Heartbeat monitoring using accelerometer and camera

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ABSTRACT

This project proposes an android application that is used to measure a heart rate using two different methodologies:

1- Photoplethysmogram (PPG) is a technique that uses infrared light to detect changes in the blood flow volume in tissues. This will be achieved using the smartphone's camera equipped with LED flash which is used for recording the intensity of light from the fingertip blood volume and derivate the red channel of RGB signals in each picture frame, that will be used to estimate the heart rate value.

2-Seismocardiogram (SCG) is the measure of the micro-vibrations produced by the heart contraction and blood ejection into the vascular tree. The signal can be measured by using the smartphone accelerometer placed on the lower end of the sternum of the subject**.**

The experimental results show that both methods have acceptable accuracy, but in any case, are vulnerable to excessive noise components.

1 Introduction

Human health is a very important factor for the development and progress of society. Home or personal healthcare technologies can resolve the inconvenience of visiting a medical office and help users to handle their health conditions well. Monitoring vital parameters such as heart rate plays a very important role in the detection and the recognition of dangerous situation.

An approach to monitor HR is using pulse oximeter which is a small device that uses photoplethysmography (PPG) to capture blood volume changes by illuminating the finger with a light emitting diode (LED) and measures the changes in skin illuminated light by transmitting it through photodiode. Another approach is replacing the photodiode, used in pulse oximeter by a smart phone camera that enables PPG imaging. Another way to monitor HR is via the Seismocardiogram signal (SCG), that is a signal derived from the micro-vibrations produced by the heart contraction and blood ejection into the vascular tree. It can be noninvasively detected by placing a sensor on the precordial area of the subject's chest, usually on the xiphoid process at the lower end of the sternum.

However, as some smartphones may have low computational power and as camera features differ across smartphones, smartphone-based heart rate computations can suffer from time-consuming processes. Hence, the results can be inaccurate or inconsistent. For this reason, in this project, we will evaluate and compare both the **Photoplethysmogram (PPG**) and the **Seismocardiogram (SCG)** techniques for heart rate measurements.

2 Architecture

As mentioned in the Introduction, this project aims to develop an android application to measure the user's heart rate in real time using two different methods. The first one uses the smartphone camera and the LED flash to obtain the photoplethysmography (PPG) signal. The other one by exploiting Seismocardiogram (SCG) caught by the accelerometer.

In addition, the application uses a local database to store and retrieve the user's heart rate measurements. In particular, it provides the user a calendar where for each day there is a list of all the made measurements. Each entry of the list shows the hearth rate (in BPM), the chosen method, and the timestamp. The user has also the possibility to delete the measurement deemed unreliable.

2.1 Heart Rate Detection Using the SCG

This section describes the chosen SGC signal processing method and its limitations. Signal Energy Thresholding has a rather simple mathematical model which has been implemented and applied to the SGC signal. SCG is extracted during the data selection phase having a duration of 10 secs.

During this period of time, the patient is asked to place the device flat on their chest, close to the heart, and stay as still as possible for the length of the measurement. The accelerometer of the device can then measure the micro-vibrations caused by the heart contractions.

As the sampling rate of Android sensors is not exact, values sampled at a constant rate of 50 Hz have been obtained through an interpolation of the original values caught by the accelerometer, by considering the timestamps. The signal is then filtered using 4th order Butterworth high-pass filter. This kind of filter has the advantage of providing maximally flat frequency response with no ripples in the pass band. Additionally, the calculation of Butterworth filter is simpler compared to other filters with similar characteristics.

