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RESEARCH PAPER

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Embedded Digital Filter System on Microcontroller to Reduce Noise in Single Lead Electrocardiography Design

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ABSTRACT

The background of this research focuses on improving the quality of ECG signals which are often disturbed by noise, which can affect the accuracy of cardiac diagnosis. The main objective of the research is to show the effectiveness of the 6th order IIR (Infinite Impulse Response) filter in reducing noise in the ECG signal and increasing the Signal-to-Noise Ratio (SNR) value. This research contributes by applying advanced filtering methods to embedded systems and analyzing the results using the Fast Fourier Transform (FFT) to transmit frequency spectrum signals. The method used in this research is to embed a digital filter in the microcontroller using a 6th order IIR filter. The results showed that the use of a 6th order IIR filter resulted in an increase in SNR of 15.97 dB, indicating a significant improvement in the cleanliness of the ECG signal after the filtering process. FFT confirmed that this filter effectively reduced noise and clarified component frequency signals, supporting the success of the method used. The conclusion of this study is that the 6th order IIR filter is very effective in improving ECG signal quality by reducing noise and increasing diagnostic accuracy. Implications of these results include the potential use of this technology in medical devices for more accurate cardiac monitoring, as well as the need for further research to explore other screening methods and validation in various clinical settings. This research opens up opportunities for the development of better filter technology and integration in medical systems to improve patient care outcomes.

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1. INTRODUCTION

The embedded filter system in electrocardiogram (ECG) machines is an important innovation in improving the quality of the ECG signal produced [1]. An ECG machine records the heart's electrical activity and produces graphs that depict heart function. However, ECG signals are often contaminated by various types of noise, such as noise from muscle tissue (EMG), environmental noise, and interference from other electronic devices. This can interfere with accurate analysis and can lead to misinterpretation of diagnostic results. To overcome this problem, an embedded filter system was developed and implemented on an ECG machine. This filter can function to remove noise without changing the important information contained in the ECG signal itself. Several types of filters that are commonly used include digital filters such as Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) [2]–[5], as well as adaptive filters which can adjust their characteristics according to the conditions of the incoming signal. The use of this embedded filter not only improves signal quality [6], but also makes the ECG machine more effective in providing accurate and reliable results [7], [8].

Several researchers have conducted similar research on denoising ECG signals using digital filters [9][10]–[13] among them, Abdallah Azzouz et al involves the use of Particle Swarm Optimization (PSO) combined with Wavelet Transform to improve the denoising of ECG signals [14]. limitations of this study are computational cost, complexity, or applicability to different types of noise, which could be the subject of further investigation or improvement. B. Deepanraj et al, Low Power Embedded Systems are used for Real Time ECG Monitoring and Analysis [15] This research succeeded in developing an effective low-power embedded system for real-time ECG monitoring. Weaknesses this system has limitations in terms of the complexity of the algorithms that can be implemented, which affects the ability to handle signals with complex noise [16]. For instance, Jayant et al. utilized an IIR filter to mitigate power line interference in ECG signals, demonstrating that a digital IIR filter can effectively reject a 50 Hz frequency. However, despite this, noise remains present as the IIR filter applied is limited to second-order [17]. Similarly, Faiz et al. employed a cascaded multistage adaptive approach to eliminate noise or artifacts, with the key benefit being its ability to remove multiple artifacts from the ECG signal

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with minimal distortion and a significant improvement in the signal-to-noise ratio [18]. Roberta Dozio et al. developed second and third-order analog high-pass filters aimed at reducing distortion in ECG recordings to achieve diagnostic quality, but it was noted that the distortion removal was less than optimal due to the filter being limited to third-order [19]. A 4th order notch filter was also designed to reject the 50 Hz power line frequency, while a 4th order low-pass filter (LPF) was created with a cut-off frequency of 100 Hz. Jain and Paul designed a digital filter for noise reduction using current amplifiers, which effectively removed noise from ECG signals [4].

