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Design and Implementation of Electrocardiogram Signal Monitoring System Using Electrode Sensors

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A R T I C L E I N F O

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A B S T R A C T

This study aims to design and create a system that can monitor electrocardiogram (ECG) signals using electrodes and an Arduino ATmega 2560. This system captures electrical signals from heart activity, processes the obtained data, and displays the results directly (in real time) on a computer screen. With this system, the shape and changes of ECG signals can be more easily observed, helping users understand the characteristics of heart signals.

Test results show that the system successfully records the ECG Lead I signal with a sampling frequency of 360 Hz. Placing the electrode on the chest produces a signal with an amplitude of 200 mV, while placing on the hand produces 1030 mV. This difference indicates that the electrode position affects the measurement results, including the level of interference in the signal. The digital filter consisting of high-pass, low-pass, and notch is able to reduce noise in the ECG signal, with an average processing time of 405 µs.

The developed GUI is capable of displaying ECG signals with an average error of 0.52%. The system also demonstrates data consistency over 7 days of testing.

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INTRODUCTION

The heart is one of the vital organs that plays an important role in maintaining the continuity of body functions. The heart's electrical activity can be recorded in the form of Electrocardiogram (ECG) signals, which describe the heart's electrical activity during contraction and relaxation processes. ECG signals have specific characteristics that can be used to observe heart activity and working conditions. Real-time ECG signal monitoring is an important part of developing health monitoring systems based on electronic technology. Monitoring systems capable of directly reading and displaying heart signals can assist in observing ECG signal characteristics and serve as a means to develop simple and easy-to-implement medical instrumentation technology. In developing ECG monitoring systems, a signal acquisition process is required that can capture the heart's electrical signals through electrodes, then process and display the data in real time. The Arduino ATmega 2560 can be used as a controller in data acquisition and processing because it has processing capabilities and an adequate number of input-output pins to support the instrumentation system.

This study aims to design and create a system that can monitor electrocardiogram (ECG) signals using electrodes and Arduino ATmega 2560. This system is designed to capture electrical signals from heart activity, process the obtained data, and display the results directly (in real time) on a computer screen. With this system, the shape and changes of ECG signals can be observed more easily, helping users understand the characteristics of heart signals.

LITERATURE REVIEW

Electrocardiogram (ECG)

An electrocardiogram (ECG) is a recording of the heart's electrical activity produced during the depolarization and repolarization process of heart muscle cells. This electrical activity can be detected through electrodes placed on the body surface and then recorded in the form of ECG waves. ECG signals generally have characteristics of P waves, QRS complexes, and T waves. P waves relate to atrial depolarization, QRS complexes represent ventricular depolarization, while T waves relate to ventricular repolarization. These characteristics form the basis for observing heart signals through monitoring systems. Electrodes are components that function as interfaces between the human body and the ECG acquisition system. Electrodes capture electrical potential differences due to the heart's electrical activity on the body surface and transmit them to the signal conditioning circuit.

ECG Signal Acquisition

Signal acquisition is the process of taking analog signals from sensors and converting them into data that can be processed by digital systems. In ECG systems, the acquisition process involves electrodes, signal amplifier and conditioning circuits, analog-to-digital converters (ADC), microcontrollers, as well as communication and visualization systems. The cardiac electrical signals captured by the electrodes have small amplitudes, so they require first amplification and conditioning. After going through this process, the signals enter the ADC to be converted into digital data. The digital data is then processed by the microcontroller and sent to a computer to be displayed.

