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PulseAI: Low-Cost IoT-Based Real-Time ECG Monitoring System Using AD8232, ADS1115, and ESP32

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Abstract – *cardiovascular diseases remain one of the leading causes of mortality worldwide, making continuous cardiac monitoring essential for early diagnosis and preventive healthcare. Conventional ECG monitoring systems are often expensive, bulky, and limited to hospital environments, reducing accessibility for routine or home-based monitoring. This paper presents PulseAI, a low-cost IoT-based real-time ECG monitoring system designed for portable cardiac signal acquisition and remote visualization. The proposed system utilizes the AD8232 ECG analog front-end for signal acquisition, the ADS1115 16-bit analog-to-digital converter operating at up to 860 samples per second for improved signal resolution, and the ESP32 microcontroller for embedded processing and Wi-Fi communication. A browser-based dashboard enables live ECG waveform visualization, heart rate monitoring in beats per minute (BPM), and PDF report generation for record keeping. Experimental implementation demonstrates stable real-time ECG monitoring using affordable embedded hardware.*

INTRODUCTION

Electrocardiography (ECG) is a non-invasive biomedical technique used to monitor and record the electrical activity of the heart over time. Each heartbeat generates electrical impulses that propagate through the cardiac muscles, producing characteristic waveform patterns consisting of the P-wave, QRS complex, and T-wave. These waveform components provide valuable information regarding heart rhythm, conduction abnormalities, and overall cardiac health. ECG monitoring plays a critical role in the early detection of cardiovascular disorders and supports preventive healthcare by enabling timely diagnosis and medical intervention.

Cardiovascular diseases remain one of the leading causes of mortality worldwide. According to global health studies, millions of deaths occur annually due to heart-related complications such as arrhythmias, myocardial infarction, and other cardiovascular disorders. Continuous monitoring of cardiac activity is therefore essential, especially for individuals at risk of heart disease. Conventional ECG monitoring systems used in hospitals and diagnostic centers are highly accurate, but they are often expensive, bulky, and require professional supervision. This limits their accessibility for routine home monitoring, remote healthcare, and use in low-resource environments.

Recent advancements in embedded systems and IoT technologies have enabled the development of compact and cost- effective biomedical monitoring solutions. Microcontrollers with wireless communication capabilities, combined with low- power analog front-end circuits, make it possible to acquire physiological signals and transmit them in real time for remote monitoring. These technologies provide new opportunities for portable healthcare applications that are affordable, user- friendly, and scalable.

This research presents **PulseAI**, a low-cost IoT-based real-time ECG monitoring system designed for portable cardiac signal acquisition and wireless visualization. The proposed system utilizes the **AD8232 ECG analog front-end module** for acquiring and conditioning low-amplitude cardiac bio-signals, the **ADS1115 16-bit analog-to-digital converter** for improved signal digitization at high sampling resolution, and the **ESP32 microcontroller** for embedded signal handling and Wi-Fi communication. A browser-based dashboard is implemented to provide real-time ECG waveform display, heart rate monitoring in beats per minute (BPM), and PDF report generation for record keeping and analysis.

The primary objective of this work is to develop an affordable and portable ECG monitoring platform that enables real- time cardiac observation outside traditional clinical environments. By integrating embedded hardware, wireless communication, and a simple monitoring interface, the proposed system demonstrates the feasibility of practical low-cost ECG monitoring for educational, research, and prototype healthcare applications.

LITERATURE REVIEW

Electrocardiogram (ECG) monitoring has long been recognized as one of the most effective methods for evaluating cardiac health and diagnosing heart-related abnormalities. ECG signals represent the electrical activity generated by the heart during each cardiac cycle and provide critical information about rhythm, conduction pathways, and overall heart function. Traditional hospital-grade ECG systems offer high diagnostic accuracy, but their size, complexity, and cost often limit their use to clinical environments. This has encouraged researchers to explore portable and affordable ECG monitoring alternatives.

