

Estimation of diffuse reflectance spectrum from RGB values by the synthesis of new colors for tissue measurements

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ABSTRACT

A modified Wiener estimation method is presented for the accurate estimation of diffuse reflectance spectra from RGB values. In this method, the original RGB values are combined with a set of synthetic optical filters to generate another new three color values by using the system matrix. A modified Wiener matrix can then be created with the RGB values and the new color values, which will yield more accurate estimation because of the new color information incorporated. This method is tested on *in-vivo* color measurements from 200 skin sites in 10 volunteers. The results show that the proposed method improves the accuracy of the estimated diffuse reflectance spectra significantly compared with the traditional Wiener estimation method. Because of the fast computation in Wiener estimation, this method could be potentially developed for a cost effective alternative to a spectral imager.

Keywords: Wiener estimation, diffuse reflectance spectroscopy, color imaging, spectral imaging

INTRODUCTION

Diffuse reflectance spectroscopy has been a widely used non-invasive technique in biomedical optics in recent years[1-4]. Diffuse reflectance spectra can provide information about the absorption and scattering properties of tissues[5]. These optical properties are correlated with several important biophysical and biochemical parameters, e.g. hemoglobin concentration, oxygenation and average nuclei size, in tissues for the early diagnosis of skin diseases. However, the common disadvantage of traditional diffuse reflectance spectroscopy is its employment of fiber-optic probes, in which only point measurements can be performed. Therefore, the data acquisition in traditional diffuse reflectance spectroscopy is slow when diffuse reflectance spectra at multiple locations are required. Multi-spectral imaging has been developed to acquire diffuse reflectance images at multiple wavelengths[6]. However, image acquisition can be still slow when the required spectral resolution is high. Although there have been efforts in the development of snapshot spectroscopic imaging techniques[7], the advantage of these techniques in quick image acquisition are usually compromised by the slow postprocessing especially when the data dimension is large. Therefore, it is important to develop a rapid spectral imaging technique, which could offer real time acquisition of diffuse reflectance spectra for tissue measurements in multiple locations without sacrificing the accuracy.

The reconstruction of diffuse reflectance spectra from color values taken by a color camera is a potential solution to this problem. A large tissue area could be captured by a color camera at a high frame rate, which typically contains the color values in Red, Green and Blue bands at each pixel. In addition, each color band covers a relatively wide range of wavelengths thus the signal is usually strong thus suitable for fast imaging. Several methods, e.g. pseudo-inverse[8], finite-dimensional modeling[9], Wiener estimation[10] etc, have been explored to recover diffuse reflectance spectra from color information in multiple bands. Among them, Wiener estimation is one of most frequently used methods because of fast data processing[11]. However, one serious problem of using Wiener estimation in the estimation of diffuse reflectance spectra is that multi-channel information is always needed for sufficient accuracy[10]. Wiener estimation with only RGB bands is considered not adequate because of the underdetermined nature of the problem, in which three values corresponding to RGB colors are mapped to diffuse reflectance intensities at a few hundred wavelengths in a spectrum. Therefore, an accurate estimation method requiring only RGB values is desired for both convenience and low cost.

strategies when doing the color correction. These two sets of estimated diffuse reflectance spectra will be selected in the selection stage in order to get a better accuracy for the estimation of the diffuse reflectance spectra. The scheme of the test stage is shown in Fig. 2.

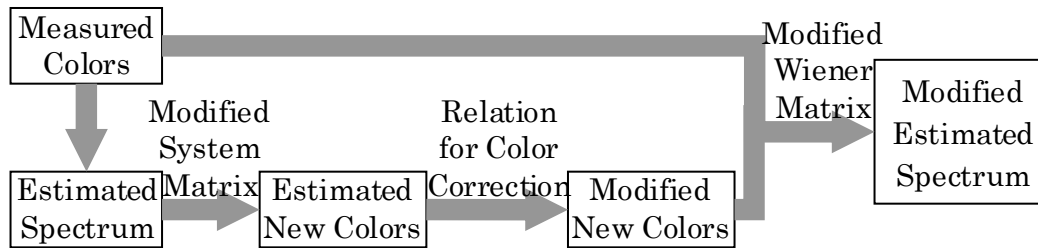


Fig. 2 Schematic of the test stage

For the second order relation, the modified new colors are generated by substituting the estimated new colors into the second order polynomial function. And for the difference relation, the difference values used to modify the estimated new colors are calculated by using the equation as follows:

$$D = \sum_{i=1}^n w_i d_i \quad (1)$$

where D denotes the difference values used to modify the estimated new colors, w_i and d_i denote the i -th weight and difference values for each point in the calibration data set, respectively. The weight w_i is calculated by the equation as follows:

$$w_i = \frac{l_i^{-1}}{\sum_{i=1}^n l_i^{-1}} \quad (2)$$

where l_i denotes the distance in the RGB color space between the measured color in the test data and the i -th color in the calibration data. From Eq. (1) and (2), the summation of w_i is 1, and the contribution of d_i to D is proportional to the similarity between the measured color in the test data set and the i -th color in the calibration data set.

Because two methods used to correct estimated new color values generate different results, selecting more accurate new color values between the two methods will subsequently yield a better estimation of diffuse reflectance spectra. In this selection stage, the estimated spectra based on the two methods are multiplied by the original system matrix to find the estimated RGB color values. Then, the estimated spectrum that yields color values closer to the measured values will be selected as the final result.

This method was evaluated in the data measured *in vivo* from ten volunteers. All the data were measured by the system shown in Fig. 3 which consists of a light source (HL-2000-FHSA, Ocean Optics, US), a spectrometer (USB4000, Ocean Optics, US), a fiber-optic probe (custom probe VIS/NIR, Ocean Optics, US) and a color CCD camera (DS-Fi1, Nikon, Japan) in which the Bayer color filter array is used for RGB image acquisition. The probe was composed of one source fiber with a core diameter of 600 μm surrounded by ten detector fibers with a core diameter of 100 μm . The measured diffuse reflectance spectrum was normalized to remove the wavelength dependence of system response by dividing the spectrum measured on the skin by the spectrum measured on a reflectance standard (SRS-99-010, Labsphere, US). Then the data points in the spectrum were binned so that the spectral resolution was 5 nm from 400 nm to 700 nm. By using this system, both RGB color values and diffuse reflectance spectrum were measured from the same position on the skin to prevent the mismatch in measurements sites between two sets of measurements.

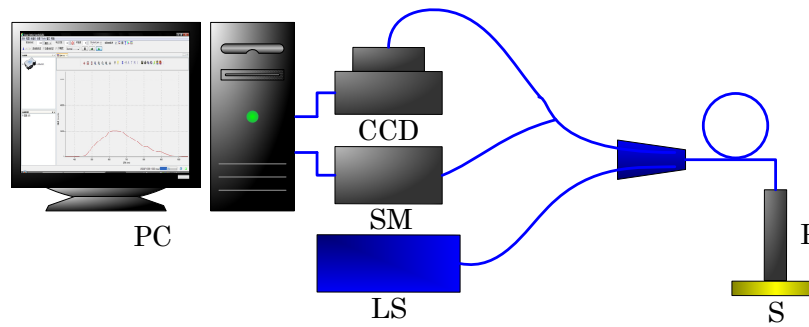


Fig. 3 Diagram of the system for taking color images and diffuse reflectance spectra. The following acronyms are used. SM: spectrometer; LS: light source; P: probe; S: sample.

RESULTS AND DISCUSSIONS

A total of 200 skin sites from 10 volunteers, which includes 6 Chinese, 3 Indians, and 1 Caucasian, were measured in this experiment. The reason of using not color chart but human skin as the calibration data is that special selection of calibration data set has obvious impact on the accuracy of the diffuse reflectance spectra estimation[12]. A leave-one-out method was used to evaluate the proposed method. Only one data point was picked as the test sample each time and other 199 data points were used as the calibration data set. The procedure was repeated until all the 200 data points have served as the test sample once. The proposed method were coded and run in Matlab (R2008a, MathWorks, US).

