

QRS Characteristic Waveform Extraction Based On Biorthogonal B-Spline Wavelet

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Abstract

In order to solve the problems of occasional occurrence algorithm of negative R waves and misdetection and false detection of irregular R waves, compensates for the misdetection and false detection of R waves is introduced to detect QRS waves using quadratic biorthogonal B-spline wavelet transform, the correspondence relationship between signal singular points and zero-crossing points is analyzed by Mallat algorithm from the perspectives of modulus maxima of signals on different scales and Lipschitz exponent, QRS waves are obtained. Finally, this paper employed Matlab to extract the QRS characteristic waveforms of ECG signals from MIT-BIH arrhythmia database. The results show that the detection accuracy rate for QRS waves is up to 99.89% with higher robustness for several common interferences with ECG signals.

Keywords: Biorthogonal B-spline wavelet; ECG; singular point; QRS wave extraction

1. Introduction

In clinical medicine, electrocardiograms can indicate the pathological states of the various cardiac parts, with the significance in cardiac disease diagnoses. The domestic and foreign experts and scholars have studied the ECG characteristic waveform extraction methods for many years. The time domain analysis method and frequency domain analysis method are included, but unable to combine the time domain and frequency domain simultaneously. While wavelet transform is known as the microscope of signal analysis, with the ability to highlight the local characteristics of signals on time and frequency domain. Transient points occur in P waves, Q waves, R waves, S waves and T waves of ECG signals [1], the local singularities of which can be accurately depicted by wavelet transform. Thus, it is possible to automatically detect different characteristics of signals. Currently, mexican_hat wavelet, haar wavelet, gaus1 wavelet and spline wavelet are frequently used in ECG characteristic wave detection. The literature [2] proposed that in 1997, by using the first derivative of gaussian function as the wavelet base and Mallat algorithm to compute wavelet function, Sahambi from India learned through analyzing different levels of wavelet function that the maxima and minimum of modulus on the third and fourth scale corresponding to the zero-crossing point could reflect the position of the R wave. Detecting by this way, Sahambi also used a series of compensation methods to improve its accuracy which actually reduce the problems about misdetection and false detection. In 2001, using the second derivative of gaussian function as wavelet and designing wavelet filter, Yu Hui [3] and others achieved good results on

computing wavelet decomposition coefficients and calibrating the position of the R wave through the modulus maxima point detection of wavelet function by using Mallat algorithm for wavelet decomposition. In the literature [4], the time-frequency analysis methods of continuous wavelet transform (CWT) and fast wavelet transform (FWT) were used to detect each piece of ECG signal waveform information. Trahanias detected QRS wave through mathematical morphology method. With this algorithm, the wave crests and troughs of ECG signal were extracted and then the QRS waves were identified.

After comparing several wavelet bases, mexican_hat wavelet can cause defects in accurate detection of the starting and end points of QRS waves; Haar wavelet is not so applicable for the signals mixed with impulse noises [1], *etc.*, so quadratic biorthogonal B-spline wavelet is selected as the wavelet function, with better ECG signal detection effect. Then positive and negative maxima couple of wavelet transform coefficients are found, the peaks of the R waves are determined, which correspond to zero crossing points between the maxima couple, and the compensation strategy for misdetection and false detection is carried out. Thus, occasional negative R waves, as well as irregular R waves can be detected, which increases the accuracy of R waves detection, then Q waves and S waves can be detected accurately.

2. The Dection Principle Of Wavelet Transform For Singular Points

Let $h(t)$ be the convolution of function $f(t)$ and $g(t)$, and namely,

$$h(t) = f(t) * g(t) \quad (1)$$

According to the nature of the Fourier transform, the following expression can be obtained:

$$h'(t) = f'(t) * g(t) = f(t) * g'(t) \quad (2)$$

If the function $f(t)$ is considered as the input, $g(t)$ is the wavelet filter function, then the convolution between the derivative of input and wavelet filter will equal that between the derivative of filter and input. Therefore, there is a corresponding relationship between the wavelet transform mutation as well as extreme points and those of function $f(t)$, which can be observed as following: if signals are processed by the first differential wavelet transform, the signal mutation points are corresponding to zero crossing points of wavelet coefficients, while if signals are processed by the second differential wavelet transform, the mutations points are corresponding to the extreme points of wavelet coefficients.

