ISSN: 2664-9640

Research on ECG R-wave location algorithm based on Otsu method

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Abstract

R-wave localization is one of the most important links in ECG signal processing. Due to different people's physique and different resistance values of body epidermis during ECG signal acquisition, the Otsu method is introduced to process the signal and the optimal segmentation threshold can be calculated. In order to improve the adaptability of the system and accurately locate the ECG R wave in different scenarios, the algorithm first filters the original ECG signal to remove the interference signal, and then performs differential processing on the signal to highlight the signal characteristics. The one-dimensional signal processing is transformed into two-dimensional image, the optimal threshold is calculated, and the peak of the signal is proposed, The accurate position of R wave is obtained by using the peak location algorithm. The experimental results show that the algorithm has the advantages of high recognition rate and strong adaptability.

Keywords

Otsu method; Differential threshold; R-wave positioning.

1. Introduction

ECG always has been one of the most important physiological signs in the human body. From pulse taking in Chinese classical medicine to ECG physical examination in modern medicine, the importance of ECG in human health detection is reflected everywhere. In recent years, with the rapid development of China's economy and people's continuous attention to the level of physical health, Physical examination and other predictive methods have attracted more and more attention, so the research of ECG is paid more and more attention. ECG detection can not only monitor the health level of cardiac function and early perception of cardiovascular diseases, but also obtain the mental state of human body by further analyzing its ECG variability, such as mental stress, sleep quality and so on. Whether it is ECG detection or heart rate variability calculation, it is necessary to locate the R-wave of ECG signal. The accuracy of R-wave location plays a key role in heart rate calculation and HRV analysis. At present, there are many ECG detection algorithms, such as wavelet analysis, template matching, machine learning, etc., but they all have a common feature, which is not conducive to embedded application, Both require a lot of calculation and consume resources. For embedded ECG equipment, the differential threshold method has always been a good choice. As long as the threshold value is calculated accurately, the R wave can be located accurately. Therefore, this paper will focus on the R-wave positioning algorithm, use the Otsu method to calculate the dynamic threshold, and then accurately locate the R-wave through the differential threshold method and peak detection.

2. ECG signal preprocessing

2.1. ECG signal

ECG is the biological pulse electrical signal when the biological heart beats regularly. The electrophysiological phenomena of depolarization and repolarization of cardiomyocytes are

ISSN: 2664-9640

the basis of cardiac movement [1]. A series of very coordinated electrical stimulation pulses generated inside the heart excite the muscle cells of atrium and ventricle respectively, making them relax and contract rhythmically [2]. These movements form different potential differences in different parts of the body surface. We usually call these potential difference signals detected from the body surface ECG signals [3]. Its central wave shape contains a variety of signals. This algorithm is mainly aimed at the location of R wave.

