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Automatic detection of atrial fibrillation using stationary wavelet transform and support vector machine

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ABSTRACT

Background: Atrial fibrillation (AF) is the most common cardiac arrhythmia, and a major public health burden associated with significant morbidity and mortality. Automatic detection of AF could substantially help in early diagnosis, management and consequently prevention of the complications associated with chronic AF. In this paper, we propose a novel method for automatic AF detection.

Method: Stationary wavelet transform and support vector machine have been employed to detect AF episodes. The proposed method eliminates the need for P-peak or R-Peak detection (a pre-processing step required by many existing algorithms), and hence its performance (sensitivity, specificity) does not depend on the performance of beat detection. The proposed method has been compared with those of the existing methods in terms of various measures including performance, transition time (detection delay associated with transitioning from a non-AF to AF episode), and computation time (using MIT-BIH Atrial Fibrillation database).

Results: Results of a stratified 2-fold cross-validation reveals that the area under the Receiver Operative Characteristics (ROC) curve of the proposed method is 99.5%. Moreover, the method maintains its high accuracy regardless of the choice of the parameters' values and even for data segments as short as 10 s. Using the optimal values of the parameters, the method achieves sensitivity and specificity of 97.0% and 97.1%, respectively.

Discussion: The proposed AF detection method has high sensitivity and specificity, and holds several interesting properties which make it a suitable choice for practical applications.

1. Introduction

Atrial fibrillation (AF) is the most common cardiac arrhythmia with an estimated prevalence of 1% corresponding to 2.3 million patients in the US and 4.5 million in the European Union [1]. This prevalence is strongly associated with age, such that over 17% of people aged 85 or above are AF patients [2]. It is expected that the number of AF patients in U.S. will increase by 2.5-fold to more than 5.6 million people by 2050 [3]. This increase not only reflects the growing population of elderly individuals, but also improved survival of people with predisposing conditions to AF (e.g. ischemic heart disease) [4]. The presence of AF is associated with a 5-fold increased risk of stroke [5] and about 2-fold increased risk of death, independent of other risk factors [6]. Furthermore, due to high rates of hospitalization and considerable health resource utilization, the economic and clinical burden of AF is substantial and will continue to increase in the future [7].

AF is usually characterized by rapidity and irregularity of ventricular contraction [8]. The chronic forms of AF can be paroxysmal AF (more than one episode with spontaneous termination within seven days); persistent AF (not self-terminated, or lasted more than seven days) and permanent AF (not terminated, or terminated but relapsed) [9]. Silent or asymptomatic AF can also occur in any of these temporal forms, carrying a similar prognosis to symptomatic AF [10]. Chronic AF adversely affects the blood flow dynamics and can result in the stroke. Early and accurate detection of AF and its management (e.g. anticoagulation, antiarrhythmic therapy and radiofrequency ablation) could substantially help in prevention of the complications associated with the chronic AF.

Currently, the diagnosis of AF mainly rests on the presence of related symptoms (e.g. shortness of breath and fatigue), followed by an electrocardiogram (ECG) study to verify the diagnosis.

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During the ECG study, a trained clinician/technician visually inspects the ECG signal collected over short period of time (e.g. less than 48 h) to identify the AF associated chaotic patterns or abnormal changes in the waveform morphology.

Early and accurate diagnosis of AF is a challenging task. As a result, a majority of the early stage and easily treatable AF cases are not diagnosed in time and evolves into chronic debilitating AF with high cardiac related complications. Several factors hinder the accurate and early detection of AF:

- Many of the AF patients do not experience symptoms. Hence, a considerable number of AF cases are undetected or diagnosed fortuitously when the subject is being evaluated for other cardiac complications. Moreover, the studies have shown that a good correlation does not always exist between symptoms and episodes of AF [11].
- ECG study can miss detection of AF in patients with paroxysmal intermittent AF who are not experiencing AF episodes during the study.
- Visual inspection of hours of collected ECG is time consuming.
- Accurate interpretation of ECG study requires extensive training and experience. Hence, the reliability of diagnosis is dependent on the level of training or experience of the clinician. In fact, studies have shown that many primary care practitioners are not able to detect AF (on an ECG) with sufficient accuracy to guide therapy [12].