3. The Selection Of Waveletbase

In the analysis the same problem, various results will be produced by different wavelet bases because of their unique time-frequency characteristics. A suitable selection of wavelet base can help detect the feature points of ECG signals with speed and accuracy. From the numerous wavelet transform studies of ECG signal singular point detection, Mexican hat wavelet and spline wavelet have been found better in R wave detection, but Mexican hat wavelet is not an orthogonal wavelet, with complex programming and unsatisfactory real-time performance, so quadratic biorthogonal B-spline wavelet is selected as wavelet base in the paper, which is a first order differential wavelet with symmetry and orthogonality. The wavelet base is calculated by the Mallat algorithm, a binary discrete wavelet transform made by adoption of the wavelet transform filter bank.

4. Mallat Algorithm

The binary wavelet transform of signals is made by Mallat algorithm, such as the formulae (3) and (4):

$$S_2^j f(n) = \sum_{k \in \mathbb{Z}} [h_k S_2^{j-1} f(n - 2^{j-1} k)] \quad (3)$$

$$W_2^j f(n) = \sum_{k \in \mathbb{Z}} [g_k S_2^{j-1} f(n - 2^{j-1} k)] \quad (4)$$

Where, $S_2^0 f(n)$ is ECG signal to be processed, $W_2^j f(n)$ is the wavelet coefficients, the binary wavelet transform of signal $f(n)$. h_k and g_k are respectively coefficients of digital low-pass filter $H(w)$ and high-pass filter $G(w)$. Since the coefficients of quadratic biorthogonal spline wavelet filter are given, the specific form of signal is not cared.

The low-pass filter coefficients are listed as follows: $h_0 = 1/4, h_1 = 3/4, h_2 = 3/4, h_3 = 1/4$, and the rest is zero.

The high-pass filter coefficients are listed as follows: $g_0 = -1/4, g_1 = -3/4, g_2 = 3/4, g_3 = 1/4$, the rest is zero.

Figure 1 is a four level decomposition chart of B spline wavelets for an ECG signal by Mallat algorithm.

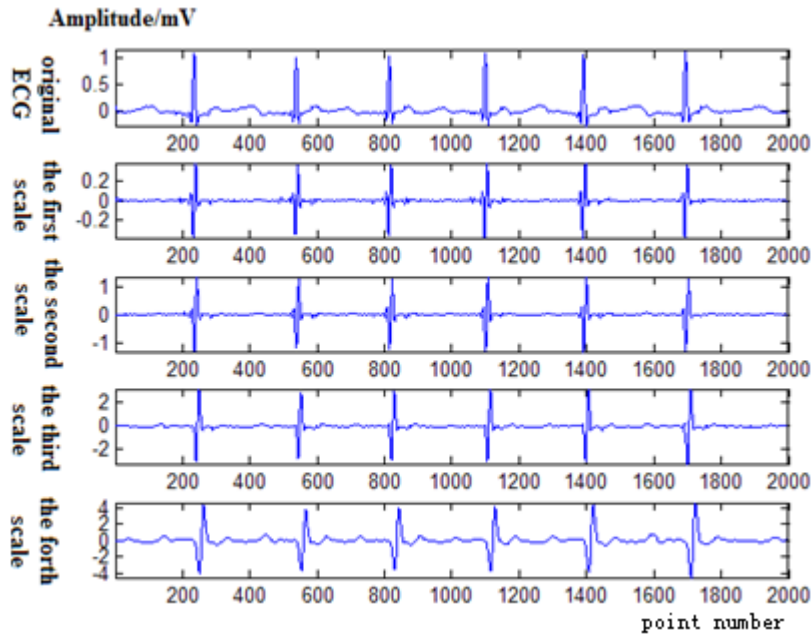


Figure 1. Four-level decomposition chart of B spline wavelets for ECG signal by Mallat algorithm

5. The QRS Characteristic Waveform Extraction Based On B-Spline Wavelet

5.1. Relationship between Lipschitz exponent and modulus maxima

The singularity of a function refers to the presence of disconnection somewhere or a discontinuous derivative for some order, which is commonly measured by Lipschitz exponent to achieve the regularity of signal in an interval or at a moment [5]. Therefore, it is an effective of detecting positions of mutation points of the signal. So, establishing the relationship between wavelet transform and Lipschitz exponent can determine the locations of singular points of the signal.

