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AN IMPROVED ALGORITHM FOR DETECTING QRS IN ELECTROCARDIOGRAM BASED ON A DIFFERENCE-THRESHOLD METHOD

Jiehua Wang, Engao Chen, Zhan Gao and Huiping Liu

School of Computer Science and Technology
Nantong University
No. 9, Seyuan Road, Nantong 226019, P. R. China
wang.jh@ntu.edu.cn

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Abstract. *Cardiac diseases are one of the major diseases that are harmful to human health. Analysis by electrocardiogram (ECG) is an important means of diagnosing cardiac disease in the clinic. A new algorithm based on the difference-threshold method for QRS detection in ECG is proposed. Initially ECG data are resampled to attenuate the influence caused by differences in sampling frequency, which improves the method generality. The detection of QRS complexes is accomplished by comparing the negative slope generated by difference operation against an adaptive threshold. The MIT-BIH arrhythmia database was used to validate the algorithm, with a detection rate of up to 99.4%. Experimental results indicate that the proposed method meets the requirement needs for ECG analysis, and it can detect the QRS complex in real-time and improve detection accuracy and stability at the same time.*

Keywords: QRS detection, Electrocardiogram (ECG), Resampling, R-R interval, Difference-threshold algorithm

1. **Introduction.** The heart is a vital organ of the human body. The electrocardiogram (ECG) is a graphical representation of the electrical activity of the heart. The ECG signal of a single cardiac cycle consists of the QRS complexes, P- and T-waves as shown in Figure 1 [1]. A QRS complex is the combination of three most visually obvious graphical deflections. It is usually the central part of the tracing. The duration, amplitude, and morphology of the QRS are useful in diagnosing cardiac diseases. Therefore, the detection of QRS is often the first step in the procedure of computerized diagnosis or health-monitoring. A new algorithm based on the difference-threshold method is proposed in this paper in order to detect QRS in ECG.

Typically an ECG has five deflections, named "P" to "T" waves. The Q, R, and S waves occur in rapid succession. Due to the high amplitude QRS, the detection of the QRS complex is the first consideration and focus of automatic ECG diagnosis of heart diseases. Besides, the Q-wave, T-wave and additional information (such as heart rate and ST segments) could be detected only after the QRS complex is determined. At present, many standard signal processing methods have been applied to QRS and R-wave detection, such as methods from the field of difference threshold [2], wavelet transform [3], support vector machine [4] and neural networks [5,6]. Compared to similar algorithms, the difference-based methods are generally much simpler and more suited to real-time applications. Considering the advantages of difference methods, in this paper we propose a simple and reliable algorithm of QRS complex detection based on difference-threshold methods. The algorithm was evaluated and justified using the MIT-BIH arrhythmia database [7]. The experiment results suggest that our algorithm is able to detect the QRS complex efficiently without complex mathematical calculation. The paper is organized as

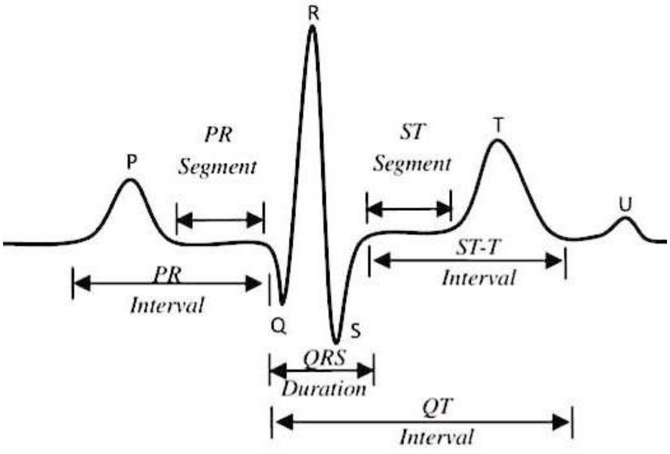

Figure 1. ECG in a single cardiac cycle

follows: Section 2 describes the implementation details of algorithms based on difference-threshold; experimental results and discussions are presented in Section 3; finally the paper is concluded in Section 4.

2. Methodology.

In general, our algorithm consists of two steps: noise removal and QRS detection. In this study, the algorithm resamples the raw ECG signal to weaken the influence caused by initial differences in sampling frequency. Noise is removed using an average smooth filter and the characteristics of the difference algorithm. Finally, the detection of QRS complexes is accomplished by comparing the feature generated by difference operation against an adaptive threshold. More details are explained in the following sections.

