Real-Time Multi-Spectral Image Processing For Mapping Pigmentation In Human Skin

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Abstract

Real-time mapping pigmentation in human skin is expected to give useful information for reproducing various skin colors and monitoring human conditions in real time. In this research, the maps of melanin, oxy-hemoglobin and deoxy-hemoglobin densities in skin are estimated and displayed in real time from digital video signals by using three pre-computed look up tables for color conversions. As the experiments to show the effectiveness of the proposed system, time dependent changes of pigmentation map in human hand are observed during the occlusion and release of middle finger, also during anaerobic by squat exercise. From the results of the experiments, human homeostasis for disturbance can be observed in real time.

Introduction

Mapping pigmentations such as oxy-hemoglobin and deoxy-hemoglobin in human skin is expected to give us helpful information about human condition and emotion. The obtained information will be used for skin diagnosis, skin color reproduction, measurement of human emotion.[1,2] We have already proposed the technique to extract qualitative information and spatial distribution of pigmentations from multi-channel visible spectral image[3-5] by inverse optical scattering technique.[1] The Monte Carlo simulation of photon migration is used as forward model of optical scattering, and the forward model is iterated to perform the inverse optical scattering technique based on non-linear optimization method. This technique needs a long time to complete the process. However, a real-time processing is required in measuring changes of human condition and emotion.

In this research, we introduce the technique of real-time mapping pigmentation in human skin by using three pre-computed look up tables for color conversions. The first table converts RGB values from digital video camera into three scores for three principal components. Wiener estimation is used to make the table between the RGB values and spectral reflectance which is analyzed into the three scores based on the pre-computed principal components. The second table converts the scores into pigmentation values by using inverse optical scattering technique. Since the values of scores effectively reflect the spectral variation of reflectance spectra, the second table is considered very effective to estimate the pigmentation values. It is noted this conversion from scores to pigmentations is originally proposed in this research. The third table converts the pigmentation values into RGB values to display on a monitor. The first and third tables are dependent on devices and environment, and the second table is independent. It is noted that the total process is constructed from the three tables to separate the device independent process and devices dependent process, because making the second tables takes about 10 days by Monte Carlo simulation of human skin model[6-9] and so on. Two experiments are performed to show the effectiveness of our system with time dependent changes of pigmentation map in human hand. Pigmentations are observed during putting hand up and down, occlusion and release of middle finger, and anaerobic by squat exercise.

Real-Time Spectral Imaging System

Figure 1 shows the schematic diagram of the proposed real-time spectral imaging system. The real-time imaging system consists of halogen-light source (Luminar Ace LA-150UE, Korin Electronic Co. Ltd) and a digital video camera (DFW-VL500, SONY). Light from light source is diffused by integrating sphere of 120 cm diameter. The object such as human hand is illuminated by the diffused light. Digital video camera captures images of the illuminated objects and transfers the images to personal computer in real time. We use IEEE1394(i-link) format to transfer the image data. In the personal computer, the pigmentation values are estimated from the RGB data and displayed in real time. We can control digital video camera by the personal computer.

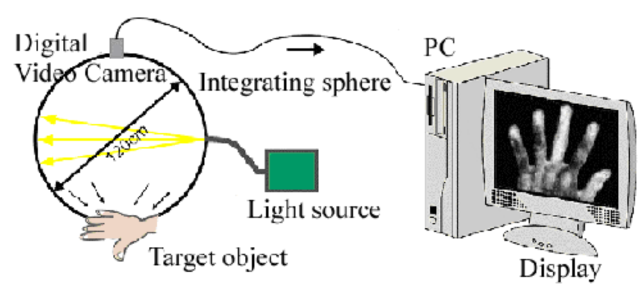

Figure 1. System configuration.

