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Robust heartbeat detection using multimodal recordings and ECG quality assessment with signal amplitudes dispersion

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ABSTRACT

Background and Objectives: The electrocardiogram (ECG) is a bioelectric signal which represents heart's electrical activity graphically. This bioelectric signal is subject of lots of researches and so many algorithms are designed for extracting lots of clinically important parameters from it. Most of these parameters can be measured by detecting R peak of the QRS complex in ECG signal, but when ECG signal is corrupted by different kinds of noise and artifacts, such as electromyogram (EMG) from muscles, power line interference, motion artifacts and changes in electrode-skin interface, detection of R peaks becomes hard or impossible for algorithms which are designed for heart beat detection on ECG signal. In modern patient monitoring devices often not only one ECG signal is recorded but also so many other biological signals are simultaneously recorded from the patient which some of them, such as blood pressure (BP), are containing useful information about the heart activity which could be very helpful in making the heart beat detection more robust.

Methods: In this study, a new method is introduced for distinguishing noise free segments of ECG from noisy segments that uses samples amplitudes dispersion with an adaptive threshold for variance of samples amplitude and a method which uses compatibility of detected beats in ECG and some of other signals which are related to the heart activity such as BP, arterial pressure (ART) and pulmonary artery pressure (PAP). A prioritization is applied in other pulsatile signals based on the amplitude and clarity of peaks on them, and a fusion strategy is employed for segments on which ECG is noisy and other available signals in the data, which contain peaks corresponding to R peak of the ECG, are scored in a three steps scoring function.

Results: The final scores achieved by the proposed algorithm in terms of average sensitivity, positive predictive value, accuracy and F1 measure on the database which is freely available in Physionet Computing in Cardiology Challenge 2014 are respectively 95.47%, 96.03%, 93.11% and 95.62%.

Conclusions: The results show the outperformance of the proposed method against other recently published works.

1. Introduction

Cardiovascular diseases are one of the main causes of death; a great percent of all sudden and unexpected global deaths was made up by the people who died because of cardiovascular diseases [1]. Electrocardiogram)ECG(signal is a tool to represent the electrical activity of heart graphically; an ordinary heart beat in the ECG signal is containing P-wave, QRS complex and T-wave and it can be easily measured by two or more electrodes on surface of the patient's body [2]. One of the main uses of ECG signal is for detection of heart beats. Detection of heart beats is mainly studied for estimation of heart rate (HR) and heart rate variability (HRV) which are clinically important parameters [3], these estimations are usually accomplished by the detection of the QRS-complexes and calculation of RR intervals between each two consecutive cardiac contractions. Using ECG for heart beat detection is the best choice because this biological signal's acquisition process is simple and noninvasive, thus this signal is most used in estimation of HR and heart beats location rather than other biological signals which contain noticeable signs of heart beats such as blood pressure (BP), pulmonary artery pressure (PAP), or photoplethysmography (PPG). So, most of the heart beat detection algorithms designed yet are based on ECG and indeed they are R peak detectors [4], a complete review of more recent ECG based peak detectors can be found in [5]. Also, there are some algorithms that measure HR using other biological signals but ECG such as [6] and [7] which respectively estimate HR based on mobile data which uses a stream of picture

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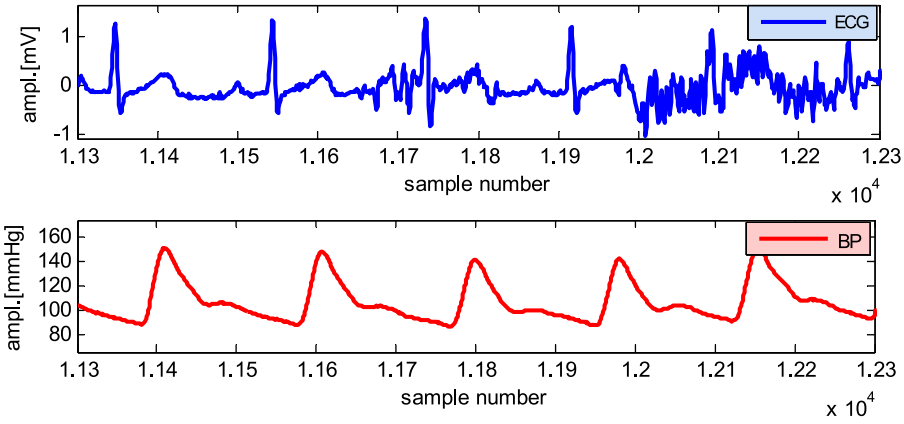

Fig. 1. A noisy ECG segment and corresponding BP segment, label of Y axis (ampl) represents the amplitude.

frames for heart beat information extraction and plethysmography which measures heart rate based on oxygen saturation of blood, optically.

