

Heart Rate Detection System Based on ADS1292 Module

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Abstract—This study addresses the high cost of commercially available heart rate monitoring devices by designing a low-cost detection system capable of real-time electrocardiogram (ECG) visualization. The system utilizes the ADS1292 module with electrode patches to acquire ECG signals from the human body. The raw signals are processed using a combination of IIR and median filtering, and heart rate is calculated based on RR interval analysis. The processed data is transmitted via a serial port and displayed in real time using VOFA software. Test results demonstrate excellent filtering performance and real-time capability, indicating strong potential for industrial application. Future work may involve integrating high-performance microprocessors to further enhance system performance.

Keywords—ADS1292, IIR filter, ECG, RR interval

I. INTRODUCTION

With the accelerating aging of China's population, the number of patients with heart disease continues to rise^[1]. The occurrence of heart disease is often closely associated with arrhythmias. The normal resting heart rate for adults ranges from 60 to 100 beats per minute, and a heart rate consistently exceeding or falling below this range is considered arrhythmic^[2]. Therefore, the detection of ECG signals and accurate assessment of heart rate are of great significance for the diagnosis and treatment of cardiovascular diseases^[3].

However, modern medical equipment for ECG detection and graphical visualization is often expensive, making long-term monitoring unaffordable for most patients. To address this issue, this paper designs a heart rate detection device based on a universal microprocessor. The system acquires ECG signals through communication between the microprocessor and the ADS1292 module, processes the raw signals via filtering, and ultimately achieves accurate heart rate assessment and real-time visual representation of ECG waveform.

II. HARDWARE PLATFORM DESIGN

The hardware platform built in this study includes the ADS1292 heart rate detection module, three electrode pads, electrode wires for configuring connection knobs, and a microprocessor.

A. Basic Control Logic

This study utilizes an ADS1292 heart rate detection module connected to electrode patches for ECG signal acquisition. The captured signals are transmitted in character format to a microprocessor via SPI communication^[4]. Upon data retrieval, the microprocessor performs time-domain and frequency-domain analysis, followed by filtering and heart rate extraction on the raw signals. Finally, the processed outcomes, including the ECG waveform and estimated heart rate values, are displayed in real-time on a TFT screen interfaced with the microprocessor. The Figure I is the control logic diagram.

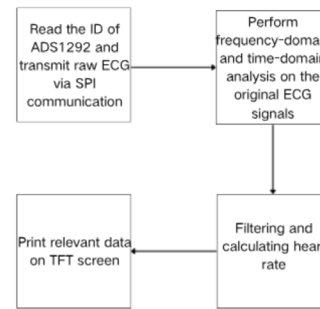


FIGURE I. Control Logic Diagram

B. Detection and Presentation

In order to prevent in the detected data, this study detected whether the waveform roughly matched the normal human ECG waveform through the presentation of the upper computer. After successfully reading the raw ECG data, the raw data is transmitted to the upper computer through the serial port^[5], and Matlab is used to present the ECG raw signal in the upper computer. As shown in the Figure II, at this time, the ECG signal has not been processed, so there are many waveform spikes in the image^[6], but it basically conforms to the normal human heart waveform.

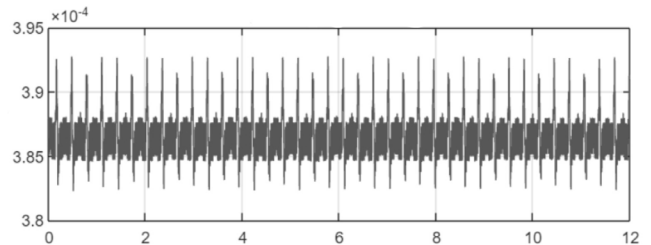


FIGURE II. Time Domain Diagram of ECG

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III. ALGORITHM IMPLEMENTATION AND OPTIMIZATION

A. Design DC Wave Limiter

At the algorithm level, this study uses fast Fourier transform^[7] to achieve time-frequency conversion of ECG. This scheme fully considers the computing power limitations of low-cost microprocessors and aims to effectively analyze the internal frequency composition of signals through frequency domain analysis. As shown in the Figure III, the obtained frequency domain image is a spectrogram.

$$X[k] = \sum_{n=0}^{N-1} x[n] \cdot e^{-j\frac{2\pi}{N}kn} \quad \text{for } k = 0,1,2,\dots,N-1(1)$$

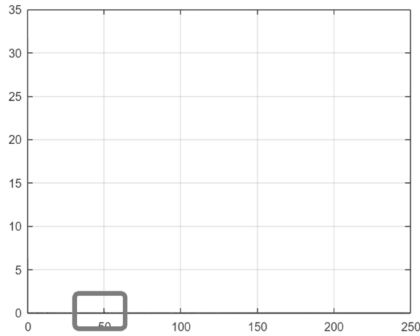


FIGURE III. Frequency Domain Diagram of ECG

From the frequency domain diagram of ECG, it can be observed that the DC component of the original signal is significant, with a small protrusion around 50Hz, indicating the need to design a DC trap to eliminate the DC component in the signal. The overall filter structure includes a first-order IIR filter in the following form.

$$H(z) = \frac{1-z^{-1}}{1-az^{-1}}, \quad \text{and } a \approx 1 \quad (2)$$

Meanwhile, through experiments, it has been proven that at $a=0.992$, the frequency response of the structure is zero at 0Hz (DC)^[8], which completely suppresses the DC component.

