A Simple Algorithm for Detection of QRS Onset and Offset

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Abstract—This paper proposes a simple algorithm for QRS onset and offset detection in ECG signal. Before detecting QRS onset and offset, we have searched junctions of Q wave and S wave using distance. And then, we find QRS onset and offset using area. The performance of our algorithms has been evaluated using the PhysioNet QT database. Experiment results show that the proposed algorithm outperforms the other algorithms.

Keywords—QRS Complex, ECG, QRS Detection, QT Database

I. INTRODUCTION

ELECTROCARDIOGRAM (ECG) is the process of recording the electrical activity of the heart over a period of time using electrodes placed on a patient’s body. These electrodes detect the tiny electrical changes on the skin that arise from the heart muscle depolarizing during each heartbeat. An ECG conveys a large amount of information about the structure of the heart and the function of its electrical conduction system[1]. Each cardiac cycle in the ECG signal is consisted of P wave, QRS complex and T wave[2][3]. Automatic detection of ECG waves provides important information for cardiac disease diagnosis. The topic of automatic detection of ECG waves has been widely studied. The great morphological variation in ECG signals makes it difficult to develop automatic and widely applicable algorithms. ECG detection algorithms have the common goal of enhancing the classification accuracy and are becoming as reliable and successful as expert cardiologists[4].

The QRS onset and offset detection is useful for the computation of QRS duration, QT and ST intervals. Though algorithms for automatic detection of waveforms in ECG signals have been intensively studied, the robustness and accuracy of these algorithms are an important issue in clinical applications[5][6]. The various types of noises can be included in ECG signals. The noises disturbing ECG involve generally the powerline interference, baseline drift, electrode polarization noise and the amplifier noise. Many approaches have been applied to the enhancement of filtering ECG, such as FIR filter, EMD method, Morphology[7].

Automatic detection of the R-peaks in a long-term electrocardiogram signal is the most important step for diagnosis of cardiac disorders, heart-rate variability analysis, and ECG coding systems[8]. Many methods have been developed for the detection of R-peaks based on the derivatives[9], digital filters, linear prediction, wavelet transform, mathematical morphology, and empirical mode decomposition, geometrical matching, neural networks and hybrid approach.

A wide diversity of algorithms have been also proposed for QRS onset and offset detection, in the literature and already validated with the PhysioNet QT database. Some of them are using linear derivative filters to get an indicator of signal variation and then thresholding the derivative of the ECG signal. The envelope of the QRS complex is also used. It is computed from the ECG signal based on the Hilbert transform. The beginning and the end of this envelope of the QRS complex correspond respectively to the QRS onset and offset.

In this paper a simple algorithm is proposed to improve the QRS onset and offset detection. The proposed algorithm mainly consists of two steps. In the first step, the junctions of Q wave and S wave are detected by searching the shortest distance between the R-R intervals. The junction of Q means the location of change form Q wave to R wave. The junction of S means the location of change form R wave to S wave. The junctions of Q wave and S wave are located close to QRS onset and offset respectively. In the second step, the algorithm remove R wave between the junctions of Q wave and S wave and then, These electrodes detect the tiny electrical changes on the skin compute area covered by moving window.

The maximum area value in the left side of R peak corresponds to the QRS onset. And the maximum area values in the right side of R peak corresponds to the QRS offset. The performances of the proposed algorithm have been evaluated using the QT database available in the PhysioNet. The experiment results show that the proposed algorithm outperforms the results obtained by the other known algorithms evaluated with the same database.

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II. METHODS

The QRS onset and offset detection is important part of the computer aided Arrhythmia Analysis. The algorithm can be divided into four steps: baseline correction and noise suppression, R peak detection, search for the junctions of Q wave and S wave, QRS onset and offset detection. These steps are detailed below.

A. Noises Cancellation

Morphological operators have been widely used in the signal- and image-processing fields because of their robust and adaptive performance in extracting the shape information in addition to their simple. We used the combined opening and closing operators for baseline correction and noise suppression of ECG signals. There are two basic morphological operators: erosion (⊙) and dilation (⊕). Opening (◦) and closing (•) are derived operators defined in terms of erosion and dilation. Noises of ECG signal are shown in figure 1.

![Fig. 1 Noises Of ECG Signal](a) Power-Line Interface (b) Baseline Wander (c) Muscle Contraction (d) Motion Artifacts

The results of morphology operation are shown in Figure 2.

![Fig. 2 Eliminate Noise And Baseline Drift By The Morphology Operation](a) noised signal (b) Filtered signal

B. R-Peak Detection

As in every method for automatic R peak detection is a very important step because it serves as a reference for other detections. Owing to the high frequency content of the QRS region [5-15 Hz] the derivative of these regions of ECG have higher amplitudes. As the sampling instants of digital ECG data remains constant the amplitude differences are proportional to the derivatives which can be used to detect the QRS regions. Pan and Tompkins proposed a real-time QRS detection algorithm based on analysis of the slope, amplitude and width of QRS complexes[10]. The algorithm includes a series of filters and methods that perform lowpass, highpass, derivative, squaring, integration, adaptive thresholding and search procedures. The proposed algorithm follow Pan and Tompkins to detect R peak.