Large quantities of data are acquired from a patient in different monitoring devices connected to the patient in intensive care unit (ICU) by connecting noninvasive and invasive sensors. So, several multimodal databases are acquired of such monitoring devices and these databases are used for so many investigations [8,9]. This acquired data might include so many different biological signals such as ECG, PPG, electroencephalogram (EEG) and electromyogram (EMG).

In addition to ECG, some of other signals that are existing in the data are related to the heart activity and in some ways displaying heart beats, such as BP or stork volume (SV), (e.g. as soon as the heart contraction occurs, QRS complex in the ECG appears, as well as a peak in SV, PPG, BP and other signals which are related to heart activity (as shown in Fig. 1)). As stated by the Physionet Challenge 2014: robust detection of heart beats in multimodal data, other signals could be used to improve heart beat detection robustness [10]. Generally, the main aim of this challenge is to motivate the development of algorithms for robust heart beats location estimation in long-term multimodal recordings.

The main goal of this study is fusing the information about heart beats acquired of all these signals to make a more accurate decision about heart beats location and a more robust HR estimation. This might also be used for false alarms reduction in ICU which was the subject of Physionet Computing in Cardiology 2015 [11].

There are some studies about detection of heart beats on multimodal data. A comparison of beats regularity among ECG and BP in 5 s window, detection of noise free periods by calculation of PSD and replacement of BP beats in noisy ECG segments, beat selection among ECG and BP by calculation of quality index for ECG and BP signals in 10 s windows, and a calculation of BP beats delay compared to ECG beats and detection of beats in noisy segments based of the delay were reported in [4,12,13], and [14], respectively. In [15], a robust algorithm for heart beat detection on multimodal data, based on slope and peak-sensitive band-pass filters, was presented. In [16], an algorithm was presented which uses ECG, BP, SV, PPG, EEG, and electrooculogram (EOG) signals for heart beat detection and fuses the extracted information from these signals with a voting approach. [17] Presented an algorithm that uses probabilistic model for detection of heart beats from ECG and BP based on hidden semi-Markov model. The method presented in [18] uses ECG, BP, EEG, EOG and EMG for multimodal heart beat detection by employing a quality assessment strategy for deciding which signal gives the best results in each segment.

In this paper, a new method for estimating the accurate location of heart beats in multimodal recordings is presented; in addition to ECG, other signals such as BP, arterial blood pressure (ART), PAP and SV are used in this method for detection of the heart beats location in a robust way. Reading the labels of the data channels is done automatically with a code available in the WFDB toolbox [19]. Several peak detectors are employed for initial heart beat detection in this method. In the first phase of peak location estimation, this algorithm mainly uses ECG, BP and ART signals and introduces a new method that uses compatibility of detected beats in these signals for assessing the quality of these signals. Also, this paper introduces a unique method for assessing quality of ECG signal by using dispersion of samples amplitude. Our proposed method employs a fusion strategy that contains scoring all sets of detections on different signals by different detectors with three scoring criteria.

In most of the methods mentioned here for heart beat detection on multimodal data, only two signals were used and only one detector was applied to each of the signals, all of these methods used only one quality assessment criteria for selecting the best set of beats in each window which is only based on beats comparison on two signals or regularity of beats on each signal, and after quality assessment one signal was completely removed and beats of the other signal were selected as final beats in a segment. The presented method of this paper uses more than two signals of each record for heart beat detection, on each of the signals more than two beat detectors are used for heart beat detection, quality assessment of the signals takes place in 3 different steps and a new quality assessment criteria for ECG is presented in this method which is adaptive and it is based on samples amplitude dispersion; after the quality assessment one of the signals is removed only if its quality is under the specified threshold, otherwise no signal is removed and all of the signals are sent to the final scoring step.

2. Data

2.1. Data description

The database used in this study is acquired from Physionet/Computing in Cardiology Challenge 2014 [20]. This database contains 200 records which are taken from 2 different databases, challenge 2014 training set and challenge 2014 extended training set. Each record in these two databases belongs to a human adult (men or women) with a wide range of different cardiac diseases. The records of these two databases mostly have 10 min length but in some records the length of the recorded data is less than 10 min, the minimum length of the records in these two databases is 19.9 s, the average length of all the records in these