Biomedical Signal Processing and Control 40 (2018) 192–203

Contents lists available at ScienceDirect

Biomedical Signal Processing and Control

journal homepage: www.elsevier.com/locate/bspc

Research Paper

Non-contact remote estimation of cardiovascular parameters

Qiang Fan, Kaiyang Li[*]

Department of Electronic Science and Technology, School of Physics and Technology, Key Lab Artificial Micro & Nanostruct, Minist Educ China, Wuhan University, Wuhan, 430072, China

ARTICLE INFO

Article history:
Received 26 June 2017
Received in revised form 31 August 2017
Accepted 16 September 2017

Keywords:
Imaging photoplethysmography
Motion artifact
Independent component analysis
Wavelet decomposition
Heart rate
Oxygen saturation

ABSTRACT

Cardiovascular disease is a serious threat to human health. It is crucial to monitor the cardiovascular parameters reliably and conveniently. Non-contact measurement has been widely studied. However, there are some inevitable factors that limit the use of the platform and even lead to inaccuracy estimation. Hence, a novel non-contact method that estimates cardiovascular parameters under ambient light is proposed. The most suitable region of interest (ROI) is determined by a colormap, which is a map consists of Fast Fourier Transform (FFT) peak amplitude of every pixel. Comparisons suggest that the region includes cheeks and nose is the most appropriate, followed by the forehead. To remove the motion artifacts caused by body movement, face detection and tracking algorithms are performed. Further, a multi-step signal process that combines independent component analysis (ICA) and wavelet de-noising is utilized to extract clean signal from the noise-corrupted raw waveform. Moreover, various distance between subject and camera and the change of ambient light intensity are considered, where statistics results reveal that this non-contact methodology is blind to these factors. Compared with the gold standard pulse oximeter, the proposed method shows a high accuracy even in the presence of motion artifacts.

1. Introduction

Cardiovascular diseases have been the leading cause of death as claimed in the reports [1,2]. The key to prevention and treatment is the early detection of angiocardiopathy. Indeed, heart rate (HR) and blood oxygen saturation (SpO_2) are two of the most vital parameters for human cardiovascular status (CVS) assessment, which can be extracted from photoplethysmography (PPG) signal [3–6].

The pulsatile component from the PPG waveform contains valuable information of a subject's cardiovascular and metabolic systems [7–9]. Pulse oximeter, which is based on PPG waveform, is a simple and robust contact device. However, it requires long time to hold and clamp, which affects people's daily life and habit. Besides, it has been shown that the contact force and placement would influence the pulse waveform [10–12]. Additional light source restrains the use of detector greatly. Ideally, for long-term recording, wearable PPG device has been widely developed [13–15]. Similar to the conventional PPG, the measurement sites for wearable PPG sensing also should be attached firmly to human skin. Yet, it is not quite suitable when physical isolation is required.

Therefore, non-contact measurement that without changing human's daily routine of vital physical signals is very important. Recently, imaging photoplethysmography (IPPG) became an attractive issue, which is comfortable physiological self-assessment [16–19]. Wim Verkruysse et al. firstly proposed a remote method for HR and respiration rate (RR) estimation under ambient light [20]. A digital camera was used to capture IPPG signal. The results show that the IPPG technology under ambient light may be available for medical purpose. However, noise that caused by motion artifacts is not considered. Lately, Kong Lingqin et al. reported the extraction of SpO_2 under ambient light with two charge coupled device (CCD) cameras [21]. Yet, special narrow band-pass filters, which mounted in front of CCD camera, were needed. However, complicated platform limits the measurement conveniently. More recently, Ufuk et al. applied a color camera to calculate HR and SpO_2 under ambient light [22]. Based on wavelet filter and band-pass filter, the method can provide acceptable accuracy to estimate HR of patients in a clinical environment. In addition, a wide range of face movement can affect the selection of ROI, thereby affecting the accuracy of results. Further, Poh et al. introduced a method based on webcam to measure HR [23,24]. The independent component analysis (ICA) algorithm was employed to separate physiological signal from original signal. Whereas, due to the lack of efficient sorting algorithms, the selection of effective IPPG signal of out-

---

[*] Corresponding author.
E-mail address: lky@whu.edu.cn (K. Li).

http://dx.doi.org/10.1016/j.bspc.2017.09.022

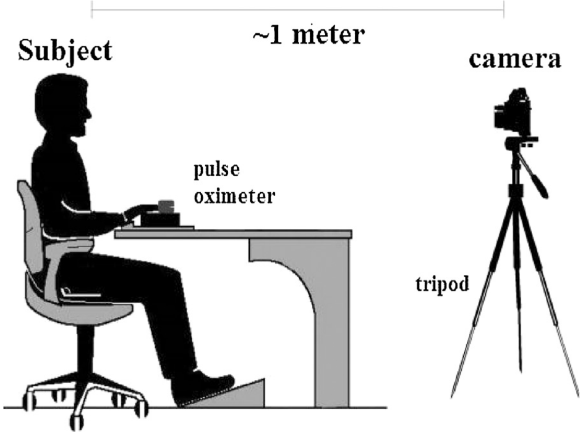

Fig. 1. Schematic diagram of non-contact method.

put components is difficulty. Moreover, calculation of SpO_2 is not discussed.