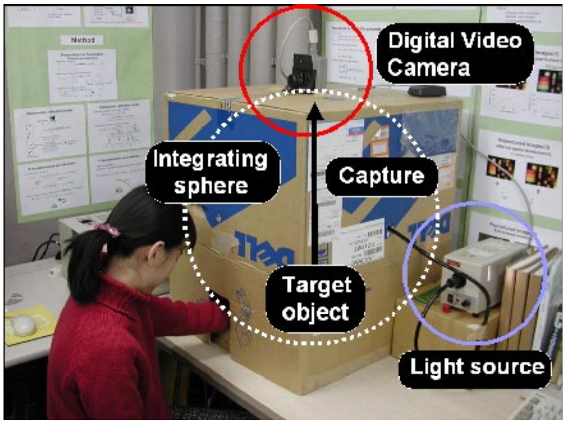

Figure 2. Overview of the proposed system.

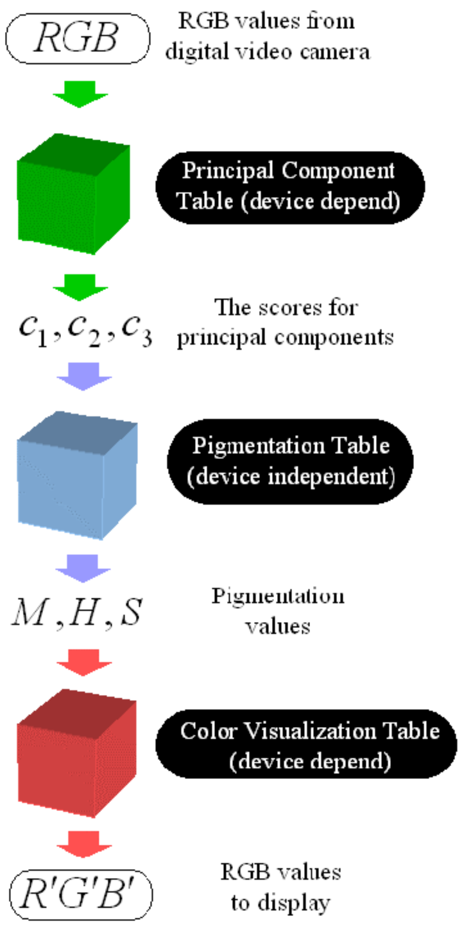

Figure 3. The flow of real-time estimation for pigmentations.

Real-Time Estimation of Pigmentation

The Flow of Real-Time Estimation

Figure 3 shows the flow of the proposed real-time estimation. At first, RGB values captured by digital video camera are converted into the scores for principle components by the first look up table that is named principle component table. The scores are converted into pigmentation values by the second table that is named pigmentation table. Finally, the pigmentation values are converted into RGB values to display on a monitor by the third table that is named color visualization table. The principle component and conversion tables are dependent on devices and environment, and the pigmentation table is independent. The principle table must be reconstructed at every devices and environment. In the case of pigmentation table, however, the table made once can be used generally. The pigmentation table needs a long time to be constructed because Monte Carlo simulation is used in inverse optical scattering technique. In our case, it took about 10 days to make the pigmentation table by Pentium 3 600MHz. It is noted that the total process is constructed from the three tables to separate the device independent process and device dependent process to reduced the dependency on the hardware. Since the values of scores effectively reflect the spectral variation of reflectance spectra used for principal component analysis, the second table is considered very effective to estimate the pigmentation values compared to the method which uses the narrow band energies. The color visualization table can be adaptive to the various purposes such as enhancement, expansion, conversion of hue and so on. The RGB values given by color visualization table are displayed on the monitor to show the images of the pigmentation maps.

Principle Component Table

The principle component table converts RGB values from digital video camera into the scores for principle components in human skin. Equation (1) shows the conversion performed in this table.

$$\boldsymbol{c} = V(W\boldsymbol{s} - \boldsymbol{a}) \quad (1)$$

where $\boldsymbol{s}$ denotes vector of RGB values, $\boldsymbol{a}$ is the average vector of spectral reflectance in human skin, V is a matrix of basis vectors for principle components in human skin. W is a Wiener estimation matrix for RGB values to spectral reflectance. $\boldsymbol{c}$ is the scores vector for principal components. This equation is used for all combinations of R,G,B values. The size of the table is 256 × 256 × 256 elements for the combinations of R, G and B. The table converts each R,G,B values into the each score vector for principal components. The values of scores are quantized by 128 levels between the minimum and maximum values in human skin.