Portable ECG monitoring systems have evolved significantly with the advancement of embedded electronics and wearable healthcare technologies. Modern systems commonly employ compact analog front-end circuits, low-power microcontrollers, and wireless communication modules to acquire and transmit physiological signals. Single-lead ECG monitoring solutions have gained popularity due to their simplicity, portability, and reduced hardware complexity while still providing useful cardiac information for monitoring purposes.

The AD8232 analog front-end has become a widely adopted component in portable ECG applications because of its ability to amplify and filter low-amplitude cardiac bio-signals efficiently. It integrates signal conditioning circuitry specifically designed for ECG acquisition, making it suitable for embedded biomedical projects. Similarly, microcontrollers such as the ESP32 have gained widespread use in IoT healthcare systems due to their built-in Wi-Fi capability, processing power, and low-cost implementation. These features make ESP32-based monitoring systems practical for wireless biomedical data transmission and remote observation.

Several research efforts have demonstrated IoT-enabled ECG monitoring platforms for real-time healthcare applications. Many systems transmit ECG data to smartphones, cloud platforms, or local dashboards for visualization and storage. Wireless ECG monitoring solutions improve accessibility by enabling remote observation without requiring constant clinical supervision. However, practical limitations still exist, including signal noise, motion artifacts, limited ADC resolution, and system affordability.

Analog-to-digital conversion quality plays a significant role in ECG signal fidelity. Internal microcontroller ADCs may introduce quantization noise or insufficient resolution for precise biomedical waveform acquisition. To address this challenge, external high-resolution ADCs such as the ADS1115 are increasingly used in embedded monitoring systems. The ADS1115 provides 16-bit conversion accuracy and configurable sampling rates, enabling improved ECG waveform digitization compared with lower-resolution embedded ADC alternatives.

Despite significant advancements, there remains a need for low-cost, easy-to-implement ECG monitoring systems that combine reliable signal acquisition, wireless accessibility, and real-time user-friendly visualization. The proposed PulseAI system addresses this need by integrating AD8232-based ECG acquisition, ADS1115 precision digitization, ESP32 wireless communication, and browser-based ECG monitoring into a practical embedded healthcare prototype.

METHOLOGY

The proposed PulseAI system is designed as a low-cost embedded ECG monitoring platform for real-time cardiac signal acquisition, wireless transmission, and remote visualization. The overall methodology consists of ECG signal acquisition, signal digitization, embedded processing, wireless communication, and user interface monitoring. The complete system architecture is structured to provide continuous ECG monitoring using affordable hardware components and IoT connectivity.

The ECG signal acquisition process begins with the placement of three disposable electrodes on the human body to capture the electrical activity generated by the heart. These electrodes are connected to the AD8232 ECG analog front-end module, which serves as the primary signal conditioning stage. Since raw ECG signals are extremely low in amplitude and highly susceptible to noise, the AD8232 performs amplification and analog filtering to produce a conditioned analog ECG waveform suitable for further processing.

The conditioned analog ECG output from the AD8232 is then connected to the ADS1115 external analog-to-digital converter. The ADS1115 is a 16-bit ADC that provides higher resolution and improved signal accuracy compared with the internal ADC of the ESP32 microcontroller. In this implementation, the ADC is configured to operate at a sampling rate of up to 860 samples per second, enabling high-resolution ECG waveform acquisition. The digitized ECG samples are transmitted to the ESP32 through the I2C communication interface.

The ESP32 microcontroller acts as the central embedded processing unit of the system. It receives ECG samples from the ADS1115, processes the incoming signal data, and performs heart rate estimation in beats per minute (BPM). Due to its integrated Wi-Fi capability, the ESP32 also functions as a wireless communication node, enabling real-time transmission of ECG data without requiring external networking hardware.

For remote monitoring, a browser-based web dashboard is developed and hosted by the ESP32 through a local Wi-Fi connection. Users can access the monitoring dashboard using a smartphone, tablet, or computer by entering the assigned local IP address. The dashboard displays the live ECG waveform, continuously updates BPM values, and provides an option for PDF report generation to allow ECG data documentation and further analysis.

