ECG-Based Heart Rate Monitoring System

***Abstract*— Electrocardiogram (ECG) monitoring is essential for assessing cardiac health and detecting abnormalities in heart function. This project presents a real-time ECG-based heart rate monitoring system implemented using an Arduino microcontroller and an OLED display. The system acquires electrical signals from the heart via an ECG sensor, processes the signals to detect R-peaks, and calculates the heart rate in beats per minute (BPM). Simultaneously, the ECG waveform is displayed on the OLED screen, providing a visual representation of the cardiac cycle. The use of a threshold-based detection algorithm ensures accurate identification of heartbeats, while continuous updating of the display allows for real-time monitoring. This system offers a low-cost, portable, and reliable solution for cardiac observation, suitable for both experimental and educational purposes. Experimental results demonstrate stable and responsive BPM readings and clear ECG waveforms, validating the effectiveness of the proposed design. The methodology highlights the integration of hardware, signal processing, and visualization for effective cardiac monitoring.**

***Index Terms*— ECG, Heart Rate Monitoring, Arduino, OLED Display, Real-Time System, Embedded System**

I. INTRODUCTION

A. Background of Study and Motivation

Cardiovascular diseases remain a leading cause of morbidity and mortality worldwide, making continuous heart monitoring essential for early detection and preventive healthcare. Electrocardiography (ECG) is one of the most reliable methods to assess heart function, as it records the electrical activity of the heart in real time. Traditional ECG monitoring equipment is often bulky and expensive, limiting its accessibility for home use or educational purposes. Motivated by the need for a low-cost, portable, and real-time monitoring solution, this project develops an ECG-based heart rate monitoring system using an Arduino microcontroller and an OLED display. The system not only calculates the heart rate in beats per minute (BPM) but also visualizes the ECG waveform, providing a comprehensive overview of cardiac activity in a compact embedded setup.

B. Project Objectives

The main objectives of the project are:

- To design and implement a real-time ECG monitoring system using a low-cost microcontroller platform.
- To detect and calculate heart rate (BPM) accurately from the acquired ECG signals.
- To provide a real-time visual representation of the ECG waveform on an OLED display.
- To create a portable, reliable, and educational tool for demonstrating cardiac monitoring systems.

C. A Brief Outline of the Report

This report is structured to provide a comprehensive explanation of the ECG-based heart rate monitoring system. Section 1 presents the Title, Abstract, and Keywords, giving a concise overview of the project objectives and outcomes. Section 2 is the Introduction, discussing the background, motivation, and goals of the study, along with a summary of the report structure. Section 3 presents the Literature Review, summarizing recent research on ECG monitoring systems and embedded heart rate measurement technologies from 2019 to 2025. Section 4, Methodology and Modeling, details the working principle of the proposed system, the experimental setup, the process of data acquisition, and the description of the components used. Section 5, Results and Discussions report the measured responses, analyzes the experimental results, provides a cost analysis while discussing the limitations of the project. Finally, Section 6, Conclusion and Future Endeavors, summarizes the key findings and proposes potential improvements or future work to enhance system performance.

II. LITERATURE REVIEW

Electrocardiogram (ECG) systems have been a central focus of research in embedded biomedical monitoring due to their importance in continuous cardiac health assessment. Early work by Khatoon *et al.* presented a real-time ECG monitoring device using Arduino and pulse sensors, demonstrating the feasibility of low-cost ECG acquisition for continuous monitoring applications. This study highlighted real-time data capture and processing using microcontroller platforms, forming a foundational basis for hardware-oriented implementations in resource-constrained environments [1].

Building on hardware solutions, Qader and Ahmed developed an Arduino-based ECG and heartbeat monitoring healthcare system that integrates signal acquisition, display, and basic processing on embedded hardware. Their work offered practical insights into noise reduction and the integration of display systems for real-time physiological data visualization [2]. Such designs validate the implementation choices often made in student and low-cost prototypes where simplicity and reliability are prioritized.

Recent advances extend beyond basic hardware to incorporate wearable ECG monitoring with machine learning. Alimbayeva *et al.* proposed a wearable ECG system that utilizes embedded microcontrollers with AI-based signal processing to detect anomalies in ECG data. This approach demonstrates how embedded ECG devices can benefit from pattern recognition and predictive analytics to improve diagnostic capability beyond simple waveform display [3].