2.1. Resampling of the ECG signal.

The different kinds of ambulatory ECG (AECG) systems usually have different sampling frequencies, which decrease the accuracy of QRS detection [8]. Table 1 lists the sensitive and positive predictivities for beat detection on the MIT-BIH arrhythmia database for several types of sampling frequencies [9]. In order to eliminate the inaccuracy caused by different sampling frequencies, this paper resamples acquired ECG signals. Considering the power frequency in China is 50 Hz, and the ECG sampling frequency usually is an integral multiple of power frequency, in this paper we take 250 Hz as the sampling frequency. This frequency does not miss useful information while keeping the amount of data sampled at a suitable level.

Figures 2 and 3 show the waveforms of Tape #100 on the sampling frequency of 360 Hz (in the MIT-BIH arrhythmia database) and 250 Hz (in this paper) comparatively. We can see from the figures that the time and morphological characteristics do not change after resampling.

Table 1. Beat detection performance at different sampling frequencies

Sampling Frequency	QRS Sens.	QRS + Pred.
100	0.996856	0.997905
175	0.997601	0.998093
200	0.997426	0.998071
250	0.997502	0.998016
360	0.997535	0.998038

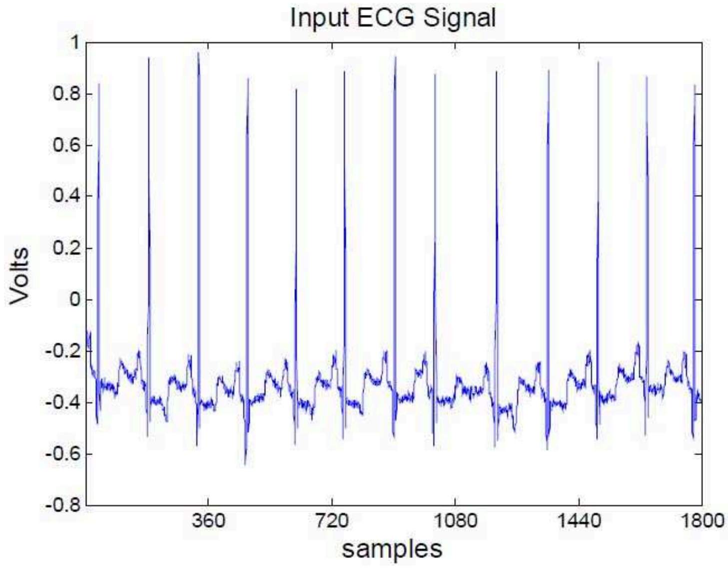

Figure 2. Tape #100 on sampling frequency of 360 Hz

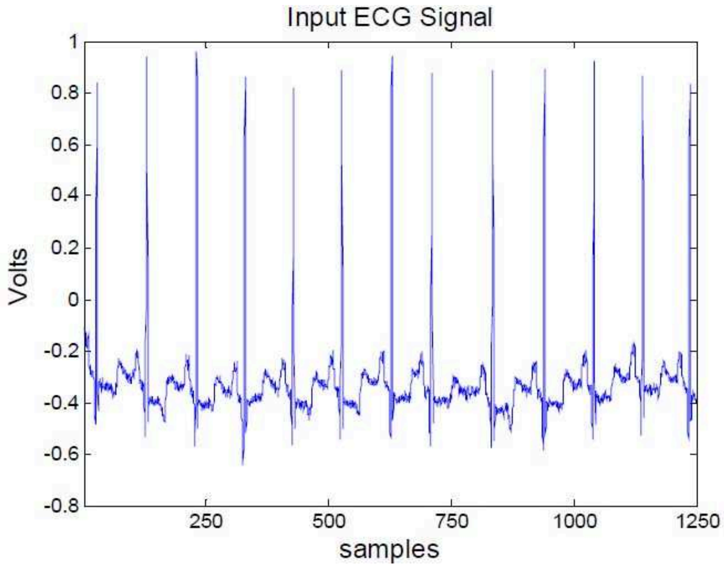

Figure 3. Tape #100 on sampling frequency of 250 Hz

2.2. **The average smooth filter.** In the process of getting ECG signals, they may be corrupted by various kinds of noise due to physical and technical impact. The maximal noise is 50 Hz power-line interference, which comes from power line of the ECG signal measurement system despite proper grounding [10]. The 50 Hz power-line interference would decrease the signal-to-noise ratio (SNR) and even submerge a weak ECG signal [11]. Taking into account the requirement of real-time detection, this paper adopts an average smooth filter to restrain the interference of 50 Hz. The processing of average smooth filtering is achieved according to the formula below:

$$y(n) = \left[x(n) + x(n-1) + x(n-2) + \cdots + x(n-M+1)\right]/M \tag{1}$$

where $x(n)$ represents the raw ECG signals and $y(n)$ represents the filtered ECG signals. The value of the coefficient M is determined by the sampling frequency, which is the quotient of the sampling frequency divided by 50. In this paper, the sampling frequency is 250 Hz; 4 is taken as the value of M.

