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IoT Based ECG Monitoring with AD8232 ECG Sensor & ESP8266

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Abstract- With the rapid development of IoT technology, considerable advancements have been made in the field of telehealth and remote health monitoring. This paper proposes the design and implementation of a small, economical, and portable ECG monitor for use in home health care. In this proposed design, the AD8232 ECG sensor is used as an analog front end to detect and condition the weak electrical signals generated by the heart. These conditioned signals are further amplified and converted to digital form using the ESP8266 microcontroller. The ESP8266 microcontroller, with its integrated Wi-Fi connectivity, transmits the obtained ECG signals to the IoT cloud platform (ThingSpeak). This ensures real-time monitoring of the heart activity, enabling early detection of any abnormality in cardiac function.

Keywords- Electrocardiography (ECG), AD8232, ESP8266, Ubidots, Remote Health Monitoring, Wireless Sensor Network.

I. INTRODUCTION

The development of biomedical tools and the rise of the Internet of Things (IoT) have led to a significant change in modern healthcare. We are shifting from traditional hospital-centered models to solutions that focus on patients and allow for remote monitoring.

Electrocardiography (ECG) remains the standard for diagnosing heart rhythm issues, heart attacks, and other heart-related problems. However, clinical-grade ECG machines are usually large, very costly, and need trained medical staff to operate, which limits their use to clinical settings. These limitations create a gap in long-term heart monitoring, where detecting intermittent heart issues, often missed during routine check-ups, is crucial for timely diagnosis.

This project presents a new IoT-integrated ECG monitoring system aimed at connecting high-quality clinical equipment with accessible home care. The system uses the AD8232

single-lead heart rate monitor, which acts as an efficient front-end for signal collection and noise filtering of low-amplitude biological signals. The collected data is processed by the ESP8266 Wi-Fi-enabled microcontroller, which handles digitization through its built-in Analog-to-Digital Converter (ADC). Then, the system sends the data wirelessly to the ThingSpeak cloud platform.

With a cloud-based dashboard, this system offers real-time data visualization and remote access. This means that patients and healthcare providers can monitor heart activity from anywhere. This paper outlines the hardware design, signal processing, and IoT integration of the proposed system. It shows the potential to support early detection of heart problems, improve patient compliance with monitoring, and ease the load on clinical facilities.

II. LITERATURE REVIEW

Evolution of the Internet of Things (IoT) has The rapid significantly transformed the landscape of remote patient monitoring, particularly in the domain of cardiac care. Conventional electrocardiography (ECG) remains the gold standard for diagnosing cardiovascular conditions; however, traditional clinical-grade ECG systems are often constrained by their bulk, high cost, and requirement for clinical infrastructure, which limits their utility for long-term, ambulatory monitoring [1].

Recent academic literature highlights a concerted shift toward the development of portable, low-cost, and wireless ECG monitoring systems. A primary area of research involves the optimization of analog front-end (AFE) modules. Studies have consistently demonstrated the effectiveness of the AD8232 sensor in this capacity, noting its ability to provide high-fidelity signal acquisition through integrated amplification and filtering circuits specifically designed to isolate cardiac signals from noise [2].

Furthermore, the integration of high-performance, low-power microcontrollers has been identified as a critical factor in the scalability of IoT-based health solutions. Research by [Priyanka Chougule,2026] emphasizes the role of Wi-Fi-enabled microcontrollers, such as the ESP8266, in facilitating seamless wireless transmission of physiological data to cloud-based repositories [3]. This wireless capability is essential for shifting monitoring from hospital settings to home-based environments, providing a foundation for telemedicine.[4]

The data management component of these systems typically relies on cloud-based IoT platforms. Existing studies have successfully utilized platforms such as Ubidots, ThingSpeak, and Blynk to facilitate real-time data storage, visualization, and remote analysis [5]. These platforms bridge the gap between data acquisition and medical interpretation, enabling the timely detection of cardiac abnormalities. Evidence from recent projects suggests that such systems not only reduce the burden on hospital infrastructure but also provide continuous monitoring solutions tailored for specific demographics, including elderly patients, athletes, and individuals with chronic heart conditions.[6]

In summary, the extant literature confirms that the integration of the AD8232 sensor with the ESP8266 microcontroller provides an efficient, economical, and scalable architecture for IoT-based ECG monitoring. By leveraging cloud connectivity, these systems present a robust framework for improving patient outcomes through proactive, remote healthcare delivery.

