ISSN: 2414-1895 DOI: 10.6919/ICJE.202102_7(2).0016

Research on ECG Signal Noise Reduction and R Wave Location Based on Digital Filter

Jingying Zhou

School of Logistics Engineering, Shanghai Maritime University, Shanghai 201306, China.

Abstract

Electrocardiogram (ECG) signal analysis is one of the key research projects in current medical related fields, which is committed to applying modern signal processing technology to ECG signal processing more widely. In this paper, the noise sources of ECG signals are analyzed, and IIR digital filters are used to reduce the three main noise interferences of ECG signals in order to achieve the effect of noise reduction. At the same time, digital filters such as IIR derivative filter and moving average filter are used to locate R wave in QRS complex, and Matlab is used for data simulation analysis.

Keywords

Electrocardiogram Signal; Noise Reduction Processing; R Wave Positioning; Digital Filter.

1. Introduction

According to China Cardiovascular Disease Report 2018, the number of patients with cardiovascular disease is estimated to be about 290 million according to the historical data. With the prevalence of unhealthy lifestyles among Chinese residents, the prevalence of cardiovascular disease will increase year by year, and its mortality rate has topped the list, far higher than other diseases such as cancer and tumor. According to the survey, cardiovascular diseases accounted for the first cause of death among urban and rural residents, with 45.50% in rural areas and 43.16% in urban areas [1]. Therefore, it is urgent to speed up the research and analysis of ECG, an important marker signal in the diagnosis and treatment of cardiovascular diseases. However, compared with other signals, ECG signal is a random weak current signal, which is easily affected by interference factors such as the accuracy of medical instruments, the patient's breathing frequency and the external environment, resulting in various noises and reducing the quality of ECG signal acquisition. In order to make the ECG signal accurately show the real situation of patients, it is necessary to preprocess it to remove the influence of noise. Common noises in ECG signals include power frequency interference, baseline drift, EMG interference and motion artifacts. In addition, electrode contact noise and noise generated by electronic equipment can cause interference to ECG signals [2]. In order to obtain ECG images which can be used for clinical diagnosis, it is crucial to denoise ECG signals.

At the same time, feature waveform location is the basis of ECG signal analysis and research, and is the starting point of clinical diagnosis. QRS complex is the most important and easy-to-locate band in electrocardiogram, and it is the premise of detecting other wave forms (P wave and T wave). Although the frequency of QRS complex is slightly different from that of different individuals, the spectrum of QRS complex is higher than that of P wave and T wave in most cases for the same individual [3]. Using digital filter to detect and locate R wave in QRS waveform, the ECG signal can be processed quickly.

2. Analysis of main sources of ECG signal noise

Because the ECG signal of human body is nonlinear and extremely weak, its amplitude is millivolts. The frequency range of normal ECG signals is concentrated between 0.05 Hz and 100 Hz, while

ISSN: 2414-1895 DOI: 10.6919/ICJE.202102_7(2).0016

nearly 90% of the spectrum energy in the actually collected ECG signals is concentrated between 0.25~35 Hz and 35 Hz [4]. This makes most effective ECG signals be interfered by various other strong signals, and the interference sources are mainly concentrated in the process of collecting ECG signals. Studies have shown that ECG signals usually have the following three interference sources: power frequency interference, baseline drift and EMG interference.

2.1 Power frequency interference

Power frequency interference is the most common and main noise interference in ECG signal acquisition, and its interference amplitude can reach 50% of the peak value of R wave of ECG signal. There are two main sources of power frequency interference. One is the 50Hz harmonic of power supply system, which makes the frequency of power frequency interference fluctuate randomly within a certain range with 50Hz as the center; The second is the antenna effect caused by the loop circuit between the human body and the lead wire used for ECG acquisition [5]. It is a kind of interference with fixed frequency, which is mainly composed of electromagnetic wave radiation. The clinical manifestation is that sine wave with fixed frequency and its superposition can be seen on ECG without noise reduction.

