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Automatic detection of onset and offset of QRS complexes independent of isoelectric segments

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ABSTRACT

Accurate location to onset and offset of QRS complex from ECG signal is help measuring other features and it is a important and challenge task to recognize these onsets and offsets from ECG signal without isoelectric segment. The algorithm, which is introduced in this paper, does not depend on isoelectric segment and can accurately detect these onsets and offsets. In the algorithm, for every sample within about a cardio cycle of locally normalized ECG signal, two fitting straight lines are obtained respectively, from two sets of samples before and after the sample. And then two gradients and a smaller included angle corresponding to the two fitted lines are calculated. Third, those samples whose two gradients satisfied a pre-set value are taken as candidates for the R peak, and the sample with the minimal included angle is regarded as the R peak in this cardiac cycle. Finally, respectively before and after the detected R peak, the algorithm researches the onset and the offset of the QRS complex according to the same decision strategy. All 32 sets of 12-lead ECG records from http://physionet.org/pn3/twadb/ are employed to evaluate the method. The experimental results show that compared with three traditional methods, the method can more accurately detect all onsets and offsets and has better robust on interference.

1. Introduction

The electrocardiogram (ECG), an old and commonly used method in cardiology, has been used clinically by cardiac clinicians for many years [1,2]. For example, the ST segment change is used to determine whether myocardial ischemia has occurred [3,4], the QT/QTc interval [5] has also received much interest because of its potential for the detection of proarrhythmogenic effects of both cardiac and non-cardiac drugs, and multiple genetic disorders of cardiac channels have been discovered. The features of the ECG signal include segments, intervals and waves. Among these features, the QRS complex is the most important, because the QRS complex can not only provide rich clinical information, but can also be used as a datum point from which other physical features such as the instantaneous heart rate can be determined [6]. On the other hand, the onset of the QRS complex is the end point of the PQ interval, and the offset of the QRS complex is the starting point of the ST segment, therefore both the onset and the offset are also two important characteristic points in the automatic measurements of the ST segment and QT/QTc interval. In this paper, the onset of the QRS complex, symbolized by a letter μ, is marked as the start of Q, or R in the absence of a Q wave, and the offset of the QRS complex, represented by a letter J, is the end point of the S wave, or the R wave in the absence of an S wave. Obviously QRS complex, μ and J must be detected before to measure other characteristic waves, segments and intervals [7–16].

Detection algorithm of QRS complex generally includes a pre-processing stage, a decision stage and a post-processing

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stage. First, some linear and/or non-linear filters are used to promote the components of QRS complex and to attenuate other components such as P and T waves. Second, a decision logic rule is applied to the filtered signal to identify some samples as candidates of the QRS complex. At last, a post-processing block may be necessary to select the exact QRS complex from these candidates of QRS complex. Once QRS complexes are delineated, μ and J would be detected from forward and backward seek windows of the located QRS complex respectively. Many algorithms have been introduced to locate the P peak or QRS complex while fewer algorithms have been proposed to detect μ and J points automatically. At present these μ and J points, which are used in scientific research and clinical diagnosis, depend on visual assessment given by cardiologist. Two reasons result in the situation. One is the lack of universally accepted criteria defined μ and J. The other is its difficulty of automatic detection algorithm because of the physiological variability of the QRS complex and interference on isoelectric PR segment and ST segment. It is necessary and important to explore some algorithms to automatically detect these μ and J points from ECG signal.

However, so far several methods have been proposed to detect μ and J points. In 1985, Pan and Tompkins method (abbreviated to PT in all figures and Tables of this paper) was introduced to recognize QRS complexes. Pan and Tompkins method uses digital analyses of slope, amplitude and width of QRS complexes, and includes three steps which are shown in Fig. 1. Firstly a derivative operator is used to suppress the low-frequency components of the P and T waves and to promote the high-frequency components arising from the high slopes of the QRS complex. Subsequently, a squaring operation and an integration operation are employed. The former makes these results positive and emphasizes large differences resulting from QRS complexes, and the later decreases multiple peaks within the duration of a single QRS complex through a moving window integration filter. The major object of Pan and Tompkins method is to locate QRS complex, however after the integration operation its two turning points on the curve, which are preferred by two dot lines in Fig. 1, can be regarded as μ and J point.