Pigmentation Table

The pigmentation table converts the scores into pigmentation values. The size of table is 128 × 128 × 128 elements for the scores c_1, c_2 and c_3 which corresponds to the first, second, and third principal components, respectively. The values of the pigmentation are quantized by 256 levels between the minimum and maximum values in human skin. At first, an inverse table from pigmentation values to scores are made by Monte Carlo simulation of optical scattering, where scores for principle components are calculated from every spectral reflectance. The size of the inverse table is 31 × 31 × 21 for all combinations of melanin, hemoglobin, oxygenated saturation. The required table from scores to pigmentation table is made by rearranging the inverse table with the linear interpolation.

Scores For Principal Components v.s. Narrow Bands

There are three ways to extract pigmentation values from multi-band image (Figure 4). In the first method, images are captured with narrow band filters. This method cannot get enough power of light and is sensitive to noise and other errors. The second and third methods, images are captured with broad band filters such as R,G,B filters, and spectral reflectance are estimated. In the second method, effective narrow band powers are extracted from the estimated spectral reflectance. In third method, obtained spectral reflectance are projected on principal component vector. Both of the score for principal component and effective narrow band extract the pigmentation values. However, the scores for principal components cover large range of the distribution as shown in Figure 5. Therefore, it is advantageous to dynamic range. The scores for effective narrow band are more sensitive to the errors than the those of the principal component.

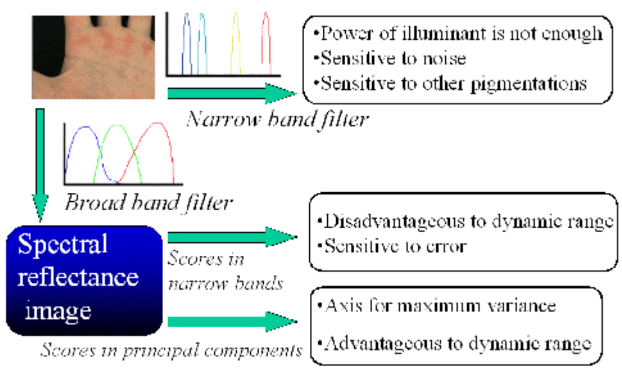

Figure 4. Three ways to extract pigmentations from multi-band image.

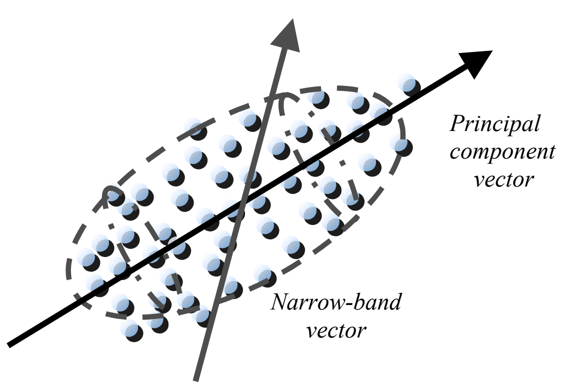

Figure 5. Principal vector covers large range of the distribution

Experiments

Mapping Pigmentation in Occlusion and Release of Middle Finger

As the experiment to show effectiveness of the proposed system, occlusion and release of middle finger was observed by the system. A root of middle finger was bound tightly with a string. After 20 seconds later, the string was cut over observation. Figure 6, 7 and 8 show the results of the experiment. During the occlusion, hemoglobin density did not change, however, the oxygenated saturation was decreased because oxygen is necessary for the middle finger. After the string was cut, both hemoglobin density and oxygenated saturation increased by afflux of arterial. Finally, amount of pigmentations returned to equation of supply and demand.