In order to show the improvement of the proposed method, Wiener estimation was applied to the same data set for comparison. The mean RMSEs (Root Mean Square Error) calculated between estimated diffuse reflectance spectra and measured diffuse reflectance spectra for different estimation methods are shown in Table 1. The representative diffuse reflectance spectra are shown in Fig. 4.

Table 1 shows that the modified Wiener estimation method reduces the RMSE by 7.2% or 4.5%, respectively, compared to the traditional Wiener estimation, when Strategies A or B is used to correct new RGB values. Moreover, a much larger reduction in the RMSE, i.e. 15.3%, is seen when the selection step is added. This infers that more accurate new color values yielded by the selection step are critical to the accurate estimation of diffuse reflectance spectra. It took 19.3 milliseconds to estimate the diffuse reflectance spectra from 400 nm to 700 nm with a resolution of 5 nm at 50 skin sites in a PC with Intel Core 2 CPU 2.4GHz, 2G RAM and Windows Vista operating system. This short estimation time implies the potential of performing real time estimation of diffuse reflectance spectra based on color images acquired from a large tissue area.

Table 1 Comparison of mean RMSE between the traditional Wiener estimation and modified Wiener estimation^a

	Traditional WE	Modified WE with Strategy A	Modified WE with Strategy B	Modified WE with the selection step
RMSE	1.11×10^{-2}	1.03×10^{-2}	1.06×10^{-2}	9.40×10^{-3}

^aWE is the acronym of Wiener Estimation

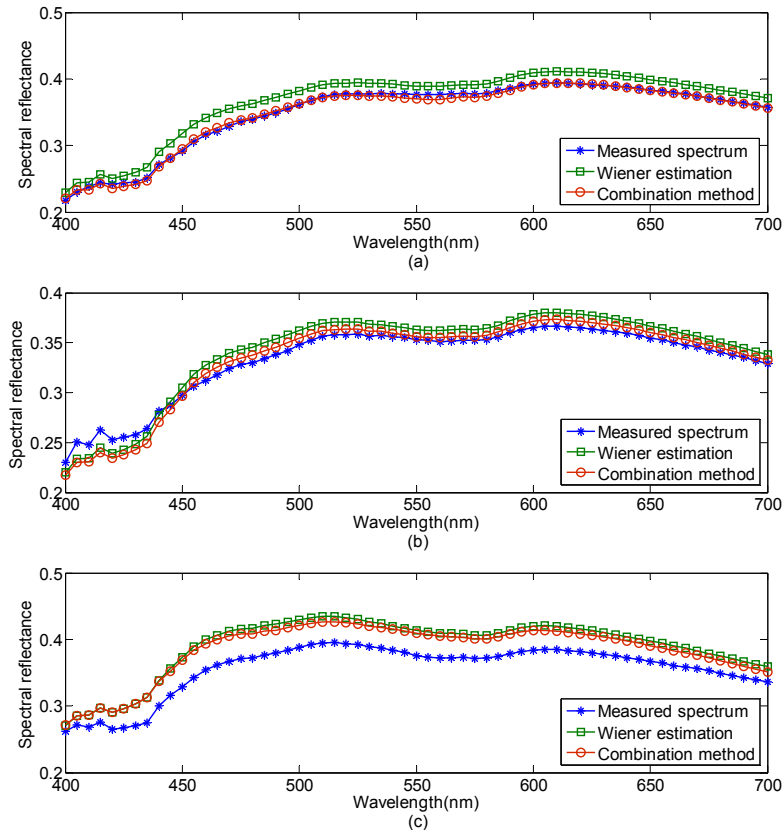


Fig. 4. Comparison of measured diffuse reflectance spectrum, Wiener estimation result and combination method result: (a) best estimation, (b) normal estimation, (c) worst estimation.

CONCLUSION

In conclusion, we developed a modified Wiener estimation method by the synthesis of new colors from the system matrix based on a calibration data set. The proposed method significantly improved the accuracy of estimated diffuse reflectance spectra for RGB color values acquired from human skin. Because of the ability to capture a large area at one time using a color camera and fast Wiener estimation, the proposed method may be developed for real-time acquisition of diffuse reflectance spectra from human skin, which provides a cost effective alternative to spectral imaging with the additional advantage of high spectral resolution.

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