Mobile Heart-rate Monitor and Arrhythmia Detection

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Abstract:

Integration of mobile technologies and healthcare informatics sets the stage for the innovative emerging research discipline called Mobile Health. Mobile Health includes a wide variety of applications for preventive healthcare, fitness, disease diagnosis and monitoring. One application area is heart-rate monitoring using mobile camera. This application area is based on signal processing. In this study, mobile heart-rate monitor is examined. The Red-based Contactless Heart-rate Detection Algorithm is proposed and application results are presented. Arrhythmia detection capabilities are discussed.

Key words: Mobile Health, Heart-rate Monitor, Arrhythmia

1. Introduction

Emerging mobile technologies contributes to health care environment as a new and innovative research discipline named as Mobile Health or in short mhealth [1]. Mobile Health includes a wide variety of applications for preventive healthcare, fitness, disease diagnosis and monitoring. Bio-monitoring using mobile devices attracts customers and healthcare professionals, and utilization of such applications is increasing with exponential acceleration trend [2, 3]. Among other bio-monitoring applications, one of the most remarkable area is heart rate monitoring via mobile devices especially mobile phone.

In healthcare environment, cardiac activities are monitored widely by commercial electrocardiograms (ECG) with straps attached to the patient's skins. The other option of pulse rate monitoring is fingertip oximetry sensors. Both of these approaches measure heart rate as beats per minute (bpm). However, they are not comfortable and require special devices connected to the patients. To meet the requirement of monitoring heart rate easily and without any extra equipment, mobile devices are utilized. These devices with cameras and processing capabilities are spreading out rapidly. The underlying fact of utilizing mobile devices for heart rate monitoring is that blood pumping to arterial vessels cause color and luminance changes on the skin. These changes especially R-R interval of heart can be captured by a digital camera and then heart rate can be computed with a processor [4, 5].

Reflection of mobile phone's flash light from the skin gives valuable information regarding heart rate that is known as reflection photoplethysmographic imaging (PPG) [6]. Based on reflection PPG and by utilizing signal processing techniques, different algorithms were proposed for webcam and mobile phone in order to monitor contactless heart rate [7-8]. Early algorithms were

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utilizing less signal processing techniques with relatively lower success rates. On the other hand, recent approaches utilizes different signal processing techniques to diminish noise and other irrelevant signal components for better success rates [9-10]. Moreover, with the help of reflection PPG, different products were developed on the mobile markets for heart rate detection [11-13].

In this study, heart rate monitoring by using mobile phone’s camera is explored. Luminance and color extraction algorithms are examined and Red-based Contactless Heart-rate Detection Algorithm is proposed as a simple and fast approach to heart rate detection in the second section. In the third section, preliminary application results are presented. The last part of the study is reserved for discussion of capabilities for arrhythmia detection, which is one of the ultimate targets of heart rate detection algorithms.

2. Materials and Method

Although early PPG applications were generally implemented with a light source generally red or infra-red, normal ambient light is utilized illumination source recently [14, 15]. In Red-based Contactless Heart-rate Detection Algorithm, we utilized ambient flash light as the source. Reflected light has luminance values affected by the blood level in the skin tissue. Luminance is a relative parameter, and perception of human eyes is not absolute but relative. For example, green is seen brighter than blue by human eyes. There are different luminance formulas; however, generally luminance is formulated as in Equation 1, and algorithms are based on this formula [16, 17].

$$Luminance = 0.3R + 0.59G + 0.11B \tag{1}$$

R, G and B are Red, Green and Blue components of the visible light accordingly in Equation 1. All visible colors are combination of R, G and B with different weights. Early algorithms utilized only R component without noise removal. In time domain, peaks of R component was assumed to be the beating instants of the heart. This approach is simple yet open to errors due to noise and motion artefacts. Error rates computed for some of these algorithms were quite high as 42% [18]

Most of the algorithms utilize all 3 components of the reflected light, and utilize complicated signal processing algorithms to detect heart rate [4]. In our study, since the color of the blood is red, when heart pumps blood into the arterial vessels, color change is mainly due to blood volume increment in skin tissue. Therefore, we concentrated on just R component. This simplifies and fastens our algorithm. Due to red component usage, we call it as “Red-based Contactless Heart-rate Detection Algorithm”.

Our algorithm is based on touching a palmar side of a finger on the mobile phone’s camera and collecting picture frames with 20fps when flash light is open. Picture frames are taken with 240x360 resolution. It takes some time to catch stable pictures due to flash light opening period. In this period, luminance changes dramatically and therefore, detecting heart rate is not possible. In addition to that, this period is used for noise detection. The noise level of the images are detected, and they are diminished for following real picture frames. To be on the safe side, first 5 seconds of the frames are discharged for heart rate detection and used as warm-up and noise detection period. 5 seconds could be decreased with fine tuning in the algorithm. For the sake of our purpose in this study, this limit is kept.

