



Design And Implementation Of Portable Ecg Monitoring System Using Esp32 And Web-Based Visualization

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Abstract: Cardiovascular diseases (CVDs) remain a leading cause of global mortality, highlighting the need for accessible early detection and continuous monitoring strategies. Continuous acquisition of electrocardiogram (ECG) signals provides valuable data for proactive cardiac health management and telemedicine. This project presents a low-cost, portable ECG monitoring system built around the ESP32 microcontroller and the AD8232 analog-front-end sensor. The AD8232 front-end module acquires the heart's bioelectrical signals, which are then digitized by the ESP32 and transmitted wirelessly via Wi-Fi to a remote device. Real-time visualization is achieved through a web-based interface (HTML/CSS/JavaScript), enabling clinicians or users to view the ECG waveform on standard devices. The system is designed for continuous operation and affordability, making it suitable for personal health monitoring and remote healthcare (telemedicine) applications, especially in resource-limited settings. In practical use, it reliably captured clear waveforms and delivered them to a web interface with effective real-time responsiveness. The system's lead-off detection correctly flagged electrode faults, and the user interface allowed immediate viewing of the data. While some challenges (electrical noise, ADC resolution, wireless dropouts) were identified, they did not prevent the device from providing accurate cardiac readings. Overall, the assembled system is validated as a working prototype: it performs comparably to other low-cost remote ECG monitors and satisfies the requirements of continuous heart monitoring. These results are consistent with reports that remote ECG systems are becoming commonplace for heart disease surveillance. In conclusion, the testing and observations confirm that the ESP32 + AD8232 platform is a viable basis for portable ECG telemetry. Future work will focus on improving enclosure design, enhancing noise immunity, and adding data logging features to further refine the system's usability and reliability. It includes integration with cloud-based platforms for data storage and analysis, and mobile app alerts for abnormal cardiac events, further extending its utility in e-health contexts.

Introduction

Cardiovascular diseases remain a leading cause of mortality worldwide, and early detection of heart abnormalities can significantly improve treatment outcomes. However, traditional ECG machines are expensive, bulky, and limited to clinical settings. In many rural or resource -constrained environments, patients lack access to timely cardiac diagnostics. Moreover, conventional ECG systems often require professional supervision and are not portable or convenient for continuous monitoring. The problem addressed by this project is the lack of an affordable, portable, and user-friendly ECG monitoring device that can be used remotely without specialized training. The goal is to design and implement a system capable of capturing real-time ECG signals and displaying them over a wireless web interface, making heart monitoring accessible, especially for home care, elderly patients, and individuals in remote locations. In summary, existing equipment is not well suited for affordable, long-term, everyday monitoring in non-clinical settings. Recent advances in low-cost electronics motivate our design of a portable ECG device. For example, the ESP32 microcontroller provides ample processing power, multiple

analog/digital I/O ports, and built-in Wi-Fi at very low cost. Paired with the AD8232 front-end chip (a single-lead ECG signal conditioner), these components can form the core of a wearable monitor. This approach promises an accessible device: an ESP32/AD8232-based board can acquire ECG signals, perform filtering, and wirelessly transmit data in real time. Because the hardware is cheap and widely available, the resulting device would be much more affordable than hospital systems. It could even be deployed in patients' homes or rural clinics, enabling remote doctors to review the data. Developing this system also yields significant educational and healthcare benefits. The project bridges multiple disciplines (microelectronics, embedded programming, signal processing, and physiology), offering a rich learning experience. In practical terms, a portable ECG monitor can enable earlier detection and management of cardiac conditions. As one study notes, prompt ECG diagnosis is key to treating heart disease. A low-cost wearable ECG could therefore help identify problems sooner, especially in underserved areas where access to medical facilities is limited.

System Overview

The portable ECG monitoring system consists of three main modules: the ECG front-end (electrodes + AD8232 sensor), the ESP32 microcontroller, and the web-based visualization interface. As shown in Figure 3.1, disposable ECG electrodes placed on the subject's body feed raw cardiac signals into the AD8232 biopotential front-end. The AD8232 amplifies and band-pass filters the tiny ECG voltages (with a high gain of ~ 100 and built-in 2 pole high-pass and 3 pole low-pass stages). Its conditioned analog output is routed to the ESP32's analog-to-digital converter (ADC). The ESP32 digitizes the waveform and transmits it over Wi-Fi to a local web browser, which plots the ECG trace in real time. The ESP32 is powered via USB or battery and provides a 3.3 V supply to the AD8232 and logic-level power to the sensor module.