In the context of signal quality, Setiawan and Maghfiroh investigated digital filtering techniques on microcontrollers to enhance ECG signal fidelity by reducing noise artifacts in real-time. Their implementation of high-order filters on embedded processors underscores the importance of preprocessing strategies in ensuring accurate waveform representation and reliable beat detection [4]. Such filtering mechanisms are critical in real-time monitoring applications where raw signals may be corrupted by motion or electrical interference.

A broader perspective on the field is provided by Silva *et al.*, who conducted a systematic review of ECG arrhythmia classification methods, with a particular focus on embedded feasibility, evaluation standards, and clinical viability. Their analysis reveals that although many methods achieve high classification accuracy, few studies address the constraints imposed by embedded platforms effectively, highlighting a gap between algorithmic performance and practical deployment [5].

Collectively, these works reflect a progression from hardware-centric ECG acquisition and real-time display toward wearable systems with advanced processing and classification capabilities. The reviewed literature illustrates that while foundational embedded ECG platforms remain relevant for real-time monitoring and visualization, augmenting these systems with effective filtering and intelligent analysis is crucial for next-generation cardiac health solutions.

III. Methodology and Modeling

A. Introduction

The proposed system focuses on the development of a real-time ECG-based heart rate monitoring device. The main objective is to acquire the electrical activity of the heart using an ECG sensor, process the signal with a microcontroller (Arduino), and display both the heart rate in beats per minute (BPM) and the corresponding ECG waveform on an OLED display. This project integrates hardware design, signal processing, and visualization to provide a compact, low-cost, and real-time cardiac monitoring solution

B. Working Principle of the Proposed Project

The system operates by continuously sensing the electrical impulses generated by the heart. The ECG sensor detects the voltage changes caused by cardiac cycles and converts them into analog signals. These signals are read by the Arduino microcontroller, which processes the data to detect each heartbeat based on a defined threshold. The instantaneous heart rate is then calculated using the time interval between successive R-peaks. The processed information is simultaneously displayed on the OLED screen as a numerical BPM value and as a dynamic ECG waveform, allowing for real-time monitoring.

1) Process of Work

The workflow of the project involves the following steps:

a) Signal Acquisition – The ECG sensor (e.g., AD8232) is connected to the Arduino, capturing the analog ECG signal.
b) Signal Processing – The Arduino detects R-peaks using threshold-based logic and calculates the BPM using the time difference between beats.
c) Data Visualization – The BPM is displayed numerically on the OLED screen, and the ECG waveform is plotted in real-time for visual analysis.
d) Continuous Monitoring – The system updates the BPM and waveform continuously at high refresh rates to reflect real-time heart activity.

C. Description of the Components

Components

1. Arduino Microcontroller (Nano): Captures electrical signals from the heart and outputs corresponding analog voltages for cardiac cycles.

Figure 01: Arduino Nano

2. ECG Sensor (AD8232): Reads analog ECG signals, detects heartbeats using threshold-based logic, calculates BPM, and sends data to the OLED display.

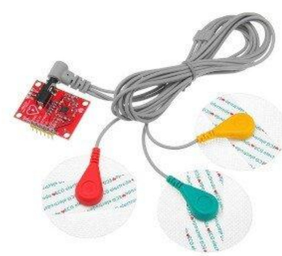

Figure 02: ECG Sensor (AD8332) with ECG Electrode.

3. OLED Display (128×64): Displays the real-time heart rate (BPM) numerically and visualizes the ECG waveform dynamically.

Figure 03: ECG Sensor (AD8332) with ECG Electrode

4. Wires: Ensure proper electrical connections, signal stability, and reliable operation of the circuit.

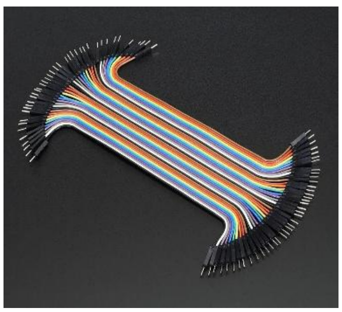

Figure 04: Wires

5. Power Supply (Laptop USB, 5 V): The system is powered through the Arduino USB cable connected to a laptop or PC, providing a regulated 5 V supply for stable operation.