A possible solution to this problem is automatic AF detection using ambulatory monitoring. This approach could eliminate the need for visual inspection, and contribute to early and accurate detection of AF by allowing for an in-depth analysis of ECG and identification of abnormal patterns.

Over the last two decades, several algorithms have been developed for automatic AF detection. Many of these algorithms either rely on the absence of P-waves (replaced by rapid oscillations or fibrillatory waves) [13–16] or R–R irregularities [17–21], or combination of both characteristics to detect AF episodes [22–24]. As P-waves are prone to contamination with motion and noise artifacts, the AF detection algorithms solely based on the absence of P-waves perform poorly in the presence of noise [25]. Therefore, employing heart rate variability for AF detection has become a preferred approach in recent years. But many of these R–R interval based methods compare the density histogram of R–R intervals for a segment of data with previously compiled histograms of R–R intervals during AF using the Kolmogorov–Smirnov test [18,24,26]. Since these algorithms require storage of large amount of histogram data, they may not be suitable for implementation in an ambulatory monitoring device with limited memory and processing power. Other R–R algorithms need various parameters' tuning to guarantee the high accuracy of AF detection [19–21]. Furthermore, most of the existing methods do not perform well with short data segments (less than one minute) [25]. This deficiency may result in missing short-duration AF episodes (prevalent in Paroxysmal or early stage AF), less accurate calculation of AF burden (a measure of the percent of time a patient spends in AF), and a lower speed of AF detection. Lastly, a majority of existing approaches for AF detection require P or R peak detection as a pre-processing step and consequently their performance will degrade if the related peaks are missed or erroneously detected.

Aimed at addressing the existing issues, the current work proposes a novel method for automatic AF detection using stationary wavelet transform (SWT) and support vector machine (SVM). As opposed to traditional methods, the proposed method does not require P or R peak detection pre-processing step. Only few parameters are involved in the development of the proposed method and the method maintains its high accuracy regardless of the choice of the parameters' values. The proposed method also performs well even for short data segments of 10 s. In what follows, we first describe (Section 2) our proposed method in detail. Then in Section 3, we present the result of applying the proposed method on MIT-BIH Atrial fibrillation database. These results are discussed and compared with those of the existing methods in Section 4. Conclusions are presented in Section 5.

2. Materials and methods

2.1. Automatic AF detection using wavelet transform and support vector machine

The proposed method consists of three major steps: pre-processing; feature extraction; and AF classification. Fig. 1 illustrates a block diagram of various steps of this method. In the following sub-sections, we will describe each step in detail.

2.1.1. Pre-processing

The incoming ECG signal is divided every T seconds into segments of length T. An elliptical band-pass filter with pass-band of 0.5–50 Hz (effective filter order of 10) is applied to each data segment to remove noise and baseline wander. After filtering in the forward direction, the filtered sequence was then reversed and run back through the filter to obtain a zero-phase distortion. Then a wavelet transform is performed on the filtered data segments.

Wavelet transform has proved to be a useful tool for denoising, delineation and compression of signals. Using wavelet transform, one can observe a signal at different scales where each scale emphasizes on various signal properties and characteristics [27]. Wavelet transform allows for the analysis of transients, aperiodicity and other non-stationary signal features where, through the

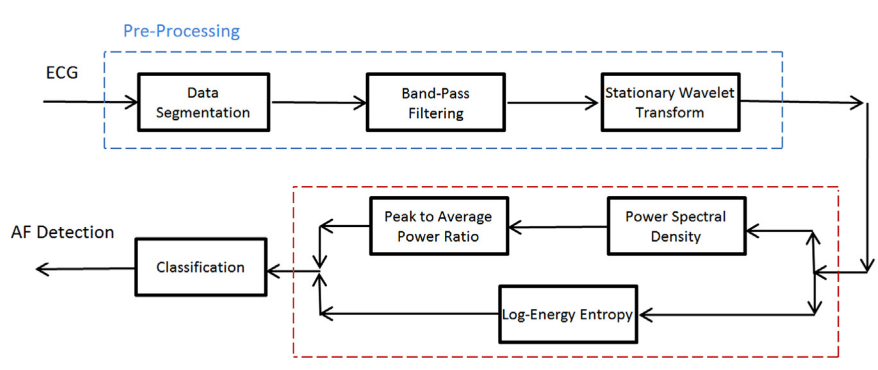

Fig. 1. Modular framework of the proposed method for AF detection.