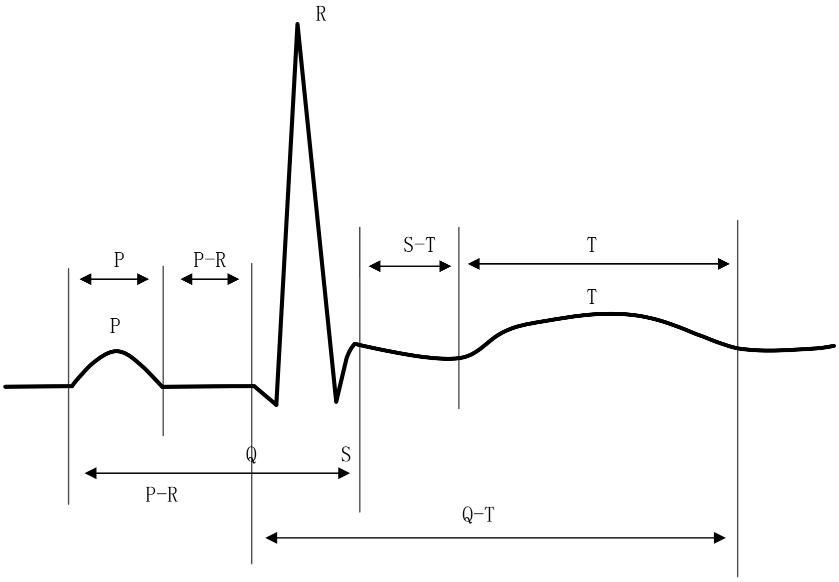

Figure 1: Cardiogram

2.2. ECG signal noise interference

Human bioelectrical signal is a huge, complex and extremely precise system. ECG signal is one of many physiological signals of human body. Human physical sign signal is extremely weak, and the frequency range is mostly low-frequency signal. Due to the high impedance and certain randomness of human skin [4]. It is easy to be disturbed by various activities in human body, external environment and electromagnetic field radiation. Due to the interference of human movement and external contact, the internal organs of human body are affected, resulting in the interference of ECG signal by noise [5]. Therefore, in the collected ECG original signal, there are not only ECG signal, but also respiratory signal, power frequency interference and human EMG signal.

2.3. ECG signal noise interference

Because the collected ECG original signal is mixed with various interference signals, the interference needs to be filtered before ECG signal analysis. In this paper, low-pass filter is used to filter out high-frequency interference and band stop filter is used to filter out power frequency interference in commercial power [6].

2.3.1. Low pass filtering

Electronic products have been everywhere. The human body is in the environment with various electronic products. Because the human body is a conductor, it will sense a certain electromotive force [7]. Due to the extremely weak ECG signal, its signal amplitude is generally 0.05 ~ 5mv, so it is easy to be disturbed by high-frequency signals [8], and the frequency of ECG signal is mostly below 5Hz [9], Therefore, the high-frequency signal can be filtered by low-pass filter.

2.3.2. Remove power frequency interference

Power frequency interference is because the mains power is AC, which is generally 50Hz AC in China. It has strong 50Hz noise interference in ECG signal through power circuit or capacitance

ISSN: 2664-9640

propagation of insulating layer, but the interference frequency is fixed. Therefore, the noise can be effectively filtered by using 50Hz and 100Hz band stop filters. Among them, 50Hz filter can filter out the main power frequency interference, but after filtering, it will produce 100Hz secondary wave. Therefore, using 100Hz filter can make the waveform more smooth. The 50Hz band stop digital filter is used in this paper, its sampling frequency is, and its amplitude frequency response diagram is as follows:

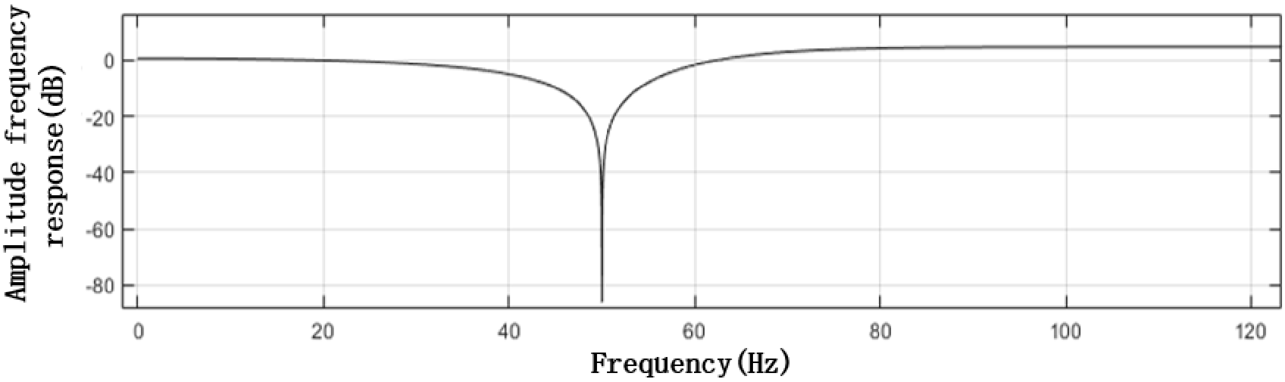

Figure 2: Amplitude frequency response curve

As shown in Figure 3 and Figure 4, the filtered waveform is smoother and cleaner, providing a better data basis for later processing.