Subsequently the signal energy is computed starting from the filtered signal as shown in the following formula:

$$E(t) = u(t)^2$$

In order to extract signal peaks from SCG, the signal energy is thresholded based on an empirical equation:

$$TH = K\,\bar{\mathrm{E}}(\mathrm{t})^2$$

where TH is the threshold parameter, $\bar{\mathrm{E}}$ is average of energy signal and factor K is selected empirically. After extracting signal peaks, heart rate can be calculated based on beat per minute (bpm) using the inter-beat time intervals average through the following formula:

$$HR = \frac{60}{\text{Interbeat Interval Avg}} \quad \text{(bpm)}$$

SET method can provide reliable results in short intervals (e.g. 10 sec) but it has its own limitations. The first challenge of SET is the filtering part which is not unique since the correct cut-off frequency may vary for each input signal. In other words, this method is not adaptive therefore some of the employed parameters such as cut-off frequency need to be changed. For this reason the user of our app can choose the appropriate level of noise filtering, that is the cut-off frequency, through a SeekBar before starting the measurement.
The second challenge is about the maximum peak extraction. Theoretically maximum peaks could be extracted with a proper thresholding but practically it does not always happen and sometimes several maximum peaks with a very short time distance from each other are produced. Moreover, also the respiration of the subject can have an impact on what has been said, producing some fluctuation of the signal at the respiratory frequency.
In order to face this problem, a constant MIN_DIST has been defined; this constant represent the minimum difference, in seconds, that two subsequent peaks need to have, in order to be considered in the measurement. All peaks whose time distances with respect to the previous ones are lower than this threshold are discarded, and not relevant in the final computation.

2.2 Heart rate detection using the PPG signal

In contrast to the measurement method using SCG in this case the heart rate was obtained by using a peak peaking technique on the spectrum, obtained thanks to the FFT, of the PPG signal. More in detail, the user requesting the measurement is asked to place his index finger on top of the camera for about 30 seconds; this can be done either by positioning the phone with the screen towards a supporting surface or by holding it with the hand (in the first case, the sounds emitted are used as feedback of the measurement, while in the second case it is still possible to use the progress bar). This method is vulnerable to noise sources such as incorrect positioning of the index finger or movement while the measurement. To mitigate this, a 35 Hz high-pass filter was applied to the spectrum of the PPG signal.

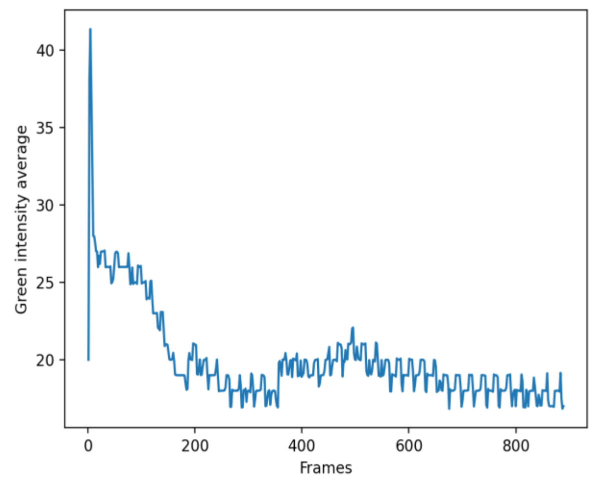

Figure 1: Photoplethysmographic signal

While the finger is held on the camera several frames are acquired, depending on the provided sampling rate. Each frame is converted from the standard picture format for Android Camera, YUV420sp (NV21), to the RGB color model and in each of these the average amount of green and red is calculated. In this way, at the end of the 30-second sampling period, two PPG signals are obtained, one containing the green intensity average (Figure 1) and one the red; the power spectrum (Figure 2) of both is then computed using the FFT. A peak peaking method is adopted on both, within which the peak corresponding to the normalized heart rate is identified, depending on the sampling frequency; this is done after removing the noise and the continuous component of the signal by applying the high pass filter previously mentioned. This peak corresponds to a certain frequency from which, after denormalization, the heart rate can be calculated as:

$$HR = frequency \cdot 60$$

Finally, if the heartbeats detected on both PPG signals, green and red, are within an acceptable range (here set between 45 and 200 bpm) the user's heartbeat will be given by an average between the two, otherwise by the acceptable one.