2.2 Baseline drift

Baseline drift mainly comes from human body's own movement, breathing, electrode contact of acquisition circuit and circuit form, which is a kind of low frequency interference. Its waveform is close to sine wave. Because human breathing is an essential physiological function, its interference always exists. The frequency is less than 5Hz, and its amplitude is about 15% of ECG signal peak-to-peak. On ECG, the baseline changes slowly, the frequency is generally less than 5Hz, and the spectrum energy is mainly concentrated at about 0.1Hz. Its amplitude is generally only 15% of the peak value of R wave of ECG signal. However, the baseline drift noise is close to the spectrum distribution of the S-T segment in the heartbeat signal. If the filtering method is not properly selected, it will easily lead to further distortion of the S-T segment, thus affecting the detection of the heartbeat signal.

2.3 EMG interference

EMG interference, as its name implies, is a noise effect caused by the potential of human muscles, which changes with the relaxation and tightness of muscles, and its potential decreases when muscles are relaxed. There are three main characteristics of EMG interference: muscle interference is high frequency noise with short duration, usually within 50 milliseconds; The frequency range is 5 ~ 2 000 Hz, and the distribution range is very wide. Compared with other interferences, the frequency signal is weaker, and its amplitude is between-90 mV and 30 mV. From the above characteristics, it can be concluded that the spectral characteristics of muscle interference are close to Gaussian white noise, which is usually characterized by rapidly changing irregular waveform.

Table 2-1 Frequency distribution and amplitude range of main noise sources of ECG signal

Noise type	Frequency distribution	Amplitude range
Power frequency interference	50Hz	About 50% of the peak value
baseline drift	<5Hz	Within 15% of the peak value
EMG interference	5Hz~2000Hz	-90mV~30mV

As shown in Table 2-1, it is the frequency distribution and amplitude range of the main noise sources of ECG signals. Noise signals in ECG signals will reduce the signal-to-noise ratio of ECG signals [6]. In severe cases, it will cause waveform distortion, interfere with the correct output of ECG waveforms, and ultimately affect the doctor's clinical diagnosis results. Therefore, removing the three major noises from ECG signals has become an important part of ECG signal preprocessing.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202102_7(2).0016

3. Noise reduction processing method of ECG signal

In the practical clinical medicine field, although hardware circuits can be designed to reduce these three main noise interferences, the problems cannot be completely solved. Therefore, a digital filter is introduced to process the digital code of the input discrete signal to change the signal spectrum. According to the analysis of main noise of ECG signal in the previous section, baseline drift belongs to low frequency signal, and EMG interference belongs to high frequency irregular signal. A high-pass digital filter is designed to filter fundamental wave drift signal, and a low-pass filter is designed to filter EMG interference signal. Aiming at the main noise-power frequency interference, IIR (Infinite Impulse Response) digital notch filter is designed to filter 50Hz power frequency interference signal. Compared with FIR (Finite Impulse Response) digital filter, IIR digital filter has much fewer orders, simpler design, less computation and faster response speed under the same filtering effect, so IIR digital filter is mostly used in ECG signal noise reduction processing.

When designing digital filters, it is necessary to carry out Laplace transform and Z transform on continuous ECG signals. The specific flow is to sample the discrete signal h(k) by means of pulse h(t), and then carry out Z transformation to obtain the transfer function H(z)[7]. The specific data of ECG signal used in this paper comes from 48 groups of heartbeat data in MIT/BIH international standard database as data samples. The sampling rate of ECG signal in this database is 360Hz and the power frequency is 60Hz.

3.1 Baseline drift and removal of EMG interference

(1) For the removal of baseline drift, a first-order IIR digital high-pass filter with cut-off frequency $\omega 1$ is designed [8]. Its transfer function is:

$$H(z)=\frac{1+\alpha}{2}\frac{1-z^{-1}}{1-\alpha z^{-1}} \tag{3-1}$$

Among them, the sampling rate of ECG signal is 360Hz, and the baseline drift interference frequency is $f_1=1Hz$, $\alpha=\frac{1-\sin\omega 1}{\sin\omega 1}$, and $\alpha\approx 0.9827$ can be calculated. Substituting into formula 3-1 gives:

$$H(z)=\frac{1.9827}{2}\frac{1-z^{-1}}{1-0.9827z^{-1}} \tag{3-2}$$

The IIR digital high-pass filter can effectively remove the interference of fundamental wave drift.

(2) For the removal of EMG interference, Butterworth low-pass filter is designed and implemented. The characteristic of Butterworth filter is that the frequency response curve in the passband is the flattest, without fluctuation, while it gradually drops to zero in the stopband. The amplitude and diagonal frequency of Butterworth filter decrease monotonously, and the higher the order of the filter, the faster the amplitude attenuation in the stop band.

