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An arrhythmia classification system based on the RR-interval signal

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Arrhythmia classification; RR-interval signal; Knowledge-based system; Deterministic automaton

Summary

Objective: This paper proposes a knowledge-based method for arrhythmic beat classification and arrhythmic episode detection and classification using only the RR-interval signal extracted from ECG recordings.
Methodology: A three RR-interval sliding window is used in arrhythmic beat classification algorithm. Classification is performed for four categories of beats: normal, premature ventricular contractions, ventricular flutter/fibrillation and 2° heart block. The beat classification is used as input of a knowledge-based deterministic automaton to achieve arrhythmic episode detection and classification. Six rhythm types are classified: ventricular bigeminy, ventricular trigeminy, ventricular couplet, ventricular tachycardia, ventricular flutter/fibrillation and 2° heart block.
Results: The method is evaluated by using the MIT-BIH arrhythmia database. The achieved scores indicate high performance: 98% accuracy for arrhythmic beat classification and 94% accuracy for arrhythmic episode detection and classification.
Conclusion: The proposed method is advantageous because it uses only the RR-interval signal for arrhythmia beat and episode classification and the results compare well with more complex methods.

1. Introduction

Arrhythmia can be defined as either an irregular single heartbeat (arrhythmic beat), or as an irregular group of heartbeats (arrhythmic episode). Arrhythmias can affect the heart rate causing irregular rhythms, such as slow or fast heartbeat [1]. Arrhythmias can take place in a healthy heart and be of minimal consequence (e.g. respiratory sinus arrhythmia which is a natural periodic variation in heart rate, corresponding to respiratory activity), but they may also indicate a serious problem that may lead to stroke or sudden cardiac death [2,3]. Therefore, automatic arrhythmia detection and classification is critical in clinical cardiology, especially when performed in real time. This is achieved through the analysis of the electrocardiogram (ECG) and its extracted features.

Several researchers have addressed the problem of automatic detection and classification of cardiac rhythms [4–23]. Some techniques are based on the detection of a single arrhythmia type and

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its discrimination from normal sinus rhythm, or the discrimination between two different types of arrhythmia [4—11]. Techniques that belong to this category include time-domain analysis [4], sequential hypothesis testing algorithm [5], threshold-crossing intervals [6], artificial neural networks [7,8], time-frequency analysis [9], fuzzy adaptive resonance theory mapping [10] and the sequential detection algorithm [11]. Another class of proposed methods for arrhythmia detection and classification is based on the detection of different heart rhythms and their classification in two or three arrhythmia types and the normal sinus rhythm [12—18]. Techniques used for this purpose include multiway sequential hypothesis testing [12], wavelet analysis [13], artificial neural networks [14], complexity measure [15], multifractal analysis [16], wavelet analysis combined with radial basis function neural networks [17] and non-linear dynamical modelling [18]. It is noticeable that all methods address the detection of only a few types of arrhythmia (atrial tachycardia, ventricular tachycardia, atrial fibrillation and ventricular fibrillation).

Another field of interest is the ECG beat-by-beat classification, where each beat is classified into several different rhythm types [19—23]. Methods of this kind classify more arrhythmic beat types. However, they focus on single beat classification and not arrhythmic episode detection. The techniques for beat classification are based on artificial neural networks [19], fuzzy neural networks [20], ''mixture of experts approach'' [21], hermite functions combined with self-organizing maps [22] and time-frequency analysis combined with knowledge-based systems [23].

Most of the studies, either for single arrhythmia type detection, detection of different heart rhythms or beat-by-beat classification, are based on the analysis of the ECG signal. In these methods ECG features are extracted and used for the detection and/or classification of arrhythmias. However, this is not always feasible due to: (a) the presence of noise making feature extraction difficult and in some cases impossible (e.g. P wave), and (b) the process being time consuming and ineffective for real time analysis. An alternative would be to use only the RR-interval signal. In this case, it is expected that certain types of arrhythmias can be detected and classified.

This work proposes a method for the classification of the cardiac rhythms, based only on the RR-interval signal. The method consists of four steps: (a) preprocessing of the ECG recording, (b) QRS detection and computation of the RR-interval signal, (c) arrhythmic beat classification and (d) arrhythmic episode detection and classification. In the preprocessing step the ECG was filtered for baseline wandering correction (step a). Then, QRS detection is performed and the RR-interval signal is constructed (step b). In the arrhythmic beat classification step beat-by-beat classification is applied using rules that utilize the duration of the examined cardiac cycle and the duration of the previous and next cycles, in a three RR-interval window (step c). Four different categories of cardiac rhythms are recognized (normal sinus beat, premature ventricular contraction, ventricular flutter/fibrillation, 2° heart block). The results of the beat classification step are used to detect and classify arrhythmic episodes (step d). The algorithm for the arrhythmic episode detection and classification is based on a deterministic automaton, utilising expert's knowledge. Six cardiac rhythms are detected and classified (ventricular bigeminy, ventricular trigeminy, ventricular couplet, ventricular tachycardia, ventricular flutter/fibrillation, 2° heart block).

2. Material and methods

The proposed knowledge-based system consists of four steps: preprocessing, QRS detection and RR-interval signal computation, arrhythmic beat classification and arrhythmic episode detection and classification. Fig. 1 shows the procedure followed.

2.1. Preprocessing

ECG signals can be contaminated with several types of noise, such as power line interference (A/C), electromyographic noise (EMG) and baseline wandering (BW), which can affect the QRS detection algorithm. The baseline wandering is modelled with low order polynomials [24], which are then subtracted from the recorded signal.

2.2. QRS detection and RR-interval signal computation

The only feature extracted from the ECG is the R wave. Initially, a point in the QRS complex is detected (QRS point), using the algorithm proposed by Hamilton and Tompkins [25,26]. Then, the main wave of the QRS complex (R wave) is identified in the window [QRS − 280 ms, QRS + 120 ms] by locating the point where the signal has its maximum absolute value. The RR-interval signal is constructed by measuring the time interval between successive R waves.