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Research and Development of Electrocardiogram P-wave Detection Technology

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Abstract: In this study, a brief overview on the ECG P-wave automatic detection was presented, including the P-wave of ECG preprocessing techniques and several common detection methods. In addition, some types of analyses and comparison of detection algorithms were carried out. Finally ECG P-wave direction was identified.

Keywords: Detection, ECG, Filtering, P-wave, Recognition.

1. INTRODUCTION

ECG examination technology not only has important reference value in the diagnosis of cardiovascular diseases, but it has been widely used in intensive care and critical care emergency [1]. The typical ECG basically consists of P-wave, QRS complex wave and T-wave, and sometimes T-wave after the U-wave. When abnormal ECG waveform is observed , according to the changes in waveform, doctors can speculate that patients may suffer from the following diseases: such as atrial or ventricular hypertrophy, cardiac arrhythmia, myocardial infarction, coronary insufficiency, cardiac displacement, pericarditis and so on.

P-wave is an atrial depolarization wave. The starting point means that the right atrial depolarization starts while the end point means that two atrial depolarization is completed. First half of P-wave represents the right atrial depolarization and latter part of P-wave represents the left atrial depolarization. P-wave's normal amplitude is about 0.22mV-0.25mV, and its width is generally not more than 0.11 seconds. P-wave detection has social significance and major economic benefits in automatic ECG diagnosis. Because of the diversity and complexity of the ECG waveform, automatic analysis and recognition also include many problems, especially P-wave recognition. In the ECG, the detection of P-wave is more difficult than the QRS complex wave because of small amplitude, low frequency, and difficulty in separating the interference and noise.

2. P-WAVE PRETREATMENT TECHNOLOGY

ECG may be interfered inevitably by various types of interferences, such as common-mode signal, the power frequency interference, baseline wander, and EMG interference. For the P-wave detection and analysis, noise suppression and exclusion are mandatory.

Currently, the filtering method of ECG signal mainly includes hardware filter and digital filter. Hardware filter is mainly designed by improvement in ECG machine. It uses the improved circuit common mode rejection ratio, reasonable shielding and grounding, and uses the analog filters, optical isolation, with excellent performance and a floating device tracking circuit technology and other measures. With the development of information technology, digital filtering technology has become an effective means for digital ECG machine for filtering out interference. Digital filtering techniques include the following four methods [2].

2.1. Levkov Filtering

In 1984, Levkov proposed an effective ECG signal processing algorithms named as digital filtering method, based on the linear and non-linear segments using different segment approach [3]. In 1988, Christov improved this method, which used the linear segment criterion M to accelerate the filtering speed [4]. This method, first needs to identify a linear segment in the process of filtering, and the value after linear filtering which is the average of the linear section of the original data value. It also calculates the frequency interference value as frequency interference template based on nonlinear segments. In the non-linear segment, its true value is subtracted from the value of interference near the linear segment template obtained by the original data. Here the original ECG signal should meet two conditions: first, the sampling frequency must be integer multiple of frequency signal; second, the amplitude of frequency interference signal acquisition points add up to 0. The method is simple, having adjustable parameters, with a small amount of computation and easy real-time processing, and it also makes it possible to follow the changes in noise frequency [5].

2.2. Adaptive Notch Method

Adaptive filter can track and adapt to the dynamic changes of the system or the environment, and it does not need to know in advance the characteristics of signal and noise. It changes the filter parameters using the expected value and the value of negative feedback through comprehensive

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judgment method. Adaptive processing is used, not only to determine the frequency interference, but it can also automatically track the drift frequency with good adaptability. The main designing criteria of adaptive notch filter is to minimize mean square error of the output signal of the system and the useful ECG signal. Adaptive notch filter has a strong inhibitory effect for frequency interference, and is able to follow the changes in the frequency and amplitude of the interference, thus achieving a higher signal to noise ratio. Wang [6] studied an ECG frequency interference suppression method based on least squares QR decomposition (QRD-LS) algorithm adaptive notch technology. They made full use of the adaptive filter's ability of automatic tracking interference, automatic removal of power line interference and improving signal to noise ratio. But this method also has deficiencies, such as complex algorithm and machine, difficult real-time implementation, and the requirement of additional reference signal channel, *etc*. [7].

2.3. Neural Network Filtering

Neural network approach has been used to explain many complex physiological phenomena, such as ECG and EEG recognition, ECG signal compression, recognition and processing of medical images. Neural networks with distributed storage capacity and fast self-evolution, have a unique role in optimizing computing. Under the initial given conditions, their evolution will be completed within a few multiplication cycles. Hardware-based neural network adaptive filter will greatly improve the timeliness of the adaptive filter [8]. Document [27] analyzed ways and means of using neural networks to calculate the adaptive filter weights, which can greatly improve computing speed and complete real-time diagnostics.