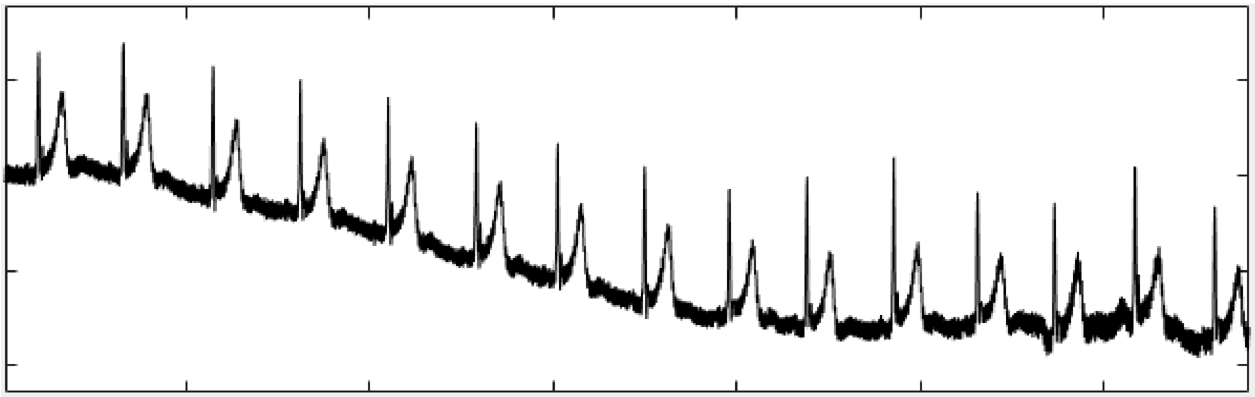

Figure 3: Original waveform

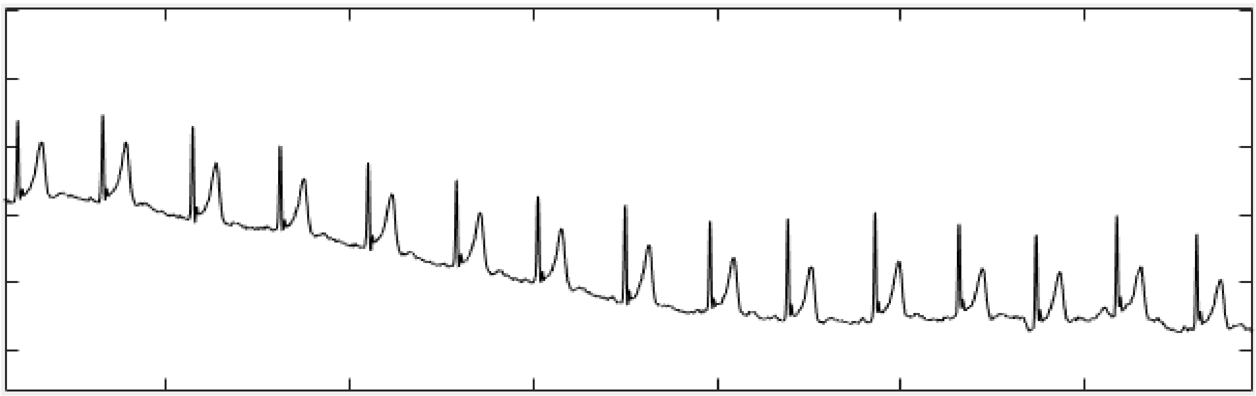

Figure 4: Waveform of filtered power frequency

2.4. Difference and conversion processing

The waveform of ECG signal is composed of P wave, PR segment, QRS complex, St band and T wave, in which the signal mutation between QR waves is particularly obvious [10]. In order to better locate R wave and avoid being affected by P wave and T wave, it is necessary to make first-order difference on the signal to make the sudden change significant. After the difference,

ISSN: 2664-9640

the waveform not only has remarkable characteristics of PR wave, but also can effectively remove the baseline drift. The baseline drift is the phenomenon that the baseline of ECG signal is transferred due to the change of body resistance and electrode relaxation. If it cannot be effectively removed, the threshold can not accurately segment the wave peak and locate the R wave accurately. The difference can effectively remove the baseline drift and highlight the PR wave.