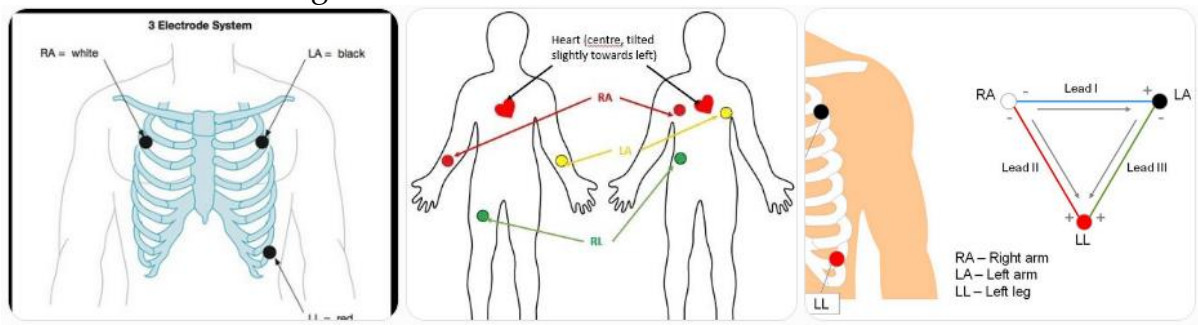
ECG Signal Processing and Filtering

ECG signals obtained from the body are not always free from interference. Some common sources of interference include baseline wander, 50 Hz electrical network interference, electromyography noise, as well as artifacts caused by body and electrode movement. Signal processing is necessary to improve signal quality before it is displayed or analyzed. One commonly used approach is filtering using low-pass filters, high-pass filters, band-pass filters, and notch filters. High-pass filters can be used to reduce slow baseline changes, while low-pass filters can be used to reduce high-frequency components. Notch filters can be used to reduce interference from electrical networks. The selection of filtering methods must maintain the main characteristics of ECG signals so that P, QRS, and T waveforms do not undergo significant changes.

ECG Signal Processing Structure

In electrode-based ECG systems, AD8232, Arduino, and Python, processing using **the Butterworth filter** is one of the most widely used types of digital filters in signal processing because it has a **relatively flat passband** characteristic, without ripples in the passband. Butterworth function in ECG. In ECG signals, Butterworth can be used to reduce: Low frequency. HPF is used to reduce **baseline wander**. LPF is used to reduce high-frequency noise. By combining HPF and LPF, a bandpass filter is obtained that maintains ECG frequencies within a certain range.

Figure 1. Placement of 3 Electrodes



For **the ECG system using the AD8232**, the placement of electrodes greatly determines the signal quality. If the **3-electrode configuration is used**, it generally consists of **RA (Right Arm), LA (Left Arm), and RL (Right Leg/reference).**

Surface Electrodes in ECG Systems

Surface electrodes are electrodes attached to the **surface of the skin** to capture the heart's electrical activity without inserting the electrode into the body. These electrodes are very commonly used in non-invasive ECG systems, including research systems using **the AD8232**.

Graphical User Interface (GUI)

Graphical User Interface (GUI) is a visual interface that allows users to interact with the system and obtain information in graphical form. In this study, the GUI is used as the medium to display ECG data obtained from the Arduino ATmega 2560. The ECG data acquired by Arduino is transmitted through serial

communication to the computer. The GUI program continuously receives this data and converts it into ECG signal graphs so that changes in the heart's electrical activity can be observed in real time.

The GUI can be developed to display various information, such as ECG signal graphs, measurement time, amplitude values, serial communication status, and other necessary parameters. With the GUI, measurement results are not only numerical data but can also be visualized in waveforms that are easier to observe. In this study, the main function of the GUI is to display ECG signals in real time as a result of the acquisition process of electrode sensors and the Arduino ATmega 2560.

Real-Time ECG Monitoring

Real-time ECG monitoring is the process of capturing, processing, and displaying heart signals directly during measurements. The real-time system must be able to carry out the acquisition process continuously with a relatively small interval so that the GUI display follows the changes in the signals obtained from the sensors.

In this study, the monitoring process was carried out through several stages, namely:

Electrode Sensor → Signal Conditioner/Amplifier → Arduino ATmega 2560 → ADC → Serial Communication → GUI → Real-Time ECG Display

METHOD

The research uses a **design method** that includes the design, implementation, testing, and evaluation of the ECG monitoring system. The system consists of **electrodes, AD8232, Arduino ATmega 2560, digital filters, and GUI** to display ECG signals in real-time. **The hardware** is designed using PCBs as electrode integration, AD8232, Arduino ATmega 2560, and communication to computers. The ECG signal from the electrode is processed and amplified by AD8232, then converted into digital data via the Arduino ADC. **The software** is designed to perform ECG acquisition, filtering, and visualization. The filter design uses **Python**, while the implementation is done on **the Arduino IDE.** The filter is used to reduce noise and improve signal quality before it is displayed on the GUI.