2.3. **The difference algorithm.** The difference algorithm is a fast method for real-time detection of ECG, which locates the R-waves based on the characteristic steep slope and high amplitude of the QRS complex. According to the frequency characteristics of the QRS complex, the amplitude of QRS is enhanced while the other waves are attenuated by an appropriate difference operation. Difference equations of possible differentiator filters are [12]:

$$y(n) = x(n+1) - x(n-1) \tag{2}$$

$$y(n) = 2x(n+2) + x(n+1) - x(n-1) - 2x(n-2) \tag{3}$$

$$y(n) = x(n) - x(n-1) \tag{4}$$

$$y(n) = \tilde{x}(n) - \tilde{x}(n),\ \tilde{x}(n) = \begin{cases} |x(n)| & |x(n)| \geq \Theta \\ |x(n)| & |x(n)| < \Theta \end{cases},\ \text{and } \Theta \text{ is threshold.} \tag{5}$$

where $x(n)$ is the raw ECG signal and $y(n)$ is the filtered ECG signal. In this paper, the difference algorithm adopted is:

$$y(n) = 2x(n) - x(n+\Delta t) - x(n-\Delta t) \tag{6}$$

and Δt is the time difference based on the frequency characteristic of difference calculation and the QRS complex. In order to analyze the frequency characteristic of difference methods, we applied the Laplace transform method to Equation (5):

$$L\left[y(n)\right] = 2L\left[x(n)\right] - L\left[x(n+\Delta t)\right] - L\left[x(n-\Delta t)\right] = 2F(s) - e^{(-s\Delta t)}F(s) - e^{(s\Delta t)}F(s) \tag{7}$$

Then, the transfer function is:

$$G(s) = 2 - e^{-s\Delta t} - e^{s\Delta t} \tag{8}$$

The frequency characteristic is:

$$G(jw) = 2 - e^{-jw\Delta t} - e^{jw\Delta t} = 2 - 2\cos(w\Delta t) \tag{9}$$

The amplitude-amplitude is:

$$|G(jw)| = 2 - 2\cos(w\Delta t) \tag{10}$$

The amplitude-frequency curve is shown in Figure 4; we can see that the curve changes periodically. Comparing the spectrum characteristics of various waves (that is, the P-wave and T-wave are low frequencies while the QRS complex waves are high frequencies) with the amplitude-frequency curve of the difference function, we observed the amplitude of QRS is enhanced and the P-wave and T-wave are attenuated if the value of the time

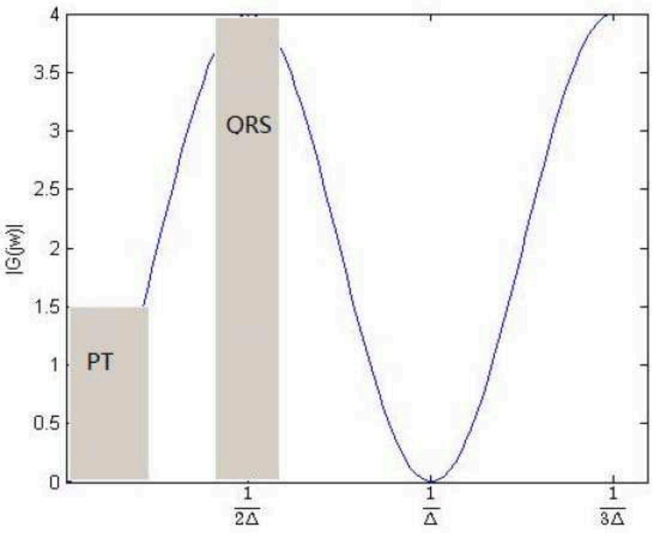

Figure 4. The amplitude-frequency of difference in QRS detection

difference Δt is taken appropriately. The paper takes the value of Δt as: $\Delta t = 5t_s - 10t_s$ [13], where t_s is the sampling interval.

2.4. **The QRS detection algorithm.** After the filtering and the difference operation, the detection of QRS complexes is accomplished by comparing the feature against an adaptive threshold. The main steps are described as follows.