From the research review explanation, the previous paragraph explains the weaknesses and advantages of the digital filter method that has been used for ECG signal denoising. However, the author has not found a discussion about the digital filter system embedded in the microcontroller to reduce noise. Therefore, the aim of this research is to embed a 6th order IIR (Infinite Impulse Response) filter system in improving the quality of the ECG signal with a focus on reducing noise and increasing the Signal-to-Noise Ratio (SNR) value. The author carried out a frequency response test using FFT to see the frequency spectrum of the ECG signal, then carried out a signal-to-noise ratio analysis to get. The contributions of this research are:

1. Designed and implemented an efficient and adaptive digital filter algorithm for transmitting ECG signals in embedded systems.
2. Integrates low-power technologies in embedded system designs, allowing devices to operate continuously with minimal power consumption.
3. Carry out implementation and validation of embedded digital filter systems in real conditions, including testing on ECG data from various sources and in various environmental conditions.

2. MATERIALS AND METHOD

A. Dataset

In this study, researchers used male participants without any heart defects and Age range 20 years to 25 years. Please note that to carry out this data collection, participants have been equipped with safety knowledge and this research has also received a certificate of ethical suitability from the Health Polytechnic of the Ministry of Health, Surabaya with No. No. EA/2824/KEPK-Poltekkes_Sby/V/2024. The electrodes are attached to the experimenter's chest as per the einthoven triangle in ledad II [20].

B. Data Collection

In this study, ECG signals were taken using the heart's electrical signals in lead II. Electrodes are attached to the patient's chest according to Einthoven's triangle rule. Creating IIR filter software that is embedded in the microcontroller so that it can reduce noise in real-time so that the resulting ECG signal can be analyzed correctly. The digital filter design embedded is an IIR filter with order 6. Data Storage Equipment: Hard disk or other storage media for storing ECG signal data recordings and analysis results. To measure evaluation metrics such as SNR (Signal-to-Noise Ratio), or other metrics. Visualization Software: Graphics software such as matplotlib (Python) or graphics software for creating graphs and visualization of results.Data Processing. In this research, The ECG signal is obtained from the electrical signal of the participant's heart. Data is collected from participants to obtain heart electrical signals which are then filtered using an analog filter circuit. The analog filter output is then digitally filtered to reduce noise. Data collection was carried out with 10 participants who did not have cardiac abnormalities as explained in Fig. 1. From this data collection, an analysis process will be carried out using FFT to see the frequency spectrum of the ECG signal, then a signal-to-noise ratio (SNR) analysis will be carried out to compare the results before filtering and after filtering [21].

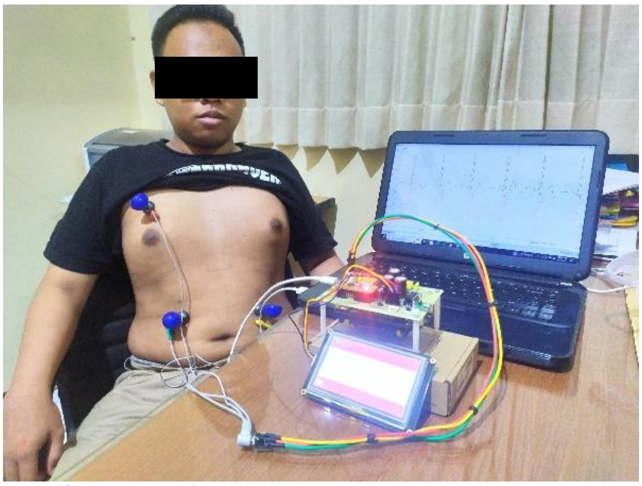

Fig. 1 Collect data from the experimenter by attaching electrodes to the chest according to Einthoven's triangle rule

C. Data Processing

In signal processing, filters are employed to remove unwanted components of a signal, such as noise, or to focus on specific aspects of a signal for further analysis. Digital filters are typically categorized into two main types: recursive filters, also known as infinite impulse response (IIR) filters, and finite impulse response (FIR) filters. Recursive filters are particularly beneficial because they can perform extended convolutions. The output generated by these filters is the filter's impulse response, which appears as sinusoidal oscillations that decay exponentially over time. Due to the fact that the impulse response of a recursive filter continues indefinitely, it is often termed an infinite impulse response (IIR) filter. [22]. IIR filters are described using difference Eq. s [23] , as shown in Eq. (1),

$$y(n) = b_0 x(n) + b_1 x(n-1) + \cdots + b_M x(n-M) - a_1 y(n-1) - \cdots - a_N y(n-N) \quad (1)$$

