Measuring Heart Rate by Using the Contact Free Video Imaging on a Built-In Camera of a Smartphone

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Abstract

Digital camera is now becoming a very popular and useful clinical tool for measuring the human vital signs such as cardiac pulse, breath rate, or blood pressure through noncontact video recording with the signal extracted from objects such as blood vessel, head motion, or human arm, etc. In this paper, we explore the potential that the reliable heart rate can be measured remotely by the facial video recorded using smartphone camera. The accuracy of the estimated heart rate was evaluated by comparing with the heart rate measured directly from the reference digital electrocardiogram (ECG). We also present our preliminary results of the heart rates measured with different lighting conditions, spectral components, facial parts, and alcoholic volume.

Keywords: Cardiac pulse, Photoplethysmography (PPG), ICA, fast Fourier transform (FFT), cardiovascular.

1. Introduction

Along with the development of the society, people are becoming more and more interested in their personal health observation. Instead of going to the hospital to examine the health condition regularly, currently, the people can monitor the physiological parameters at home. The most commonly measured vital signs are the heart rate and blood pressure. Besides the personal health observation, the heart rate measurement possibly applies to many other applications such as lie detector [1], polysomnography [2] and orthostatic test [3]. Resting heart rate is one of the simplest cardiovascular parameters, which usually averages 60 to 80 beats per minute (b.p.m), but can occasionally exceed 100 b.p.m. in unconditioned sedentary individuals and be as low as 30 b.p.m. in highly trained endurance athletes [4]. Today, pulse oximeters are widely accepted as monitoring devices based on contact methods, i.e. finger sensors [5] and light sources that are in contact with the tissues under investigation [6-7]. Although successful, current methods are not preferred in situations of movement and sometimes cause discomfort especially when the people are sleeping. Recent advancements in this field have led to automatic non-contact methods for monitoring the heart rate. The detection of cardiovascular pulse wave traveling through the body is referred to as Plethysmography and can be done by means such as variation in air pressure or strain. Photoplethysmography (PPG), introduced by Verkruysse et al.[8], uses light reflectance or transmission and is a cheap method and simple to use. PPG is based on the principle that blood absorbs light more than surrounding tissue so variations in blood volume affect transmission or reflectance correspondingly. Many PPG experiments were performed with blood vessel, head motion, or human arm recently [9-12]. Typically, PPG has always been implemented using delicate LED or red wavelength light sources [12-14] and thermal camera [9-10, 13-15]. In this paper, we explore the potential that reliable heart rate can be measured remotely by recording the facial video using the tungsten lamp as the light source and a LED built-in camera of a smartphone. Firstly, the facial videos were recorded with different illuminance conditions using the front facing preset digital camera. Face region of each frame was then detected according to the pixel coordinates. Secondly, we yielded the raw trace signal of the red channel of the image. To extract a more accurate cardiac pulse signal, instead of using ICA [16-19], we applied the alternative custom developed software written in MATLAB to filter the raw signal. The heart rate was extracted from the power spectrum by applying the convolution of fast Fourier transform (FFT) technique and Gaussian window function on the selected source signal. The accuracy of the estimated heart rate was evaluated by comparing with the one measured from the reference digital electrocardiogram (ECG). Then, the digital camera was replaced by a smartphone for testing with 30 people. Finally, we showed how this method could be extended in the case of different

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alcoholic volume. To the best of our knowledge, this has never been done so far.

2. Experimental

2.1 Materials and set-up

Firstly, we used a simple, inexpensive digital camera (Sony 20.1 megapixels model DSC-H300) to perform the indoor video recording with different illuminance conditions (ranging from 50 to 300 lx). After setting the camera in movie mode, the volunteer was seated at a table in front of the camera at a distance of approximately 1.0 m. During the experiment, the participant was asked to keep still, breath normally, and face the camera while the video was recorded for one minute. All videos were recorded in color (24 – bit RGB with three channels $\times$8 bits/channel) at 30 frames per second (fps) with pixel resolution of 1280×720 dpi and saved as MP4 format. A small incandescent lamp (collimated to avoid stray light on tissue) was placed within a fixed position in a corner of the camera's field of view and used as the illuminating source. A high stability voltage regulator was used to control the lamp voltage and thus the illuminance. We also recorded the cardiac pulse (ECG) simultaneously by using the automatic electrocardiogram (Microlife BP A2 Basic) wrapped around the participant's arm for reference.

After determining the range of proper illuminances, we choose the channel which shows the best signal-to-noise ratio (SNR) in the power spectrum. We did the comparison between the obtained signal acquired by the digital camera and the smartphone (SAMSUNG Galaxy J7 Prime) over the object. The similarity between the digital camera and the smartphone suggested the application of the smartphone instead of using the individual digital camera.

