|$ is the radiance of the light source, $\boldsymbol{n} = (n_x, n_y, n_z)^t$ as the unit surface normal, and ρ as the absolute reflectance of the surface. The captured intensity of camera v is written as follows.

$$v = \rho\, \boldsymbol{n}^t \boldsymbol{l} \tag{1}$$

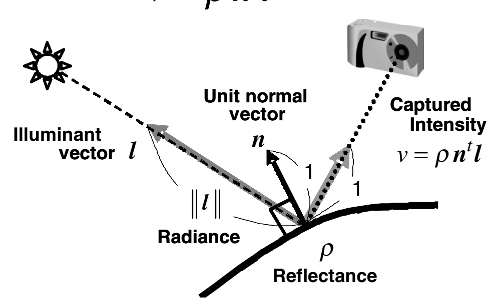


Figure 1. Geometry for photometric stereo technique

Equation (1) is based on the Lambertian model of skin surface. For multiple illuminants, we have following equations.

$$v_1 = \rho \boldsymbol{n}^t \boldsymbol{l}_1$$
$$v_2 = \rho \boldsymbol{n}^t \boldsymbol{l}_2$$
$$\vdots$$
$$v_m = \rho \boldsymbol{n}^t \boldsymbol{l}_m \quad (2)$$

where m is the number of illuminants. Equations (2) can be rewritten by vector-matrix form as follows.

$$\boldsymbol{v} = \boldsymbol{L}\boldsymbol{x} \quad (3)$$

where $\boldsymbol{v} = (v_1, v_2, ..., v_m)^t$ is the captured intensity vector, is the light matrix which is measured *a priori*, $\boldsymbol{x}\ (= \rho\,\boldsymbol{n})$ is the unknown vector to be estimated. If the light matrix $\boldsymbol{L}$ is nonsingular, the vector $\boldsymbol{x}$ can be estimated by the following equation using the Moore-Penrose generalized inverse of light matrix $\boldsymbol{L}$.

$$\boldsymbol{x} = \left(\boldsymbol{L}^t\boldsymbol{L}\right)^{-1}\boldsymbol{L}^t\boldsymbol{v} \quad (4)$$

Since $\boldsymbol{n}$ is a unit vector, absolute reflectance ρ will be the length of obtained vector $\boldsymbol{x}$, and $\boldsymbol{n}$ is the direction of $\boldsymbol{x}$. The reflectance ρ is obtained at each band of the camera, and the obtained values are transformed into the spectral reflectance.

Proposed Monitoring System

Figure 2 shows the concept of the proposed system for monitoring elder people without any restriction in their daily life. In the system, a main computer controls a spatio-temporal modulation of several illuminants, and also the camera with synchronizing the light sources. The illuminants are set under the ceiling on the different position each other for photometric stereo. It is expected that the light will be modulated at higher frequency than critical fusion frequency of human vision, where a blinking light just appears to be continuous. Therefore, the elder people will not recognize the modulation of light sources, and their skin color is monitored in their normal daily life.

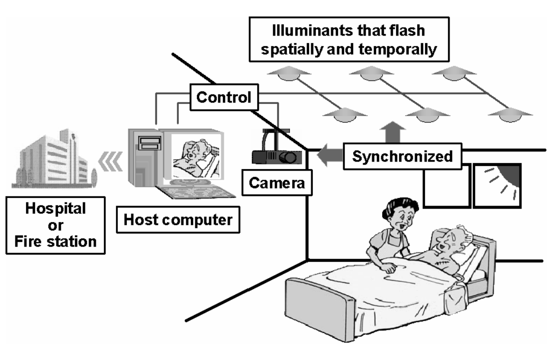


Figure 2. Concept of the proposed System

In this paper, we constructed a prototype system for monitoring skin pigmentation, where a 4-bands camera is used to capture the image and 4 strobe lights are used to achieve the spatio-temporal modulation of light source. Figure 3(a) shows the configuration of the prototype system. This system can take 4 images under different illumination angle in 0.144[s]. The prototype system will be explained in detail below.