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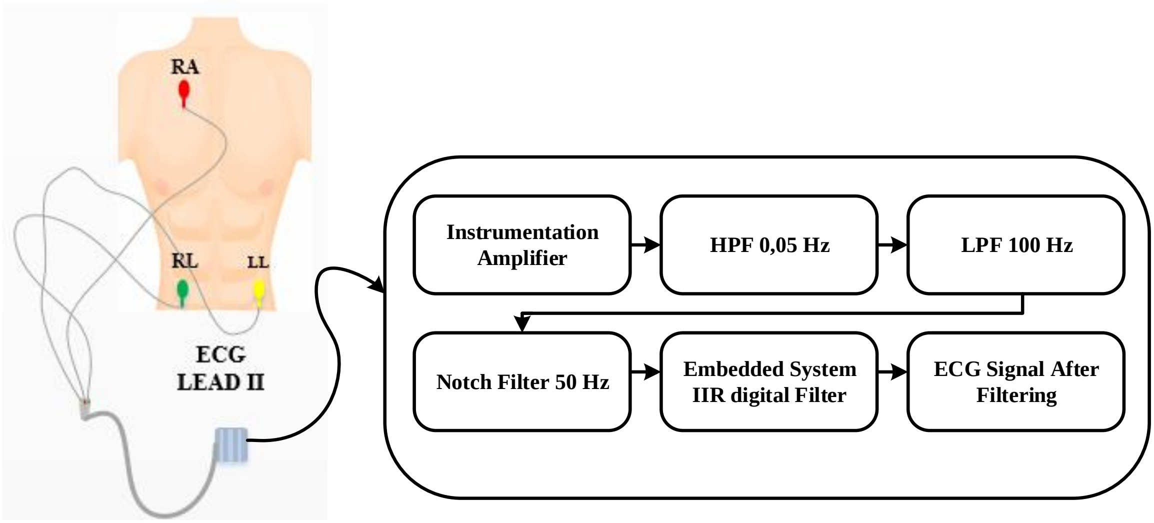

Fig. 2. Block diagram of the ECG signal processing system

where b_i, 0 ≤ I ≤ M and a_j, 1 ≤ j ≤ N, represents the system coefficients and n is the time index. Eq. (2) can also be written as follows,

$$y(n) = \sum_{i=0}^{M} b_i x(n-i) - \sum_{j=1}^{N} a_j y(n-j) \qquad (2)$$

From Eq. (1) and (2) it can be observed that the filter output is the weighted sum of the current input value x(n) and the previous value, namely x(n-1)….x(n-M) and the previous output value, namely y(n). -1)…. y(n-N). Assuming that all initial conditions are zero, the Z transformation described in Eq. (3),

$$H(z) = \frac{Y(z)}{X(z)} = \frac{b_0+b_1z^{-1}+\cdots+b_Mz^{-M}}{1+a_1z^{-1}+\cdots+a_Nz^{-N}} \qquad (3)$$

where H(z) is the transfer function of the system. H(z) and h(n) are called impulse responses. Next, analyze the SNR digital signal processing results to compare the filter orders described in Eq. 5 [24],

$$SNR: \frac{\bar{S}}{\sigma_N} \qquad (4)$$

where σ_N is the baseline and activation related to noise, and $\bar{S}$ average represents signal power. To determine the signal-to-noise ratio's (SNR) average and standard deviation, statistical analysis was performed.

D. The Diagram Block

The instrumentation used for data collection is an electrocardiography signal detection tool. Electrodes are placed on the skin surface according to Einthoven's Equilateral Triangle to obtain lead II signals. Electrocardiogram signal detection is described in Fig. 2. In Fig. 2 it is explained This figure illustrates the setup and process for capturing and filtering an ECG (Electrocardiogram) signal using Lead II configuration: Electrodes Placement: Electrodes are attached to the right arm (RA), left arm (LA), and left leg (LL) of the human body. Instrumentation Amplifier: The signals from the electrodes are fed into an instrumentation amplifier, which amplifies the small bioelectric signals from the heart. Signal Processing Pathway: High-Pass Filter (HPF): The amplified signal first passes through a high-pass filter set at 0.05 Hz to remove low-frequency noise. Low-Pass Filter (LPF): Next, it goes through a low-pass filter set at 100 Hz to eliminate high-frequency noise. Embedded System/Digital Filter: The filtered signal is then processed by an embedded system or digital filter for further refinement. Filtered ECG Signal: The final output is the ECG signal after filtering, ready for analysis. This setup is crucial for accurately monitoring heart activity in medical settings.