- Determine the time difference based on the sampling frequency. Calculate the difference of the ECG signal. Make zero clearing of data at the beginning and end.
- Divide the first 8 s data of the difference result into eight parts (a normal R-R interval, or a beat, is 0.4 s-0.12 s, if 1 s is the estimated value of the R-R interval, then 8 s is the time of eight beats) and find the maximum of the negative slope in each part. The specific process is: find the sampling point located in $n \times 250$ ($n = 0, 1, 2, 3, 4, 5, 6, 7$), and then move backward 250 sampling points (1 s). Calculate the average of the maximums of negative slope in each part (marked by k_n), and take the value $T_{k_n} = 0.7 * k_n$ as the initial threshold.
- From the initial point, compare the difference result against the threshold T_{k_n}. If the data are greater than the threshold value, take the point of the data as the centre, and search the surrounding area 40 ms to find the point with the maximum amplitude, which is the candidate R point. Store the candidate R point and update the threshold value according to the following equation: $new(k_n) = 0.75 * old(k_n) + 0.25 * k_n$; $new(T_{k_n}) = 0.7 * new(k_n)$. Then restart the detection after 150 ms of the candidate R-wave.
- Calculate the R-R interval. If $RR > 166\%\overline{RR}$ ($\overline{RR}$ is the mean value of the R-R interval), calculate the mean value of the amplitude of the detected R-wave (marked by k_a), and re-research the same interval by comparing the amplitude of the signal with the threshold T_{k_a} ($T_{k_a} = 0.5 * k_a$).
- A normal QRS complexes duration is 0.04 s-0.11 s (that is, 10-30 sampling points at a sampling frequency of 250 Hz), so we detect the Q-wave and S-wave in an interval with 15 sampling points (55 ms). That is to say, search the minimum amplitude in the 15 sampling points before and 15 sampling points after the point R, respectively. The position of the minimum amplitude in front of point R is point Q and the position of the minimum amplitude behind the R-wave is point S.

3. **The Experiment Result and Analysis.** In this section, the MIT-BIH arrhythmia database is used to evaluate the effectiveness of the proposed algorithm on the platform of Matlab 8.3.0. Some typical ECG records from the first channel data (MLII) are used to accomplish the detection. The result of the detection data is shown in Table 2. Four experiment results are shown in Figures 5-8, where the detected R waves are marked as 'Δ'.

Experiment results in Table 2 show that the accuracy rate of the proposed algorithm is approximately 99.4%, which is higher than that of the traditional algorithms-based difference threshold (about 95%) [14,15]. Compared with the wavelet transform algorithm,

Table 2. The result of the algorithm for the typical ECG signals in the MIT-BIH database

Tape#	Total beats	Detected beats	Misdetected beats	Accuracy Rate (%)
100	2273	2273	0	100
105	2572	2550	22	99.1
113	1759	1747	12	99.3
118	2271	2254	17	99.3