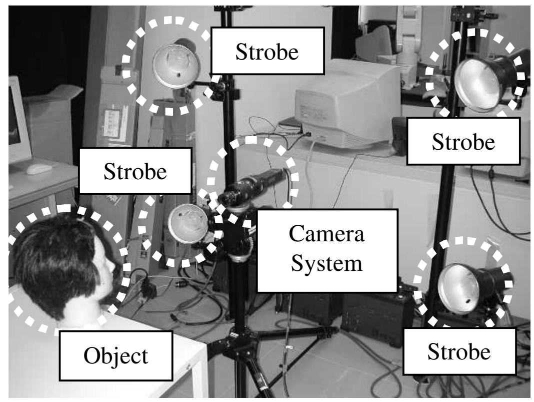


Figure 3(a). System Configuration

Figure 3(b). 4-bands Camera System

4-bands Camera System

We use a 4-bands optical system (MultiSpec Agro-Imager, Optical Insight) for this prototype system. In this system, the optical system is set in front of a monochrome video camera (XCD-X700, SONY). Figure 3(b) shows the camera system. The left is the optical system, and the right is monochrome video camera. The optical system can duplicate an image into 4 images on CCD as shown in Figure 4. Prism devices in the optical system achieve these duplications. Four color filters are inserted in the optical system, and the duplicated images are filtered each other by the inserted filters.

Strong strobe lights are used in the prototype system in order to obtain enough power of light for imaging, since the optical system reduces the power into quarter by the duplication.

Synchronization of Illuminants and Camera

The digital video camera and four strobe lights are controlled by personal computer (Pentium 4, 1.9GHz). The I/O board connected with the PC sends the signal into the four strobe lights sequentially, and also sends the trigger signals into the camera to capture an image with the synchronization of the light sources. An image is taken at the interval of 0.048 [s] because of the limitation of frame rate of the camera (15 frame per second). Therefore this system can captures 4 images under different illumination angle in 0.144 [s].

Figure 4. Example of captured Image

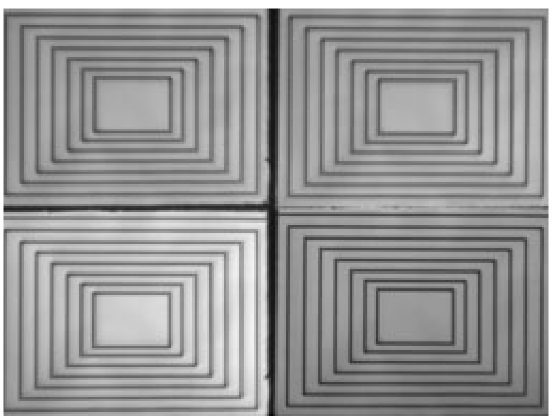


Figure 5. Pattern for Calibration

System Calibration

We performed geometry calibrations in the prototype imaging system. The geometry between the camera and 4 illuminants is measured *a priori* for photometric stereo. It is also necessary to calibrate the duplicated image, since it is not exactly arranged on the CCD array. The duplicated four images are aligned in slightly shifted and rotated position. Therefore we use affine transform to calibrate the position of the duplicated images. Affine transform is the transform that can rotate, enlarge, reduce, shear, and translate the image. The equation of the transform is written as follows.

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} \tag{5}$$

where x, y is the coordinate before the transformation, x', y' is the coordinate after the transformation, a_{ij} $(i = 1,2\ j = 1,2)$ is a coefficient for rotation, enlargement, reduction, and shearing. $b_i\,(i = 1,2)$ is a coefficient for translation. If the corresponding points between duplicated four images can be obtained, transform matrices that adjust the position between duplicated four images can be also obtained. Therefore, by using the image for calibration as shown in Figure 5, four corners of biggest rectangle in each duplicated image are chosen manually. Transform matrices are calculated from these coordinates of corners. Finally, the duplicated four images are transformed to the aligned positions to correspond the pixels in the duplicated image each other.