III. MAIN COMPONENTS

The main components of these projects are from two entities which are follows:

Hardware components:
ESP8266 Development Board
The heart of the proposed data acquisition and transmission system is the ESP8266, a high-integration, low-cost Wi-Fi-enabled microcontroller.

The module serves as the primary processing unit, facilitating the bridge between the analog sensor hardware and the cloud-based visualization interface.

The ESP8266 is architecturally suited for portable, battery-operated medical devices due to its compact physical footprint and power-efficient operation. In this implementation, the module utilizes its integrated Analog-to-Digital Converter (ADC) to digitize the conditioned ECG signals received from the AD8232 sensor. The onboard TCP/IP protocol stack enables the device to act as an IoT endpoint, autonomously managing secure connectivity with external cloud services such as ThingSpeak.

The system development was conducted within the Arduino Integrated Developme Environment (IDE), which provides an extensive library support for managing Wi-Fi connectivity and data packet transmission. The microcontroller is configured to sample the analog signal at a frequency sufficient to maintain clinical signal fidelity, subsequently transmitting these packets via Hypertext Transfer Protocol (HTTP) to the cloud. This architectural approach ensures that real-time cardiac data can be processed, stored, and accessed remotely, satisfying the requirements for low-latency telemedicine and continuous patient observation.

AD8232 ECG Sensor Module

The core of the system’s physiological data acquisition is the AD8232 heart rate monitor, an integrated signal-conditioning block specifically engineered for ECG and other bio-potential measurement applications. In this architecture, the module serves as the primary analog front-end (AFE), designed to extract, amplify, and filter small bio-potential signals in the presence of noisy environments, such as those caused by motion or remote electrode placement.

The module implements a three-electrode configuration—Right Arm (RA), Left Arm (LA), and Right Leg (RL)—to capture the heart's electrical activity. This setup is critical for common-mode rejection and signal stabilization. The AD8232 performs essential signal conditioning, including a high-pass filter to remove motion artifacts and electrode half-cell potential, and a low-pass filter to suppress electromyogram (EMG) noise. The resulting analog output, a clean waveform representative of cardiac activity, is interfaced directly with the Analog-to-Digital Converter (ADC) input of the ESP8266 microcontroller.

Given its low-power consumption profile and compact physical dimensions, the AD8232 is particularly well-suited for portable, long-term monitoring applications. By ensuring high-fidelity signal acquisition at the source, the

module enables the ESP8266 to reliably digitize and transmit cardiac data, facilitating real-time monitoring and analysis through the IoT-enabled cloud architecture.

ECG Electrodes & Lead Wires
The integrity of the ECG signal is fundamentally dependent on the electrode-skin interface and the efficiency of the transmission media. This system employs a standard three-lead electrode configuration—comprising Right Arm (RA), Left Arm (LA), and Right Leg (RL)—to capture bio-potential differences generated by the cardiac cycle. These electrodes function as transducers, converting ionic currents from the skin surface into electrical signals that can be processed by the AD8232 sensor.

The electrodes are connected to the AD8232 module via shielded lead wires, which are critical for maintaining a high signal-to-noise ratio (SNR). Given that cardiac potentials are low-amplitude signals, the wiring is designed to minimize electromagnetic interference (EMI) and motion-induced artifacts, which are common sources of baseline wander in ambulatory monitoring. The utilization of the Right Leg (RL) electrode as a reference point further assists in reducing common-mode noise, thereby providing a stable signal for the Analog-to-Digital Converter (ADC) of the ESP8266 microcontroller.