3. RESULTS

This chapter describes the process of recording and analyzing ECG (Electrocardiogram) signals to assess the performance of an embedded IIR digital filter system. The following is a detailed explanation: Electrodes are placed on the participant's chest according to the method described in Fig. 1. These electrodes are responsible for detecting the heart's electrical activity, which is then captured as an ECG signal. After the electrodes are installed, the ECG signal is recorded. The recorded signal is then analyzed using the Fast Fourier Transform (FFT), a mathematical technique used to convert time domain signals into a frequency spectrum. This helps in understanding the various frequency components present in the ECG signal. Once the frequency spectrum is obtained, the effectiveness of the embedded IIR (Infinite Impulse Response) digital filter system is evaluated. This is done by performing a Signal to Noise Ratio (SNR) analysis, which measures how well the filter reduces noise in the ECG signal, resulting in a clearer and more accurate representation of the heart's electrical activity.

A. Design Module Build

This research was carried out to reduce noise in the ECG

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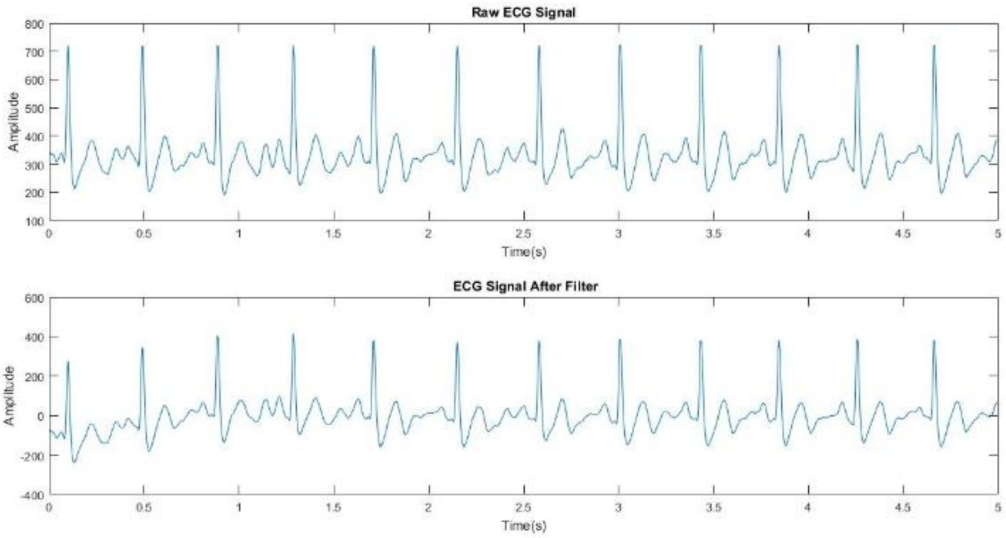

Fig. 4. Comparing an ECG signal before and after applying a 6th-order Infinite Impulse Response (IIR) filter

signal results using an embedded digital filter system IIR order 6. As an analysis of the filter results, the SNR value was looked for to carry out the appropriate filter analysis process. Fig. 3. Shows the ECG instrumentation used to collect data on trial participants. The Fig. 3 shows ECG instrumentation to display ECG signals. The setup includes electrodes being attached to the experimenter, then the ECG signal is displayed on the LCD. In the background, the laptop screen also shows a graph of the shape of the ECG signal. This setting shows the input and output signals of an ECG circuit. Waveforms on both displays show signal comparison, highlighting.