Lastly, the smartphone was then used to test with 30 Vietnamese students of both genders (six females), different ages (18-22 years), Asian skin color at rest in which one person has different alcoholic states.

2.2 Measurement methodology

All the video and physiological recordings were analyzed offline using the algorithm written in MATLAB. Figure 1 provides an overview of the stages involved in our approach to reveal the cardiac pulse from the recording videos. Firstly, we separated each frame from the recorded facial video using VideoReader procedure offered by MATLAB and a pixel was chosen to extract the values in 8-bit scale for all the red (R), green (G) and blue (B) channels. The data were read throughout whole movie frames providing an array of PV(x,y,t) where x and y are horizontal and vertical positions, respectively, and t is the time corresponding to the product of frame number and frame rate [8]. The region of interest for detecting the cardiac pulse herein is a facial point (the green cross on the right cheek of coordinate (x,y) as seen in Fig. 2(a)). Plotting the PV of each facial point from each frame of each channel in the time domain yields a PPG trace signal.

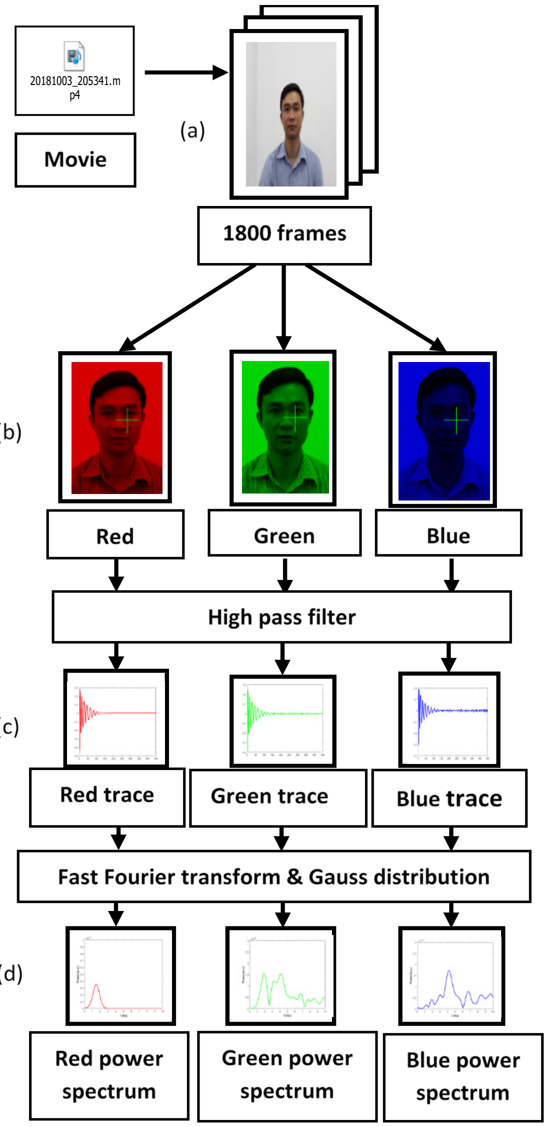

Fig. 1. Schematic for the measurement of heart rate noncontact with a camera record. (a) Face within the first video frame. (b) The signal is separated and then removed DC component from the red, green, and blue channels. (c) The PPG ac signals. (d) The power spectra.

The variation of the pixel values in each frame is influenced by the change of the absorption as the blood pulsate varies [13]. Since PPG contains a dc offset due to absorption by venous blood, other tissues, and scattering losses [12], we applied the 10^{th} order high pass filter with cut frequency of 0.1 Hz to the raw PPG signals to get the PPG ac signals [see Fig. 1(c)]. To get the power spectrum [see Fig. 1(d)], we performed the convolution of the Gaussian window function and the fast Fourier transform technique on the PPG ac signals and the heart rate frequency can be extracted here in the range from 0.5-4 Hz.

3. Results and disscution

3.1 Heart rate measurements with different illuminances

Inasmuch as our method is based upon the reflected light from the face, the ambient light has an effect on the values. When the facial illuminance was low (less than 150 lx), we could not determine the heart rate as the noise was so high. When the facial illuminance was brighter (equal to or greater than 150 lx), the heart rate could be determined as the SNR was high enough (ca. 10:1 or greater).

Since the white light, emitted from the incandescent lamp, composes of different colors, we separated the collected video signal into three different monochromatic channels (Red, Green, and Blue) in order to get the most visible power spectra.