The overall signal flow of the proposed system follows the sequence:

ECG Electrodes → AD8232 Signal Conditioning → ADS1115 ADC Conversion → ESP32 Embedded Processing → Wi-Fi Transmission → Web Dashboard Visualization → BPM Monitoring and PDF Export

This methodology provides a practical and efficient framework for portable ECG monitoring by combining biomedical signal acquisition, embedded processing, and wireless IoT-based visualization in a compact implementation.

Sr. No.	**Component**	**Specification**	**Function**
1	AD8232	ECG Analog Front-End Module	Acquisition and conditioning of ECG bio-signals
2	ADS1115	16-bit ADC, 860 SPS	High-resolution analog-to-digital conversion
3	ESP32	Wi-Fi Enabled Microcontroller	Signal processing and wireless communication
4	ECG Electrodes	3-Lead Disposable Electrodes	Capture cardiac electrical activity
5	Web Dashboard	Browser-Based Interface	Real-time ECG waveform visualization
6	BPM Monitoring Module	Software-Based Calculation	Heart rate estimation in beats per minute
7	PDF Export Feature	Software Utility	ECG report generation and storage

DESIGN

The proposed PulseAI system is designed as a compact embedded ECG monitoring platform integrating biomedical signal acquisition hardware, precision analog-to-digital conversion, embedded processing, and wireless user interface monitoring. The system architecture is developed to ensure reliable ECG acquisition, improved signal quality, and real- time accessibility through IoT-based communication.

The ECG acquisition stage consists of three disposable electrodes placed on the human body to detect the electrical activity generated by the heart. These electrodes are connected to the AD8232 ECG analog front-end module, which is specifically designed for portable biomedical signal acquisition. The AD8232 performs amplification and analog filtering of the weak ECG bio-signals, reducing unwanted interference and producing a conditioned analog output suitable for digitization.

To improve signal acquisition accuracy, the analog ECG output from the AD8232 is interfaced with the ADS1115 external analog-to-digital converter. The ADS1115 provides 16-bit conversion resolution and supports sampling rates up to 860 samples per second, enabling precise ECG waveform digitization. Compared with lower-resolution internal microcontroller ADCs, this external ADC improves waveform fidelity and signal clarity.

The digitized ECG samples are transmitted to the ESP32 microcontroller through the I2C communication interface. The ESP32 acts as the central embedded controller responsible for receiving ECG samples, managing signal data flow, calculating heart rate in beats per minute (BPM), and controlling wireless communication. The integrated Wi-Fi capability of the ESP32 allows direct hosting of a browser-based monitoring dashboard without requiring additional communication modules.

The software architecture includes real-time ECG sample acquisition, BPM computation, waveform rendering, and PDF report generation. The ECG waveform is continuously updated on the web dashboard, allowing users to monitor cardiac activity remotely through a smartphone, tablet, or computer connected to the same network. The PDF export functionality enables documentation of ECG data for future analysis and record maintenance.

The overall system architecture ensures a practical low-cost ECG monitoring solution suitable for embedded healthcare applications, educational biomedical research, and prototype remote monitoring systems.

IMPLEMENTATION

The practical implementation of the PulseAI system was carried out using low-cost embedded hardware components for real-time ECG monitoring and wireless visualization. The hardware setup consists of the AD8232 ECG analog front-end module, ADS1115 16-bit analog-to-digital converter, ESP32 microcontroller, disposable ECG electrodes, and a browser- based monitoring interface.

For ECG signal acquisition, three disposable electrodes were connected to the human body in a single-lead configuration to capture the electrical activity generated by the heart. These electrodes were interfaced with the AD8232 ECG sensor module, which amplified and conditioned the weak analog cardiac signals. Since ECG signals are highly sensitive to external noise and interference, the signal conditioning provided by the AD8232 improved waveform stability and reduced unwanted disturbances.