3.2 Elimination of power frequency interference

For the removal of power frequency interference, a second-order IIR narrowband notch filter with angular frequency $\omega 2$ is designed. The working principle of notch filter is that the amplitude characteristic of ECG signal changes with the change of actual frequency at a certain point of Z transformation. If the frequency of ECG signal is given, the signal amplitude at this frequency is zero, so its working principle adapts to and removes 60Hz power frequency interference with fixed frequency. Its transfer function is:

$$H(z)=\frac{(z-e^{j\omega 2})(z-e^{-j\omega 2})}{(z-re^{j\omega 2})(z-re^{-j\omega 2})} \tag{3-3}$$

The transfer function of the second-order IIR narrowband notch filter can be calculated by taking the frequency $\omega 2=\pi/3$ and the stopband width $r=0.95$.

ISSN: 2414-1895
DOI: 10.6919/ICJE.202102_7(2).0016

With the digital filter designed above, the original waveform of ECG signal and the waveform filtered by the digital filter can be obtained through data simulation analysis with Matlab, and the desired effect can be achieved.

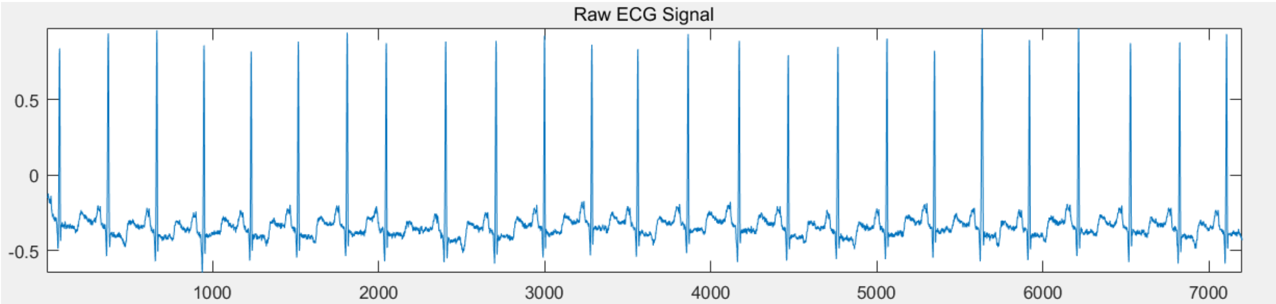

Figure 3-2 Original waveform

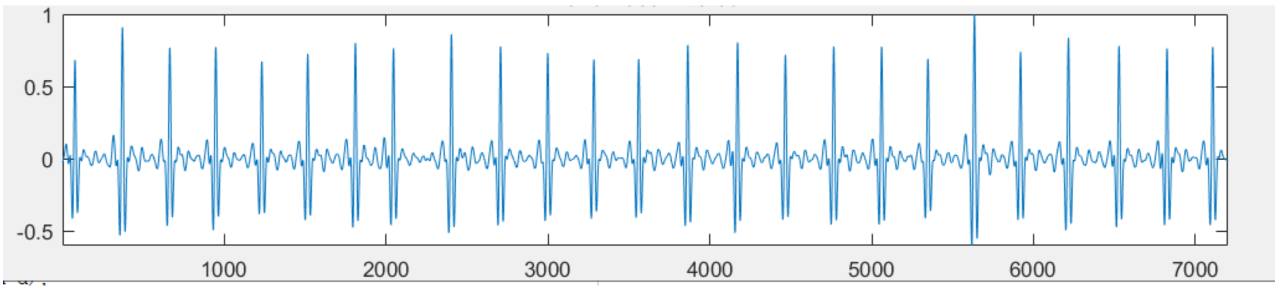

Figure 3-3 The waveform aft removing that interference of three major noise

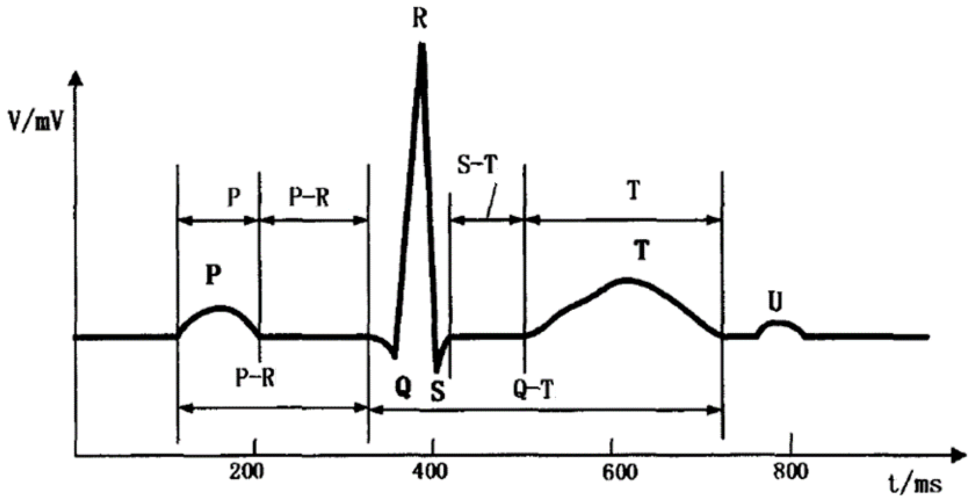

Figure 4-1 Heartbeat image

4. R wave detection and location