Methodology Table :

Tahap	Input	Proses	Output
Akuisisi	Aktivitas listrik jantung	Elektroda menangkap sinyal bioelektrik	Sinyal ECG
Pengkondisian	Sinyal ECG beramplitudo rendah	Penguatan dan pengkondisian menggunakan AD8232	Sinyal ECG terkondisi

Konversi	Sinyal analog	ADC Arduino ATmega 2560	Data ECG digital
Filtering	Data ECG digital	HPF + LPF + Notch Filter	Sinyal ECG terfilter
Visualisasi	Data ECG terfilter	Pengiriman ke komputer dan pemrosesan GUI	Grafik ECG real-time
Evaluasi	Sinyal sebelum dan sesudah proses	Pengujian dan evaluasi sistem	Hasil evaluasi sistem

RESULTS

This section is the core of the research progress report because it reflects the actual and measurable level of achievement of research activities up to the current reporting point. The description in this section must be systematically compiled to show how the research implementation process produces data, analysis, and scientific contributions or outputs that have been compiled, disseminated, or published. This chapter discusses the stages of testing and data processing carried out on the system that has been designed and implemented. The test is carried out to evaluate performance and ensure that each subsystem can function according to the specifications and designs that have been set. In the initial stage of testing, three electrodes are placed on the subject's body according to the predetermined configuration and position. The placement of the electrodes is carried out to obtain an optimal electrocardiogram (ECG) signal as input for the signal acquisition and processing system. The configuration and mounting positions of the three electrodes are shown in Figure 5.1.

Figure 5.1 Electrode Mounting Position

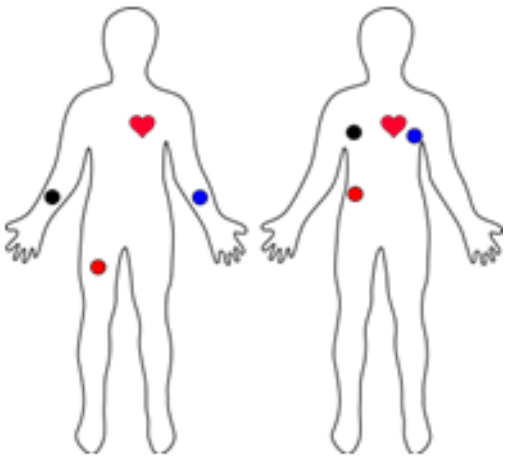
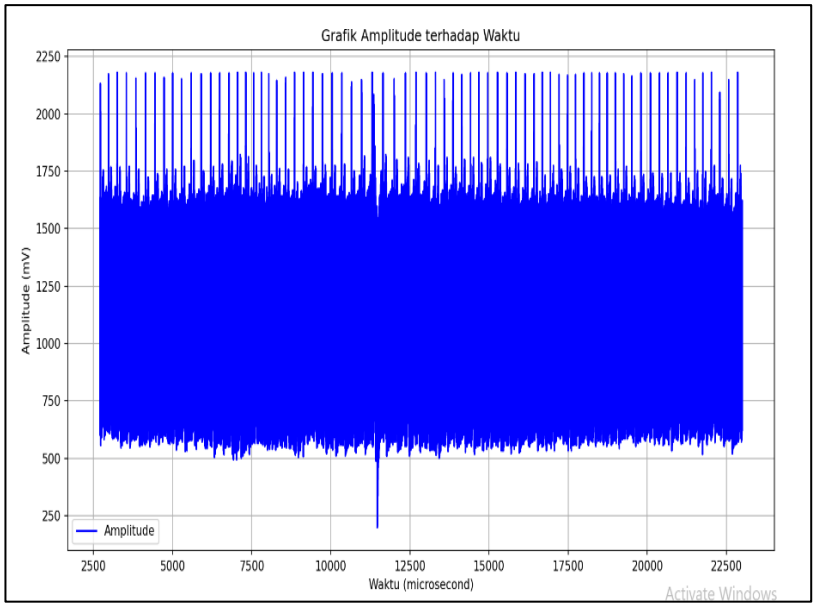


Figure 5.1 is the position of the placement of the electrode on the patient. The red RA (Right Arm) electrode is placed on the right chest of the electrode, the left chest for the LA (Left Arm) electrode which is yellow, and the green RL

(Right Leg) is placed on the bottom of the right chest as a ground or reference to reduce noise and interference.