Complete algorithm is shown in Figure 1. The algorithm starts with finger touch without pressure. Video capturing, noise level detection and removal of first 5 seconds are as described above. RGB values are computed for each pixel. R components are added up to find a value for each picture frame. These values are grouped in an array of 20 values together which corresponds to data of 1 second. Afterwards, Fast Fourier Transform of each array is computed. Resulting frequency spectrum of the signals are filtered with a butterworth band-pass filter with cutting edges as 30-200 rates per minute. These values are typical heart rate values of normal people. Anomaly detection out of this boundary is left as a future work.

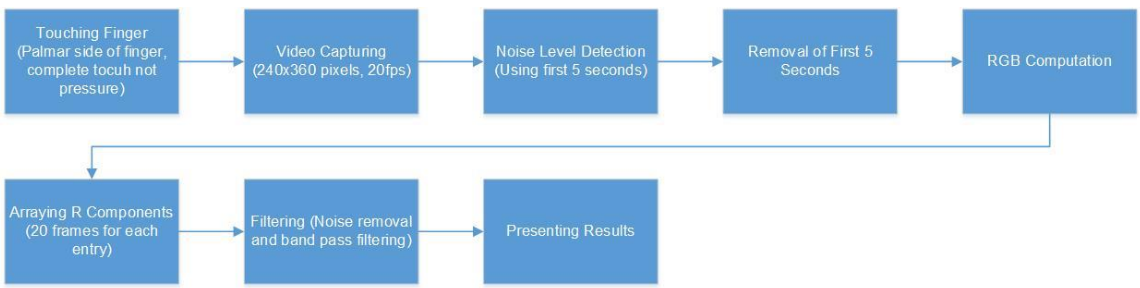

Figure 1. Red-based Contactless Heart-rate Detection Algorithm.

3. Results

The Red-based Contactless Heart-rate Detection Algorithm was implemented with an IPhone 4S (Apple Inc.) and Galaxy S4 (Samsung Inc.) as mobile devices. Signal processing steps were prepared in Matlab (Math Works Inc.). The results presented below are from Iphone 4S with iOS.

Data were collected from two voluntary people, we call them as A and B for confidentiality. They are healthy without any known disease and at the ages of 25 and 27. A is male and B is female. Measurements were taken during resting to detect resting heart beats. Heart beats during activity is left as a future study.

For A, sample red components of RGB values of finger picture frames are shown in Figure 2. For each frame red components were determined and total red luminance values were computed. Frequency domain representation of raw luminance values are demonstrated in Figure 3. After filtering and noise removal steps, results of The Red-based Contactless Heart-rate Detection Algorithm is sketched in Figure 4. Peaks are the points where blood is maximum at skin tissue. This occurs after contraction of heart ventricles plus time elapsed by blood traveling from heart to finger skin tissue.

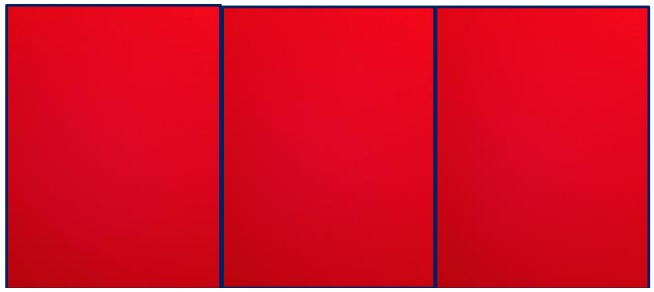

Figure 2. Sample red components of RGB values of finger picture frames.

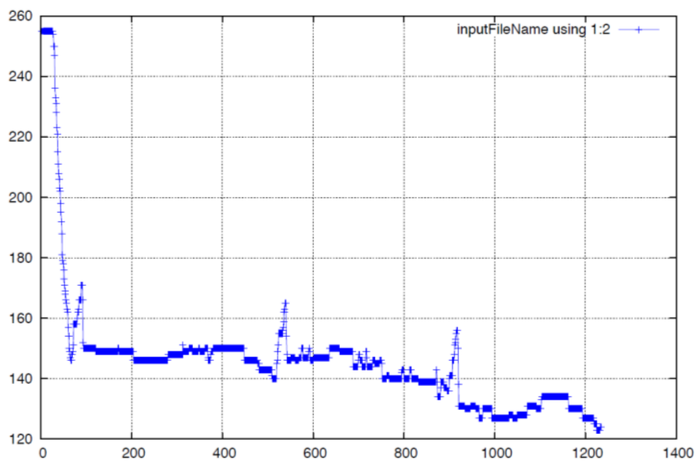

Figure 3. Power Spectral Density of raw luminance.