Software Modules:

Arduino IDE
The Arduino IDE is the software used to write, compile, and upload the program to the ESP8266 board in this project. It provides an easy coding environment and includes all required libraries for reading ECG data from the AD8232 sensor. The IDE helps monitor real-time ECG values through its Serial Monitor. Overall, it acts as the main tool for developing and testing the ECG monitoring system.

Iot cloud platform: ThingSpeak

ThingSpeak is an open-source Internet of Things (IoT)platform. Itenables the collection, analysis, and acting upon data from various sensors and IoT devices. The primary features of the platform include real-time data collection, data processing and visualization, and the ability to trigger alerts and actions.

FLOWCHART

The following diagram gives a practical illustration of how the device can be implemented physically, giving attention to the small scale of the equipment. In this particular arrangement, the analog front-end interface chip AD8232 is connected with three surface skin electrodes that acquire cardiac biopotentials. This signal is then directly fed into the microcontroller chip where it is converted to digital data using the microcontroller’s internal ADC pin. Within one power-efficient platform, the microcontroller uses its in-built Wi-Fi module to transmit the physiological data to the IoT platform.

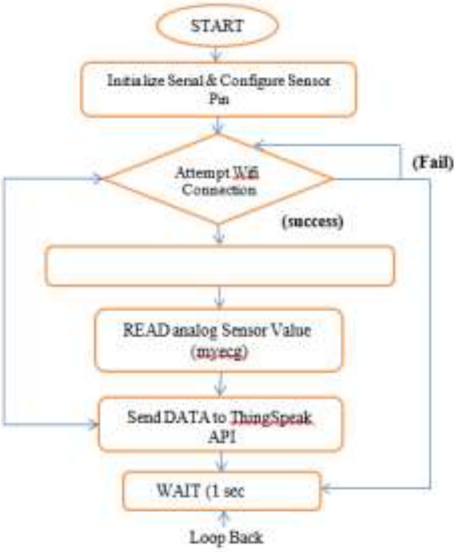

Figure A: Flowchart illustrating the system architecture of ECG Monitoring

IV. METHODOLOGY

Fig B: Block Diagram

The operational model of the proposed IoT-enabled ECG monitoring solution is based on a series of stages, which include physical signal acquisition, analog signal processing, hardware conversion, and cloud telemetry of data. An outline of the entire process is provided below:

A.Signal Acquisition and Transduction The process of data acquisition starts from the bio-electricity interface, where three surface electrodes on the body surface record the bioelectric potentials that occur due to the depolarization and repolarization of the heart. Since these bioelectrical potentials are quite low (millivolts), they are prone to external degradation. For this purpose, shielded lead wires are used for the transmission of these low-amplitude microvolt signals to the analog front-end circuit, AD8232, so as to ensure the highest SNR levels at this stage.

B.Analog Signal Conditioning

The raw biopotential signals applied into the AD8232 circuit are subjected to extensive hardware conditioning process. The AFE is capable of rejecting common-mode noise through instrumental amplifier gain. At the same time, high-pass and low-pass filters reject the baseline drift caused by the subject's body movement and muscle electrical activity or electromyogram noise along with the 50/60 Hz interference from the power line.

C.Microcontroller Digitization and Transmission

The conditioned analog output signal is directly connected to the analog input port of the ESP8266 microcontroller unit (MCU). This is done using the internal ADC present in the ESP8266 MCU to sample the signal and convert it into digital information. With the help of its inherent TCP/IP protocol stack and internal 2.4 GHz Wi-Fi transmitter/receiver, the ESP8266 MCU is made to authenticate itself with the local gateway network and establish a connection with the remote cloud server through an HTTP POST protocol.

D.Cloud-Based Analytics and Remote Telemetry

The data streams received from the uploading process are fed into the ThingSpeak IoT cloud system as the primary storage and telemetry hub. After being received and interpreted, the time-stamped ECG data is displayed on visual interfaces in real time. The visualization system enables medical professionals and caregivers to monitor the patient continuously from anywhere with an internet connection.