Block Diagram

The block diagram of the portable ECG monitoring system illustrates the high-level workflow from signal acquisition to web-based visualization. The process begins with ECG electrodes placed on the patient's body to capture electrical activity generated by the heart. These raw analog signals are minute in amplitude and require conditioning before processing. The signals are first fed into the AD8232 ECG front-end amplifier, which is specifically designed for biopotential signal acquisition. This IC filters and amplifies the ECG signal while also helping to reduce noise caused by motion or power-line interference.

The filtered analog output of the AD8232 is connected to one of the analog input pins of the ESP32 microcontroller, which acts as the system's processing and communication core. The ESP32 reads this analog signal using its built-in Analog-to-Digital Converter (ADC) and converts it into digital data. Once digitized, this data is either streamed via Wi-Fi in real-time or buffered before transmission depending on system requirements. The ESP32 is programmed to function as a local web server, and it serves a web interface (built using HTML, CSS, and JavaScript) directly to any device connected on the same Wi-Fi network. Users can then visualize the ECG signal on a browser-enabled device like a smartphone, tablet, or PC, enabling portable and wireless ECG monitoring without the need for additional software or cloud infrastructure.

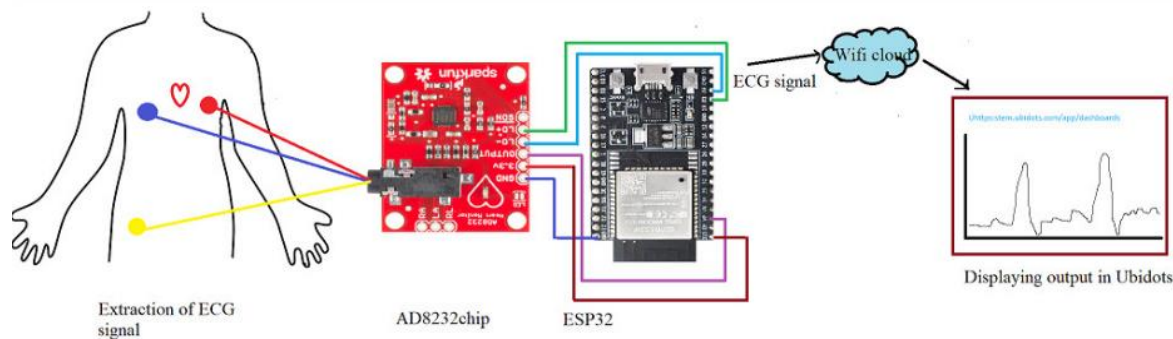
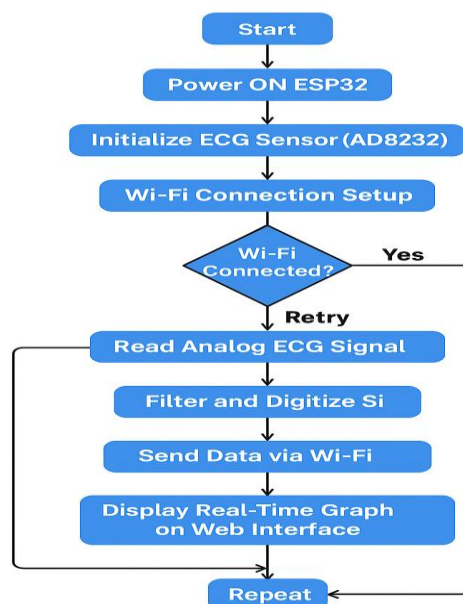


Figure:3.4 Block Diagram of Portable ECG Monitor

System Overflow:

The following flowchart illustrates the logical flow of data acquisition, processing, and transmission in the ECG system:

SYSTEM FLOWCHART



Circuit Connections:

The following Table shows the connection between AD8232 and ESP32:

Table:3.1 Circuit Diagram Connections

AD8232 Pins	Pin Functions	ESP32 Connection
GND	Ground	GND
3.3V	Power supply	3.3 V
OUTPUT	Output Signal	A0
LO-	Leads-off detected-	11
LO+	Leads-off detected+	10
SDN	Shut down	Not Used

Hardware Assembly:

The Key component used in the above prototype are described below:

- **AD8232 ECG Sensor Module:**

This analog front-end contains an instrumentation amplifier and filters tailored for ECG. It has a fixed gain (~100), a 2nd-order high-pass filter to remove DC and motion artifacts, and a 3rd-order low-pass filter to reduce high-frequency noise. It also includes a right-leg-drive (RLD) amplifier to suppress common-mode interference and lead-off detection circuitry. The module operates from a single 3.3 V supply and draws only microamps, making it low power.

- **ESP32 Microcontroller:**

A 32-bit dual-core microcontroller with built-in Wi-Fi and Bluetooth radios. It serves as the system's brain. ESP32's ADC samples the ECG signal (default 12-bit resolution) and its Wi-Fi interface streams the data. The on-chip flash and peripherals allow it to host a TCP/IP web server. The chosen ESP32 module includes a PCB antenna and necessary support circuitry, offering robust wireless range in compact form.

- **ECG Electrodes:**

Three medical-grade adhesive electrodes (silver/silver-chloride) are used in a standard Lead-I configuration (right arm, left arm, and right leg reference). They provide a skin-electrode interface to capture the heart's biopotentials. Good skin contact and proper placement are important for a clean signal.

- **Interconnects and Connectors:**

Female-to-male jumper wires or shielded cables connect the AD8232 module to the ESP32. A USB cable connects the ESP32 dev board to a power source and PC (for programming/debugging). Optionally, a battery pack (e.g. a 3.7 V Li-ion cell with a 3.3 V regulator) can power the ESP32 for untethered use.

- **Power Supply:**

The ESP32 and AD8232 can be powered from the USB port or a battery. A stable 3.3 V regulator is used. Low-dropout regulators and decoupling capacitors are recommended to minimize power-supply noise that could corrupt the ECG signal.

Each component is chosen for low cost, small size, and low power consumption, enabling a lightweight portable design.

Software Tools:

- **Arduino IDE Setup:**

The development environment is the Arduino IDE, which simplifies programming the ESP32. First, the ESP32 board support is installed: in the Arduino IDE's Preferences dialog, the "Additional Boards Manager URLs" field is given the ESP32 package URL, and then "ESP32 Arduino" is installed via the Boards Manager. After installation, the specific board (e.g. "ESP32 Dev Module" or similar) is selected under the Tools → Board menu, and the correct COM port is chosen.

- **Web Interface Access**

With the IP address obtained:

- We copy the IP shown in the Serial Monitor and paste it into a web browser on any device connected to the same Wi-Fi network.
- This launches the custom ECG monitoring interface we programmed using HTML, CSS, and JavaScript.

DESIGN CONSIDERATIONS:

Designing a portable ECG monitoring system required careful attention to several practical factors, including power supply, signal integrity, patient comfort, and overall ergonomics. Each aspect was considered to ensure a functional, user-friendly, and medically safe prototype.

- **Power Consumption**

USB-Powered Prototype

The current prototype is powered via USB (5 V) from a computer or USB adapter. The ESP32 dev board includes a voltage regulator that steps this down to 3.3 V for the processor and peripherals. In active monitoring mode (Wi-Fi on and ADC sampling), the entire system draws on the order of tens to hundreds of milliamps. (For example, measurements on similar ESP32 modules show active currents around 20–100 mA depending on Wi-Fi usage, plus the AD8232's ~0.17 mA and any LEDs or other sensors.) The USB port can easily supply up to 500 mA or more, so the prototype runs without battery constraints during development. However, constant USB tethering is not convenient for a wearable system.