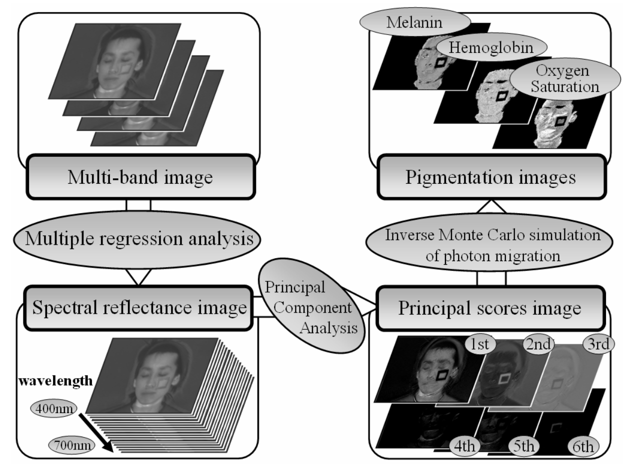


Figure 6. The process of the estimation

Estimation of Pigmentation Map from Multi-Band Image

We introduce techniques of the estimation of pigmentation from the multi-band images in this section. Figure 6 shows the process of the estimation. The multi-band image is transformed into spectral reflectance image by multiple regression analysis of samples. Spectral reflectance is transformed into principal scores by principal component analysis to reduce the dimension of the spectral reflectance. Finally pigmentation values are obtained from the scores by using inverse Monte Carlo simulation of photon migration.[5] In the Monte Carlo simulation, a three-layered skin model is used as shown in Figure 7. The first layer is an epidermis layer, the second is a dermis layer, and the third is a subcutis layer. In this skin model, the absorption coefficient, scattering coefficient, and anisotropic scattering coefficient are set in each layer. If pigmentation values are input to this model, spectral reflectance can be obtained by Monte Carlo simulation. Each spectral reflectance is calculated *a priori* from all pigmentation values in the range of spectral reflectance in human skin. From the look up table between spectral reflectance and pigmentation values, pigmentation values can be obtained from spectral reflectance.

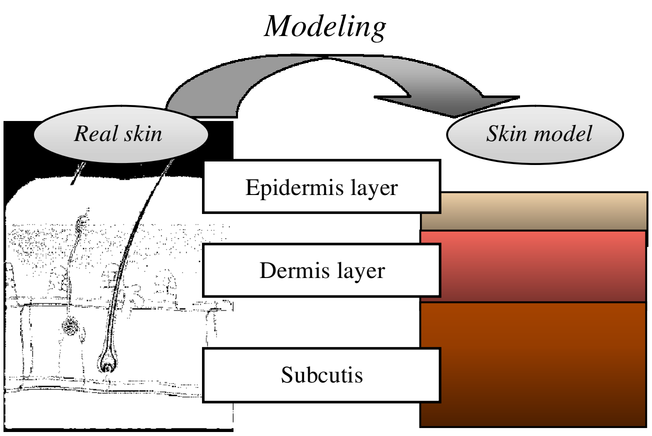


Figure 7. Three layered skin model

Experiments

To confirm the effectiveness of the proposed system, we performed two experiments. In the first experiment, human face was captured by changing the facing angle to the camera. In the second experiment, the change of pigmentation of a subject in drinking alcohol was examined.

Experiment 1: Change of Facing Angle To Camera

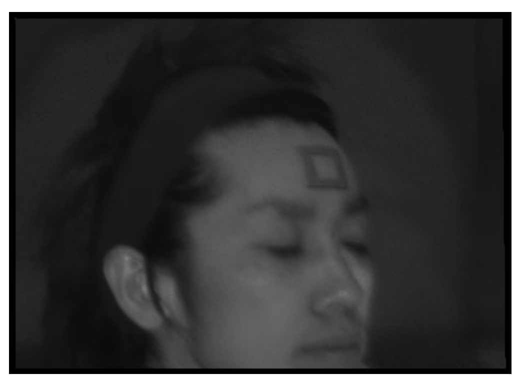
We captured images of human face by changing the direction of facing to the camera in order to confirm the effectiveness of photometric stereo technique. Each image was captured at angle of 0 degree, 30 degrees, and 45 degrees for facing to the camera, respectively. The resultant images after the application of photometric stereo technique are shown in Figure 8. As shown in these images, the influence of shading is removed by the photometric stereo technique. Spectral reflectance in a small area of the forehead surrounded by the square patch is compared for each angle of facing. It is also compared with the data measured by the spectrometer (CM-2600d, Minolta). Figure 9(a) shows the comparison of spectral reflectance in changing the angles of facing. Regardless of the change of the angles of facing, spectral reflectance of the skin is estimated stably. Estimated data is also close to the data that was measured by the spectrometer. On the other hand, Figure 9(b) shows the comparison of spectral reflectance estimated from only one image captured under unidirectional illuminant. It can be seen that the change of facing angle causes the change of the estimated reflectance by the shading. These results show the effectiveness of our system to remove the shading on the face.