2.4. Wavelet Transform Filtering

Typically, the experimental results show that wavelet transform can effectively filter out interference based on edge detection dyadic wavelet, with relatively good real-time performance [9]. Wavelet analysis has been widely used in automated ECG analysis and Addison [10] reviewed the application of wavelet transform in ECG in detail. In addition, Sahambi [11] used a Gaussian function as the mother wavelet function. Young [12] and Zhang [13] used a cubic spline and Weng [14], Xia [15] and Duan [16] used orthogonal quadratic spline wavelet decomposition.

3. P-WAVE RECOGNITION ALGORITHM

Commonly used positioning methods to identify the P-wave characteristics are mainly point method and the area incremental method [17]. In addition, scholars explored the use of median filtering, template, function approximation method, evolutionary algorithms, ANN, wavelet transform [18-21] and so on. P-wave recognition is far less reliable than the identification of QRS. At the same time due to the lack of unified labels' databases to be compared, it is difficult to compare the accuracy of each algorithm, and to improve the algorithm as well. Some commonly used detection algorithms are discussed below.

3.1. P-wave Detection Based on Rules

P-wave recognition is mainly based on the rules recognition, such as scanning all the inflection point in the QRS wave front in a particular area, with the maximum amplitude as peak inflection point of the P-wave . Because of simplicity of its implementation, this method is widely used with QRS wave based detection algorithm. Based on ECG parameters amplitude, slope length, and RR, a threshold was used to judge the [22] formula. Sahambi [10] used 5% of the modulus maxima as the threshold for P-wave.

Yang [11] pretreated ECG signal using three order spline wavelet, and initially determined whether there is P-wave. He searched candidate P-wave value according to the fifth layer of thresholding, and used the airfoil function to highlight the volatility changing characteristics, and determined P-wave by thresholding. Finally, he accurately detected peak point of P-wave and determined P-wave morphology. By using 320 cases among the actual cases (from Shanghai Sixth People's Hospital, not including atrial fibrillation), he detected these P-waves, and the accuracy rate was observed to be as high as 98%.

Zhang [12] decomposed ECG signal using three order spline wavelet algorithm ,and selected the first five scales as P-wave detection. P-wave peaks ranged between wavelet transform modulus maxima and crossed zero. This algorithm used the amplitude, curvature, span and other parameters to pinpoint P-wave peak, and extracted the start and end of the P-wave, and finally calculated P-wave time and amplitude parameters according to the discrimination. Test samples randomly selected 702 cases to obtain ECG data (normal 469 cases, and 233 abnormal cases). Comparing the test results of 469 normal cases manually, the accuracy was observed to be 98%.

Weng [13] also selected the fifth scale for P-wave detection scale using two orthogonal spline wavelets. The principle is that magnitude greater than a dynamic threshold in this window is searched using a time window on the scale of 5.

Xia [14] used the following algorithm. The ECG signal was preprocessed to remove the baseline and the high-frequency interference. He wavelet decomposited the ECG data, using orthogonal two splines with compactly supported set and a disappearance factor. On the scale of 4, first he found all modulus in the region from R-wave front 450ms to R-wave. Following this, he obtained the magnitude of extreme value (amplitude maximum or minimum) for candidate points of P-wave's peak on the original signal. To remove all the non-P-wave, they got radians of P-wave and the correlation coefficient of P-wave and polyline P-wave were obtained after obtaining all the starting and end points of the P-wave. According these two values, all non-P-waves were screened and the rest of the P-waves were considered as the real P-wave. The complex P-wave, was determined by the correlation coefficient because the correlation coefficient indicates the correlation between candidate P-wave and polyline p-wave generated by the candidate wave. For some of the noise P-waves, although there are significantly extreme pairs and higher amplitude and radians, but they are less relevant with polyline p-wave, therefore, they can be accurately excluded using the correlation coefficient threshold value.

3.2. P-wave Detection Based on Artificial Neural Networks

Artificial neural network is a neural network used to mimic animal behavior characteristics, and it is a distributed parallel information processing algorithm which is based on mathematical models. This network relies on the complexity of the system, adjusts the relationship between the large number of internal nodes, to achieve the purpose of processing information. Vasquez *et al.* [23] described a neural network algorithm to eliminate QRS-T wave and detect P-wave. The algorithm of time delay neural network consists of two ECG signal shift functions. The authors compared three delay neural networks' layout: front pure propagation, simple cycle, and all cycle. The experimental results show that the effect of simple cycle layout was the best. Valfredo *et al.* [24] detected P-wave by the three-tier structure of fuzzy neural network. The structure had three nodes, an input node, an intermediate layer and an output node. Its input sequence sample was obtained from ECG signal, corresponding to the input layer and the ECG signal sampling windows based on Genetic Algorithm. They tested the algorithm using ECG signal collected from three volunteers with accuracy of 85%. Liu *et al.* [29] proposed ECG waveform detection and identification methods, based on sparse decomposition and neural networks. Their algorithm can simultaneously detect and identify the P-wave and other major waveforms.

