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Ectopic beats detection and correction methods: A review

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ABSTRACT

The present paper is concerned with a review and evaluation of different methods that are intended to detect and correct ectopic beats. Ectopic beats are abnormal beats that are due to unusual impulses. These abnormal excitations originate from atrio-ventricular junction or ventricles rather than the sino-atrial node. Ectopic beats can be seen in the ECG signal as abnormal waveforms. Their presence can extremely affect the heart rate variability (HRV) measures as they cause ambiguities. Thus, they must be detected and corrected before any HRV signal analysis. Indeed, ectopic beats have a remarkable influence on the time domain, frequency domain and nonlinear domain measurements of the HRV.

In fact, too many efforts have been devoted to detect and correct the ectopic beats presence leading to the development of many methods and algorithms.

In this article, we shed light on the different methods existing in the research domain literature; that are intended to be used in ectopic beats detection and correction. First, the different methods used in the ectopic beat detection are reviewed. Then, those dedicated to correct their presence are discussed. Finally, the effect of ectopic beats and the ectopic beat correction methods on the HRV signal parameters are highlighted.

1. Introduction

Heart activity is associated with ionic current flow caused by the cardiac fibers contraction and subsequently relaxation. This electrical activity can be recorded using electrodes suitably placed on the body surface. The potential difference measured between those electrodes is known as electrocardiogram signal (ECG). Indeed, heart contraction and relaxation can be observed as successive waveforms in the ECG signal denoted *P*, QRS and *T* waves. Cardiac arrhythmia can be diagnosed using ECG signal especially waves shape and duration as well as their time intervals.

In fact, the heart rate variability (HRV) appears to be the most important parameter that can be used in cardiac arrhythmia. HRV refers to beat to beat spontaneous variations. It can be extracted from ECG signal by measuring the time differences between successive *R* peaks. In fact, HRV have been extensively studied since it is used to investigate the cardiac arrhythmia recognition and the autonomic nervous system effects determination [1,2].

Unfortunately, the presence of different noise types can extremely affect the HRV signal analysis and consequently yields incorrect diagnosis. Noise presence can lead to misrecognition of the QRS complex leading to erroneous generation of the HRV signal. Noises affecting ECG signal are divided into two categories. The first category refers to technical artifacts which may be caused by patient motion, low skin-electrode contact and power-line distribution. They can also be caused by the QRS detection software when it fails to detect correctly the *R* peaks as it is illustrated in Fig. 1. Fig. 1 illustrates an example of the *R* peaks delineation using inaccurate software. Fig. 1a shows the result of the *R* peak delineation. Fig. 1b shows the corresponded heart rate variability signal. It is clearly seen that false *R* peaks detection introduces sudden variations in the HRV signal. The false *R* peaks detection is mainly related to QRS detection errors. This may lead to abnormal and abrupt long (missing heartbeat) or short (false positive) RR intervals [3]. Hence, the negative and the positive false detection of the *R* peaks can extremely affect time, frequency and nonlinear measurements of the HRV signal. Due to its importance, the QRS misrecognition effects on the HRV measurements were potentially studied [3–6].

Besides technical artifacts, the second noise category includes biological artifacts such as ectopic beats (EBs). In fact, heart contractions and relaxations are due to periodic impulses originating in the sino-atrial node. When these impulses occur in unusual places,

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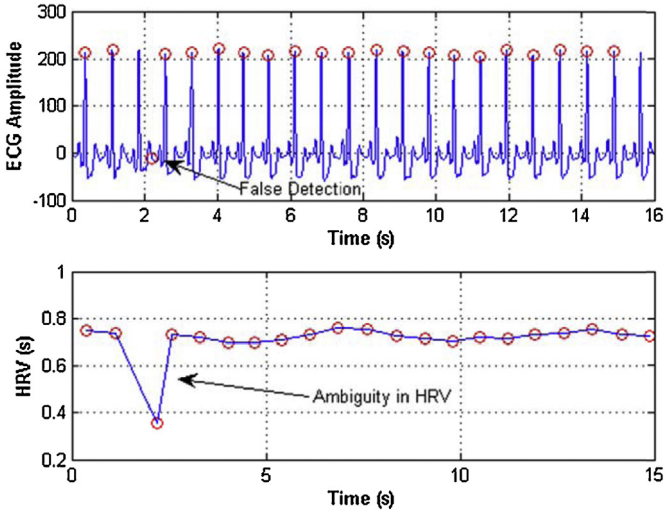

Fig. 1. Ambiguities in HRV signal due software error.

the ECG beats appear irregular and abnormal. These beats are called ectopic beats. They originate for atrioventricular junction or ventricles rather than the sino-atrial node. When such pulses occur in the atrioventricular junction, ectopic beats are called atrial premature contractions (APCs), whereas, when occurring in the ventricles, the EBs are known as premature ventricular contractions (PVCs).

