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Premature ventricular contraction analysis for real-time patient monitoring

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ABSTRACT

Background and objective: Improvements in wearable sensor devices make it possible to constantly monitor physiological parameters such as electrocardiograph (ECG) signals for long periods. Remotely monitoring patients using wearable sensors has an important role to play in health care, particularly given the prevalence of chronic conditions such as premature ventricular contraction (PVC), one of the prominent causes of death world-wide. PVC is a serious cardiovascular condition that can lead to life-threatening conditions. The instant recognition of life-threatening cardiac arrhythmias based on a wearable ECG sensor for a few seconds is a challenging problem of clinical significance.
Method: Twenty seconds of consecutive ECG beats that were identified empirically to characterise a PVC episode were analysed. Three morphological features and seven statistical features were directly extracted in real time. These features were normalized and fed into an artificial neural network (ANN) classifier for classification. The PVC detector was uploaded into a smartphone to classify each episode as either PVC or non-PVC.
Results: The proposed algorithm was tested on the MIT-BIH Arrhythmia, St. Petersburg Institute of Cardiological Technics (INCART) and Shimmer3 ECG databases. The proposed method resulted in an improved sensitivity, positive predictive value and accuracy of 98.7%, 97.8% and 98.6% respectively compared to recently published methods. In addition, the proposed method is suitable for real-time patient monitoring as it is computationally simple and requires only a few seconds of ECG recording to detect a PVC rhythm.
Conclusion: This study provides a better and more accurate identification of the presence of PVC beats from wearable ECG recordings/mobile environment and standard environment, leading to more timely diagnosis and treatment outcomes.

1. Introduction

The improvement of wearable sensor devices in recent years makes it possible to constantly monitor physiological parameters such as electrocardiograph (ECG) signals over long intervals of time [1]. ECG signal is commonly used in heart monitoring applications. An ECG records the electrical impulses of the heart and indicates rhythm anomalies for diagnostic purposes [2]. A typical ECG tracing of the cardiac cycle consists of a P wave, Q,R,S waves/ QRS complex, and T wave [3]. The most effective inter-beat intervals or the time from a normal ECG peak of the beat (the R peak) to the next normal R peak is called the RR interval or RR data which is typically measured in milliseconds [4]. The R peak is the largest upward deflection of a QRS complex segment in normal ECG waves and reflects the depolarization of the ventricles [5].

Ranck [6] estimated there will be 170 million wearable devices for measuring medical indicators such as ECG, heart rate variability (HRV) and body temperature in the world by 2017. Many of these devices are likely to be operated by hospitals to monitor the progress of discharged patients at home in order to identify disease progression or anomalies in a timely manner and achieve real cost savings in an era of increasing healthcare costs and reduced government capacity to meet the gap. Some early examples of field trials and prototypes with the use of wearable devices are emerging for diabetes complications [7], early detection of heart failure, arrhythmias and depression [8,9].

The use of wearable devices requires the sensor devices themselves and a body area wireless sensor network (BAWSN), so that the sensors can transmit data using a wireless protocol such as Bluetooth, ZigBee or WiFi to a nearby base station, which is often

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a mobile smartphone. In addition, healthcare applications (HA) are required to process the data in order to raise alarms or perform other actions if a change in the patient's health profile occurs. Fig. 1 illustrates a patient wearing an ECG sensor, an electromyographic (EMG) sensor and an accelerometer taken from Balasubramanian and Stranieri (2014) at Federation University.

The sensors illustrated in Fig. 1a are programmable sensors from Shimmer3 [10] that stream data in real time to a mobile device that executes a program to analyse the data, port it to cloud repositories and raise alarms.

Real-time systems require the continuous and reliable processing of data [11]. They require algorithms that continuously process input data with minimal drain on power, storage or processing resources because devices have limited battery and memory capacity [11,12].

PVC beats represent the most common ventricular arrhythmia and are found in about 60% of healthy hearts [13]. A PVC beat is a pulse that appears earlier than the subsequent coming sinus pulse. PVC beats can appear in normal healthy persons, but in diseased hearts, the frequency of appearance in an ECG is increased and can be an indicator of a life threatening condition [14,15]. The main causes of PVCs and their complex samples in the heart are still poorly understood [16].

Existing methods have focused on improving the efficiency of ECG assessment techniques for implementation using mobile phones [17]. This increased effort is evidenced in the 2011 PhysioNet/Computing in Cardiology Challenge [18], the aim of which was to promote the enhancement of ECG software that can be executed on a mobile phone.

Continuously monitoring for life threating arrhythmia based on wearable and smartphone devices is pivotal. Accordingly, this research proposes a new PVC arrhythmia detection method that employs an ANN classifier to reliably detect PVC beats in a few seconds within the constraints of remote patient monitoring.