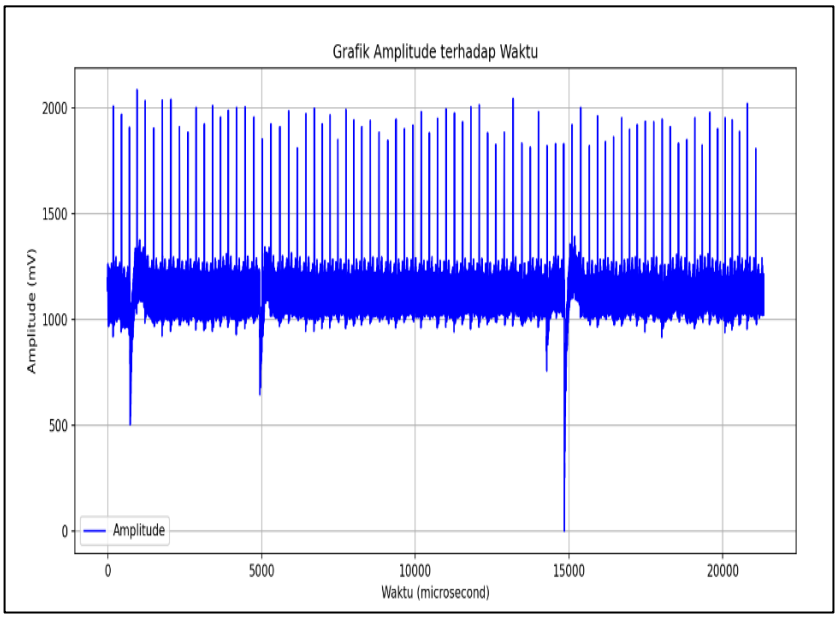
Lead I, will measure the potential difference between RA and LA. This configuration is used to see the electrical activity of the heart horizontally. In addition to the placement on the chest as shown in Figure 5.1, data collection is



also carried out on the placement of electrodes on the hands. The placement of electrodes on the chest and on the hands in the data collection process has the same purpose, namely to measure Lead I. Data Acquisition from the AD8232 Module

Unfiltered zoom results at hand

It is known that the signal noise is very large and interferes with the analysis process. In the next experiment, the placement of electrodes on the human chest in a standing position. The results of the signal were obtained as follows:



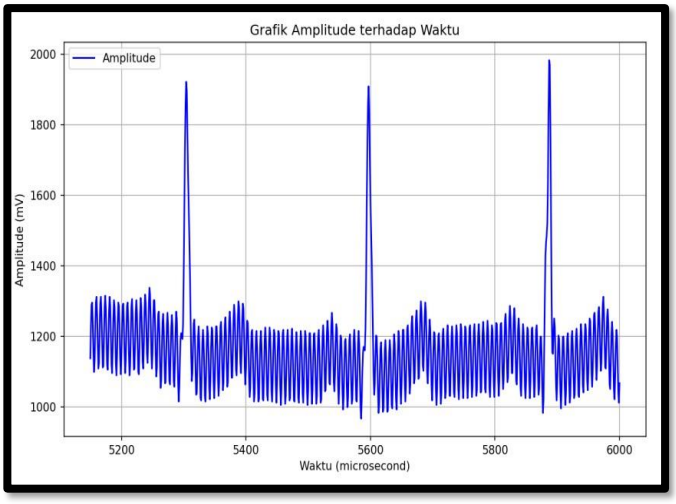


Image Unfiltered chest ECG signal

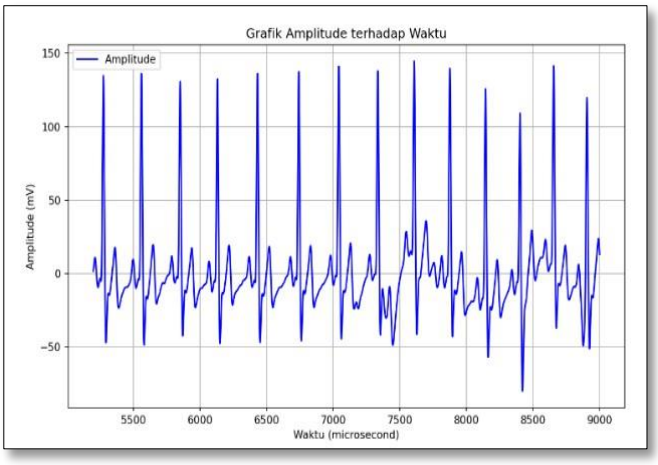


Image Placement signals on filtered hands

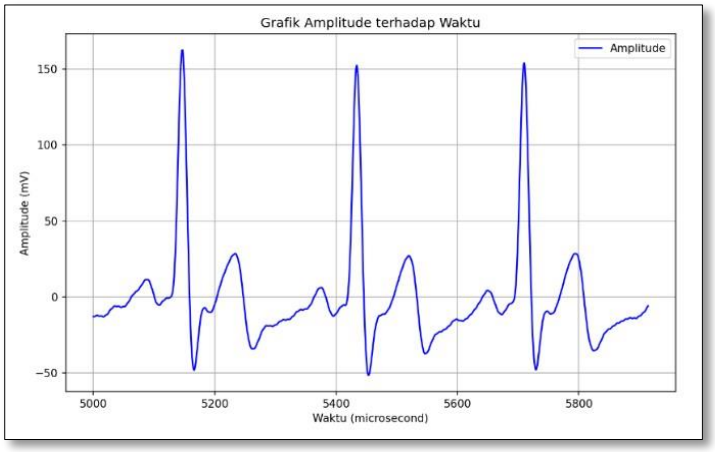


Image Filtered signal zoom results

CONCLUSION

1. **ECG Signal Acquisition**

   The acquisition system using the AD8232 module is capable of capturing electrocardiogram signals with a sampling rate of 360 Hz and a 16-bit data resolution.

2. **Signal Processing with Digital Filters**

   To improve the quality of the ECG signal, a series of digital filters consisting of a 0.5 Hz High Pass Filter, 35 Hz Low Pass Filter, and 50 Hz Notch Filter were applied. The filter was used to reduce the noise and interference components in the AD8232 acquired signal. The implementation results showed a decrease in amplitude characteristics of around 0.7 at the cutoff frequency, with an average filtering process execution time of 405.94 µs on the Arduino ATmega 2560.

3. **Visualization and GUI Features**

   The developed GUI is able to display the ECG signal in real-time with a sampling frequency **of 360 Hz**. The measurement results show an error rate of **0.52%.** In addition to displaying the ECG waveform, the GUI is also equipped with an illustration of ECG signals.

ADVICE :

1. **Development of system accuracy**

   Conduct testing and validation of the ECG monitoring system by comparing the measurement results against standard ECG devices or reference ECG data to determine the level of system accuracy more comprehensively.

2. **Electrode placement optimization**

   Develop various configurations and positions of electrodes to obtain better quality ECG signals and reduce artifacts due to movement and changes in electrode contact with the skin.

3. **Development of filtering methods**

   The digital filters used can be developed by comparing Butterworth with other filtering methods, such as FIR, IIR, Savitzky-Golay, adaptive filters, or wavelet transforms, so that the most appropriate method can be found to reduce noise without eliminating the important characteristics of the ECG signal.

4. **GUI feature development**

   The GUI can be developed by adding features such as automatic detection of P, QRS, and T waves, heart rate calculation, R-peak detection, data storage, and data export to enhance system functions as a monitoring and learning tool.

5. **Testing with varying conditions**

   The research was conducted under more diverse conditions, such as changes in body position, light activity, and the presence of motion artifacts, so that the system's resistance to disturbances can be determined.

6. **Development of communication systems**

   The system can be developed using wireless communication, such as Wi-Fi or Bluetooth, so ECG data can be transmitted wirelessly to computers or other devices.

Further Study

1. **Improved system accuracy**

   - Compare ECG results with **standard/medical-grade ECG**.
   - Calculating the parameters of accuracy, sensitivity, specificity, and system error.
   - Test the system on more signal conditions and characteristics.

2. **Development of ECG abnormality detection algorithms**

- Develop algorithms to detect changes in **P, QRS, and T waves**.
- Calculates **heart rate, RR interval, PR interval, QRS duration, and QT interval**.
- Develop early detection of conditions such as tachycardia, bradycardia, or rhythm irregularities.

3. **Development of digital signal processing**

- Optimizes filters to eliminate **baseline wander, 50 Hz power-line interference, and motion artifacts**.
- Compare several filtering methods, such as Butterworth, FIR, IIR, and adaptive filters.
- Optimize algorithms to work in real-time on microcontrollers.

4. **Development of IoT-based systems**

- Send ECG data from the device to the server/cloud wirelessly.
- Monitoring can be done via **smartphone or computer remotely**.
- ECG data can be stored as a history for periodic monitoring.

5. **GUI development into an ECG analysis system**

- The GUI not only displays ECG graphs, but also provides:

    a. heart rate,
    b. R-peak detection,
    c. RR interval analysis,
    d. signal quality indicators,
    e. patient data storage,
    f. report of the results of the examination.

6. **Application of machine learning/AI**

- The recorded ECG data can be used as a dataset.
- Develop models for the classification of normal and abnormal signals.
- The next stage can be directed to **the automatic detection of some types of arrhythmias**.

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