To achieve improved signal digitization accuracy, the analog ECG output from the AD8232 was connected to the ADS1115 external analog-to-digital converter. The ADS1115 was configured for 16-bit resolution with a sampling rate of up to 860 samples per second, allowing higher-quality ECG waveform acquisition compared with standard microcontroller ADCs. Communication between the ADS1115 and ESP32 was established through the I2C interface.

The ESP32 microcontroller served as the main processing and communication unit of the system. Embedded firmware was developed using the Arduino programming environment to continuously acquire ECG samples, process waveform data, calculate heart rate in beats per minute (BPM), and transmit ECG information wirelessly through Wi-Fi. The built-in wireless capability of the ESP32 enabled real-time access to the monitoring interface without requiring additional communication hardware.

A browser-based web dashboard was developed to provide real-time ECG visualization and user interaction. The dashboard displayed continuously updating ECG waveforms along with BPM values for live cardiac monitoring. Users could access the dashboard through a local IP address using smartphones, tablets, or computers connected to the same Wi-Fi network. An additional PDF export feature was implemented to allow generation and storage of ECG monitoring reports for analysis and documentation purposes.

The complete implementation successfully integrated biomedical sensing, embedded processing, wireless communication, and real-time user interface monitoring into a practical prototype ECG monitoring platform.

Fig. 1 Proposed System Architecture:

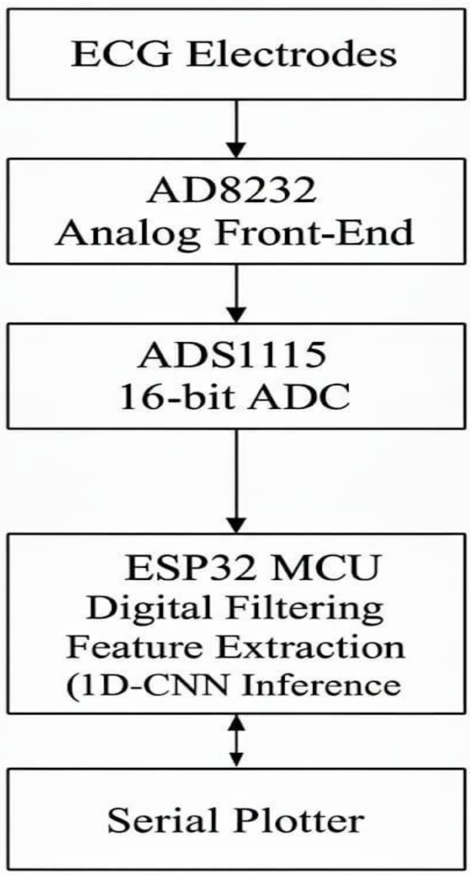
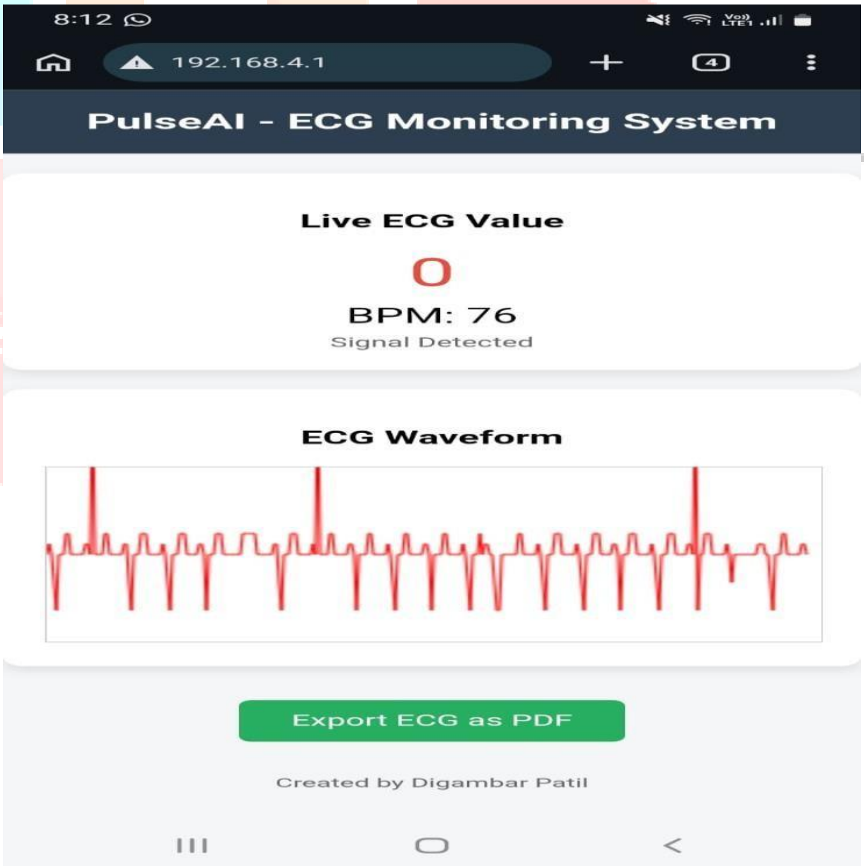