By comparing the frequency spectrum of the original signal with that of the signal processed by the DC notch filter, it was found that the amplitude around 0Hz decreased significantly (notch), indicating that the DC component was successfully suppressed. The overall energy of the low-frequency part decreases, but other useful frequency components (such as harmonics of electrocardiogram) are basically retained. As shown in the Figure IV, there is no significant impact in the mid to high frequency range, indicating that the filter only works on DC.

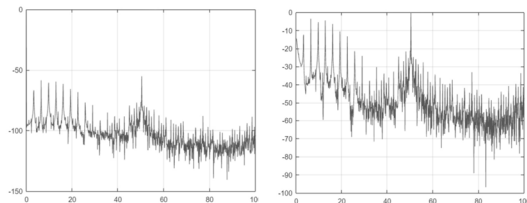


FIGURE IV. Spectrum Diagram of The Original Signal and Spectrum Diagram of the Signal Processed by The DC Notch Filter

B. Heart Rate Estimation

To accurately estimate heart rate, this article starts from the filtered ECG signal and aims to improve detection accuracy by enhancing the R-wave. Firstly, a third-order Butterworth bandpass filter (0.5-40 Hz)^[9] is used to filter out DC drift and high-frequency interference, and zero phase filtering is implemented using the built-in library function of the microcontroller to avoid R-peak misalignment. Subsequently, the signal is normalized to its maximum absolute value and smoothed using a 50 ms moving average window to suppress local spike interference.

This study uses an R-wave detection algorithm based on derivative filters. It applies the derivative filter to ECG signal to obtain the slope information of the R-wave and detects R-waves using an adaptive double-threshold method^[10]. As shown in the Table I, the simulated ECG signal being tested is low-frequency and stable over a short period.

TABLE I. R-waves Detection Data

ECG count	Numbers of R-waves	Numbers of tests	Accuracy
1	38	38	100.00%
2	40	41	97.50%
3	31	32	96.77%
4	41	40	97.56%
5	50	50	100.00%
6	35	34	97.14%
7	42	40	95.24%

Although this method performs poorly in detecting high-frequency ECG signals, it is sufficient to support the applications of this study.

Based on the smoothed signal, perform R-wave detection, set the minimum peak value to 35% of the maximum amplitude of the signal, and apply a minimum peak to peak distance constraint of 0.3 seconds to ensure that only one R-wave is recognized for each heartbeat. Finally, the RR interval is obtained by calculating the time interval between adjacent R waves. After removing outliers less than 0.3 seconds or greater than 1.5 seconds, the final heart rate value is calculated using the formula:

$$HR = \frac{60}{\text{mean}(RR)} \quad (3)$$

Figure V shows the filtering and heart rate estimation results of a 190bpm electrocardiogram signal:

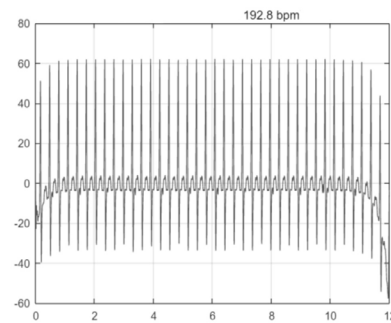


FIGURE V. Test Signal Electrocardiogram and Heart Rate Estimation

To demonstrate that the filtering effect is good from the perspective of the frequency domain, the study performed a second spectral analysis on the filtered ECG signal by fast

Fourier transform. And this time, as shown in the Figure VI it can be observed that the DC component around 50Hz is eliminated.

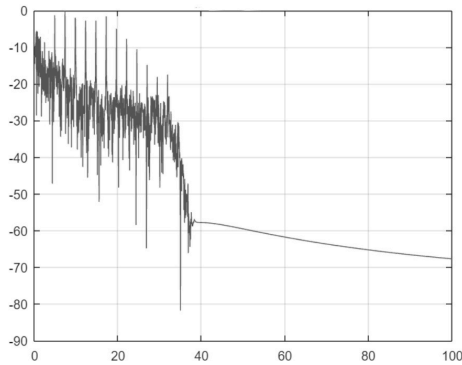


FIGURE VI. Spectrum of ECG Signal after Filtering

From the image, it can be seen that the filtering effect is good, and the estimated heart rate is 192.8bpm, with an error within 10% compared to the given known value of 190bpm.

C. Optimization of Filtering Algorithm

This study aims to adapt to various ECG signal analysis scenarios, with particular focus on the morphological analysis of the P wave (atrial depolarization) and T wave (ventricular repolarization)—key indicators for arrhythmia diagnosis. Given that P and T waves are low-frequency^[11], low-amplitude signals, specialized filtering processing must be introduced for their morphological analysis. The core design requirement for such filters is to effectively suppress noise while maximally preserving the original morphological characteristics of the waveform and the temporal information of each wave segment. The applicable filters include FIR (Finite Impulse Response) filters and IIR (Infinite Impulse Response) filters.