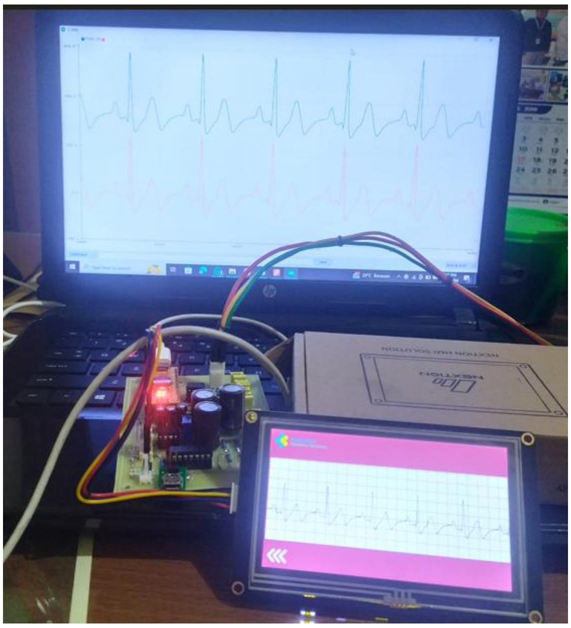

Fig 3. Desain ECG Instrumentation The signal results are displayed on the LCD screen and laptop screen

B. Filter performance test results

This chapter details the outcomes of applying a 6th order IIR (Infinite Impulse Response) digital filter, with the results visually represented in the accompanying Fig. 4. The chapter explores how this specific filter order impacts the quality of the filtered signal, particularly in terms of noise reduction and signal clarity. Additionally, the analysis highlights the effectiveness of the 6th order filter in enhancing the accuracy of ECG readings, making it a valuable tool for precise heart monitoring and diagnostics. The Fig. 4 shows two graphs comparing an ECG signal before and after applying a 6th-order Infinite Impulse Response (IIR) filter. Raw ECG Signal: The top graph displays the raw ECG signal, which is noisy and contains many sharp peaks and fluctuations. This noise can interfere with accurate heart monitoring and diagnosis. ECG Signal After Filter: The bottom graph shows the ECG signal after it has been processed through a 6th-order IIR filter. The filtered signal is much smoother, with reduced noise and clearer waveform patterns. This improved signal quality is crucial for reliable ECG analysis and interpretation. The application of the IIR filter effectively reduces noise, enhancing the clarity and usability of the ECG signal.

This chapter also presents the results obtained from applying the Fast Fourier Transform (FFT) to the ECG signal, providing insights into the frequency components of the heart's electrical activity. By analyzing the frequency spectrum, the chapter illustrates how various frequencies contribute to the overall ECG signal and identifies any noise or anomalies present. The discussion further emphasizes the importance of FFT analysis in understanding the underlying patterns of the ECG signal, which is crucial for accurate diagnosis and the

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subsequent application of digital filters for noise reduction described in Fig. 5.

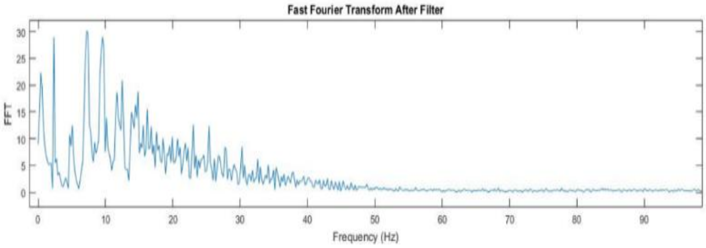

Fig 5. Displays the Fast Fourier Transform (FFT) of an ECG signal after filtering

The Fig. 5 displays the Fast Fourier Transform (FFT) of an ECG signal after filtering. The horizontal axis represents frequency in Hertz (Hz), ranging from 0 to 90 Hz, while the vertical axis represents the magnitude of the frequency components. The graph shows a series of peaks that decrease in height as the frequency increases, with the tallest peak near 0 Hz. This pattern indicates that the lower frequencies dominate the signal, which is typical for ECG signals. The FFT helps in analyzing the frequency components of the ECG signal, allowing for the identification of noise and other artifacts that can be filtered out to improve the signal quality. This process is crucial for accurate heart monitoring and diagnosis.

C. SNR Measurement

This chapter discusses the comparison of Signal-to-Noise Ratio (SNR) values obtained after filtering the ECG signal. It highlights how different filtering methods impact the quality of the ECG signal by comparing the SNR values before and after the filtering process described in FIGURE 6. The analysis focuses on evaluating which filtering technique most effectively reduces noise while preserving the integrity of the ECG signal, providing a clear understanding of the filter's performance in enhancing signal clarity for accurate heart monitoring.