Fig. 2 Hardware Implementation Setup:

Fig. 3 Web Dashboard Interface:



RESULTS AND DISCUSSION:

The developed PulseAI prototype was successfully implemented and tested for real-time ECG signal monitoring using embedded IoT hardware. Experimental testing confirmed successful acquisition of ECG bio-signals through the AD8232 analog front-end, high-resolution digitization using the ADS1115 external ADC, and wireless real-time monitoring through the ESP32-based web dashboard.

During testing, the system successfully captured live ECG waveforms from the electrode setup and displayed them continuously on the browser-based dashboard. The waveform visualization showed stable real-time signal behavior suitable for monitoring cardiac electrical activity. The use of the ADS1115 16-bit analog-to-digital converter significantly improved signal acquisition quality compared with lower-resolution ADC approaches, resulting in clearer ECG waveform representation.

The BPM monitoring functionality operated successfully by continuously calculating heart rate values from incoming ECG data. The dashboard interface provided real-time numerical heart rate display along with live ECG waveform updates, improving practical usability for monitoring applications.

Wireless data transmission through the ESP32 Wi-Fi interface functioned reliably within the local monitoring environment. Users were able to access the ECG dashboard through connected devices such as smartphones and computers using the assigned IP address. The browser-based approach improved system accessibility without requiring dedicated application installation.

The implemented PDF export functionality successfully generated ECG monitoring reports for record keeping and documentation purposes. This feature enhances the usability of the system for educational demonstrations and prototype healthcare monitoring applications.

Overall, the experimental implementation demonstrated stable performance, practical portability, and successful integration of biomedical sensing, embedded processing, wireless communication, and user interface monitoring. The developed system validates the feasibility of a low-cost ECG monitoring solution using readily available embedded hardware components.

CONCLUSION:

This paper presented PulseAI, a low-cost IoT-based real-time ECG monitoring system developed using the AD8232 ECG analog front-end, ADS1115 16-bit analog-to-digital converter, and ESP32 microcontroller. The proposed system successfully achieved real-time acquisition of ECG bio-signals, high-resolution waveform digitization, embedded signal handling, wireless data transmission, and browser-based remote monitoring.

The implementation demonstrated stable ECG waveform visualization, continuous heart rate monitoring in beats per minute (BPM), and successful PDF report generation for ECG documentation. The integration of Wi-Fi communication through the ESP32 enabled convenient access to the monitoring dashboard using commonly available devices such as smartphones, tablets, and computers.

By utilizing affordable and widely available hardware components, the developed system provides a practical embedded healthcare monitoring solution suitable for academic research, biomedical education, and prototype remote monitoring applications. The project demonstrates that low-cost embedded IoT platforms can be effectively applied to biomedical signal monitoring outside conventional clinical environments.

Future enhancements may include improved digital filtering techniques, battery-powered portable operation, cloud-based remote ECG monitoring, mobile application integration, and extended validation using clinical-grade ECG comparison systems.

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