Monitoring and locating R wave in QRS complex of ECG signal is also an important link in ECG signal processing. Firstly, we need to know the specific definition of R wave and the purpose of locating it. Taking a heartbeat cycle as an example, a heartbeat waveform is mainly composed of P wave, Q wave, R wave and T wave. P wave represents the excited state of left and right atria. The time from P wave to QRS complex represents the time from atrial excitement to ventricular excitement. In QRS complex, the first descending waveform is Q wave, the rising waveform is R wave and the second descending waveform is S wave. It represents the time taken for ventricular

ISSN: 2414-1895 DOI: 10.6919/ICJE.202102_7(2).0016

conduction excitation. Generally, the time range of QRS complex in normal people is between 0.06 seconds and 0.1 seconds. The time interval from S wave to T wave indicates the depolarization state of each part of the heart. T-wave indicates ventricular relaxation to prepare for the next heartbeat. Figure 4-1 shows a complete heartbeat image.

4.1 Calculate the R wave interval

After filtering the three main interference signals, it is necessary to further determine the distance between two R waves. In this paper, IIR derivative filter is used to eliminate DC component and amplify the slope of R wave in QRS complex. Then, the signal is squared point by point, and all signal points are made positive by nonlinear square function, so as to further strengthen the slope of R wave, amplify R wave signal and avoid the trouble of distinguishing positive and negative peaks. Use a moving average filter. Output smooth waveform and obtain characteristic information such as slope and width of R wave. Figure 4-2 below shows ECG signal waveforms filtered by derivative filter and moving average filter.