After the first-order difference, the wave crest will be more prominent, and the accurate position of R wave is located between the peak and peak valley. At this time, it is more convenient for the accurate positioning of R wave in the later stage. The difference formula is shown in formula (1), where n is the length of data, y '(n) is the data after difference, and Y (n) is the data before difference.

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

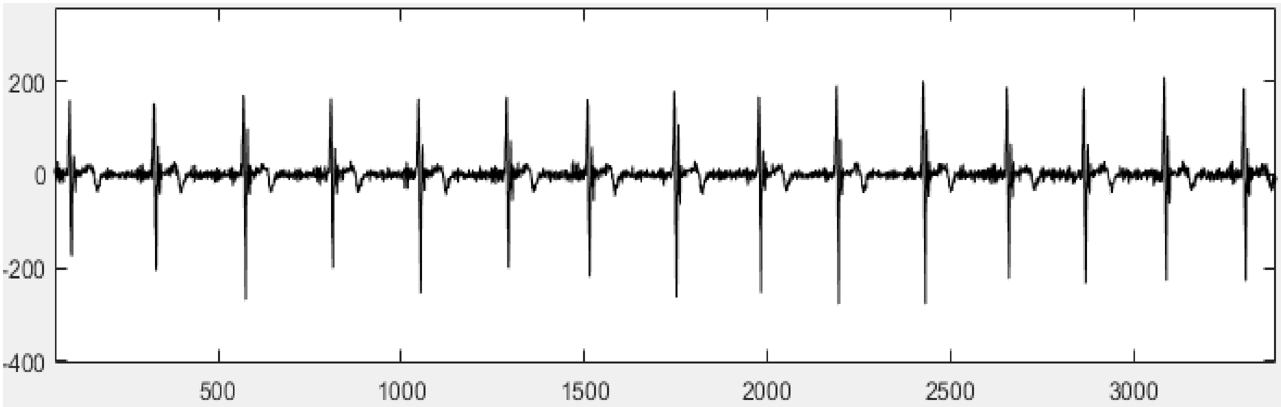

Figure 5: Waveform after difference

Firstly, the waveform is transformed so that the values without zero crossing are set to zero. Secondly, the values are normalized. Each processed data point is multiplied by 256 and rounded. Each processed data point can be regarded as the gray value of a pixel, and the whole waveform can be regarded as a row of gray pixels. The processing formula (2) shows the processed data. After the differential data is processed, only the data waveform greater than zero is left, as shown in Figure 6.

$$f(n) = \begin{cases} 0 & y'(n) < 0 \\ y'(n) & y'(n) \geq 0 \end{cases} \tag{2}$$