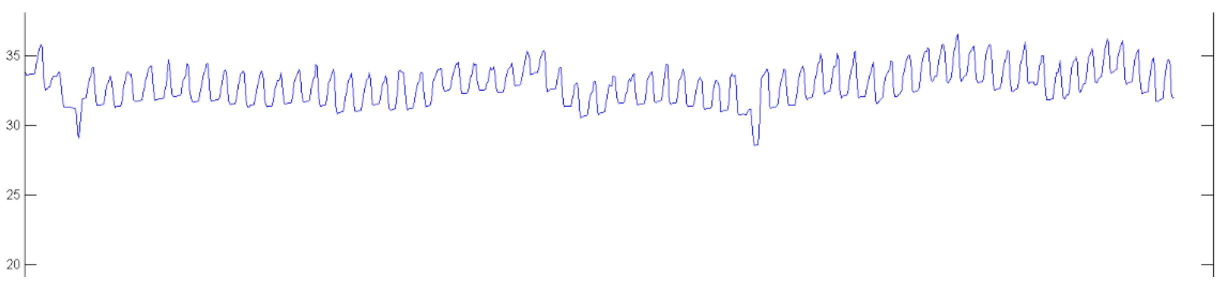

Figure 4. Results of Red-based Contactless Heart-rate Detection Algorithm.

As the first outcomes, resting heart rates of A and B were measured for 60 seconds. The mean rates were found as 68 and 82 relatively. At the same time, the ECG device (Tepa Inc.) monitors heart rates and mean rates were given as 66 and 81 relatively. Since A and B are healthy people, this preliminary work is not focused to detect any arrhythmia.

4. Discussion

Implementation of The Red-based Contactless Heart-rate Detection Algorithm produced fairly reliable results as errors of 3% for A and %1 for B. These first outcomes mimic the potential of using red component of RGB for heart–rate detection. However, these results are preliminary and the testing should be extended to more people and longer durations.

Another important point for contactless heart-rate detection algorithms is the motion tolerance or motion artefacts. That is to say, the skin part which is used for heart-rate detection, cannot be stationary. To reduce motion artefacts, different algorithms were proposed [4]. These algorithms contributes to better heart-rate detection, particularly for webcam and distant heart-rate detection approaches. However, they increases computational complexity. Since our motivation is to produce simple and stable heart-rate detection algorithm, we proposed not to use such extra algorithms and rather proposed covering camera by palmar side of a finger. By this way, we also eliminated extra effort for detection and choosing the proper skin part.

Our ultimate goal is to propose an algorithm for arrhythmia detection. As the first step, arrhythmias originated from sinus like tachycardia, bradycardia and pause will be our focus. Then we will focus on more difficult to detect arrhythmias like atrial fibrillation. Arrhythmia detection approaches start with Heart Rate Variability (HRV), which is based on measuring time intervals between heart beats. In our mobile phone case, we have only R points of QRS complex of heart signal. Special term of analysing these points are named as RR variability. There are mobile phone applications capable of HRV or RR analysis, but they require another assistant device for heart rate collection such as wrist or chest bands [19, 20].

Real-time arrhythmia classification algorithm was proposed based on R peak to R intervals by Tsipouras et al [21]. This algorithm was further developed by Pierleoni et al [22]. In this study, sinus rhythm classification was done by calculating average of the heart-rate as the first step. These classification types are Bradycardia when HR is below 60 bpm; Tachycardia when HR is above 100 bpm; Normal in between. Then more complex arrhythmia types like premature ventricular contraction (PVC), ventricular fibrillation (VF), 2^{nd} degree block (BII) were tried to be identified with RR variability. Even though this algorithm provided reasonable results, it required a wearable device other than mobile phone for heart signal collection. Our motivation is to diminish the lack of any extra device other than mobile phone itself, for signal collection and processing. Our other motivation is to extend mobile phone HRV analysis to detect atria originated arrhythmia types like Atrial Flutter or Atrial Fibrillation.

At present, due to permission issues, we cannot test our algorithm with real arrhythmia patients. We will test our algorithm with ready data, and then by taking required permissions, we will test and compare our results with ECG in terms of arrhythmia.

Conclusions

In this study, we have proposed The Red-based Contactless Heart-rate Detection Algorithm. This algorithm utilizes mobile phone's camera and processor to detect heart beats from skin and to compute heart rate by employing signal processing accordingly. The algorithm is simplified by employing R component of the RGB color values. It was implemented in iOS. The results of two measurements were also presented with high success rates.

As future study, the algorithm will be tested with wider groups and under different physical activities such as running etc. Later, Heart Rate Variability analysis will be added to the algorithm to detect arrhythmia such as tachycardia, bradycardia and pause. Contribution of these studies will be to develop a software for mobile phones for heart signal collection and processing.

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