APPLICATION FOR HEART RATE ESTIMATION USING SMARTPHONE

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Abstract: This work deals with estimation of the human heart rate (HR) using a mobile phone camera. The goal was to create a functional application for a smartphone with a real-time HR detection. A preliminary functional algorithm was tested on a sample of 10 independent subjects and a mean deviation of 8.3 beats per minute (BPM), relative to an ECG reference record, was reached. Considering only visibly calm subjects, the mean deviation was 1.5 BPM.

Keywords: photopletysmogram, PPG, heart rate, HR, mobile application, Swift, iOS, electrocardiogram, ECG, online detection of HR, Matlab, mHealth, telemedicine

1 INTRODUCTION

The modern age can be characterized by the rise of information technology, which is also related to the expansion of mobile devices usage. The daily use of smart devices is becoming more and more common. One often can no longer imagine everyday life without their help. Phones as personal helpers penetrate into many spheres of human life including healthcare. The problem with mobile applications, however, is that they are only minimally tested and their accuracy is often unknown. [1]

The estimation of heart rate (HR) can be performed in many ways. The main conventional techniques include palpation of the palpable arteries with stopwatches, or taking the electrocardiogram (ECG) record, which is the gold standard for other human HR measurement techniques. Using a mobile phone one can get an acoustic expression of heart activity (phonocardiogram, FCG), a video recording of blood flow in the fingertip using a flashlight and a camera (photoplethysmogram, PPG), or one can use an accelerometer to record chest movements (mechnical activity of the heart). [2, 3, 4]

2 ONLINE DETECTION ALGORITHM

Due to the computational complexity and nature of the detector itself (a real-time, online detector), the acquired PPG signal from the camera is processed in the time domain, and the algorithm is simplified to reduce computational and energy demands. Swift 5 programming language was used for the implementation; a block diagram of the algorithm is shown in the Figure 1.

The algorithm starts by acquiring a scene, which is provided by a built-in rear camera. By default, the camera sampling frequency is set to 30 Hz (Frames per second, FPS). After converting such scene into the Swift image class `UIImage`, the red channel is extracted, because it carries the largest amount of information neccessary for HR estimation [4]. Then, the *PPG* signal sample is calculated as an average of one frame of the red channel, and the first difference signal *dPPG* sample can be obtained by (according to [5]):