The Lipschitz exponent is defined as following:

If a constant $A > 0$ and an n -order polynomial “ P_n ,” can be found to let function $X(t)$ meet the following inequality when it is near the point t_0 ,

$$|X(t_0+h) - P_n(t_0+h)| \leq A|h|^a, n < a < n+1$$

Then, “ a ” is the Lipschitz exponent of $X(t)$ at the point t_0 , and h is sufficiently small.

Generally, the singularity of a signal is directly proportional to Lipschitz exponent. The increase in transform scale will result in the increase of the wavelet transform modulus maxima when $a > 0$, but the decrease of them when $a < 0$; when $a = 0$, they do not vary with the change of transform scale [6]. As shown in Figure 1, R wave with the highest amplitude is a piece of ramp signal in the raw ECG signal and positive and negative extreme couples appear in the sharp waveform through the multiple decomposition of wavelet transform. Besides Lipschitz exponent “ $a > 0$ ” at these two points, so the modulus maxima of wavelet transform enlarge with the increase in transform scale.

5.2. Relationship between R wave peaks and the crossing zero point of modulus maxima couple

If signals are processed by first-order differential wavelet transform, that is biorthogonal B-spline quadratic wavelet transform, it can be obtained that the zero-crossing point of modulus maxima couple is corresponding to the peak of R wave.

As shown in Table 1, the energy of QRS wave group mainly concentrates on the scales of 2^3 and 2^4 , while the energy of motion artifact, baseline drift mostly concentrates on the scales of 2^5 and 2^6 [7, 8]. Therefore, the primary task is searching the zero point of between modulus maxima couple on the scale of 23 after the signal is transformed at the 4 scales.

Table 1. Wavelet transform equivalent filter bandwidth

Transform scale	3dB bandwidth (Hz)	The center frequency
2^1	90.0~180.0	129.77
2^2	29.92~84.24	54.46
2^3	1.52~38.88	18.97
2^4	5.76~19.44	12.04
2^5	2.8~9.4	6.63

5.3. QRS wave detection algorithm flow

5.3.1 R wave detection flow

Figure 2 is the flow chart of R wave detection.

(1) Decomposition of the ECG signal for quadratic biorthogonal B spline wavelet by Mallat algorithm obtains the wavelet coefficients on the 4 scales;

(2) On scale 3, the point p with a wavelet coefficient larger than 0, and the point n with a coefficient smaller than 0, are found;

(3) p is divided into four sections to find the threshold, or “pth”, the mean of maxima for each section; any of them greater than the threshold “pth” is the positive maximum.;

(4) Similarly, n is divided into four sections to find the threshold, or “pth”, the mean of minima for each section; any of them smaller than the threshold “pth” is the negative maximum;

(5) The zero point between the maximum and minimum is checked, where the peak of R wave is.