In order to improve the shortcomings that mentioned above, we raise a novel multi-step method that combines face tracking, ROI selection and a blind source separation algorithm. The accuracy and robustness are verified by different measurements. There are many factors such as capture distance and illumination conditions restrict the convenient use of the IPPG platform. Therefore, the influence of these issues on measurement are discussed.

2. Material and methods

2.1. System design

The non-contact platform is plotted in Fig. 1. Different from the traditional contact oximeter, we adopted a CCD camera (Model: MV-GED32C-T, MindVision, China, maximum resolution of 640 × 480 pixels, sensitivity 1.8 V/lux-sec) as the capture detector instead of photodiode without additional light source. The illumination source was ambient light. All videos were recorded in color (24-bit RGB with three channels 8 bits/channel) at 30 fps (frames per second). During all of the experiments, a pulse oximeter (Prince-100F, HR range: 30–250 bpm (beats per minute), SpO_2: 35–100%, Heal Force, China) was adopted to record the values of HR and SpO_2 as a reference. The subjects were requested to sit at a distance of approximate 1 m from the camera (except the experiment of different distances). All measurements were under stable ambient light (except the experiment of different ambient light intensities). The room temperature was kept at 25 °C. In addition, a photoelectric illumination meter (MS6612, HYELEC, China) was used to record the light intensity.

65 volunteers (included 18 females and 47 males, age: 21–53, Body Mass Index (BMI): 19.5–25.8 kg/m^2) were enrolled from Wuhan University. All subjects received an explanation of the experimental tasks, also were asked to sign an informed consent form before testing. All subjects certified that they were healthy, and not taking any medicine within 4 weeks to enroll in this study.

2.2. Physiological parameter calculation

The theory of PPG technology, which pulse oximeter based upon, is demonstrated as follow [8,25]: when the incident light penetrates the human skin, the absorption by various tissues is constant. This absorption can be defined as a direct current (DC) component. Meanwhile, the absorption by oxygenated arterial blood is variable due to arterial pulsation and can be defined as an alternating current (AC) component. The HR is then calculated given by measuring the frequency maximum of the AC component. The pulsation waveform, which is initiated by a heartbeat, travels through the arterial vascular and reaches the face. Consequently, it causes a short-termed volume change of blood. Extraction of the subtle changes in amount of reflected light will indicate the timing of cardiovascular events [18,21–24].

However, a color camera under ambient light is adopted in this paper. Therefore, the usage of the three channels of color camera needs analysis. The absorption curves of hemoglobin and camera sensors are plotted in Fig. 2. It can find that the green channel of the camera corresponding to a high extinction coefficient of hemoglobin. Articles presented that the green channel is more suitable for calculating heart rate [26–28]. For the above reasons, the green channel is chosen for HR calculation.

Then, the green channels trace is processed by the Fast Fourier Transform (FFT) to achieve the related power spectrum. The location of the highest power f_{max} in the power spectrum corresponds to the frequency of HR:

$$HR = 60 \times f_{max} \quad (1)$$

With regard to SpO_2 estimation, which can be defined as:

$$SpO_2 = \frac{HbO_2}{HbO_2 + Hb} \times 100\% \quad (2)$$

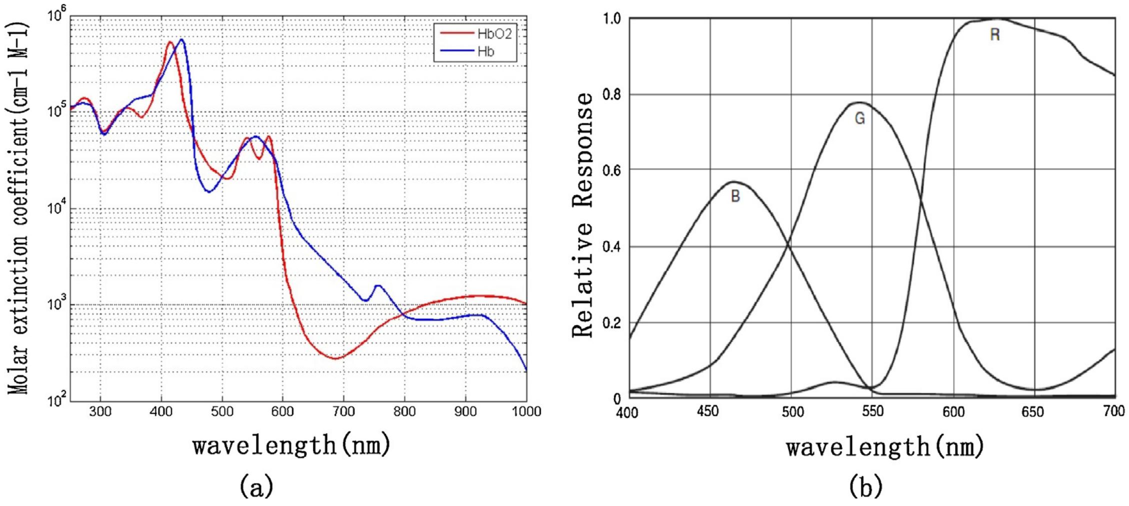

Fig. 2. Spectrums of hemoglobin and camera sensors. (a) Spectrum of HbO2 and Hb absorption. (b) Quantum efficiency for colored pixels of CCD camera.