Experiment 2: Drinking Alcohol

We estimated the change of pigmentation in drinking alcohol in order to confirm that this system is useful to detect the change of pigmentation. Figure 10 shows the pigmentation map of human face of a subject before drinking alcohol, where (a) shows the original image of his face, (b) shows the map of melanin density, (c) shows the map of total-hemoglobin density, (d) shows the map of oxygen saturation, respectively. As is shown in these figures, this system can estimate the map of each pigmentation value in the skin.

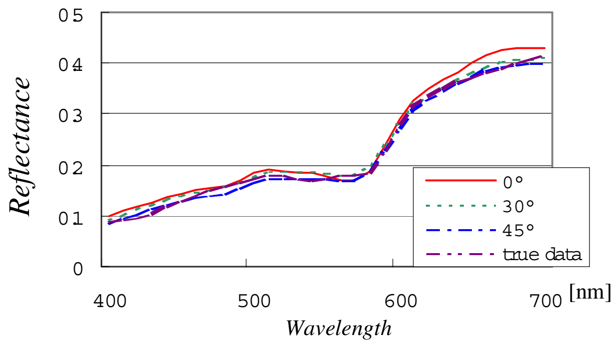
(a) 0 °

(b) 30 °

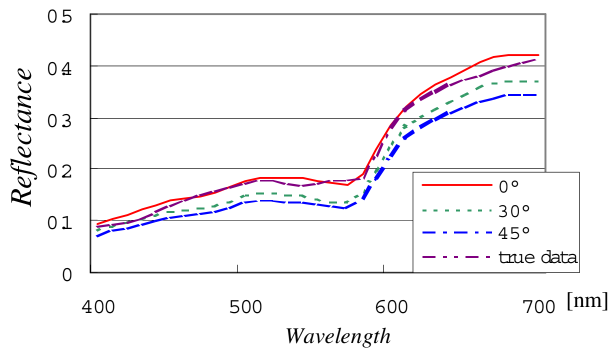


(c) 45 °

Figure 8. Resultant images in change of facing angle to the camera



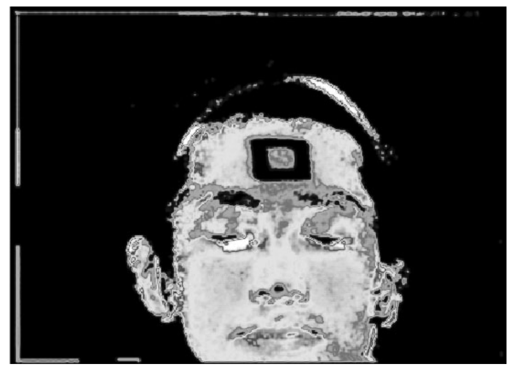
(a) Photometric Stereo



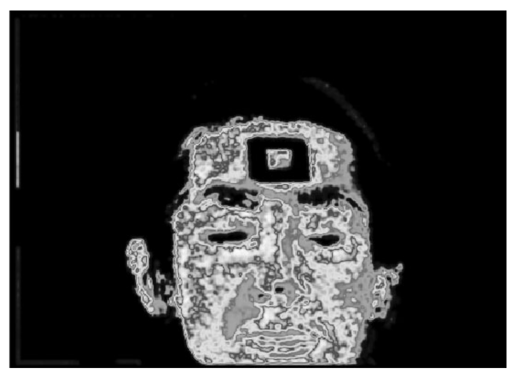
(b) Unidirectional illuminant

Figure 9. Comparison of Spectral reflectance

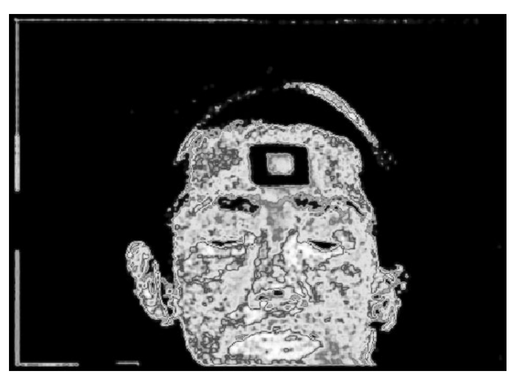
(a) Original



(b) Melanin



(c) Hemoglobin



(d) Oxygen saturation

Figure 10. The images of pigmentation.