Future Battery-Powered Operation

For true portability, the design will transition to battery power. A common choice is a single-cell lithium-polymer (LiPo) battery (e.g. 3.7 V nominal, 1000–2000 mAh capacity) with a 5 V boost converter if the ESP32 dev board requires USB-level voltage. Estimating battery life requires accounting for all modes of operation. The AD8232's analog front-end draw is negligible (hundreds of microamps) during measurement and virtually zero in shutdown. The major consumer is the ESP32's radio and microcontroller. In active mode (with Wi-Fi transmitting), the ESP32 might draw ~50 mA on average. If the device can be put into sleep between ECG samples or during idle, its current can drop dramatically. In deep-sleep mode, modern ESP32 modules draw only single-digit microamps. For instance, one test showed about 8.14 μ A in deep-sleep and ~23.9 mA when act. To maximize battery life, power-saving strategies will be implemented. For example, the ESP32 could wake periodically (sample 250 Hz for a few seconds to send data, then sleep) if continuous streaming is not needed. The AD8232 can also be put into shutdown (using its SDN pin) between readings to conserve its ~170 μ A. With careful duty cycling, a 2000 mAh battery could potentially power the device for many hours or days. Even in the worst case (continuous operation at ~50 mA), a 2000 mAh battery provides ~40 hours of runtime. In practice, optimizing sleep and reducing transmission frequency can extend this further, making battery power feasible for field or wearable use. In summary, while the USB-powered prototype demonstrates functionality, a battery-powered design will require attention to component quiescent currents and the use of the ESP32's low-power modes. The ultra-low-power characteristics of the AD8232 and the ESP32's power management suggest that long-term, portable ECG monitoring is achievable with appropriate hardware design and firmware controls.

- **Signal Quality**

The ECG signal has very low amplitude (usually in the millivolt range), making it highly susceptible to noise from surrounding electrical devices and body movement. The **AD8232 module** addresses this challenge by incorporating built-in analog filters to eliminate low-frequency baseline drift (below ~0.5 Hz) and high-frequency noise (above ~100 Hz), including 50/60 Hz mains interference. Additionally, good wiring practices were followed to enhance signal quality. Short signal paths, proper grounding, and secure pin connections were maintained to minimize noise. While the circuit was not built on a shielded PCB, care was taken to keep analog signal paths short and isolated from high-speed digital lines. The **Right Leg Drive (RLD)** output of the AD8232 further stabilizes common-mode voltages, reducing motion artifacts.

- **User Comfort and Safety**

Patient safety and comfort were key priorities. Standard **adhesive ECG electrodes** with gel pads were used to ensure skin contact and minimize resistance. These were connected using lightweight ECG cables that do not restrict movement. All patient-contact components operate at **3.3 V**, with microampere-level currents, ensuring safety from electrical shock. Since no mains-powered elements directly connect to the patient, and the power is isolated via USB, the risk of electric hazard is minimal. Further precautions

include well-insulated cables, secure electrode connections, and minimal exposed wiring. No high-voltage elements are present in the circuit, and the overall design meets basic low-voltage medical electronics safety standards suitable for prototyping.

- **Portability and Ergonomics**

While this prototype is not battery-operated, it is **compact and lightweight**, consisting of only three main components: the ESP32 board, the AD8232 ECG module, and the connecting leads. These components are assembled either on a custom PCB or with firm jumper connections, ensuring structural stability during use. The overall size of the system allows it to be **easily carried in a small case or pouch**, and the Wi-Fi-enabled operation ensures a wireless data link to the visual interface. The patient or user only needs access to a nearby laptop or smartphone to view the ECG trace in real-time, eliminating the need for complex infrastructure or cables.

- **Usability and Flexibility**

This system is **platform-agnostic** and requires no special software on the user's device, only a web browser. After flashing the firmware to the ESP32 and connecting it to a Wi-Fi network, the system automatically begins serving a web-based ECG display. The web interface updates continuously with incoming data, providing smooth waveform rendering and optional interactive features (like zoom, pause, or heart rate display, if added).

TESTING AND PROCEDURE:

Electrode Placement and Contact Quality

The three electrodes (right-arm, left-arm, and right-leg) were placed according to the standard limb-lead configuration. Specifically, the negative input (RA) electrode was placed on the subject's right forearm or shoulder, the positive input (LA) on the left chest, and the right-leg (RL) electrode on the right lower abdomen as a reference. The skin was cleaned with alcohol and conductive gel was applied to minimize impedance. Firm but comfortable pressure was applied when attaching the pads; maintaining stable electrode-skin contact proved critical for signal clarity. We noted that loose or poorly attached electrodes immediately caused baseline drift and noise. Good contact quality was verified by first observing a flat baseline output (no ECG) when the subject held their breath, and then by seeing a clean waveform once the heart was beating. Ensuring reliable contact prevented artifacts and was a prerequisite for all further tests.