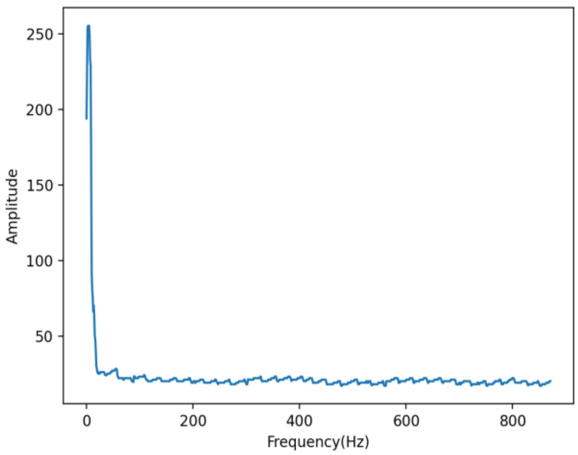

Figure 2: Power Spectrum of Signal corresponding to the green color space

3 Experimental results

Different experiments were carried out to evaluate how close the measurements obtained by using the app are close to the results obtained by using a sphygmomanometer (Beurer BM28). Six subjects, both male and female, were recruited for these experiments (group age ranging from 22 to 92 years) and each subject performed two different recording session employing both methods. In the first session the subject was at rest, after sitting for at least 5 minutes, then in the second one the subject is analyzed after a physical activity, such as after climbing the stairs or after a short run.

	At rest	Physical activity
MSE	3.620	6.517
STD	8.662	16.012
Mean Accuracy	97.982%	98.212%

Table 1: Performance indexes camera measurements

Table 1 shows the results of the measurement using the PPG signal. From this it can be seen that the accuracy both at rest and under stress is quite high. The fact that the accuracy is higher in the second scenario is mainly due to the fact that the measurements were taken in a controlled and optimal environment; probably in a real scenario the accuracy at rest could be higher than physical stress.

	At rest	Physical activity
MSE	33.256	26.965
STD	6.01	16.023
Mean Accuracy	93.213%	96.412%

Table 2: Performance indexes accelerometer measurements

Table 2 shows the results of the measurement using the SCG signal. In this case the accuracy is lower than in the other method, although it remains quite high; here after physical activity there is better accuracy than at rest, the motivations are those of the camera scenario and also due to the fact that the intensity of the beats may be greater than the noise, thus more easily distinguishable. The degradation, although slight, of the performance in this case is mainly due to the fact that in the second method there is a strong dependence on the positioning of the accelerometer which is strongly influenced by noisy components. In this scenario, sources of noise such as the diversity of the body of the person who wants to make the measurement, the positioning on the sternum in a manner, the movement of the hand become apparent much more frequently than in the other method in which one simply has to pay attention to positioning and maintaining the index finger on the camera correctly.

4 Conclusions

The purpose of this study was to demonstrate the feasibility of measuring heart rate with some accuracy using two different methods, both of which are possible through the possession of a smartphone. This solution, which does not require the purchase of additional external sensors, is therefore quite affordable and accessible. In fact, this method could be of help to many people who can check for the presence or absence of a sudden change in heart rate with just a smartphone. Another advantage, not to be overlooked, is that you don't need any internet connection: in this way the data are only local, and it is possible to make measurements even in the absence of coverage. During the development of the application, as mentioned above, it could be observed that the camera measurement method is rather inaccurate in case the user moves or misplaces the finger during the measurement. Such wrong movement and/or positioning leads to the introduction of a non-negligible noise component, which cannot be filtered out with the simple filter introduced at 35 Hz. A future improvement of this measurement, which could solve this problem, could be the introduction of more sophisticated filters obtained from a previous study with possible support of artificial intelligence. As far as the SGC measurement is concerned, the experimental results show quite a decent accuracy, when the conditions for a precise computation are met. That is, if the subject stays perfectly still during the measurement, and the device is pressed tightly to the chest. Further improvements in the signal filtering could be made, to deal with the presence of noise. Even so, SCG is not a suitable option for measuring the heart rate in the presence of external vibrations, as the heart contractions are perceived as extremely weak vibrations on the chest.

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