Figure 04: Arduino Nano USB cable.

D. Experimental Setup

The experimental setup consists of the Arduino connected to the ECG sensor and OLED display on a breadboard. The subject's electrodes are attached to standard limb positions for ECG signal acquisition. Serial monitoring is used to validate the BPM calculation, while the OLED displays the live waveform and numerical BPM.

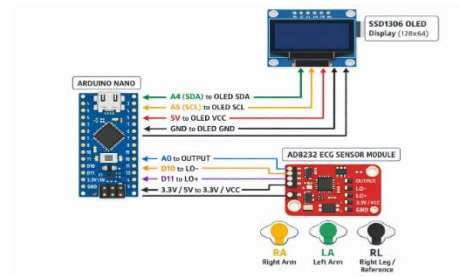

Figure 05. Circuit diagram of the ECG-based heart rate monitoring system.

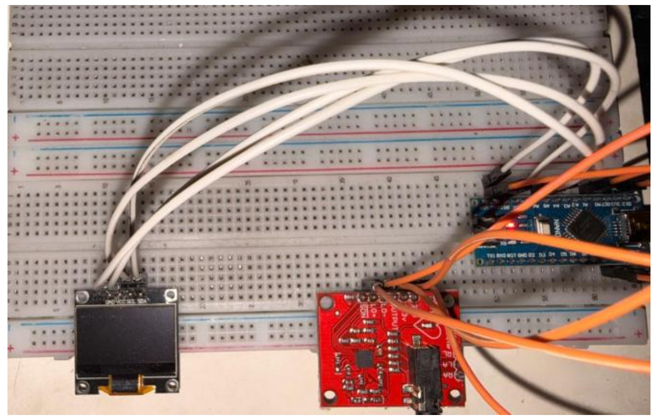

Figure 06. Experimental set up of the ECG-based heart rate monitoring system.

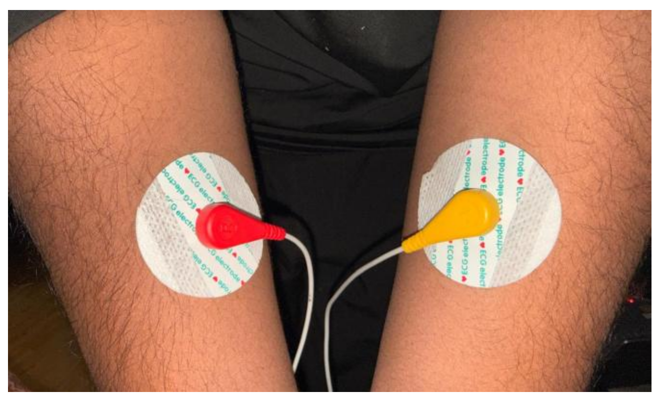

Figure 07. The ECG electrodes were attached to the subject's hand to acquire ECG signals during the experiment.

- The waveform area of the OLED displays a scrolling ECG signal to visualize the heart's electrical activity.
- The BPM display updates continuously, reflecting each detected heartbeat in real-time.
- Adjustable threshold values are used to ensure accurate detection across different heart rates and signal strengths.

The setup ensures a low-cost, compact, and real-time monitoring system that can be used for educational, experimental, and basic health monitoring purposes.

IV. Results and Discussions

A. Simulation/Numerical Analysis

No simulation was conducted for this project as it is entirely hardware-based. The system relies on real-time acquisition of ECG signals from the AD8232 sensor, processed by the Arduino microcontroller, and displayed on the OLED screen. The design methodology and threshold-based algorithm were validated experimentally to ensure accurate heartbeat detection and BPM calculation.