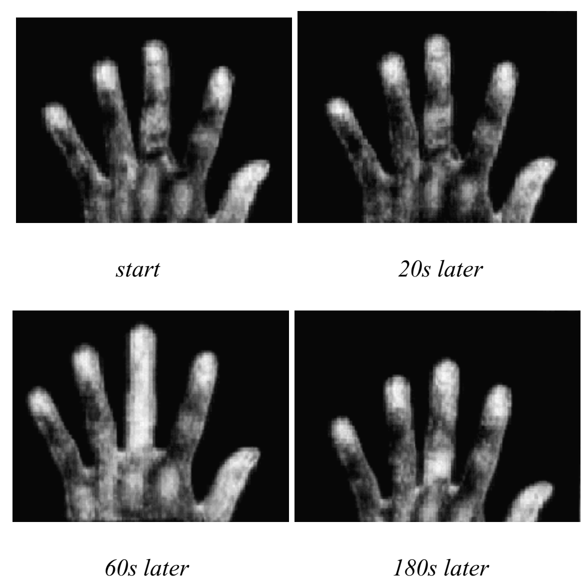

Figure 6. Maps of hemoglobin density in occlusion and release.

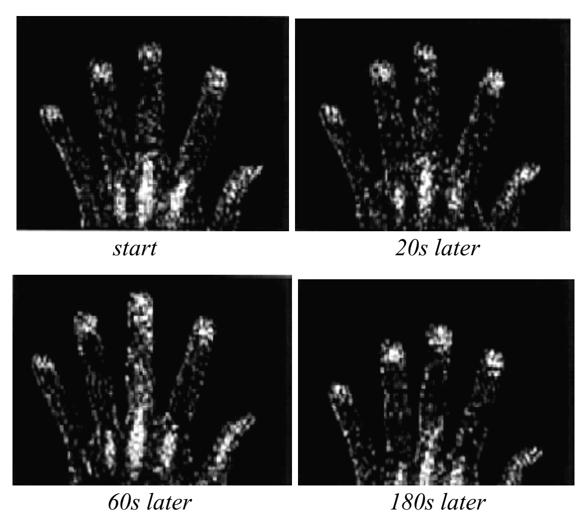

Figure 7. Maps of oxygenated saturation in occlusion and release.

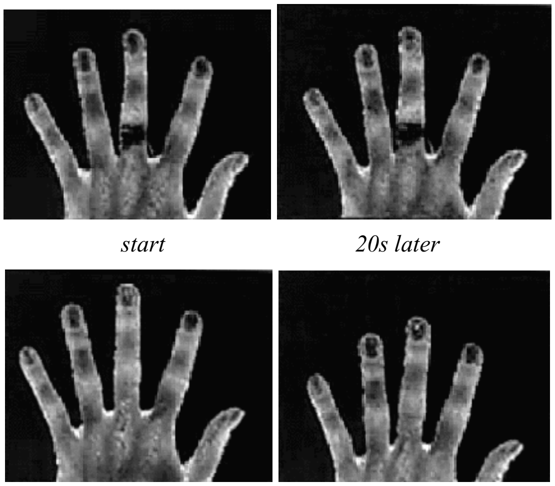

Figure 8. Maps of oxygenated saturation in occlusion and release.

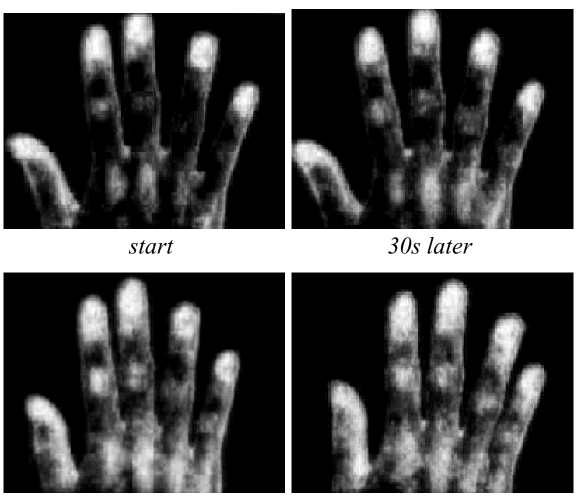

Figure 9. Maps of hemoglobin density in anaerobic.