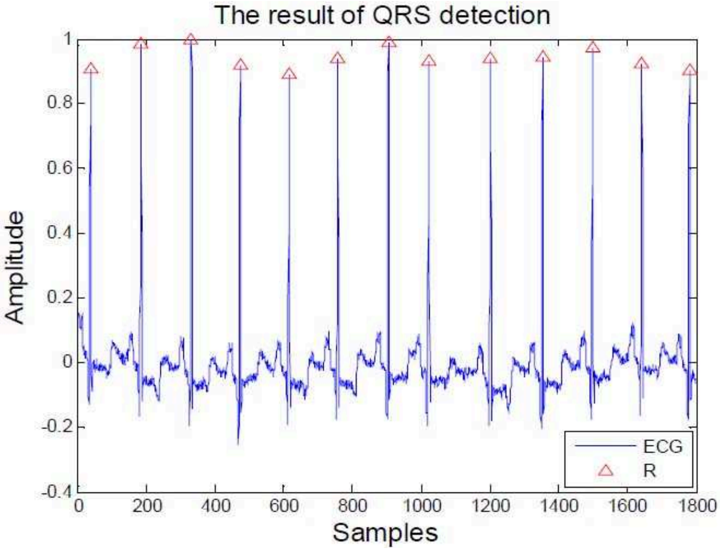

Figure 5. Detection results of tape #100

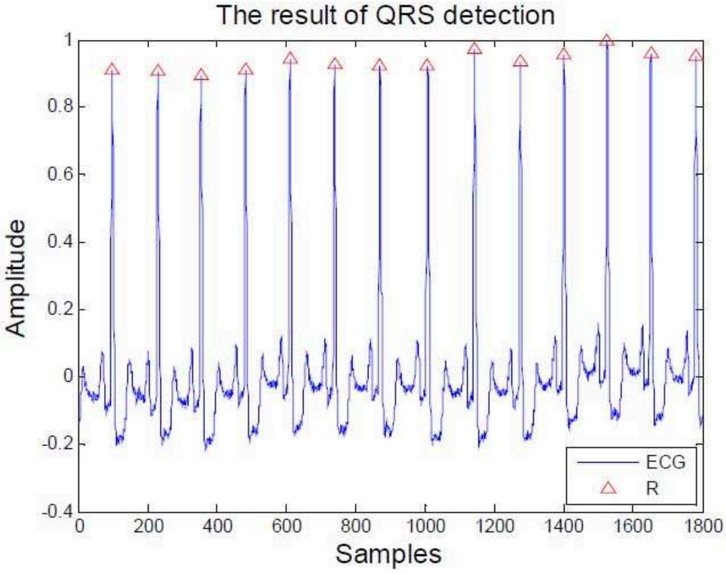

Figure 6. Detection results of tape #105

the accuracy of detection is not as high, but the algorithm proposed in this paper is simpler to implement and can be applied in real-time automated analysis systems.

4. **Conclusions.** The detection of QRS complexes is the vital part in ECG analysis systems. In this paper, we introduce a QRS complex detection algorithm based on the difference threshold. The algorithm resamples the raw ECG signal to weaken the influence caused by different sampling frequencies, which improves the method generality. The noise is removed using an average smooth filter and the characteristics of the difference algorithm. The detection of QRS complexes is accomplished by comparing the negative slope generated by a difference operation against an adaptive threshold. The algorithm was evaluated using the MIT-BIH arrhythmia database and the accuracy rate is up to 99%. In addition, the algorithm can be realized at a low computational cost, which makes the algorithm suitable for real-time health monitoring systems. In future work, we will focus on the detection of P-wave as the QRS complexes detection proposed in this article has laid a good foundation for the detection of the P-wave.

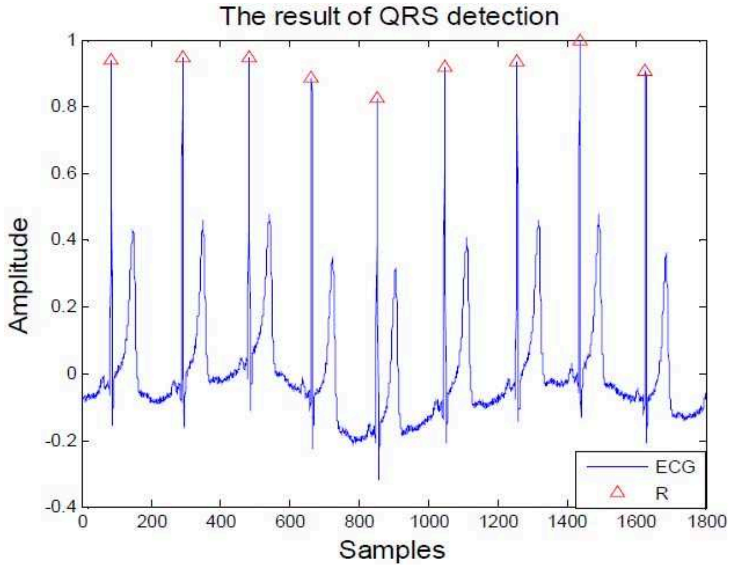

Figure 7. Detection results of tape #113

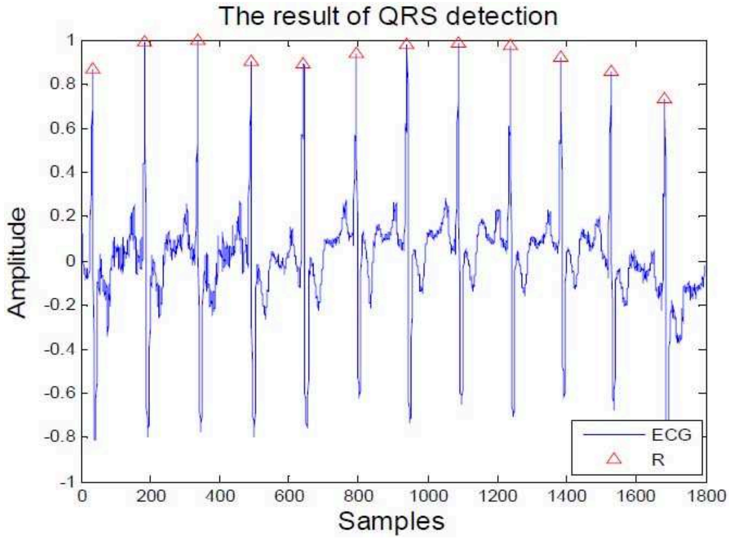

Figure 8. Detection results of tape #118

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