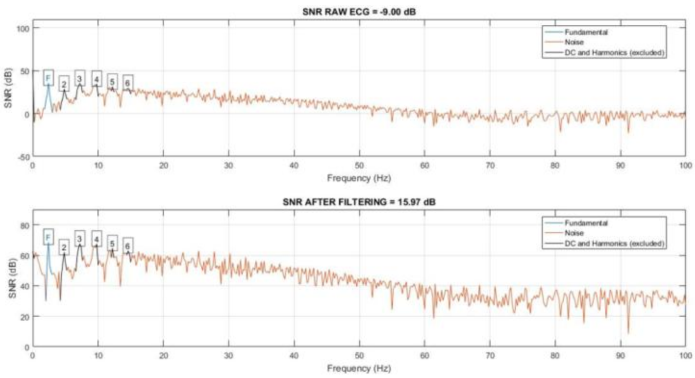

Fig. 6. Compares the Signal-to-Noise Ratio (SNR) values of an ECG signal before and after filtering

The Fig. 6 compares the Signal-to-Noise Ratio (SNR) values of an ECG signal before and after filtering. SNR Raw ECG = -9.06 dB: The top graph shows the SNR of the raw ECG signal, which is quite low at -9.06 dB. This indicates a high level of noise relative to the signal, making it difficult to accurately interpret the ECG data. SNR after filtering = 15.97 dB: The bottom graph displays the SNR after applying a filter, significantly improving to 15.97 dB. This higher SNR indicates that the noise has been effectively reduced, resulting in a clearer and more reliable ECG signal. The graphs demonstrate the effectiveness of the filtering process in enhancing the quality of the ECG signal by increasing its SNR.

IV. DISCUSSION

The findings from this experiment indicate that the embedded filter system using a 6th order IIR (Infinite Impulse Response) filter produced favorable outcomes, particularly with a significant increase in the Signal-to-Noise Ratio (SNR) by 15.97 dB. This increase in SNR demonstrates that the filter effectively reduced noise in the ECG signal, leading to a clearer and more accurate signal. Additionally, the FFT (Fast Fourier Transform) results further support these findings by providing a detailed frequency analysis, showing how the filter improved the signal quality across different frequency components.

In another research Abdallah Azzouz et al involves the use of Particle Swarm Optimization (PSO) combined with Wavelet Transform to improve the denoising of ECG signals [14]. limitations of this study are computational cost, complexity, or applicability to different types of noise, which could be the subject of further investigation or improvement. B. Deepanraj et al, Low Power Embedded Systems are used for Real Time ECG Monitoring and Analysis [15] This research succeeded in developing an effective low-power embedded system for real-time ECG monitoring. Weaknesses This system has limitations in terms of the complexity of the algorithms that can be implemented, which affects the ability to handle signals with complex noise.

The strength of this research is in terms of filter effectiveness. Research shows that the 6th order IIR filter significantly increases the Signal-to-Noise Ratio (SNR) value by 15.97 dB. This shows that the filter is effective in reducing noise and improving the quality of the ECG signal. Meanwhile, the weakness of this research is that although FFT is useful for frequency analysis, this technique can be less effective if the signal has a very high noise component or if the data varies greatly. The implications of this research pave the way for further development of digital filter technology, including improved filter designs and more sophisticated filtering methods. Additional research could explore different filter orders and other filtering techniques for further optimization.

V. CONCLUSION

This research aims to embed a 6th order IIR (Infinite Impulse Response) filter system in improving the quality of the ECG signal with a focus on reducing noise and increasing the Signal-to-Noise Ratio (SNR) value. The findings show that the use of a 6th order IIR filter significantly increases the SNR value by 15.97 dB, which indicates a substantial improvement in the cleanliness of

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the ECG signal. Analysis using the Fast Fourier Transform (FFT) confirmed that this filter succeeded in reducing noise and clarifying the signal frequency components, supporting the effectiveness of the method used. For future research, the development of more sophisticated and adaptive digital filter technology can be carried out to further improve signal quality and overcome complex noise challenges.

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