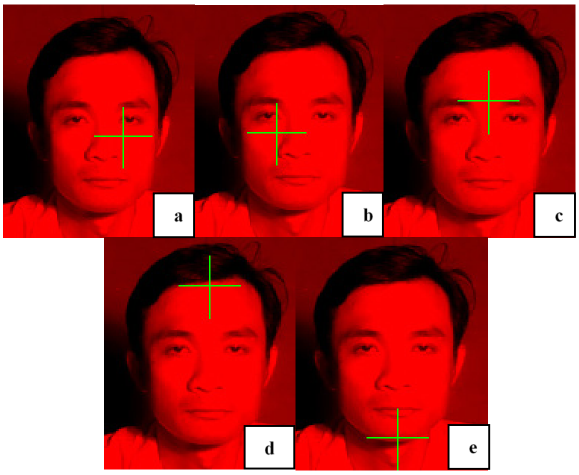

Fig. 2. Measurement of heart rate at different parts of the face using the green cross of coordinate (x,y): (a) Right cheek. (b) Left cheek. (c) Forehead. (d) Top forehead. (e) Chin.

Figure 3 shows the result of a heart rate measurement by facial video recording using the digital camera. The experiment was conducted with a person at rest. The region of interest was a pixel (the green cross on the right cheek [see Fig. 2(a)]). The illuminance in this case was set at 260 lx. Because of the whole blood optical absorption spectra [20], the signal in red channel provided the measured value with higher SNR and closest heart rate value compared with the other two channels, so we used red channel for all remaining experiments.

3.2 Heart rate measurements with different parts of the face

For the facial video recording, the intensity of reflected signal is closely related to the coordinate of the pixel. We measured the heart rate at five different parts of the face by five pixel points including right cheek, left cheek, forehead, top forehead, and chin as depicted in Fig. 2, and the results showed that all the points presented the visible spectra when the illuminance was greater than 230 lx. When the illuminance was greater than 150 lx and less than 230 lx, there were only three points including the right cheek, left cheek, and forehead showing the clear spectra. Below 150 lx, the power spectra were invisible since there was too much noise.

3.3 Heart rate measurements by using smartphone for different people

Using digital camera helped us to know the dependency of power spectrum on the illuminance of the ambient light. However, digital camera is so cumbersome and inconvenient to use as a remote heart rate monitoring tool. Smartphone emerged as a potential alternative to digital camera for this purpose.

In order to check the accuracy of this methodology with smartphone, we conducted the experiment with 30 Vietnamese students of both genders including six females and 24 males of different ages (18-22 years) and Asian skin color with rest state, consciousness, and in normal health condition. For each person, a video of one minute length was recorded using the built-in webcam of the smartphone and in the meantime, the electrocardiogram signal was recorded as a reference. The participants were asked to sit as still as possible during the recording.

Figure 4 shows the correlation between heart rate measured by PPG method and the one by ECG in units of beat per minute (b.p.m) for 30 people. Each blue point in the plot has the (x,y) coordinate, in which, x corresponds to the ECG value and y corresponds to the PPG value. The correlation was found to be fairly good compared to the results of Tanako et al. [21] since the majority of the points distributed in the neighborhood of the bisector of the plot. However, almost video signals are greater than the ECG values. This can be accounted for the fluctuation of the intensity of the incident light and from the difference in skin colors of the volunteers causing different optical absorption and then different SNRs. When the SNR was low, the AC component could not detect the small variation of blood flow. The above reasons are believed to be the cause of higher values of PPG signals in comparison with the ECG ones, which do not relate to the skin colors of the measured objects.

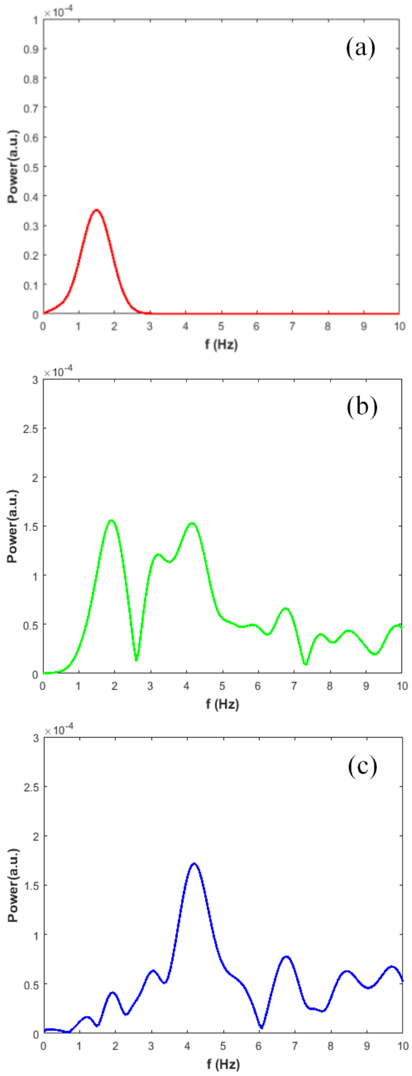

Fig. 3. Power spectra of three different channels measured by the the green cross of coordinate (730,300) on the right cheek: (a) Red. (b) Green. (c) Blue.