RESULTS AND OBSERVATIONS:

ECG Signal Capture

Under normal conditions, the device captured clear ECG waveforms with all characteristic features visible. The results indicate that the instrumentation amplifier and filters in the AD8232 are functioning correctly, providing an analog ECG output.

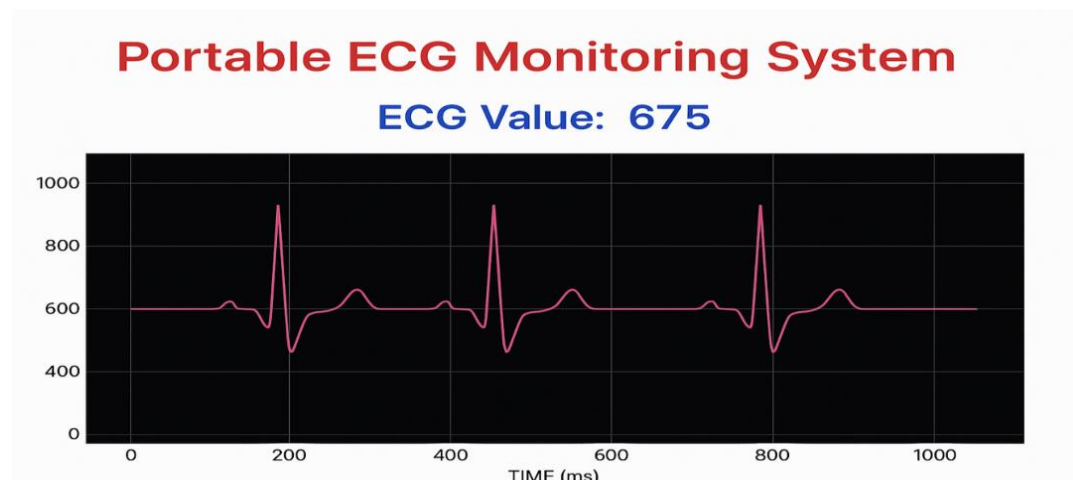


Figure: 4.1 Simulated browser-based ECG waveform output

USER EXPERIENCE AND INTERFACE REVIEW:

- Device connection and ease of use: Setting up the device was straightforward. Once powered on, the ESP32 automatically joined the configured Wi-Fi network. The user then simply opened a browser and navigated to the device's IP address, with no additional software required. In our tests, a new user could achieve a working connection in under a minute. The only manual step was entering the Wi-Fi credentials in the firmware at first use; this could be streamlined in future with a configuration portal. Overall, the system behaved in a plug-and-play manner and the startup procedure was intuitive.
- Browser display accessibility: The web interface was compatible with all modern browsers (Chrome, Firefox, Edge). The ECG chart scaled dynamically to the window size and was readable on both desktop and laptop screens. We chose clear axis labels and gridlines so that waveform details were easily seen. No browser plugins were needed – the interface ran on standard HTML5/JavaScript (e.g. using a plotting library). The controls (if any) and indicators were responsive: for example, a “leads off” warning appeared promptly if an electrode was removed. In summary, accessing the ECG data was as simple as visiting a web page, and the display presented the information in a user-friendly way.
- Portability and comfort: In operation, the device imposed very little burden on the subject. The main components are light and compact (no heavy wires or attachments), and the only contact with the body is via small adhesive pads. During short monitoring sessions, users reported that the electrodes felt comfortable and non-invasive. The prototype's rigid base is not meant to be worn on the body, but a final version could be housed in a slim case and perhaps clipped or carried easily. Compared to traditional wired ECG machines, our design greatly increases mobility: only thin leads tether the patient, and data is viewed wirelessly. This portability and ease of access (via any browser) were viewed positively by test users.

