Multispectral imaging realized by unmodified smartphone

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Abstract

We propose a novel method and system that utilizes a popular smartphone to realize hyperspectral, autofluorescence and photoplethysmography imaging for analyzing skin morphological features and monitoring hemodynamics. The imaging system is based on a built-in RGB camera and flashlight on the smartphone. We apply Wiener estimation to transform the acquired RGB-mode images and videos into "pseudo"-hyperspectral images in visible range. Compared with expensive hyperspectral imaging systems, the smartphone-based system delivers similar results but with very high imaging resolution. Besides, it is easy to operate very cost-effective and fast a wide consumer base. The use of an unmodified smartphone overcomes the cumbersome issue of manual data collection and enables a wide range of practical applications in the context of remote and mobile health monitoring. Hyperspectral analysis of skin cut from laboratory and clinical settings and daily life, which may also impact on health care in low-resource settings and rural areas.

Smartphone-enabled multispectral imaging

To reconstruct hyperspectral images from RGB images, we assume the reconstruction matrix is W. The process is expressed as

\[ \mathbf{V} = \mathbf{W} \mathbf{V}' \]

where \( \mathbf{V} \) is the reconstructed hyperspectral image, \( \mathbf{V}' \) is the vector of smartphone camera response. To ensure the accuracy of reconstruction, the minimum square error between the reconstructed hyperspectral image and the original hyperspectral image should be minimized. The reconstruction matrix is derived as

\[ \mathbf{W} = (\mathbf{D}^T \mathbf{D})^{-1} \mathbf{D}^T \]

where \( \mathbf{D} \) is an ensemble-averaging operator. \( (\mathbf{D}^T \mathbf{D})^{-1} \) is the correlation matrix between the hyperspectral response and smartphone camera response, \( \mathbf{D} \) is the autocorrelation matrix of the smartphone camera response. The reconstruction matrix \( \mathbf{W} \) was obtained from the calibration of a color chart which contains 392 color patches. After a smartphone camera can be reconstructed into hyperspectral images.

Smartphone-enabled multispectral imaging of photoplethysmography

Under the illumination of flashlight, we took RGB-mode videos of the skin as raw data and then reconstructed them into multispectral data cubes. Then, we selected 2 channels as the target channels in further processing stage. In each channel, we calculated the light absorption change by the modified Beer-Lambert law:

\[ \Delta \alpha = \alpha_0 - \alpha = -\log (R) - (\log (R_0)) = -\log \left( \frac{R}{R_0} \right) \]

where \( \Delta \alpha \) is the light absorption change from time \( t_1 \) to time \( t_2 \) and \( \alpha_0 \) and \( \alpha \) are the light absorptions at time \( t_1 \) and \( t_2 \), respectively. \( R \) and \( R_0 \) are the signal intensities in selected channels at time \( t_1 \) and \( t_2 \). \( \alpha_0 \) is the intensity of incident light. Afterwards, we applied weighted subtraction method to decode the absorption changes of two chromophores. The change of oxyHb concentration can be expressed as:

\[ \Delta \text{oxyHb} = \frac{\Delta \alpha - \Delta \text{deoxyHb}}{\alpha_0 - \alpha_{\text{oxyHb}}} \]

\[ \Delta \text{deoxyHb} = \frac{\Delta \alpha - \Delta \text{oxyHb}}{\alpha_0 - \alpha_{\text{deoxyHb}}} \]

where \( \Delta \alpha \), \( \Delta \text{oxyHb} \), and \( \Delta \text{deoxyHb} \) are the concentration changes of oxyHb and deoxyHb, respectively. \( \alpha_0 \) and \( \alpha_{\text{oxyHb}} \) are the absorption coefficients of oxyHb and deoxyHb, respectively. The light interaction path length by conducting similar weighted subtraction processing. The output of oxyHb concentration can be extracted. To conduct spectral-temporal measurement of the decoupled hemoglobin pulsations, we applied a window-based lock-in-amplification algorithm on the oxyHb and deoxyHb perfusion change data. The hemoglobin pulsation amplitude at pixel \((x,y)\) can be calculated as:

\[ A(x,y) = 2 \alpha_0 (2 \alpha_0 - 2 \Delta \alpha) \sum_{R=1}^{R_{\text{oxyHb}}} \sum_{G=1}^{G_{\text{oxyHb}}} (A(x,y)) \]

where \( A(x,y) \) is the amplitude of the extracted hemoglobin pulsation signal \( Z(x,y) \) is the time integral of the product of standard function and input perfusion data \( R(t) \) is the standard function. \( A(x,y) \) is the input hemoglobin perfusion change signal of pixel \((x,y)\) at time \( t \).

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References


Fig. 1 (A) Schematic of calibration step of Wiener estimation. (B) Error map based on standard RGB colorimeter. (C) Multispectral data reconstruction. (D) Surface reflectance data of two skin color charts. (E) (F) Comparison between standard and reconstructed reflectance and color profiles, respectively.