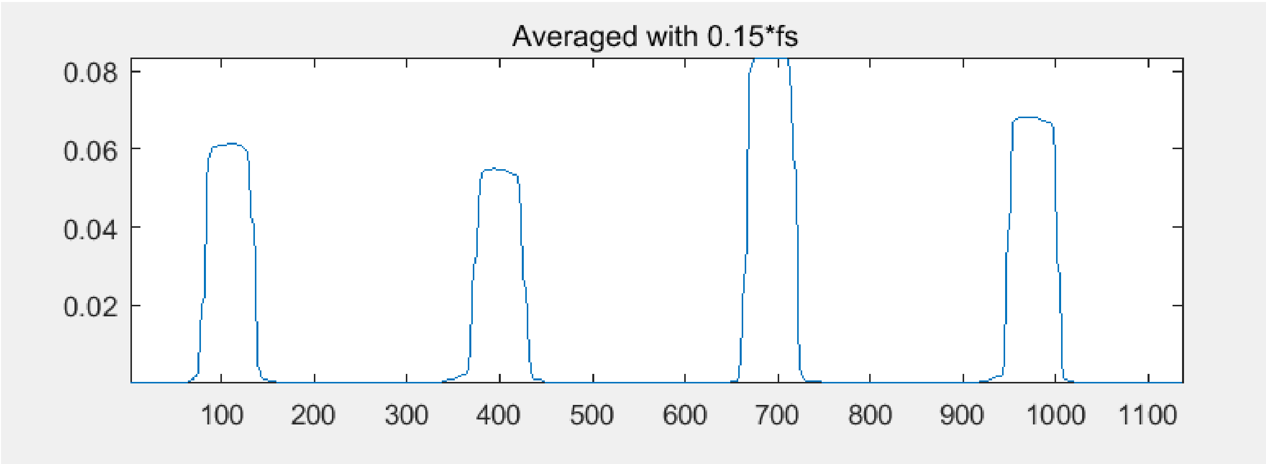

Figure 4-2 Processed waveform

4.2 R wave positioning

Take one third of the maximum value of the data in the first two seconds of the signal as the signal threshold THR_SIG. That is to say, when the peak point is larger than the threshold value, it is determined as R wave. Figure 4-3 below shows the R wave image determined by this precaution.

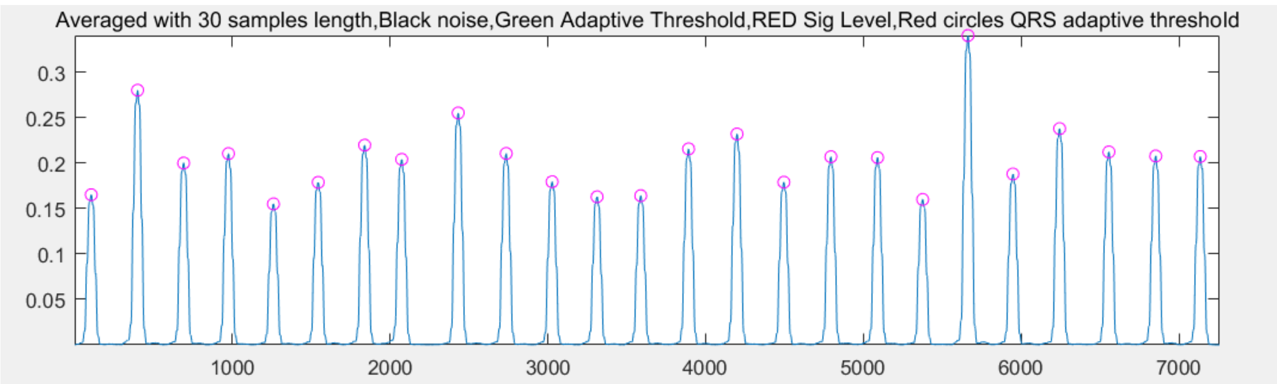

Figure 4-3 Determine the R wave

5. Conclusions

In this paper, the noise sources of ECG signals are analyzed, and various IIR digital filters are used to reduce the three main noise interferences of ECG signals, so as to achieve the purpose of ECG

ISSN: 2414-1895 DOI: 10.6919/ICJE.202102_7(2).0016

signal noise reduction. At the same time, digital filters such as IIR derivative filter and moving average filter are used to calculate and locate the R wave interval in QRS complex. Based on the theoretical formula, the data simulation analysis is carried out in Matlab software. The simulation image shows that the digital filter designed in this paper can achieve the expected result of signal noise reduction and locate R wave more accurately.

References

[1] Hu Shengshou, Yang Yuejin, Zheng Zhe. Summary of China Cardiovascular Disease Report 2018. Chinese Journal of Circulation.Vol. 034 (2019) No.003, p. 209-220.

[2] Wu lang, Ceng Chao. application of EMD decomposition and IIR filter in ECG signal preprocessing. Fujian computer. (2015) No.06, p. 97-98.

[3] Jiang Feng. ECG signal filtering and QRS waveform location [D]. Wuhan Institute of Technology, 2012.

[4] Li Jia, Zhang Yang. Research on the algorithm of removing high frequency noise from ECG signal based on wavelet analysis. Science and Technology and Innovation. (2019) No.19, p. 33-34.

[5] Yang Xudong. Research on ECG signal feature parameter extraction based on wavelet transform [D]. University of Electronic Science and Technology of China, 2020.

[6] Zhangqian. ECG signal analysis based on wavelet transform and its FPGA implementation [D]. Jilin University, 2014.

[7] Wang Yubo. Research on noise reduction of digital filter based on Matlab. Information and Communication. (2019) No.11, p. 33-35.

[8] Ji Xin. Practical Exploration of Digital Campus Construction in Colleges and Universities. Computer CD Software and Application. (2012) No.18, p. 136-137.