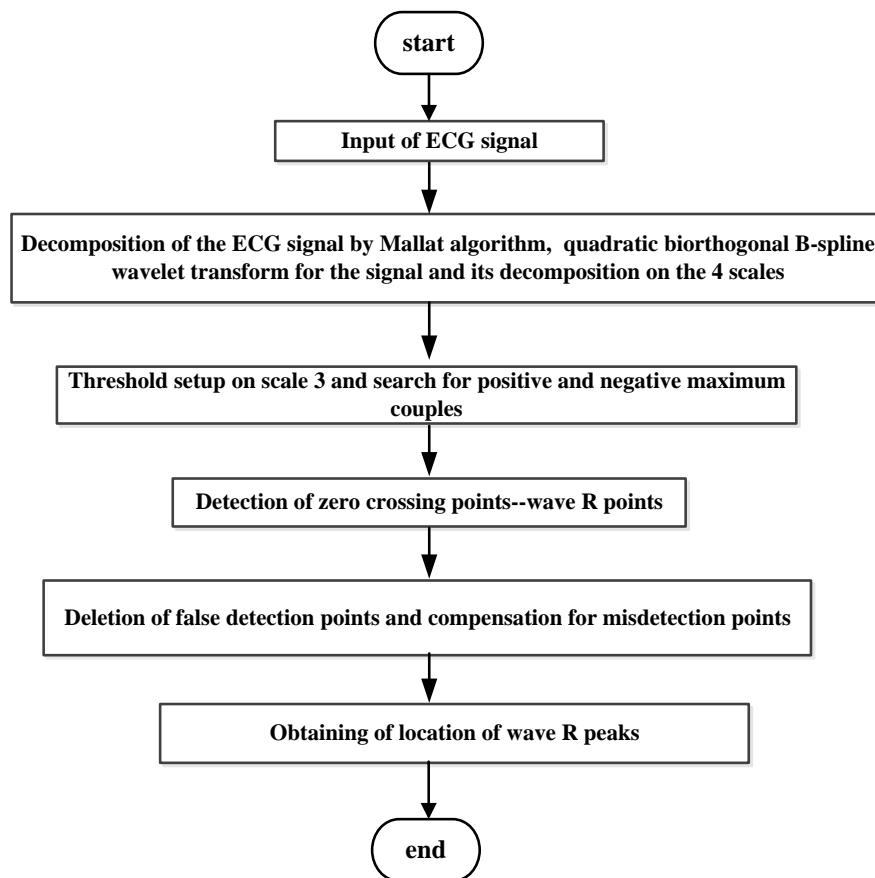


Figure 2. The flow chart of R wave detection

5.3.2 Compensation strategy for false detection and misdetection

(1) Figure 1 shows time shift arises between the peaks of the signal and their corresponding zero point. Therefore an amendment is needed to have more accurate detection. The time shift is $\frac{2^j - j}{2}$, where j is the transform scale.

(2) Individual differences in ECG signals may lead R wave peaks to irregular and the above threshold method can cause false detections or misdetections, which require compensation scheme as following: First all “R_R” intervals are calculated to find “RR means”. If the “RR” interval >1.6 (RR mean)”, it is viewed as occurrence of misdetections. So the threshold is reduced to half of the maximum mean to search within the RR interval. If nothing is found in the “RR” interval, it may be a negative R wave. In the same way, if “R_R” interval <0.4 (RRmean), misdetection happens. Then the larger one is kept as R wave and the smaller one is eliminated.

Figure 3 and Figure 4 are the compensation result of false detection and misdetection about negative R wave of the signal 200 and 207.there are positive and negative R waves in these signals. Figure 5 is the compensation result of false detection and misdetection about positive R wave of signal 100.

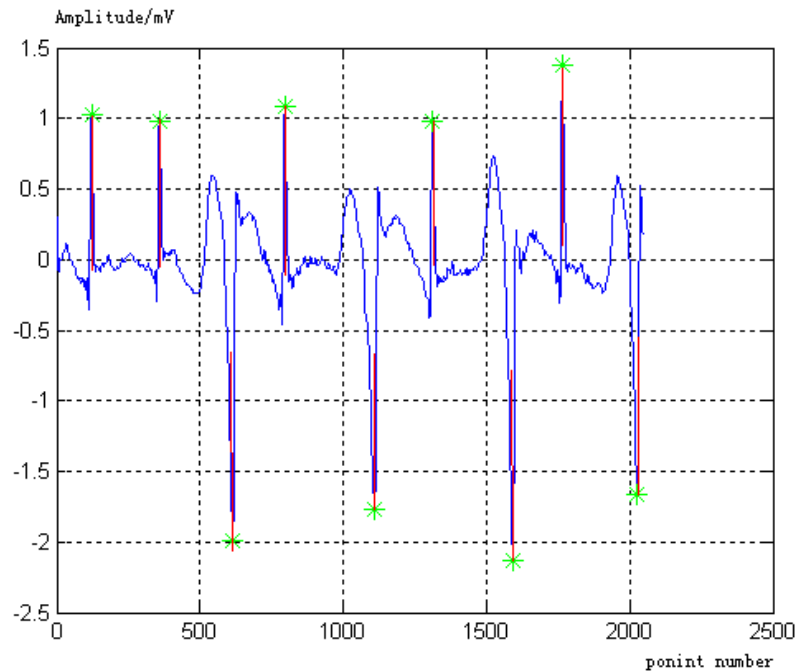


Figure 3. Compensation result of false detection and misdetection about negative R wave of signal 200