3.4 Heart rate measurements for one person at different alcoholic states

We also evaluated the robustness of the proposed methodology for the heart rate measurements in the presence of alcoholic excitation. A person's heart rate was measured at three alcoholic excited states. The electrocardiogram values were obtained simultaneously for reference too. During the experiment, the person was asked to keep still. In the first state, the person's cardiac pulse was measured without alcohol. In the second state, the person's cardiac pulse was measured in the same time length after having drunk 330 ml beer 5.3% v/v within 30 min. In the third state, the person's cardiac pulse was measured with the same conditions after having drunk 660 ml beer 5.3% v/v within 60 min. Figure 5 presents the comparison between the heart rate measured by our PPG method (red) and the one measured by ECG (blue). The graph shows that in the higher alcoholic excited states, the measurement values of the both methods are closer than the lower. This can be accounted for the change of the skin color under the effect of alcohol that influenced on the measurement accuracy more clearly in the higher alcoholic excited state.

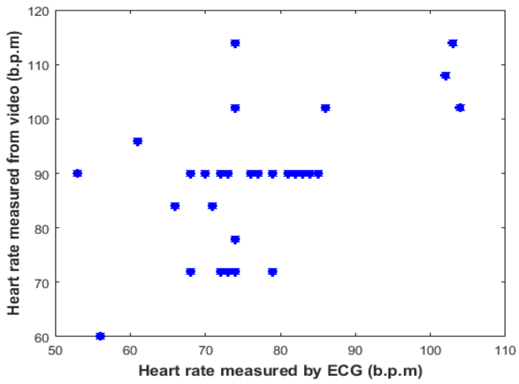

Fig. 4. Correlation between heart rate measured by our method (PPG) and the one by electrocardiogram (ECG).

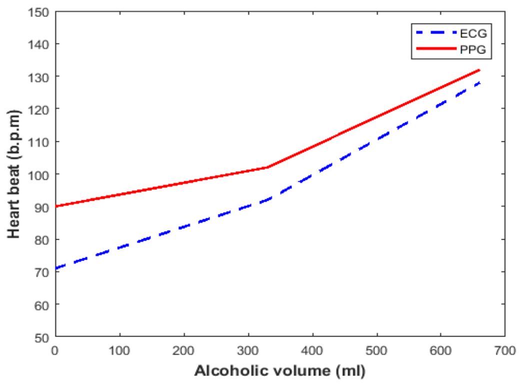

Fig. 5. Comparison between heart rate measured by our method (PPG) and the one by electrocardiogram (ECG).

4. Conclusion

A simple and cost effective method for measuring the heart rate by using the facial video recording has been demonstrated practically. The procedure used a tungsten lamp as the illuminating source and a digital camera for investigating the dependence of reflected PPG signals on the facial illuminances since the digital camera does not have the software to control the incident light automatically. The separation of reflected light into R, G, and B channels allowed us to have the more accurate results with red light since it had a better SNR than the other two, and this is consistent with [12]. The investigation of reflected signal with respect to different parts of the face with different values of facial illuminances revealed to us the fact that when the facial illuminance was limited on 150 lx, we could not have good SNRs (equal to or greater than 10:1) because of the high level of noise. When the facial illuminance was greater than 150 lx and less than 230 lx, there were only three parts including right cheek, left cheek, and forehead showing good SNR values since there are many arteries in these areas. When the illuminance was greater than 230 lx, we had good SNRs for all parts because of uniform illumination in this case.

Although we have the clear signals when the facial illuminance is greater than 230 lx, the heart beats are almost the same in all cases. It means that the video does not have enough the number of samples for small change detection in reflected light. This problem can be addressed by using an advanced camera with higher frame rates, e.g. high speed camera.

The switching from digital camera to smartphone is necessary since smartphone is smaller and easy to use in normal activities. Our results with smartphone showed that it is possible to obtain accurate heart rate measurement with smartphone either in the rest condition or in the excited condition with alcohol. The deviation of ECG values from PPG signals might come from the intensity fluctuation of the illuminating source as well as the difference of the human skin colors. This problem can be solved by enhancing the intensity quality of the illuminating source and using the appropriate illuminance value.

In the future, we try to develop the investigation with the approaches towards moving objects. This is complicated because a small head movement is quite large compared to pulse motion. With larger motion such as talking or laughing, more sophisticated filtering and decomposition methods will be needed to isolate pulse.

Another future direction is to investigate the variation of the heart rate in aspect of the change of the distance from the camera to the object. The longer distance might lead to the reduction of the signal to noise ratio. Using camera with stronger optical zoom and higher pixel definition, we believe into feasibility to measure the heart rate at greater distances.

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