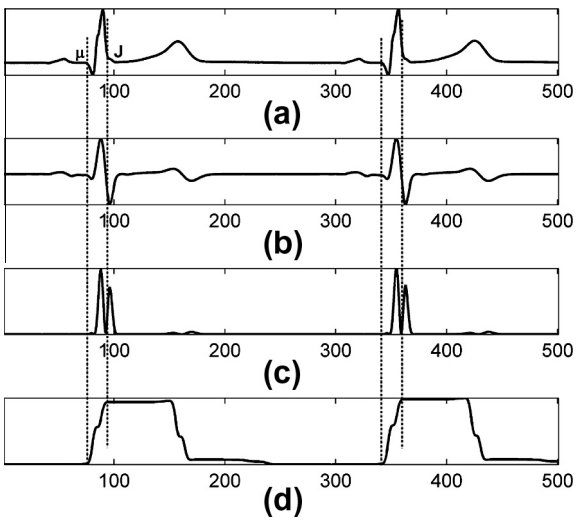

Fig. 1. Illustration of Pan and Tompkins method [17]. Two dot lines indicated μ and J, respectively. (a) Raw ECG signal; (b) after derivative operation; (c) after squaring operation; and (d) after integration operation.

In 1999, Daskalov and Christov [18] introduced a tactics for automatic detection of QRS boundaries, which is called DC algorithm in this paper for simplicity. DC algorithm firstly identifies the PR segment and ST segment, and then decides μ and J points, respectively, from these identified segments. After QRS complexes are recognized by other algorithm, an isoelectric segment has to be searched from the steepest part of the QRS back on the time axis up to 120 ms. If successive differences between some adjacent samples (spaced at 2.5 ms) are less than a preset value and the difference between the end samples of the segment are lower than the same value, the segment composed of these adjacent samples is thought to be isoelectric. The coming step is to calculate angles of some samples near the end point of the found isoelectric segment. The sample with the minimum value is taken as the QRS onset. The above procedure is repeated for detecting the QRS offset. The algorithm can often get good results. However, once the isoelectric line changed, i.e. ST changed [3,4], their results would become worse. Therefore, it might be more reasonable that the algorithm would perform better if firstly used to detect the μ/J point and then to look for the PR/ST segment.

For this reason, it is also necessary to explore an algorithm independent of the PR/ST segment to locate the μ/J point. Recently, an algorithm based on a triangle is proposed for detection of μ/J points [19]. In the triangle method(TM), three samples $ecg(n-2)$, $ecg(n)$ and $ecg(n+2)$ are used to form a triangle shape $\triangle ABC$. $ecg(n-2)$, $ecg(n)$ and $ecg(n+2)$ are three vertexes of $\triangle ABC$ (B, A and C respectively). The angle of vertex A and the vertical distance between the vertex A and the base BC are used as the features to recognize QRS complex and its onset and offset points. Although this algorithm is able to detect QRS complex, μ and J points, it needs two feature parameters: angle and height. However, the side AB or AC spans only three samples and lasts for only two sample points. As a result, the height, the distance from vertex A to the opposite side BC, might usually be smaller than noise's amplitude. On the other hand, the span of side AB or AC should not be beyond the span covered by one peak's slope. Among these ECG signal used in this paper, there are a part of small peaks (such as r, q and s) whose slope covers only about several sample points and even fewer. After some experiments about the span, 4 sample points (lasted for 3 sample cycles) are more appropriate than other number of sample points. Thirdly, there is a fact that the same kinds of characteristic points might not be classified if their included angles are too dispersal. So later, a modified triangle morphology (MTM) method without height feature is introduced to detect QRS complex's characteristic points [20]. In MTM algorithm, after raw ECG signal is firstly processed by local normalization, these vertex angles belonged to the same kind of characteristic points would become more identical and their included angles cluster in a narrower scope. There is no doubt that clustering angle is useful for the