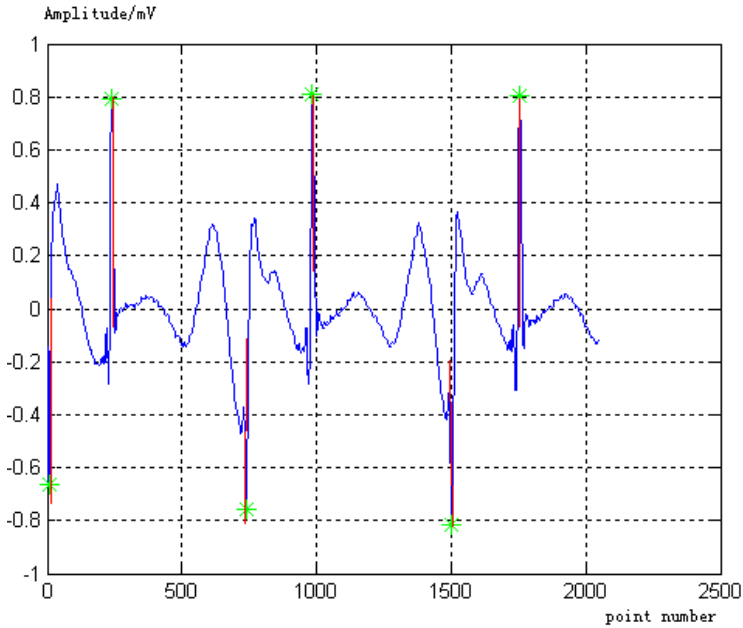


Figure 4. Compensation result of false detection and misdetection about negative R wave of signal 207

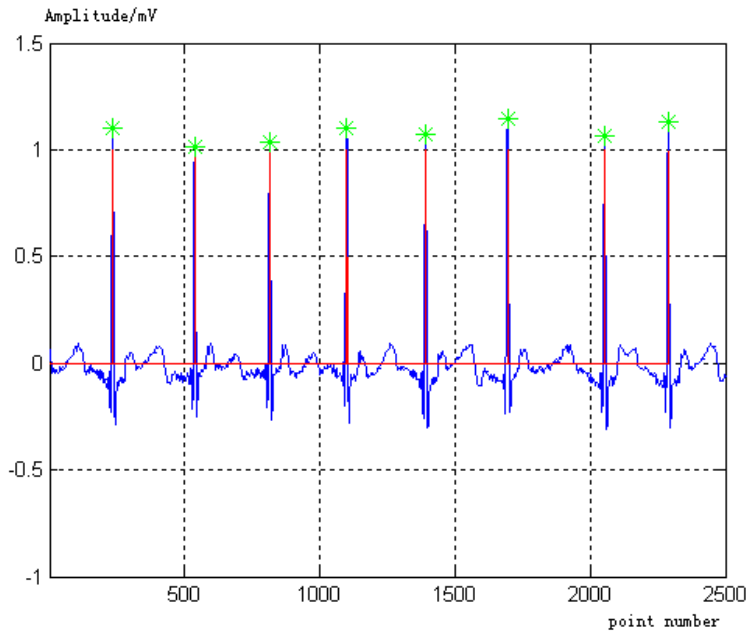


Figure 5. Compensation result of false detection and misdetection about positive R wave of signal 100

5.3.3 Detection of the starting and end points for QRS waves

Since QRS interval is one of important diagnostic parameters of cardiac function, the starting and end points of the QRS waves need further detection--the starting point of Q wave and the end point of S wave if R wave is determined. Q wave and S wave are those with high

frequency and low amplitude, thus distribution of their energy is mainly on scale 2^1 of wavelet transform. Search windows are respectively determined on scale 2^1 before and after the peak point of R wave to find the modulus maxima. Where they appear are the starting points of Q wave and the end points of S wave. Then QRS wave is fully detected, which lays the foundation for clinical detection of other waveforms. Figure 4 and Figure 5 are the detection results of signal 101 and signal 201 from MIT-BIH arrhythmia database, where ‘*’ represents the position of R peak, and between each two black vertical lines is QRS interval.