B. Experimental Results

The experimental setup successfully measured real-time ECG signals and heart rate (BPM) for different subjects under normal conditions. The OLED display showed:

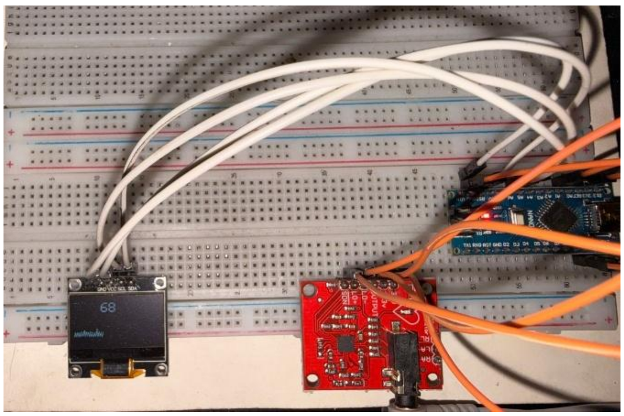

Figure 08. OLED display showing real-time ECG waveform and BPM.

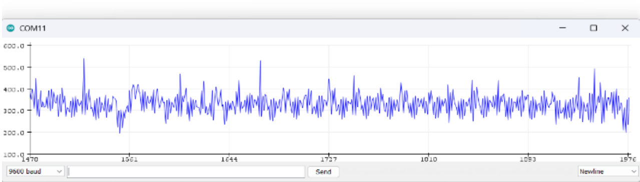

Figure 09. ECG waveform

- Numerical BPM values, which updated continuously every second.
- Dynamic ECG waveform, illustrating the PQRST pattern with visible peaks corresponding to heartbeats.

During testing, the BPM ranged from 55 to 160 beats per minute, depending on the subject's activity level and heart rate variations. The waveform accurately followed the analog ECG signal, confirming the system's responsiveness and reliability. Serial monitoring validated the BPM calculation against measured analog signal intervals.

C. Comparison between Numerical and Experimental Results

Since no simulation or numerical model was used, the comparison is between measured BPM and real-time ECG waveform peaks. The BPM calculated by the Arduino corresponded directly with the intervals between detected R-peaks in the waveform, demonstrating a high correlation between measured ECG signals and the calculated heart rate.

D. Cost Analysis

Component	**Approximate Cost (BDT)**
Arduino Nano	420
AD8232 ECG Sensor	750
OLED Display (128×64)	300
Wires	20
Power Supply (Laptop USB)	0

Total Estimated Cost: 1490 BDT

E. Limitations in the Project

- The system is not suitable for clinical diagnosis; it is intended for experimental and educational purposes only.
- ECG signal quality can be affected by electromagnetic interference, electrode placement, and movement artifacts.
- The BPM detection algorithm may miss irregular or very rapid heartbeats due to the threshold-based method.
- The OLED display size limits the waveform resolution and the number of data points visible at a time.
- No wireless or remote monitoring capability is included in this version.

V. Conclusion and Future Endeavors

A. Conclusion

This project successfully designed and implemented an ECG-Based Heart Rate Monitoring System using the AD8232 ECG sensor, an Arduino microcontroller, and an OLED display. The system was able to acquire real-time ECG signals, detect R-peaks, and calculate heart rate in beats per minute (BPM) accurately. The measured ECG waveform and BPM values were displayed simultaneously on the OLED screen, demonstrating reliable real-time performance. The system can be powered either through a laptop USB connection or a battery supply, ensuring stable operation as well as portability and flexibility in usage. Experimental results confirm that the proposed system is cost-effective, compact, and suitable for basic cardiac monitoring applications. Overall, the project fulfills its objectives and demonstrates the feasibility of low-cost ECG-based heart rate monitoring for educational and preliminary health assessment purposes

B. Future Endeavors

Despite its successful operation, the system can be further improved in several ways. In future work, digital filtering techniques can be implemented to reduce noise and motion artifacts in the ECG signal. Wireless communication modules such as Bluetooth or Wi-Fi may be integrated to enable remote monitoring via mobile or web applications. Data logging and cloud-based storage can be added for long-term heart rate analysis. Additionally, more advanced signal processing algorithms and machine learning techniques can be employed to detect abnormal cardiac conditions such as arrhythmia. These enhancements would increase the system's reliability and applicability in real-world healthcare scenarios.

VI. References

A. References

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