In this experiment, the subject drank alcohol (beer, 500ml), and after drinking alcohol, he was measured by this system every 2 minutes until 10 minutes later. The subject was kept at ease without the restriction for the face movement, and was measured by the proposed system. A small area of the forehead surrounded by the square patch is monitored. Pigmentation values in the small area were estimated, and these values are averaged among the area. Figure 11 shows the result of the change of pigmentation during the experiment. Each pigmentation value is normalized by each value at 0 minute (just after drinking). As is shown in the figure, melanin density and oxygen saturation remained stable. However hemoglobin density slowly increased. This result shows that the proposed system can detect the increase of hemoglobin by drinking alcohol.

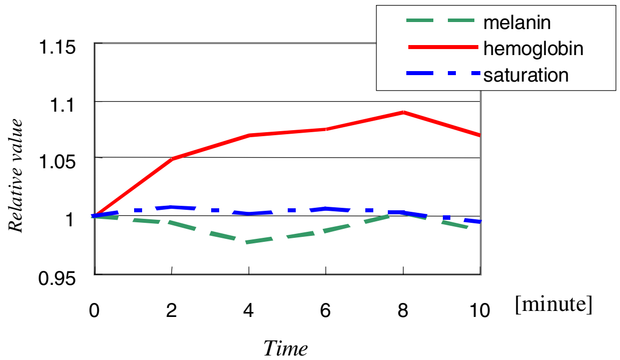


Figure 11. The change of pigmentation after drinking alcohol

Conclusion

We constructed a prototype system for monitoring elder people in daily life, where 4-bands camera is used and several illuminants modulate spatially and temporally for photometric stereo. The system can capture absolute reflectance images in 0.144[s]. We performed the two experiments to confirm the effectiveness of the proposed system. The first experiment showed the effectiveness of photometric stereo to remove the shading. The second experiment showed that the proposed system is useful to detect the change of pigmentation.

References

1. Daisuke Nakao, Norimichi Tsumura, and Yoichi Miyake, "Real-Time Multi-Spectral Image Proceeding For Mapping Pigmentation In Human Skin", Proc.9th Color Imaging Conference, pp.80-84, (2001).
2. Daisuke Nakao, Masahiro Okuyama *et. al*, "Mapping melanin, total-hemoglobin, oxygen saturation in human skin by real-time multi-spectral imaging", Proc. Asian Symposium on Biomed. Optics and Photomed. (2002).
3. R. J. Woodham. "Photometric method for determining surface orientation from multiple image", Optical Engineering, 19(1) pp.139-144, (1980).
4. N. Tsumura, "Medical Vision", Medical Imaging Technology Vol.20 No.2, 94-100 (2002).
5. Wang, L., Jacques. S. L., Monte Carlo Modeling of Light Transport in Multi-layered Tissues in Standard C, University of Texas M. D. Anderson Cancer Center (1992). Web page http://omlc.ogi.edu/software/mc/index.html

Biographies

Masahiro Okuyama was born in Saitama, Japan, on 31 July 1977. He received B.E. degree in department of information and image science from Chiba University in 2002. Now he is the master course student in Chiba University. He is interested in multi- spectral imaging and biomedical optics.

Norimichi Tsumura was born in Wakayama, Japan, on 3rd April 1967. He received the B.E., M.E. and D.E. in applied physics from Osaka University in 1990, 1992 and 1995, respectively. He moved to the Department of Information and Image Sciences, Chiba University in April 1995, as assistant professor. He is currently associate professor since 2002, and also researcher at PREST, Japan Science and Technology Corporation (JST). He was visiting scientist in University of Rochester from March 1999 to January 2000. He got the Optics Prize for Young Scientists (The Optical Society of Japan) in 1995, and Applied Optics Prize for the excellent research and presentation (The Japan Society of Applied Optics) in 2000. He received the Charles E. Ives award in 2002 from the IS&T. He is interested in the color image processing, computer vision, computer graphics and biomedical optics.

Yoichi Miyake has been professor in the Department of Information and Image Sciences, Chiba University since 1989. He received the B.S. and M.E. in Image Science from Chiba University in 1966 and 1968, respectively. He received Ph.D. from the Tokyo Institute of Technology. During 1978 and 1979 he was an academic guest of Swiss Federal Institute of Technology. In 1997, he was a guest professor of University of Rochester. He received the Charles E. Ives award in 1991 from the IS&T. He became a fellow of IS&T in 1995. He also received Electronic Imaging Honoree of the Year in 2000 from SPIE and IS&T. He is one of the pioneers of multi-spectral imaging. He was served as president of Japanese Association of Science and Technology for Identification and the Society of Photographic Science and Technology of Japan. He is currently served as vice president of IS&T.