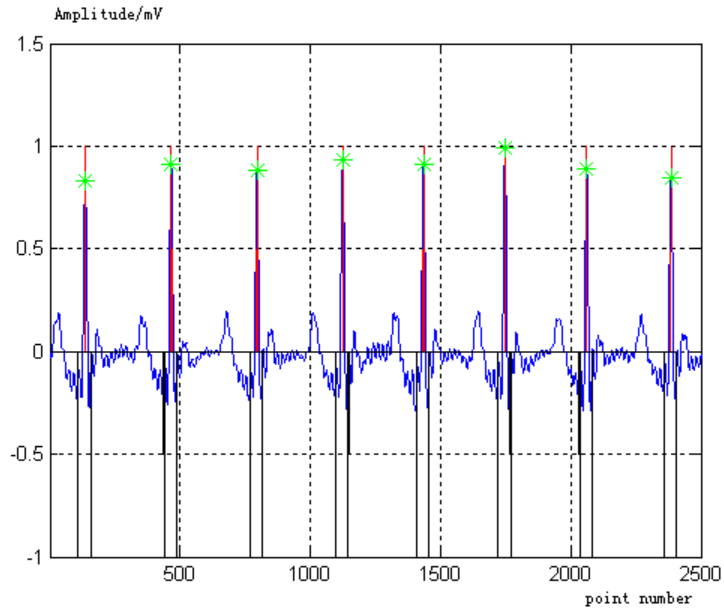


Figure 6. Detection result of signal 101

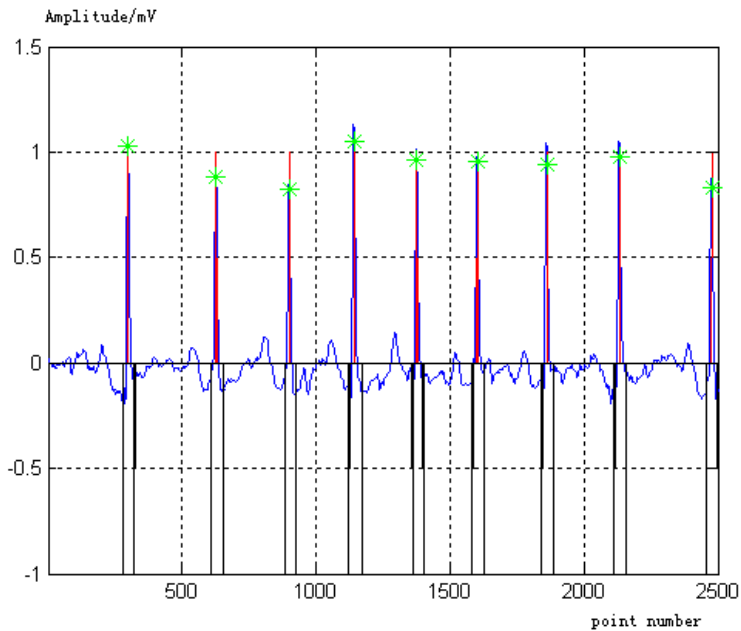


Figure 7. Detection result of signal 201

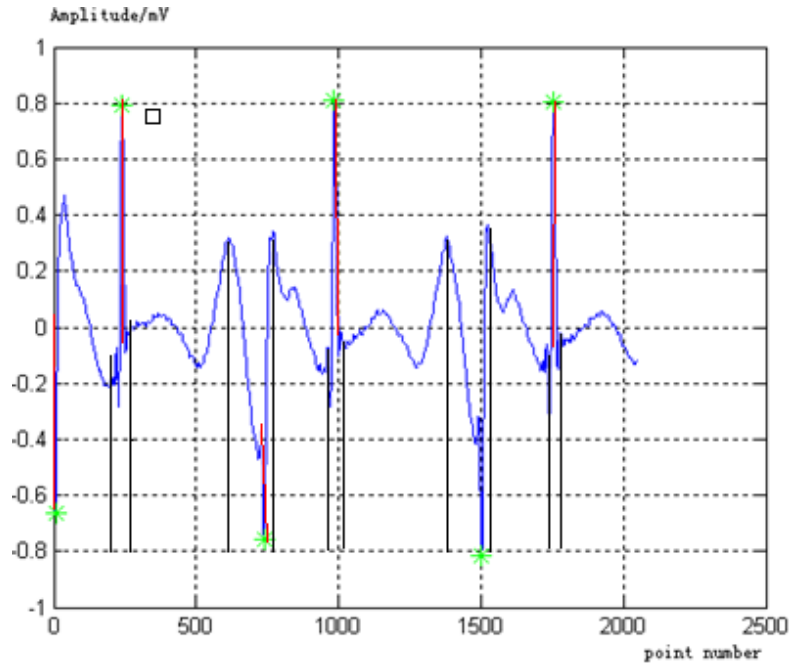


Figure 8. Detection result of signal 207

5.3.4 Experiment results

From Figure 6, 7 and 8, it can be found that this algorithm can not only detect positive R waves but also sense occasional occurrence of negative R waves accurately, without significant impact on detection accuracy of Q waves and S waves.

