Medical Vision : measurement of skin absolute spectral-reflectance-image and the application to component analysis

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Abstract

Mapping the oxygen saturation of blood and melanin in skin is expected to give useful information for skin diagnosis. We have already proposed a technique to estimate the map of skin components from absolute spectral reflectance image obtained by multi-channel visible spectrum images based on the inverse optical scattering analysis. The spectral reflectance image is a result of dividing the spectral radiance image of object by the spectral radiance image of absolute white reference plane. However, the shape of skin is not 2 dimensional plane, so that the required absolute spectral reflectance is not obtained in the wide region of skin by the conventional method. In this paper, the absolute spectral reflectance and normal vector of the surface are obtained by using the photometric stereo technique. In the photometric stereo technique, four illuminants are used, and an image is taken by each illuminant. The pixel values in the obtained several images are used to calculate the absolute spectral reflectance and normal vector of the surface on the corresponding pixel. The index finger where the second joint was bind by a string was captured and analyzed by the proposed technique. The results show that the components are extracted in the wide range of the finger.

1 Introduction

Mapping the spatial distribution of skin pigmentation through analyzing an observed image is expected to give useful information for skin diagnosis[1]. Spectral characteristics of the components are useful information to identify the skin pigmentation, because different pigments have different spectroscopic responses to electromagnetic waves of a certain energy band[2].

We have already proposed a technique to extract the map of skin pigmentation from skin color images[3] or skin spectral absorbance image[4] by independent component analysis. The facial color images were separated into the images that correspond to distribution of melanin and total hemoglobin. This technique was practical for skin color reproduction in various imaging systems[5-8]. Within the framework of medical imaging, however, the extraction is not precise to diagnosis skin diseases. The hemoglobin has two type of state: oxy-hemoglobin (HbO_2), and deoxy-hemoglobin (Hb), and ratio between HbO_2 and Hb will change spatially in a large area of skin image or in an area of skin diseases. The oxygen saturation is defined by the ratio between oxy-hemoglobin and total hemoglobin. Mapping oxygen saturation of blood in skin is expected to give useful information for skin diagnosis[1]. We have also proposed the improved technique for mapping the pigmentations of melanin, oxy-hemoglobin and deoxy-hemoglobin in skin[9,10]. These were estimated from absolute spectral reflectance image by using the inverse optical scattering technique. In the inverse optical scattering technique, first of all, a forward model of optical scattering is build to simulate the spectral reflectance of the skin. Changing the variable parameters in the forward model, the simulation is repeated until the simulated spectral reflectance matches with the absolute spectral reflectance at each pixel of the spectral image. The conventional non-linear optimization technique was used to change the variable parameters at each iteration.

The spectral reflectance image used in the analysis is a result of dividing the spectral radiance image of object by the spectral radiance image of absolute white reference plane. The normal vectors of reference white plane and skin surface are required to face the same direction to get the absolute reflectance. The reference white plane is 2-dimensional plane,

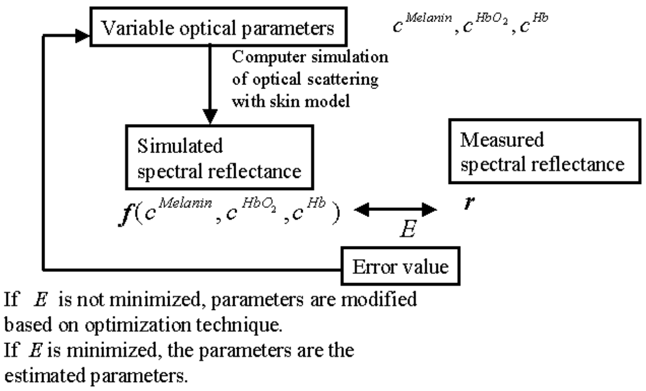


Figure 1: Estimation of pigment concentrations from diffuse spectral reflectance

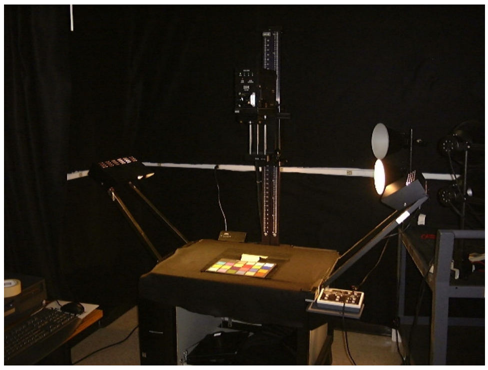


Figure 2: Experimental imaging setup for multiband photometric stereo

however, the shape of skin is not 2-dimensional. The required absolute spectral reflectance is not obtained in the wide region of skin by the conventional method. In the region where the normal vectors of reference white plane and skin are different from each other, the obtained spectral reflectance is a relative spectral reflectance that is the multiplication of absolute spectral reflectance by a constant value.

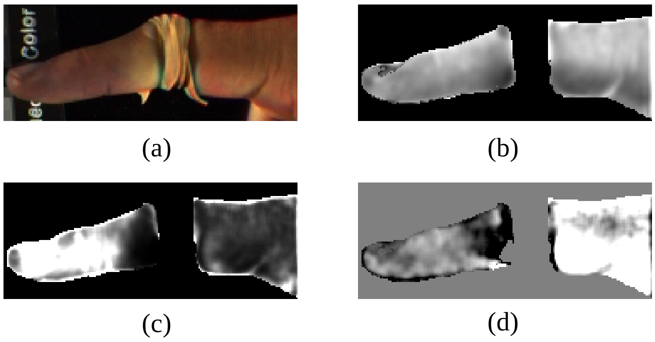
In this paper, the absolute spectral reflectance and normal vector of the skin surface are obtained by using the photometric stereo technique[11]. The extracted shape information and result of component analysis are displayed in arbitrary point of view and arbitrary illumination by using the computer graphics technique. The photometric stereo is one of the popular computer vision techniques. In recent development of computer performance, an image based rendering and modeling[12] is getting notable in the world. The image based rendering and modeling is a technique that extracts the 3-D, color and texture information from taken images by using computer vision technique, and display the captured information of image in arbitrary point of view and arbitrary illuminant by using the computer graphics technique. The proposed technique is considered the application of image based rendering and modeling technique to the medical imaging. We name this technique as medical vision. The index finger where the second joint was bound by a string was captured and analyzed by the proposed technique.