2. Related work

Many existing studies utilize RR data in the classification and detection of PVC beats however these approaches tend to be lacking in accuracy and they cannot be executed rapidly to detect PVCs in real time. Sliding window techniques [19] have been used to classify heart beats and have demonstrated positive predictive accuracy and sensitivity values of 86.54% and 87.27% respectively for PVCs.

In [20], a low complexity algorithm was proposed to detect PVC in real time using a template matching approach, and achieved convincing results of 98.2% accuracy and 93.1% sensitivity on the MIT-BIH Arrhythmia database. Despite being highly accurate, the template matching approach requires five minutes of training in order to detect QRS complex and T waves in real time. Furthermore, it can only be applied on ECG data sampling at 360 Hz.

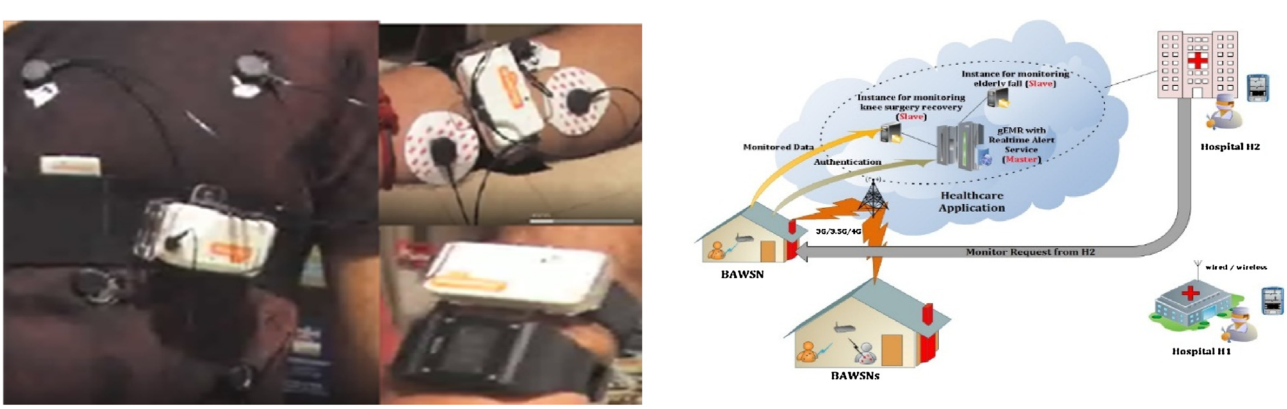
Cuesta and Lado [21] employed a linear discrimination analysis method based on only two QRS features that are generated from knowledge-based rules to recognize the PVC beats obtained from the MIT-BIH Arrhythmia database with specificity of 82.52% and sensitivity of 90.13%.

Other techniques have been applied to classify PVC beats, including nonlinear complexity measures, wavelet transform and sophisticated artificial neural networks [20]. For example, Zhou and Jin [22] combined clinical knowledge-based rules with deep neural networks for PVC detection. Support vector machines (SVMs) have been deployed to distinguish PVC from non-PVC beats [23].

Many arrhythmia recognition techniques have been developed that can be executed on mobile phones [24]. The work in [24] selects the most recent algorithms that use only QRS data for abnormal beat classification using the MIT-BIH Arrhythmia database. For example, atrial fibrillation (AF) can be detected based on a smartphone solution. The system used short-term RR data features and achieved an accuracy of 97%, specificity of 100% and sensitivity of 93% [25] in detecting AF.

Gradl and Kugler [26] introduced a real-time ECG monitoring system using Android-based mobile devices and Shimmer3 ECG sensor to detect abnormal arrhythmia. The system implemented the Pan-Tompkins [27] algorithm for QRS-computation and rules-based method proposed by [28]. It resulted in the detection of more than 99% of QRS complexes, with 89% sensitivity and 80% positive predictive values for overall abnormal beat discrimination. However, the authors did not test their system with real ECG data and long-term ECG monitoring on mobile phones nor did they investigate how long the system can work with limited battery-driven devices.

A real-time classification system for arrhythmia detection on Android-based mobile devices compared the calculation and memory costs for each classification method using the Embedded Classification Software Toolbox [29]. The comparison study relied on 16 features (statistical, heartbeat, and template-based) that were extracted only from QRS data. Classification methods include AdaBoost M1, C4.5, linear regression, multilayer perceptron, naive Bayes, nearest neighbor, PART and SVM. The C4.5 classifier was not complex and resulted in a high detection accuracy of 91%. There-



(a) (b)

Fig. 1. a. A patient wearing Shimmer ECG devices on the chest, EMG on the forearm and an accelerometer on the wrist (a). Fig. 1b. Schematic of patient monitoring architecture. Reproduced with permission from Balasubramanian and Stranieri (2014).