Smartphone Based Application for Online Premature Ventricular Contraction Detection

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Introduction. Premature ventricular contractions (PVCs) are the early heart beats originating from the heart ventricles. The PVCs are one of the most common heart arrhythmias. The occurrence of the PVCs may or may not be [1] associated with the heart disease. However, recent studies deny harmlessness of the PVCs and link them to various heart disorders [2, 3], other arrhythmia triggering [4] and predictions [5, 6]. During the PVCs, due to the low blood volume in the ventricles, blood circulation is inefficient, especially in case of multiple PVCs such as the bigeminy (where every second beat is premature). Thus, even in the absence of the structural heart diseases, PVCs may lead to the temporal loss of consciousness (fainting) [7], which e.g. during the walking may result in a falling with the upcoming consequences. The occurrence of the PVCs may be used as an early warning marker for both the upcoming heart diseases and/or other symptoms such as the temporal weakness or the fainting. Thus, in order to take the preventative actions early enough, the online PVC detection would be of great benefit.

The comfortable, low cost and unobtrusive online PVC detection could be accomplished with the use of the photoplethysmography (PPG) signals which require only a single sensor attached to the body, e.g. on the comfortable part such as a wrist.

Nowadays the use of the smartphones is widespread and will possibly grow even more in the future. Moreover, the functional capabilities and computational power of the current smartphones empower them to run sophisticated applications and are also continuously being improved. In order to extend smartphone applications and/or use them as the data acquisition and transmission systems, various external accessories and devices are being developed (e.g. Motorola Moto 360) [8]. For the data exchange, these devices commonly use wireless communication technologies, of which the most popular one is Bluetooth (various versions) [9]. As a matter of fact, Android is the most widely used mobile operating system (OS) nowadays with the huge community [10]. Thus the developed PPG based PVC detection and classification method was implemented as the application for the Android OS smartphones.

The PPG signal is transmitted via classic Bluetooth connection. The Android Studio compiler [11], was used to develop the mobile application. Signal processing (filtering, feature extraction, classification) methods were implemented in Java programming language.

Method and implementation. The PVC detection method uses the peak-to-peak intervals (PPIs) of the PPG signal as the features. The structure diagram of the method is presented in Fig. 1.

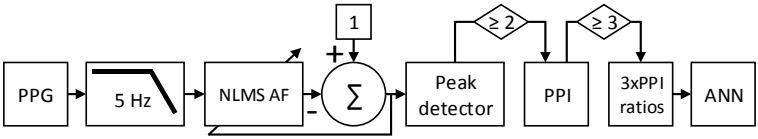

Fig. 1. Scheme of the online PVC detection method

The PPG signal samples are transmitted as the hexadecimal strings with the attached termination character "#" and at the receiver side samples are decoded to floating point values. At the receiver side, the PPG signal is pre-processed in a sample by sample manner. High frequency noises are filtered using the 31st order, 5 Hz cut off frequency finite impulse response low-pass filter. The PPG signal baseline wandering is removed with the standard normalized least mean squares (NLMS) adaptive filter (AF) with the reference input constant equal to 1 [12]. The order and the step size of the NLMS filter are 6 and 0.014, respectively. This adaptive filter could also be used to cancel sensor motion induced artefacts if the noise source (e.g. accelerometer signal or the signal from the reference light source of different wavelength) was fed into the reference input. Parameters of all filters were chosen empirically.

After the baseline wandering is removed, simple peak detector, based on the threshold crossing technique, is used to detect positive PPG peaks. The PPI calculation begins right after the detection of the second PPG peak. Feature set of the PPG signal consists of the mutual ratios of 3 consecutive PPIs, thus in all 3 features. Feature set overlaps by two PPIs. Feed-forward artificial neural network (ANN) with back-propagation is used to classify PPG pulses into 2 classes: normal beats *(NORM*) and extrasystolic beats (*PVC*).

AChartEngine [13], a free open source charting library for the Android OS, was used to visualize received PPG signals as well as both detected peaks and PVCs. The screenshot of the running application is presented in Fig. 2.

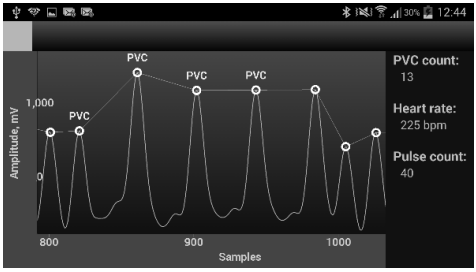

Fig. 2. Screenshot of the online PVC detection application

Data. The online PVC detection method was evaluated using PPG signals from the MIMIC and the MIMIC II databases located in the PhysioNet [14] portal. The PPG signals were resampled to 75 Hz sampling frequency which is sufficient as the bandwidth of the PPG is rather narrow, typically less than 5 Hz [15]. A patient using the PPG sensor was simulated with a personal computer by sending the PPG signal to the smartphone via Bluetooth module, using the Serial Port Profile. For this purpose, simple LabVIEW application was developed. The Matlab .mat files, acquired from the PhysioNet, were read using LabView's "Open Data Storage" function and sent sample by sample via virtual serial (COM) port. The data transmission scheme is presented in Fig. 1:

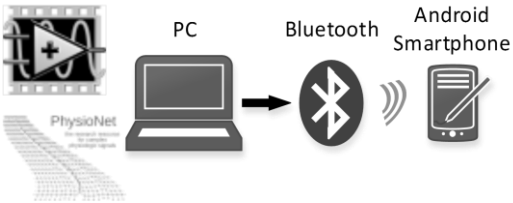

Fig. 3. Data transmission scheme

Results. The pre-processing of a single PPG sample takes 50 multiplications, 49 additions and 1 division operations. Preliminary tests with 3, ~17 min duration, PPG signals of, each containing PVCs, were made to determine PVC detection sensitivity (*Sen*) and specificity (*Spe*). The preliminary results are presented in Table 1:

Table 1. The results

	Sen, %	*Spe*, %
NORM	99,2	96,3
PVC	93,1	98,5

Discussion and Conclusions. The developed online PVC method can detect both single and multiple PVCs (e.g bigeminy, where every second beat is PVC). The ANN was chosen due to its universality and ability to approximate linear and non-linear functions, though, more simple classifiers and condition based approaches are considered. The aim of the further research is to test method with a larger number of signals, to improve the method with the addition of the new capabilities (e.g. the detection of other arrhythmias such as the atrial fibrillation), to optimize PPG pre-processing and feature extraction, to implementing data reception via Bluetooth Low Energy and to use the wrist sensor as the source of the PPG signals.

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The purpose of this work was to develop and investigate the online premature ventricular contraction (PVC) detection method based on the photoplethysmography (PPG). The method was implemented as the application for the Android OS smartphone. PPG signals are received from the external source via Bluetooth. The patient was simulated by transmitting real PPG signals from the PhysioNet portal via personal computer. For the PVC detection, this method relies on the temporal PPG features comprised of peak to peak intervals. PPG pulses are classified with the artificial neural network. Detection effectiveness of the method was evaluated by sensitivity and specificity.