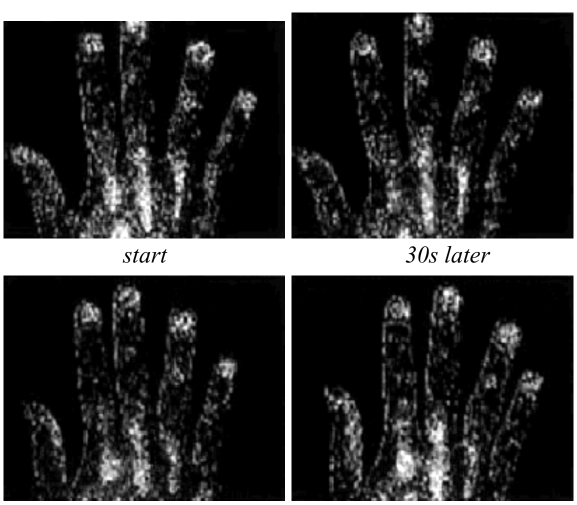

Figure 10. Maps of oxygenated saturation in anaerobic.

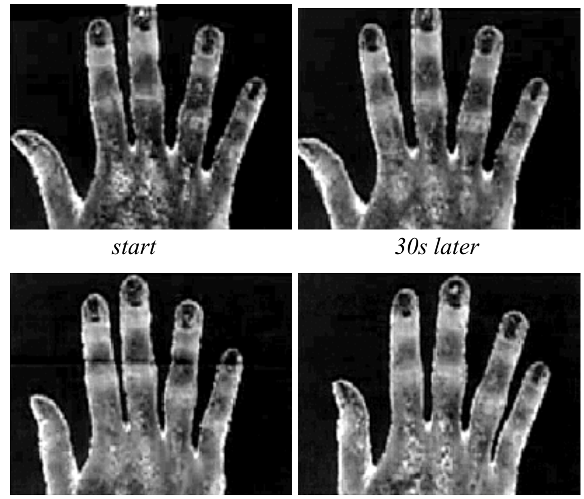

Figure 11. Maps of melanin density in anaerobic.

Mapping Pigmentation in Anaerobic

Figure 9, 10 and 11 show the change of pigmentation maps during anaerobic. We did squat exercise for 180 seconds as an anaerobic. The oxygenated saturation began to decrease as soon as squat exercise was started, however, hemoglobin density was increased gradually because the exercise stimulated the circulation of blood. After 90 seconds, the oxygenated saturation began to recover with increase of hemoglobin density. Melanin density did not change at all during the experiment.

Conclusion

The maps of pigmentations in human skin are estimated from digital video camera by using the inverse optical scattering technique in real time. We used an integrating sphere to resolve the problem of inhomogeneous illumination. The results of our experiments showed human homeostasis can be observed with our system, and the real-time map will give useful information in reproducing various skin colors and diagnosing human skin.

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Biography

Dasiuke Nakao was born in Fukuoka, Japan, on 28 January 1979. He received the B.E. degree in department of information and computer science from Chiba University in 2001. He got the first prize for his thesis in the department. Now, he is the master course student in Chiba University. He is interested in multi spectral imaging, medical imaging, Java programing for web browser.

Norimichi Tsumura was born in Wakayama, Japan, on 3 April 1967. He received the B.E., M.E. and Dr. Eng degrees 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 was a 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 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 his BS and ME in Image Science from Chiba University in 1964 and 1968, respectively. He received Ph.D. from the Tokyo Institute of Technology in 1978 for his study of color image processing and analysis. He joined to the Kyoto Institute of Technology as research associate in 1970. In 1978 he became an associate professor. During 1978 and 1979 he was an academic guest of Swiss Federal Institute of Technology (ETHZ). In 1982, he moved to Chiba university as an associate professor, and he became a full professor in 1989. 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 color image processing research in Japan. He has published more than 150 original papers, 2 books and 15 book chapters in the fields of image processing, image analysis, color image evaluation. Prof. Miyake has also been active in many professional organizations. From 1990 to 1993 he has served as editor-in chief of the Journal of SPSTJ, He was served as president of Japanese Association of Science and Technology for Identification from 1997 to 1999. He is currently served as president of the Society of Photographic Science and Technology of Japan and vice president of the Society for the Imaging Science and Technology (IS&T).