C. QRS Onset And Offset Detection

Using detected R peak sequences, R peak interval is obtained. Figure 3 present many feature points including $Q_i$ and $S_j$ that denote junctions of Q wave and S wave respectively. $Q_i$ is located at the left side of R peak. $S_j$ is located at the right of R peak. $Q_i$ and $S_j$ are obtained by the distance from the R-R line to sample point in R-R interval. R-R means the time from a R peak to the next R peak.

The distance($D_i$) from the R-R line to sample point($P_i$) in R-R interval is computed by (1).

\[
D(p_i) = \frac{|(y_R - y_L)x_i - (x_R - x_L)y_i + x_Ry_L - y_Rx_L|}{\sqrt{(y_R - y_L)^2 + (x_R - x_L)^2}}
\]

(1)

\[
p_i = (x_i, y_i), \quad i = x_i + 1, \quad x_i + 2, \ldots, x_R - 2, x_R - 1
\]

\[
R_R = (x_R, y_R), \quad R_L = (x_L, y_L)
\]

$P_i$ has location($x_i$) and amplitude($y_i$) in R-R interval. $R_R$ has location($x_R$) and amplitude($y_R$) of R peak in right. $R_L$ is the value of left R peak. As $Q_i$ and $S_j$ are located at near R peak, we define weight function ($W_i$) as following.

\[
W(p_i) = \cos\left(2\pi \frac{x_i - x_L}{x_R - x_L}\right)
\]

(2)

To adjust the value of the distance($D_i$) according to weight value($W_i$), the weight value is multiplied by the distance value.

\[
WD(P_i) = W(p_i)D(p_i)
\]

(3)

Using (3), $Q_i$ is founded in the location that is maximum value $WD(P_i)$ in left side of R peak. $S_j$ is founded using same method in right side of R peak. Figure 3 shows detected locations of $Q_i$ and $S_j$.

![Fig. 3 Peak And S-Peak](QRS onset is the point where signal begins to move away the baseline, and offset is the point where signal come back to the baseline. The QRS region has the largest amount of change in the electric potential value. After the $Q_i$ and $S_j$ detection, we remove R wave area covered by $Q_i$ and $S_j$ as figure 4. when R wave area is removed, the slope between Q-onset and Q$Q_i$ is
more steep than other location around QRS complexes.

After removing R peak, area values will be computed. The computation of the area covered by length $S_w$ is integral function. The detection function of $Q_{onset\_area}$ is in (4).

$$Q_{onset\_area} = \arg \max_{i \in S_w} \sum_{i=1}^{i+M_w} (A'(i) - A'(i))$$  \(4\)

$Q_{onset\_area}$ is the maximal summation of the potential value in the ECG signal without R peak. $M_w$ is moving window size, $i$ is location that is belong to integral range. $i$ is starting point of integral function and $S_w$ is search range. We compute the sum of the difference between and within the window size $M_w$. The maximum value in (4) is selected as $Q_{onset\_area}$.

Figure 5 show the process of detection in ECG signal without R peak. In figure 5, the shaded area has maximum value and the location of $Q_{onset}$ is detected. We can apply same method to find $Q_{offset}$.

III. EXPERIMENT RESULTS

The performances of the proposed algorithm are experimentally evaluated in this section. For validation purposes, the QT database available on the PhysioNet website has been used. This database has been built by researchers specifically for the evaluation and comparison of algorithms for ECG signal segmentation. The signals in this database have been manually annotated by cardiologist experts for various events. The database consists of 105 fifteen minutes excerpts of two channels ECG Holter recordings sampled at 250 Hz.

To evaluate the accuracy of the proposed algorithm, the mean and standard deviation (STD) of the differences between automatic detection and cardiologists annotations are computed. The results of proposed algorithm are compared with the result of 3 different detection algorithms which have been evaluated with the PhysioNet QT database in publications: LPD [11], WT [12], EA [6], as shown in Table 1. The tolerances for the STD of detection errors for QRS onset and offset are presented in [13]. Experiment results show that the proposed algorithm outperforms the other algorithms.

### IV. CONCLUSION

An ECG signal conveys a large amount of information about the structure of the heart and the function of its electrical conduction system. Automatic detection of ECG waves provides important information for cardiac disease diagnosis. This paper proposes a simple algorithm for QRS onset and offset detection in ECG signal.

In the first time, he junctions of Q wave and S wave are detected by searching the shortest distance between the interval R-R intervals. And then the algorithm remove R wave between the junctions of Q wave and S wave and then compute area covered by moving window. Finally The maximum area values are selected for QRS onset and offset.

When evaluated the proposed algorithm with the PhysioNet QT database, the mean and the standard deviation of the error of the proposed algorithm are under tolerances accepted by cardiologists. Experiment results show that the proposed algorithm outperforms the other algorithms.

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