$$dPPG(n) = \Delta PPG(n) = PPG(n) - PPG(n-1) \tag{1}$$

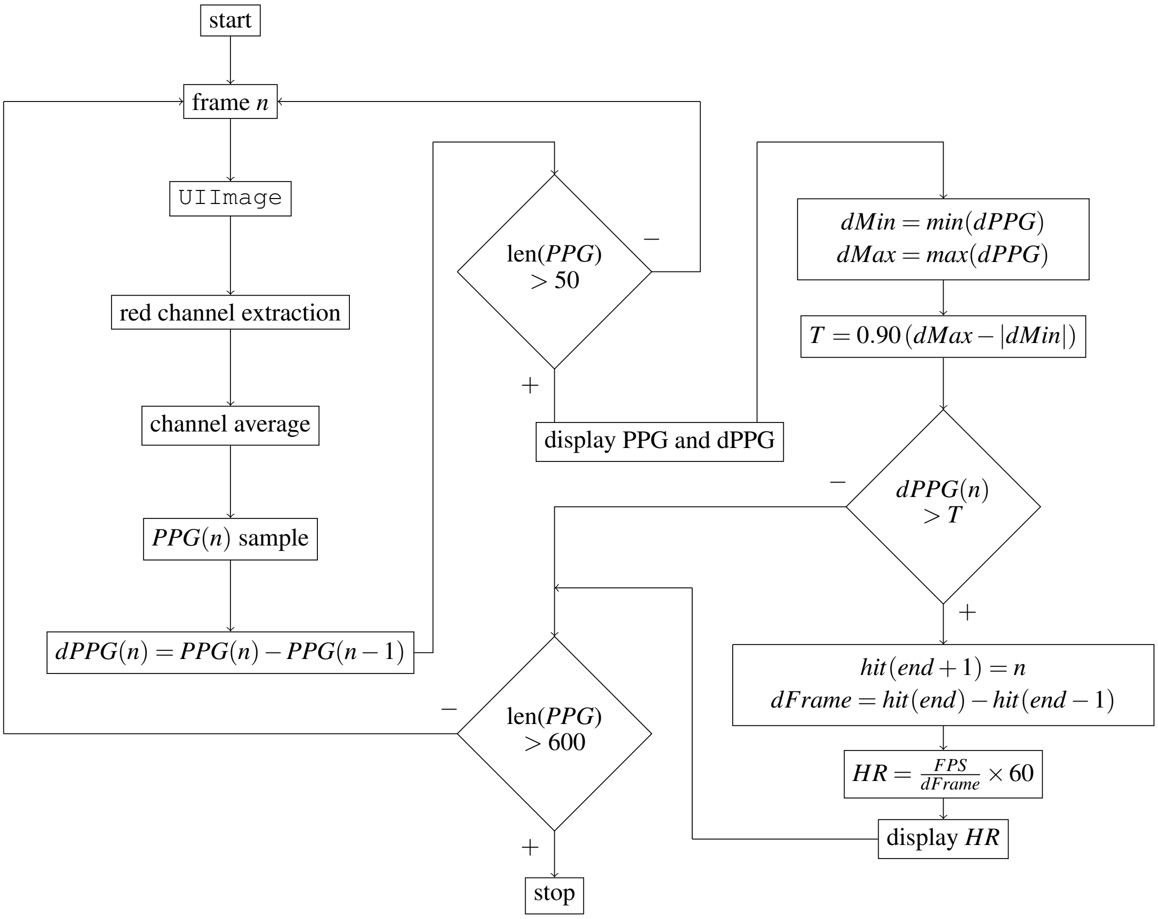


Figure 1: Block diagram of the algorithm for obtaining an instantaneous HR by proposed application, pseudocode.

Furthermore, the *dPPG* is used for the calculation of the instantaneous HR value. In the sliding window of 80 samples length the maximum and minimum are found and based on these two values, the threshold T is set. By thresholding the differential signal, a vector of passes (*PPG* peak positions) *hit* is created. The distance of PPG peaks $dFrame$ is calculated and further used according to [4] to calculate the instantaneous HR value (in beats per minute, BPM):

$$HR = \frac{FPS}{dFrame} \times 60 \tag{2}$$

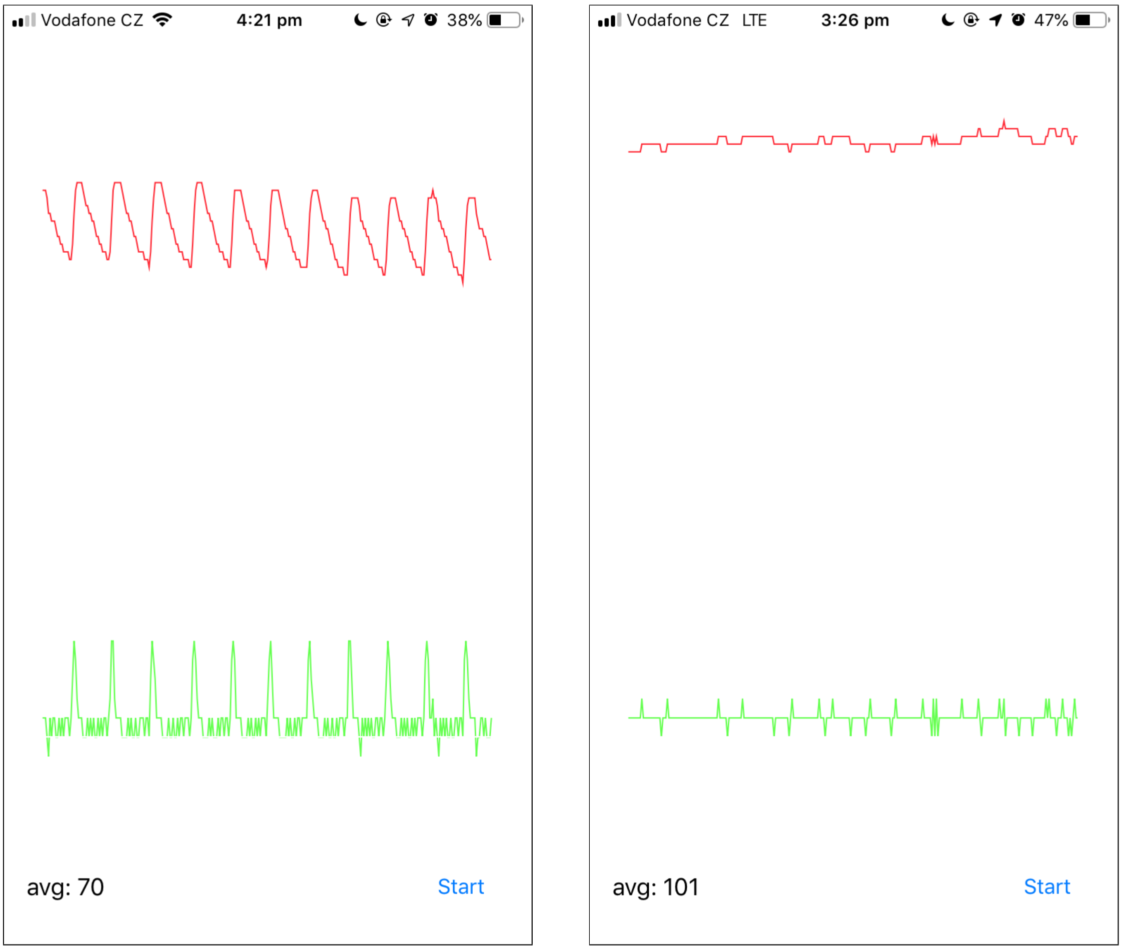
The instantaneous HR value is displayed in the lower left corner of the application prototype, and the average HR value is displayed after the acquisition (shown in Figure 2). The algorithm ends by pressing the *Stop* button, or after collecting 600 samples of the *PPG* signal (approximately 20 seconds).