This article has carefully compared the advantages of FIR filtering and IIR filtering at the algorithmic level. FIR filters have stability and can be designed with linear phase response^[12], but it is a non recursive filter whose output depends only on a finite number of past input values. The response function can be obtained through z-transform:

$$H(z) = \sum_{k=0}^N b_k z^{-k} \quad (4)$$

In the embedded field, FIR are usually designed using the window function method or frequency sampling method. However, due to the higher order required for FIR and the possibility of extremely unstable signals when collecting heart rate analog signals, we use IIR, which is more stable than FIR filtering. By transforming the transfer function of IIR through z-transform:

$$H(z) = \frac{\sum b_k z^{-k}}{1 + \sum a_k z^{-k}} \quad (5)$$

IIR filters are usually obtained through analog filter conversion, but in the algorithm library of microprocessors, IIR filters are implemented through cascading second-order sections. Each second-order section can be seen as an independent filter, which can be connected in series to

achieve higher-order filters. The advantage of this structure is that it is relatively easy to implement and can effectively utilize hardware resources.

The median filtering algorithm is a nonlinear filtering technique based on sorting algorithms^[13]. The core principle of median filtering lies in replacing the value of each point in a signal with the median value of all sample points within its neighborhood window. This method demonstrates remarkable effectiveness in suppressing impulse noise while preserving the edge characteristics of the signal. These properties make it particularly valuable for preprocessing non-stationary biomedical signals, especially ECG signals. The algorithm principle is to use a median filter with a window length of $M=2k+1$ (k is a positive integer) for a one-dimensional discrete signal $x(n)$ of length N . The mathematical expression of the output signal $y(n)$ is:

$$y(n) = \text{median}\{x(n-k), x(n-k+1), \dots, x(n), \dots, x(n+k)\} \quad (6)$$

The electromyographic noise generated by muscle activity manifests as randomly occurring spike pulses in the time domain. The median filter is highly sensitive to such outliers with amplitudes significantly higher than those of normal QRS complexes^[14]. Since these impulsive values typically lie at the extremes of the sorted sequence, they are unlikely to be selected as the median. Consequently, they can be effectively eliminated without substantially affecting the main components of the QRS complex.

After algorithm optimization, this study transmitted data to the PC through serial communication, which can present heart rate curves in real time and enlarge and shrink the curves. This study mainly use “FireWater” protocol to achieve communication between VOFA and the host computer. In this study, when using this protocol, only the “printf” function in the MCU was redirected, and serial data transmission was implemented by inputting in a certain format. As shown in the Figure VII, then present data in the form of a curve by VOFA.



FIGURE VII. Time Domain Waveform Image of Electrocardiogram Signal after Algorithm Optimization

It can be seen that the simulated electrocardiogram signal at this time is basically close to the normal signal of the human body.

At the same time, the electrocardiogram electrode is attached to the left wrist, right wrist, and abdomen of the human body, and yellow, red, and green electrodes are respectively connected to obtain the human electrocardiogram signal (filtered) and spectrum. The heart rate amplitude is presented on the right side, and the estimated heart rate value (97bpm) is presented below the electrocardiogram signal waveform. As shown in the Figure VIII, it directly connect the TFT screen to the microprocessor to display waveform.

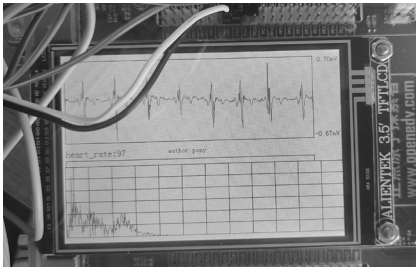


FIGURE VIII. Real Human ECG Signals and Heart Rate Estimation Presented by TFT

ACKNOWLEDGMENT

This study successfully developed an ECG signal acquisition and processing system based on the ADS1292. After verifying the feasibility of the algorithm through MATLAB simulation, it was deployed on an embedded platform, ultimately achieving real-time display of ECG waveform and heart rate values on a TFT screen. During system development, key technical challenges such as noise interference, real-time processing requirements, and R-wave detection were encountered. To address power frequency interference, the system integrated an IIR notch filter with a low-pass filtering strategy. To meet real-time processing demands, the microcontroller's built-in algorithm library was fully utilized to optimize computational efficiency. By dynamically adjusting the RR interval threshold and incorporating median filtering, the issue of R-wave missed detection was significantly improved. These measures effectively enhanced the overall performance of the system, but only fit the low-frequency and stable ECG signal.

Ultimately, the system successfully displays the filtered ECG signals in real time on the TFT screen and simultaneously transmits them to the VOFA host computer software for visual analysis, demonstrating a high degree of completion. In the future, this system is expected to be further integrated with modern medical devices^[15], enabling low-cost, at-home ECG self-testing and providing a feasible means for personal health risk assessment.

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