In addition, this system employs the built-in MATLAB-driven analysis engine provided by Ubidots to carry out dynamic processing of the incoming data stream, allowing for automatic detection of anomalies. If an irregular heartbeat or unusual ECG pattern is observed, then predefined React triggers and Webhook mechanisms are set up to send out emergency alerts or web-based notifications to medical professionals almost immediately. The combination of biomedical equipment, edge computing telemetry, and cloud computing forms a cost-effective and scalable model of remote cardiological care

CIRCUIT DIAGRAM

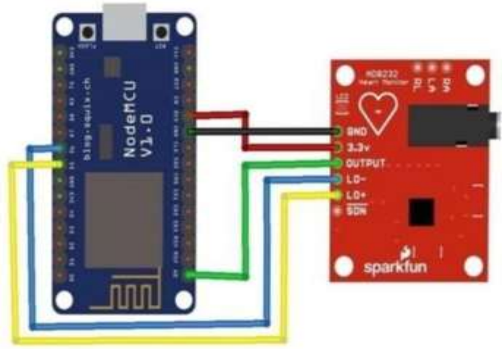

Figure C: Pinout Diagram.

A.Power Distribution Framework

The design of the system operates on the principle of a universal logic level of 3.3V. The ESP8266 chip uses a low drop-out (LDO) voltage regulator in order to supply the 3.3V logic output for the operation of the amplifiers contained in the AD8232 module. Grounding is common in the entire system, as to avoid any ground loops that may distort the measurements.

B.Analog Signal Pathway

The primary data channel maps the OUTPUT pin of the AD8232 to the A0 successive-approximation register (SAR) Analog-to-Digital Converter (ADC) pin of the ESP8266. The AFE outputs an amplified, filtered voltage sweep constrained between 0V and 3.3V, making it perfectly compatible with the ADC operating range of the microcontroller without requiring external voltage divider networks.

C. Leads-Off Detection (LOD) Network The LO+ and LO- pins are configured as digital inputs on the ESP8266 (mapped to GPIO pins D6 and D5 respectively). These pins monitor the connection integrity of the skin electrodes. When an electrode detaches from the patient's body, the AD8232 pulls these lines high via internal pull-up resistors, instantly alerting the microcontroller to halt data transmission and flag a "Leads-Off" error on the remote telemetry dashboard.

RESULT

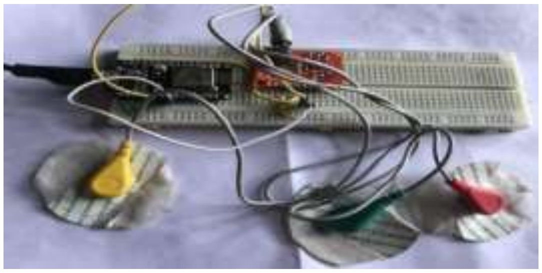

Fig D: Component Setup

This image displays a hardware prototype for an IoT-enabled ECG monitoring system constructed on a breadboard. It features a NodeMCU ESP8266 microcontroller module interfaced with an AD8232 ECG sensor board (the red PCB) to capture and wirelessly transmit biopotential cardiac signals. Three color-coded electrode pads (Yellow, Green, and Red) are connected via a lead cable to acquire the heart's electrical activity using standard Einthoven triangle placement.

Fig E: ECG Waveform on Cloud platform

This image shows a real-time cloud telemetry dashboard on the Ubidots IoT platform, displaying live sensor data streaming from your ECG prototype. The line graph plots raw data points—showing a specific reading of 547 at 21:59:41 on June 1, 2026 WHICH capturing the rhythmic peaks of a biopotential cardiac signal. The left panel shows device configurations, such as the API label "sensor" and raw preprocessing settings, confirming successful hardware-to-cloud integration.