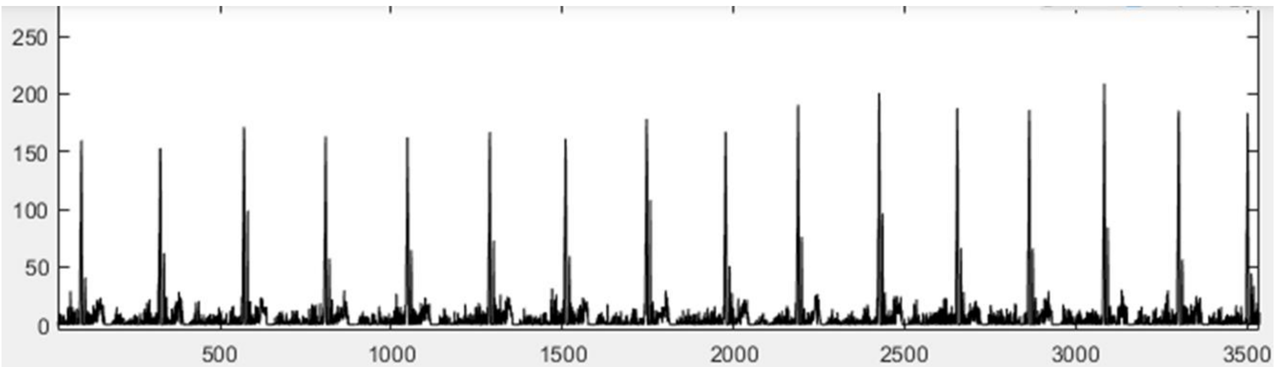

Figure 6: Waveform of zero crossing

ISSN: 2664-9640

3. Dynamic threshold of Otsu method

Otsu method is a common algorithm in image binarization algorithm. It is used to segment the foreground and background of the image, so that the effective features of the image are enhanced. Otsu method is also known as the maximum inter class variance. Its principle is to select a threshold T to divide the data in the image into two groups. The gray level of pixels in one group is less than this threshold, which is called background [11], and the gray level of pixels in the other group is greater than or equal to this threshold, which is called foreground. If the variance of the gray value of the pixels in the two groups is the largest, the obtained threshold is the best threshold. Variance is a measure of the uniformity of gray distribution. When the inter class variance between background and foreground is greater [12], it indicates that the difference between the two parts of the image is greater. When part of the foreground is wrongly divided into background or part of the background is wrongly divided into foreground, the difference between the two parts will become smaller. Therefore, the segmentation that maximizes the variance between classes means the minimum misclassification probability. Using this threshold, the image can be divided into foreground and background [13]. For the R-wave location of ECG signal, its purpose is to separate the differential peak from the following interference waveform, so as to provide good data waveform for subsequent peak detection.

Set the threshold value as t, and divide the processed gray-scale pixels into two categories according to the threshold value T, with the mean values of, and the probability of being divided into two categories of. The total pixel mean is:

$$M = m_1 p_1 + m_2 p_2 \tag{3}$$

According to the concept of variance, the expression of inter class variance is:

$$\delta^2 = p_1(m_1 - M)^2 + p_2(m_2 - M)^2 \tag{4}$$

The simplified formula can be obtained by substituting (3) into (4), as shown in formula (5):

$$\delta^2 = p_1 p_2 (m_2 - m_2)^2 \tag{5}$$

According to the pixel size of 0 ~ 256, the cross class variance value of T within the value range of the pixel is obtained through traversal, and the threshold T at this time is the best segmentation threshold. Divide the original waveform with the threshold T, assign all pixels less than the threshold to zero, and only retain the waveform greater than the threshold to obtain the following waveform diagram:

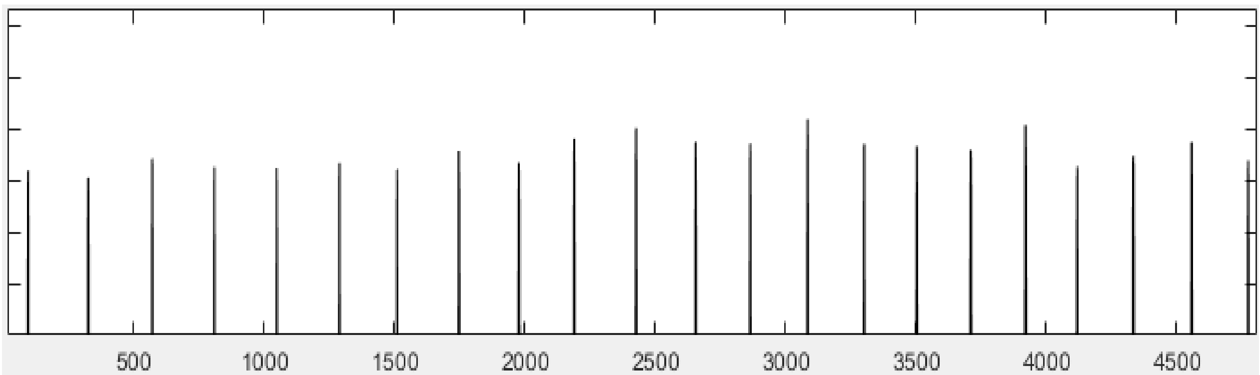

Figure 7: Intercepted wave crest

4. Peak detection and R-wave location

After the threshold segmentation, there are only one peak left in the data. At this time, it is only necessary to quasi locate the peak position. According to the peak is the only peak point, the method of point by point comparison can be used for identification. Set the amplitude of the first pixel point as. When the point meets and, the point is the maximum peak point. Record the abscissa of the point, that is, the abscissa of R wave.