2 Inverse optical scattering technique using multi-channel visible spectrum image

The concentration of pigments is estimated from diffuse spectral reflectance. At each pixel of the image, the diffuse spectral reflectance is calculated from multi-channel visible spectrum image by using Wiener estimation technique. Figure 1 shows the schematic diagram of the estimation method for pigment concentrations. At first, the initial values of variable parameters; concentrations of melanin $\boldsymbol{c}^{Melanin}$, oxy-hemoglobin $\boldsymbol{c}^{HbO_2}$, deoxy-hemoglobin $\boldsymbol{c}^{Hb}$ are randomly given, and the spectral reflectance is simulated using the initial parameters based on the Monte Carlo simulation[13] of optical scattering in human skin[14]. The amount of error is calculated between the simulated spectral reflectance and measured spectral reflectance. If the error is not small enough, the variable parameters are changed, and spectral reflectance is simulated again by using the changed parameters. If the error is small enough, the parameters used for the simulation are results of the estimation. To decide the change of parameters, a conventional optimization technique is used by MATLAB optimization tool box. The absolute spectral reflectance is required in this analysis. However, as is mentioned in the previous section, the obtained spectral reflectance is a relative spectral reflectance in the region where the normal vectors of reference white plane and skin are different from each other.

3 Photometric Stereo

The photometric stereo technique is used to get the absolute spectral reflectance in wide range of skin. In the photometric stereo technique, more than three illuminants are used, and an image is taken by each illuminant. We assume Lambertian reflectance and infinite point source illumination. Let $\boldsymbol{l} = (l_x, l_y, l_z)^t$ be the vector that directs to the light source and whose length $\|\boldsymbol{l}\|$ is the radiance of the light source. Let $\boldsymbol{n} = (n_x, n_y, n_z)^t$ be the unit surface normal, and ρ be the absolute reflectance. Based on the Lambertian model of skin surface, the observed intensity v is written as follows



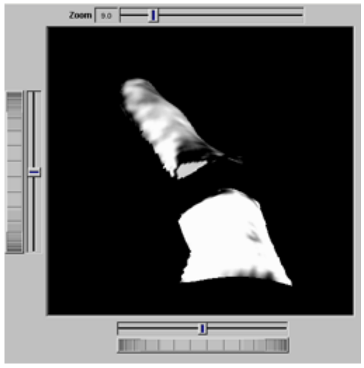


Figure 3: The result of component analysis for index finger where the second joint was bind by string, (a) original image, (b)melanin, (c)total hemoglobin, (d) oxygen saturation

Figure 4: Display of oxygen saturation by computer graphics technique

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

For multiple images, we have following equations.

$$\begin{aligned} v_1 &= \rho \boldsymbol{n}^t \boldsymbol{l}_1 \\ v_2 &= \rho \boldsymbol{n}^t \boldsymbol{l}_2 \\ &\vdots \\ v_m &= \rho \boldsymbol{n}^t \boldsymbol{l}_m \end{aligned} \tag{2}$$

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

$$\boldsymbol{v} = \mathrm{L}\boldsymbol{x} \tag{3}$$

where $\boldsymbol{v} = (v_{1,} v_2, \cdots, v_m)^t$ is the captured intensity vector, $\mathrm{L} = [\boldsymbol{l}_1^t, \boldsymbol{l}_2^t, \boldsymbol{l}_3^t]^t$ 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 L is nonsingular, the vector $\boldsymbol{x}$ can be estimated by the following equation using the Moore-Penrose generalized inverse of light matrix L.

$$\boldsymbol{x} = (\mathrm{L}^t \mathrm{L})^{-1} \mathrm{L}^t \boldsymbol{v} \tag{4}$$

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 is estimated for each wavelength to get the absolute spectral reflectance.

4 Experiment

The index finger where the second joint was bound by a string was captured and analyzed by the proposed technique. In this experiment, four directions of illuminant were used for photometric stereo. Figure 2 show the experimental imaging setup for multi-band photometric stereo technique. Ambient illuminant such as light from windows is also considered in the experiment. To remove the ambient illuminant, the illuminants for photometric stereo are controlled. The images with controlled illuminant and without controlled illuminant are taken, and the subtraction between the images removes the influence of the ambient illuminant.

Figure 3 shows the result of component analysis for index finger where the second joint was bound by string. Figure 1(a) shows original image, (b) melanin component, (c) total hemoglobin, and (d) oxygen saturation. The results show that the components of pigmentation are extracted well in the wide range of the finger. Figure 4 displays the distribution of oxygen saturation in different point of view from originally taken image. The change of view point is simulated by computer graphics technique from the estimated shape information of skin. In this demonstration, the both of shape and component are observed at the same time.

5 Conclusion

It will be required to consider about the complex reflection such as specular reflection on rough skin surface. In this research, however, it is shown the effectiveness of using computer vision technique into the medical image measurement, and the possibility of novel medical imaging system that will be applicable into tele-medicine system by combining the computer vision technique and computer graphics technique.

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