V. FUTURE SCOPE

While the proposedIoT-based ECG monitoring system successfully achieves real-time data acquisition, wireless transmission, and cloud visualization, several optimizations can be introduced to enhance its clinical viability, security, and scalability. Future advancements of this work can be categorized into the following technical dimensions:

A. Hardware Optimization and Multi-Parameter Sensing

Future iterations of the system will focus on transitioning from a single-lead setup to a multi-lead configuration (such as a 3-lead or modified 5-lead system) to capture a more comprehensive vectors of the heart's electrical activity, enabling the detection of localized ischemia or complex arrhythmias. Furthermore, the system can be upgraded to a multi-parameter patient monitor by integrating additional low-power bio-sensors, such as the MAX30102 for photoplethysmography (PPG) to track SpO2 (blood oxygen saturation) and pulse rate, and a digital temperature sensor (e.g., MAX30205). To enhance mobility, the hardware form factor can be reduced by developing a custom multi-layer Printed Circuit Board (PCB) utilizing surface-mount technology (SMT) and replacing the ESP8266 with the ultra-low-power ESP32, which supports both Wi-Fi and Bluetooth Low Energy (BLE).

B. Edge Computing and TinyML Integration

The solution for the problem of bandwidth cost and dependency on internet connectivity can be achieved using edge intelligence or Tiny Machine Learning (TinyML) that can be embedded right into the MCU itself. By applying DSP algorithms at the edge of the network, such as Pan-Tompkins digital algorithm, to perform local detection of QRS complexes, any kind of artifact can be filtered out from the data, as well as detecting important conditions, like ventricular fibrillation. Instead of constantly transmitting data packets to the cloud, the system would send high-frequency data packets during an abnormal event only or physiological snapshots, reducing power costs and improving battery life.

C. Advanced Cloud Analytics and AI-Driven Diagnostics

In relation to the cloud layer, the present architecture can be further enhanced through adding machine learning models, like CNNs or LSTM models, which are trained using standard datasets for cardiac diseases (such as the MIT-BIH Arrhythmia Database). Such models would automatically classify different types of cardiovascular diseases. The implementation of prediction capabilities in the system will enable it to predict future cardiac occurrences well in advance, hence offering a warning system to high-risk individuals.

D. Enhanced Data Security and Privacy

Given the sensitive nature of physiological medical records, incorporating robust cryptographic frameworks is essential for HIPAA compliance. Future work will investigate the deployment of lightweight encryption algorithms (such as AES-128 or ChaCha20) at the microcontroller level to secure data-in-transit over HTTP/MQTT protocols.Additionally, exploring decentralized data storage solutions, such as blockchain-enabled access control, could guarantee immutable patient data logs and prevent unauthorized third-party tampering.

Lastly, the platform can be expanded to create an entire telemedicine closed-loop ecosystem. With the use of specially designed cross-platform mobile applications (Flutter or React Native), patients will be able to easily monitor their cardiac telemetry. Using APIs, the cloud server will automatically interface with EHR systems at hospitals, thereby facilitating clinical reporting and triggering direct video consultation alerts for cardiologists once the thresholds for critical anomalies are crossed.

CONCLUSION

This paper presented the successful design, implementation, and evaluation of a low-cost, portable, and real-time Internet of Things (IoT) based electrocardiography (ECG) monitoring system. By systematically integrating the AD8232 analog front-end with the ESP8266 Wi-Fi microcontroller, the project effectively addressed the constraints of high financial cost, structural bulk, and localized clinical dependency associated with conventional diagnostic equipment.

Experimental results validated that the analog front-end accurately captures weak biopotential signals from the body surface using a standard three-electrode layout (RA, LA, RL), reliably filtering ambient electromagnetic noise, power-line interference, and muscle-induced motion artifacts. The onboard processing unit seamlessly digitized this conditioned waveform and utilized its native TCP/IP protocol stack to transmit time-stamped physiological data streams to the ThingSpeak cloud telemetry server over a local gateway.

The cloud-hosted dashboard achieved continuous, low-latency visualization of cardiac activity, facilitating real-time remote patient observation accessible from any internet-enabled geographical location. Furthermore, the framework's architecture supports early anomaly detection, providing a reliable baseline for automated healthcare alerts and notifications that can optimize patient care workflows for elderly patients, athletes, and individuals requiring long-term ambulatory care.

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