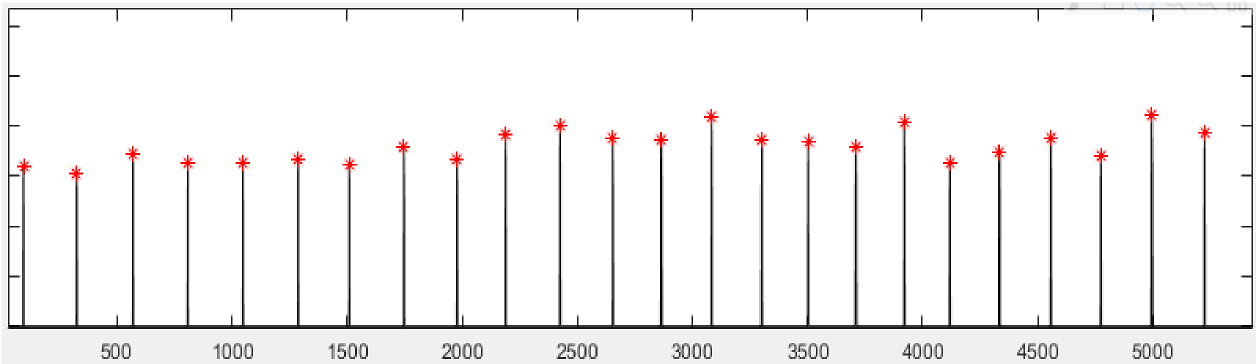

Figure 8: Peak location diagram

5. Experimental verification and result analysis

In order to verify the reliability and accuracy of this method, this paper makes an experimental analysis. The ECG data is collected through openbci v3. The acquisition chip ads1299 uploads the collected data to the computer, and calculates and analyzes the error of the data.

First of all, the experiment conducted multiple data collection for different experimenters and different scenes, and divided the experimenters into two groups for measurement respectively. The first group had no strenuous exercise and drinking alcohol, coffee, tea and other products within two hours before the test, and the second group measured immediately after running for one kilometer before the test. Each group selected 7 groups of effective data for analysis and comparison, The selected ECG waveform measurement data are measured in ten minutes. The number of R waves calculated by this method is compared with the actual number.

In the first group of experiments, the experimental objects are all heart rate measurements in a calm state. Their heart rates belong to a stable state, and the data are stable as a whole. The algorithm in this paper is calculated with MATLAB, and the results are compared. The comparison results are shown in Table 1:

Table 1: (group 1) Comparison of R-wave recognition number in ten minutes

Sample number	Positioning quantity	Real quantity	Error rate %
1	701	702	0.142
2	687	687	0
3	731	732	0.137
4	694	696	0.287
5	692	692	0
6	682	683	0.146
7	705	705	0

In the second group of experiments, due to the high psychological level after the exercise, the center rate gradually decreased during the ten minute measurement process, which will increase the difficulty of R-wave recognition and heart rate calculation. The calculation results are shown in Table 2 below:

Table 2: (group 2) Comparison of R-wave recognition number in ten minutes

Sample number	Positioning quantity	Real quantity	Error rate %
1	1372	1370	0.146
2	1456	1455	0.069
3	1253	1256	0.239
4	1547	1546	0.065
5	1623	1622	0.062
6	1467	1467	0
7	1434	1436	0.139

Experiments show that the results of this method in different environments are relatively ideal and the error is small. Through the comparative analysis of the identified waveform annotation, it is concluded that the error data of the experiment is mainly the identification misjudgment of the beginning and end of the data. In the preprocessing process, when the head and tail are not complete waveforms, it is easy to misjudge and can not be identified accurately.

6. Conclusion

This paper mainly studies the R-wave location algorithm of ECG signal. By improving the processing of ECG signal, the one-dimensional waveform of ECG signal is transformed into two-dimensional pixels, which opens up a new method for ECG signal processing. The optimal separation threshold calculated by Otsu method can make the system used in various scenarios. It greatly improves the shortcomings of the traditional differential threshold method. Then, after extracting the wave crest, locate the wave crest to get the position of R wave, and count the number of R waves. The experimental results have high accuracy and good reliability. Although there are still some errors in the experiment, it mainly exists in the beginning and end of the waveform, and it needs to be optimized in the later stage.

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