3.3. Wavelet Transform Combined with Neural Network P-Wave Detection

Because wavelet transform has good time-frequency, localization properties and zoom features, and neural network has self-learning, self-adaptability, robustness and generalization ability, therefore, combining wavelet transform and neural networks has become an issue of concern. If there are M-type P-wave and biphasic P-wave in ECG, Domider *et al.* [25] proposed that the simple use of wavelet analysis to detect the P-wave will result in serious drawbacks and false detection. In view of this situation, the author proposed wavelet neural network algorithm, which first decomposed the signal using Gabor wavelet, and then transferred the detection results from the third scale into the recognition module composed of neural network for further analysis. The experimental result showed that the algorithm is effective in improving undetected error detection in irregular P-wave. The wavelet transform modulus maxima in multi scales of variation can characterize the nature of signal mutation point. Duan *et al.* identified [15] Cross-scale detected ECG P-wave. They used back-propagation neural network to re-confirm and identify the quasi-P-wave which has been detected. P-wave detection accuracy reached 97 percent. Ming-Yao Yang *et al.* [26] extracted ECG feature value by wavelet analysis, and followed the identification of feather by using artificial neural networks. They used this algorithm to achieve a simple and intelligent diagnosis of a disease. Wang *et al.* [28] proposed an ECG feature detection algorithm based on lifting wavelet and improved envelope. Firstly, they lifted wavelet decomposition ECG signal, and reconstructed signal after improved semi-soft threshold processing to the extracted wavelet coefficients. After Hilbert transform to extract improved approximate envelope, they detected R-wave using threshold slope algorithm from the envelope signal. In accordance with the detected R-wave position, they detected other feature points in the reconstructed ECG signal. Simulation results showed that the algorithm can accurately detect the P-wave position.

3.4. P-wave Detection Based on the Area Incremental Method

In area incremental method, P-wave is considered as lots of triangles, and then summing the area of the triangles. When detecting, first we extend the calculated P-wave amplitude from the center to reach to the maximum point X (seeking maximum at T-Q domain) . Following this, its area is calculated and extended in a direction to calculate the area increment. In point-by-point calculation, until the difference between two consecutive areas is zero or less than a limit value, the addition of the sub-area forms the area of P-wave. The left of the peak point is PON and the right side is POFF. Finally, P-wave width represents PON-POFF time and PR interval is the time among P-wave and Q-wave.

Paper [17] proposed a method to determine the position of the P-wave by calculating the area starting from the line cutting the curve. Following further search, the starting point and end point of the P-wave were determined. This method used to detect the starting point and end point of P-wave, can compensate for error detection waveform of other methods to a certain extent. It achieved good detecting results.

3.5. P-wave Detection Based on the Stationary Segment Identified

Due to the fact that inappropriate P-wave search window would cause P-wave starting and ending point positioning error, Dai [30] proposed P-wave detection algorithm based on the identification of the plateau. Firstly, he reliably determined the P-wave search window by identifying the ECG plateau. Following this, he determined the starting and ending point of the P-wave by threshold method in accordance with the degree of data points' deviation from the plateau in the search window, thus avoiding the specific form of the P-wave description. Experimental result shows that the algorithm improved the positioning accuracy of starting and ending point of the P-wave.

4. DEVELOPMENT TRENDS AND PROSPECT

Because of the difficulty of P-wave identification, it is difficult to automatically identify various types of the diseases from the characteristic signal detection algorithm. Further improvements and research are required on the algorithms for assisting doctors for accurate diagnosis.

(1) P-wave is a short part of the total ECG signal, which has varying shapes. There is no effective solution available for variation waveform which affects the entire ECG testing. Therefore further research is required in this area.

(2) Since the P-wave amplitude is flat and has complex waveforms, it can easily be overwhelmed by severe noise. Therefore, improving the P-wave detection accuracy in complex environments also requires further study.

(3) At present, a sound clinical ECG database has not been established at home. Therefore, the need is to work with major research institutes, using recognized standards to build a large database to facilitate future research.

(4) Through remote ECG monitoring system, real-time ECG analysis and recognition can be carried out. In addition, comprehensive intelligence analysis of information can be done to further improve the accuracy of ECG diagnosis of clinical classification.

CONCLUSION

In recent years, with the improvement in microprocessor performance and information technology, in order to improve the accuracy of automatic detection and analysis diagnostic, P-wave analysis algorithms will become increasingly complex. High sampling rate, multi-parameter analysis, combined with the patient's symptoms and physicians' experiences, and establishment of an integrated expert system, all of these are the development prospects of P-wave detection.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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