APCs alter the *P* wave morphology without changing the QRS complex. Usually, the APCs have similar morphological features as the normal sinus beat. However, PVCs modify widely the QRS complex. This is related to the paths of conductions that are tremendously different from those of the normal sinus beat. When PVCs are present, QRS complexes appear wider and abnormally shaped.

EBs introduce ambiguity in the HRV since they lead to RR intervals different from the preceding and the succeeding ones. This can be clearly observed in HRV signal generated using 105 ECG record of MIT-BIH database (Fig. 2). In this case, RR intervals preceding the ectopic beat are short whereas RR intervals succeeding the APC are long. Consequently, irregularities are introduced in the HRV signal leading to erroneous measurements of the HRV indices. Therefore, ectopic beats must be first detected and then corrected by removing, replacing or by using interpolation methods. Unfortunately, editing ectopic beats can affect the measured indices of the HRV signal. Studying such effects according to the different methods of detection EB and correction is the aim of this paper. It is in fact, concerned with a review and evaluation of different methods that

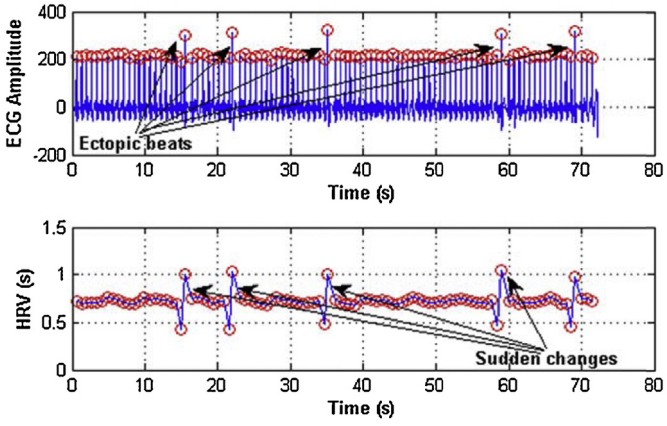

Fig. 2. Effect of ectopic beat on the HRV signal.

can be used to deal with ectopic beats, mainly their effect on time, frequency and nonlinear parameters measure of the HRV.

2. Ectopic beats detection and classification

The automatic analysis of the ECG signal is indispensable due to large number of patients in intensive care units requiring continuous observation [7].Consequently, many principles and methods are used to develop algorithms that can be applied in ECG signal enhancement, waves' detection and heartbeat classification. Generally, ECG enhancement stage is related to noise elimination. In the wave's delineation stage, the onset, offset and the peaks of the QRS complex, *P* wave and *T* wave are determined. The wave's detection is carried out in order to extract clinical parameters such as QRS duration, RR interval, PR interval, QT interval and ST segment. Those parameters are used in the classification stage.

The QRS complex delineation is the most vital task in the ECG signal analysis as it is used in the heart rate determination. Besides, QRS delineation may be considered as a preprocessing stage in the *P* and *T* waves' location [8]. Moreover, QRS complex characteristic are very useful in the ectopic beats location especially the PVC beats identification.

Because of the above mentioned, many researches are devoted to the QRS complex identification [9–12]. The QRS detection algorithms are already reviewed in Ref. [13].

The QRS complex detection is also considered as a key step in most ectopic beats detection algorithms. Others informations, such as RR intervals, can also be used to identify the ectopic beats. As already cited, the first part of this paper is an overview of most recent papers dedicated to ectopic identification, recognition and classification. Algorithms details can be found in corresponding references cited at the end of this article.

2.1. Time and morphological approaches

Classical QRS detection methods used time domain features to extract ectopic beats [14]. In fact; on the contrary of the APCs identification, those methods are successfully applied in PVCs recognition. Indeed, most of the time domain based algorithms used the fact that PVCs have a wide QRS shape. Using this approach, a set of time features is usually determined from the QRS complex, independently of the surrounding ECG waveforms.

TeerramongKonrasmee et al. [14] developed an algorithm based on RR interval duration and the QRS width. In Ref. [15], Tsipouras et al. used a sliding window to extract RR intervals information in order to build simple rules that can be used in arrhythmia beats classification. Time domain features based algorithms are simple to implement and they have the advantage of low complexity. They are widely applied in real time systems. Unfortunately, they suffer from the low sensitivity in PVC detection due to the presence of noise. Certainly, the main drawbacks of those methods are their high noise sensitivity and their low efficiency when dealing with odd morphologies [16].

The PVCs are better recognized by morphological descriptors [17]. Morphological based methods use the fact that QRS waveform in PVC beats is widely different from the normal ones. When PVCs occur, the QRS complex shape appears wide and bizarre because of the abnormal conduction paths. Supat et al. [18] consider the QRS pattern as another feature besides of those used by Ref. [14]. Indeed, QRS duration, RR interval duration and QRS pattern are used to distinguish PVC beats from Non-PVC ones. Even if the proposed algorithm performs better than classical time approaches, it fails to detect PVC beats with narrow QRS width. In addition, it still suffers from high interference of various noises. Garcìa et al. [19] algorithm used basically eight temporal features and four