DISCUSSION AND WORK:

Summary of Results:

The portable ECG monitoring system built using the ESP32 microcontroller and AD8232 analog front-end successfully met its core objectives. The system was able to:

- Capture clean ECG signals with visible wave components.
- Stream real-time waveform data wirelessly to a browser-based interface.
- Maintain signal fidelity under resting conditions.
- Detect lead disconnection reliably and flag it appropriately.
- Operate with minimal setup and a user-friendly interface.

The results confirmed that the hardware and software design choices—such as using the AD8232 with its integrated filtering and lead-off detection, and the ESP32 with WebSocket-based data streaming—were effective for a low-cost prototype. Latency remained low, heart rate calculations were accurate, and signal quality was sufficient for basic monitoring. The small physical and simple setup also validated the system's portability and its way of using it.

Design Trade Offs:

Several design choices were made to keep the ECG monitor low-cost and user-friendly, at the expense of advanced features and robustness. In particular, the ESP32 microcontroller and AD8232 analog front-end were selected for their affordability and ease of integration. These components are widely available and open-source libraries exist, which simplifies development. However, both parts are less precise than specialized medical-grade hardware: the AD8232 is intended for hobbyist or consumer use and, as one study notes, “should not be used on a professional scale” without improvements. Thus, the choice of cheap parts trades off performance and regulatory compliance for simplicity and cost savings.

- **Affordability vs. Performance**

By using a low-cost SOC (ESP32) and single-lead AFE (AD8232), the system stays inexpensive and power-efficient, but sacrifices signal quality and reliability. Khan et al. emphasize that low-cost biopotential modules are easy to build and interface, yet they acknowledge inherent limits in gain and noise. In practice, the AD8232 provides adequate amplification for basic ECG but lacks the precision of higher-end instrumentation. In our design this means we accept higher noise floors and limited filtering capability in exchange for an economical solution. In other words, the component choices reflect a trade-off: low unit cost and simplicity versus measurement fidelity and precision.

- **Simplicity vs. Feature-Richness**

The firmware and hardware were kept straightforward: no real-time operating system, minimal user interface, and no complex wireless stack. We omitted features like Bluetooth streaming, encryption, or onboard analytics to make the system easier to implement. For example, instead of pairing with smartphones, the ESP32 can simply print data to a USB console. This eases development and reduces debugging burden, but also limits functionality. Notably, without built-in Bluetooth or Wi-Fi security layers, the design provides little data protection. Prior work on IoT ECG systems highlights that lack of encryption and authentication is a security risk. Similarly, choosing a simple single-lead design over a multi-lead configuration simplifies the circuit and electrodes, but at the cost of diagnostic power.

- **Impact on Security, Scalability, and Clinical Use**

The above trade-offs have downstream effects. On the security side, omitting encryption or secure authentication makes the system vulnerable if wireless connectivity were added later. Georgieva-Tsaneva et al. note that many basic IoT health devices face “security risks” and limited scalability when data are exposed. In our case, data are not encrypted, so any future wireless link would be insecure. Scalability is also constrained: the system is a one-user, one-lead monitor with no network or cloud interface. It cannot easily be scaled to multiple leads, multiple patients, or integrated into hospital systems without a major redesign. Clinically, the trade-offs mean this device cannot meet medical standards. As noted in the literature, an AD8232-based academic kit “cannot be trusted on a professional scale” without improvement. Our design similarly lacks regulatory certification, multi-lead ECG capability, and fails to meet many performance criteria required for clinical diagnostics. In summary, ease-of-use and low cost were prioritized, but these choices limit security, expandability, and medical applicability.

Conclusion:

The project successfully realized a portable ECG monitoring system that integrates a complete analog front-end with wireless data transmission. The AD8232 sensor module served as the analog amplifier and filter, capturing biopotential signals at microvolt levels with low power consumption. These conditioned ECG signals were digitized by the ESP32 microcontroller’s 12-bit ADC (sampled at 1 kHz). The ESP32 firmware performed basic signal processing and then used its built-in Wi-Fi to stream the data to a web-based interface. As demonstrated in similar IoT ECG systems, the transmitted waveform can be rendered in a standard web browser for real-time visualization. The final hardware prototype was powered by batteries and built on a compact PCB, resulting in a truly portable form factor.

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