Skin Reflectance Model for Multispectral System

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Abstract. This is a pre-study on the non-invasive detection and contrast observation of pigmented lesions. We obtained a proper skin reflectance model of a multispectral imaging system that generates images perpendicular exposure of skin perpendicularly exposed reflectance in the wavelength ranging from 470 to 630 nm at an internal of 2 nm, altogether 81 different wavelengths in the visible range. The reflectance data was collected from 27 different skin lesions each 500*500 pixels in various conditions from 8 persons. Since the spectrum is mixture of layers of skin tissue distribution, independent component analysis (ICA) and pure components analysis were proposed to fit the experimental data, and the layered-dependent skin parameters melanin content, blood volume fraction, and haemoglobin content were extracted from the skin reflectance model. The skin reflectance model fitted spectrum curves show 4% average (12% maximum) difference from the experimental data, which were acceptable. The skin model is accepted for the multispectral imaging system in further studies.

1. Introduction
Human skin appears various colors due to its structural variations within its layers. This heterogeneity may occur due to disease or artificial forces. Building skin reflectance models to describe reflect spectrum could acquire skin parameters. Recently, it has been widely used for measurements of specific chromophores within skin tissue for biomedical applications[1-3]. This makes it a promising tool for quantifying the changes of optical properties of lesions. Leukoplakia is our further target skin disease, the pathogenesis of which needs to be improved. The appearance of the unhealthy tissue depends on the degree of the disease progression. Initially, the skin may appear white, thickened and excoriated[4]. Skin models[5-6] could simulate the change in skin layers. To add variations, here we used pressure and heat as the artificial force, and find the best fitted skin model for our reflectance system.

1.1. Skin layers
We consider skin as a three-dimensional half-infinite medium divided into layers, the epidermis layer (100–120 μm), the dermis layer (1–3 mm) and subcutaneous fat (6–7 mm). Reflection, scattering, and absorption are the optical properties affecting the nature of the interaction of ultrasound in biological tissues[7]. The absorbents in skin tissue can be used to identify the optical properties of skin tissue. Changes in absorbents content will affect the reflectance of the skin tissue[8]. The light passes through some layers then back again, and is detected by the camera.

1.2. Instrumentation
The multispectral imager used in this work contains Brimrose hyper-spectral imager to produce hyper-spectral images of the target area, a 500-Watt continuous white light source (Xenon Lamp Source,
Beijing Optical Century Instrument Co., CHINA), a 20 cm focal length lens (THORLABS, US), the 2D InGaAs camera and the AOTF adapter with the program provided with the camera and AOTF by the Brimrose company to control the system. This work used central part of the image, with 980x980 pixels each pixel 16-bit digital signal. The multispectral image system were calibrated by a standard reference card (Eastman Kodak, Rochester, New York) and XeF (C-A) blue-green laser to remove all elements of bias.

2. Analysis

An example of the image collected by the multispectral imaging system is shown in figure 1, figure 1(a) in 550nm shows the intensity of the reflected light, with white being a higher intensity, roughly consider the reflectance model to be mainly absorption with the same penetration depth. The absorption coefficient $A$ should be:

$$ A = \frac{-\log(R)}{t}, $$

where $R$ is the reflectance, $t$ is the penetration depth.

In order to leave out the influence of camera angle, the absorption coefficient $A$ is normalized by divided by its means. Figure 1(b) shows the corresponding normalized absorption coefficient lines from figure 1(a).

2 different types of skin reflection models, ICA, pure components were used to fit the spectrum as described in the following sections.

2.1. ICA

When mainly consider absorption, absorption coefficient is linear add of unknown absorbents. It becomes a blind source separation (BSS) problem, and independent component analysis (ICA) is a very effective tool for solving the BSS problems.

The noise-free model of basic ICA is as follows[9]:

$$ A = L s, $$

where $L$ is a linear mixing matrix, $s$ is the independent sources. In general, the number of sources should be equal to the number of the mixtures. This is way larger than the number of absorbents in skin, so we used Fast-ICA to find independent component one by one till the source signal seems more noise than absorbents.

The result shows in figure 2.
Figure 2. Result of ICA model_1. (a) The independent components separate by Fast-ICA. (b) The fitting pair of model_1 with the raw data from figure 1(a) red dot.

As shown in figure 2(a), the independent components seems to influence each other and multiply the noise in the raw data. This model_1 obtain average of 11% fitting error in figure 2(b).

Consider the layers of skin are quite different from one another, though the error is not acceptable, this model suggest that the penetration depth should mainly be 2 layers.

2.2. Pure components

In the visible range, melanin and different types of hemoglobin are the principal absorption components in skin tissue, which should be considered in hyper-spectral data analysis. According to the characteristic peaks of the spectra, melanin and Oxy-hemoglobin(HbO2), Deoxy-hemoglobin(Hb) were main absorption components. The penetration depth suggest for the red laser in very fair skin is around 0.5 mm and 0.07 mm for dark skin[10]. In the suggest layer above, the pure skin components in epidermis, dermis and subcutaneous fat are presented in figure 3(a).

Figure 3. Result of pure components model_2. (a) The pure components in skin. (b) The fitting pair of model_2 with the raw data from figure 1(a) red dot.

The absorption coefficient is:

\[ A = \sum_{k=1}^{n} c_k a_k + S, \]

where \( a_k \) is each components \( c_k \) is the corresponding density and \( S \) is a constant related with the reflect angel which represent stripe patterns. Figure 3(a) show the pure components of human skin[11], this model_2 obtain average of 4% fitting error in figure 3(b).

3. Discussion

The result images of model_2 shows in figure 4. The stripe patterns, the melanin content and the hemoglobin content were separated from multispectral images. The stripe patterns indicate the palmprint, the melanin content in figure 4(c) highlight the nevus in figure 4(a) and the hemoglobin map (figure 4(d)) shows the blood flow beneath the epidermis.
The result in the shadow area at the bottom of the images is obscured. To ensure enough light for the imaging system, the Xenon light and camera angle should be less than 30 degree perpendicular to the skin surface.

![Image of multispectral imaging system results](image)

**Figure 4.** Result of the multispectral imaging system. (a) 550nm spectral image. (b) Stripe pattern. (c) Melanin (epidermis). (d) Hemoglobin (dermis).

### 4. Conclusion

The fitting model provide clues to the relative amounts of melanin content (average 42%), blood volume fraction (average 14%) and oxygen saturation (average 38%) from our multispectral images. Vasculature area retrieve a higher percentage of dermis components, which decrease significantly while pressing the subject’s forearm to induce temporary ischemia.

The skin reflectance model fitted spectrum curves show 4% average fitting error from the experimental data, which are acceptable for the multispectral imaging system in further studies.

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