Table 2 records the detection results of several signals from MIT-BIH arrhythmia database. The average accuracy rate is up to 99.89%. For signal 200 and 207, negative R waves appear, which can be accurately detected by this method; for signal 201, irregular R wave peaks can be also detected with better effect. For signals that have positive and negative R waves, some errors occur on the starting and ending points of their Q waves and S waves, but this has no strong impact on the detection effect.

Table 2. ECG Signals Detection Records From MIT-BIH Arrhythmia Database

File (total heart beat number)	false detection number	Misdetection number	Total false detection number	Accuracy rate
100 (2273)	0	4	4	99.82%
101 (1865)	0	3	3	99.84%
102 (2187)	2	0	2	99.9%
103 (2084)	4	0	4	99.81%
104 (2229)	1	1	2	99.95%
105 (2572)	0	0	0	100%

106 (2027)	0	0	0	100%
107 (2137)	1	0	1	99.95%
108 (1763)	0	0	0	100%
109 (2532)	1	1	2	99.92%
111 (2124)	2	2	4	99.81%
112 (2539)	2	0	2	99.92%
113 (1795)	1	0	1	99.94%
114 (1879)	2	0	2	99.89%
121 (1863)	2	3	5	99.73%
201 (1960)	0	3	3	99.64%
207 (1860)	3	1	4	98.76%
208 (2955)	0	1	1	97.73%
210 (2650)	1	0	1	99.96%
Total (39434)	22	19	41	99.89%

6. Conclusions

With the biorthogonal B-spline wavelet as the wavelet base, the ECG signals are decomposed by wavelet transform by using the Mallat algorithm, and then the signal frequency characteristics are analyzed on each scale. It is learned that the characteristics of R waves on the third scale could be better reflected. Then on this basis, R waves are detected by introducing misdetections and false detections compensation. The positive R waves could be detected accurately, while the occasionally appeared negative R waves well. In this way, the non-detection or poor effect of negative R waves are solved, with minor effects on the Q waves and S waves detection.

With a better detection effect, this overcomes the shortcomings of Mexican_hat wavelet in this aspect. The experiment results indicate that, without filtration, QRS waves can be also better detected with better robustness for several common interferences with ECG signals. As a conclusion, quadratic biorthogonal B-spline wavelet has high application value in ECG signal detection.

Acknowledgements

Sincerely thanks to all my relatives who gave me encouragements during my paper writing, as well as my friends and colleagues who gave me lots of inspiration and guidance with their careful guidance, rigorous scholarship and tireless teachings. I hope that they would write more high-level papers and we can discuss with each other.

Last but not the least, I would like to thank my college who gives me a platform to study and work. Without her help, I would not have the opportunity to keep on improving my ability and show myself.

References

- [1] Q. Ying, "Several Cases Comparison of Singularity Detection of ECG Signal", Science & Technology Information, vol. 10, (2009), pp. 62.
- [2] J. S. Sahambi, S. N. Tandon and R. k. Bhatt, "Using wavelet transforms for ECG characterization: an on-line digital signal processing system", IEEE Engineering in Medicine and Biology Magazine, vol. 16, no. 1, (1997), pp. 78-83.
- [3] Y. Hui, Z. Lixin and L. Yangsheng, "The QRS wave Detection based on Wavelet Transform", Biomedical Engineering and Clinical Medicine, vol. 5, no. 2, (2010), pp. 65-70.
- [4] Chenokov, Nerukh and Glen, "Individually Adaptable Automatic QT Detector", <http://www.physionet.org/challenge/2006>.
- [5] C. Zhen-cheng and B. Jia-lian, "Study of Detection Method on QRS Complexes Based on Wavelet Transform", Chinese Medical Equipment Journal, vol. 30, no. 2, (2009).
- [6] Z. Hong-jun and Z. Fu-qiang, "Detection of ECG QRS Wave Group Based on Matlab", Journal of Shandong Education Institute, vol. 4, (2010), pp. 41-43.
- [7] L. Cui-wei, Z. Chong-xun and Y. Chao-wei, "A Detection Method of ECG Using Wavelet Transform", Chinese Journal of Biomedical Engineering, vol. 14, no. 01, (1995), pp. 59-66.
- [8] R. Guo-hai, Y. Li-hai, J. hao and D. Peng-ying, "The ECG Signal Detection and Pretreatment in Portable ECG Monitor", Chinese Journal of Scientific Instrument, vol. 30, no. 6, (2009), pp. 239-242.

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