3 MEASURING PROTOCOL AND DATA ACQUISITION

To determine accuracy of the algorithm and to test the functionality of the smartphone application, measurements were performed on ten human subjects. The Bittium Faros 360 ECG recorder with a 5-electrode lead system and silver chloride (Ag/AgCl) electrodes were used for the measurement together with Apple iPhone 5s and 6 and stopwatches.

Each subject was asked not to drink coffee and alcohol, and not to smoke or exercise 2 hours prior to the measurement. The person placed the index finger of the right hand on the rear camera of Apple iPhone 6 and the index finger of the left hand on the rear camera of Apple iPhone 5s, ensuring that the fingers were also illuminated by the integrated LED flashlight. The electrodes of the ECG recorder were loaded on the person's chest. Then the 2–minute simultaneous acquisition was made. A note was taken, if any apparent restlessness (e.g. tremor, *Stress*) was present during.

The average HR values from the application prototype and measurement examples of the *PPG* and *dPPG* signals can be seen in the Figures 2a and 2b. A special case is the record No. 3 (Figure 2b), which was very weak. The subject was not compliant with the protocol (smoking). The vasoconstrictive effect of nicotine then probably caused a short-term poor blood flow to the fingertips [2].



(a) Subject No. 5. **(b)** Subject No. 3.

Figure 2: Examples of two waveforms – the *PPG* signal (red), and the differential signal *dPPG* (green) from the application prototype.

4 RESULTS AND DISCUSSION

For each subject, the average HR values were estimated from the application, and from the reference ECG record, which was processed using the Matlab R2019b environment. The values, together with the assessed restlessness of the person, are shown in the Table 1. To determine the accuracy, the total average absolute deviation δ (in BPM) was calculated:

$$\delta = \frac{1}{n}\sum_{i=1}^{n}|ECG_i - App_i| = \frac{1}{10}(|74-70|+|80-84|+\ldots+|52-52|) \approx \pm 8.3 \qquad (3)$$

Table 1: Average HR values from the application (*App*), and from the ECG recorder (*ECG*). Also, each subject is labeled with their stress level during the acquisition.

Subject No. [–]	*App* [BPM]	*ECG* [BPM]	*Stress* [–]
01	70	74	No
02	84	80	Yes
03	101	107	Yes
04	70	71	No
05	70	69	No
06	80	68	Yes
07	80	76	Yes
08	94	59	Yes
09	87	71	Yes
10	52	52	No

From the calculated total deviation of the measurement (Equation 3) one can easily tell that the currently proposed algorithm for getting the instantaneous, and the average human HR value using a smartphone is burdened with a big mistake. However, if the deviation is calculated over the restful subject only (*Stress* No), we obtain the following deviation (in BPM):

$$\delta_{No} = \frac{1}{4}\left(|74-70| + \ldots + |52-52|\right) \approx \pm 1.5 \tag{4}$$

The difference between the Equations 3 and 4 shows a significant effect of false positive detections (motion artifacts) to the average HR value estimated by the app. Therefore, the addition of a motion detector prior to HR calculation, or the image color control using an RGB score are considered as optimization elements of the algorithm.

5 CONCLUSION

The presented application prototype was tested on a sample of ten independent human subjects with a simultaneous recording of ECG. The average deviation of the online detector, relative to the ECG record, was 8.5 BPM. Considering only stressless subjects, the deviation was only 1.5 BPM. The presented application prototype could be considered as usable for a quick on-the-spot HR estimation.

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