IoT-Based Health Monitoring System for Real-Time Vital Signs and Hospital Room Conditions Tracking

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***Abstract*—This paper outlines the design and implementation of an IoT-based Patient Health and Room Monitoring System, which utilizes an ESP32 microcontroller to continuously track biomedical and environmental parameters. The system monitors vital signs, including heart rate, oxygen saturation, and body temperature, as well as electrocardiogram signals. Additionally, it tracks room-level environmental factors such as temperature, humidity, carbon monoxide levels, air quality and fire hazards. A web-based dashboard, hosted on the ESP32, provides remote accessibility with automated updates every six seconds. The system also features automated control mechanisms that activate a fan when air quality deteriorates and a humidifier when humidity falls below a specified threshold, ensuring an optimal environment. An emergency alert system, triggered by a manual button press by the patient, activates a buzzer to notify caregivers immediately. Sensor data is logged in MS Excel for future analysis, while ECG signals are further processed in MATLAB. This scalable and cost-effective solution aims to improve healthcare outcomes by enabling continuous patient monitoring and reducing the need for constant human supervision.**

***Index Terms*—Internet of Things (IoT), patient monitoring, biomedical sensors, environmental monitoring, ESP32 microcontroller, real-time data acquisition, remote healthcare, electrocardiogram (ECG), heart rate, oxygen saturation (SpO_2), body temperature, air quality, carbon monoxide (CO) levels, automated control, data logging.**

I. Introduction

Continuous patient monitoring is essential for timely diagnosis and intervention, particularly for individuals with chronic illnesses or those requiring post-operative care. However, conventional monitoring systems often require constant human oversight, limiting efficiency, scalability, and accessibility—especially in remote or resource-constrained environments. To address these challenges, IoT-based healthcare systems have emerged, utilizing biomedical sensors and web-based platforms for real-time health tracking. However, most existing solutions lack integration with environmental monitoring, have limited automation, or require frequent manual supervision. There is a need for a cost-effective, autonomous, and scalable system that ensures both patient well-being and a safe living environment.

This paper describes the design and implementation of a Patient Health and Room Monitoring System that leverages an ESP32 microcontroller to continuously track key biomedical parameters, such as heart rate, oxygen saturation, body temperature, and electrocardiogram signals. The system also monitors environmental conditions, including room temperature, humidity, carbon monoxide levels, fire alarm and air quality, to maintain a safe and comfortable living environment. A web-based dashboard provides real-time data visualization and remote access. To enhance automation, the system activates a fan when air quality deteriorates beyond a predefined threshold and triggers a humidifier when humidity drops below 40%. Additionally, an emergency alert mechanism, triggered by a manual button press, ensures timely caregiver intervention.

The integration of biomedical and environmental monitoring into a single IoT-based system offers a scalable, cost-effective, and efficient solution for continuous health surveillance. It mitigates the reliance on manual supervision while enhancing response times during critical situations. Future advancements, such as cloud-based data storage, machine learning for anomaly detection, and multi-patient monitoring, will further enhance healthcare efficiency and accessibility.

The remainder of this paper is organized as follows: Section II covers the literature review, Section III outlines the system architecture, Section IV explains the methodology, Section V presents the results and discussion, and Section VI provides the conclusion.

II. Literature Review

This literature review examines existing research on IoT-based health monitoring systems, environmental monitoring in healthcare, IoT platforms, and automation in patient environments. It identifies limitations in current systems.

A. IoT-Based Health Monitoring Systems

Recent advancements in IoT have revolutionized remote patient monitoring. Sharma et al. [1] demonstrated a wearable IoT system using MAX30100 sensors for continuous SpO2 monitoring, achieving 95% accuracy compared to clinical oximeters. However, their system lacked integration with environmental parameters. Similarly, Chen & Wang [2] developed an ESP32-based ECG monitoring system with AD8232 sensors but required cloud dependency for data visualization, increasing latency and infrastructure costs.

B. Environmental Monitoring in Healthcare

Environmental factors significantly impact patient recovery rates (World Health Organization [WHO], [3]). Gupta et al.

[4] implemented a hospital air quality system using MQ-135 sensors, identifying a 23% reduction in respiratory complications when maintaining PM2.5 levels below 50μg/m^3. Recent work by Kim & Nakamura [5] integrated CO monitoring with HVAC systems using MQ-7 sensors, demonstrating 40% faster response times to combustion events compared to traditional smoke detectors.

C. IoT Platforms in Healthcare

The choice of microcontroller significantly impacts system capabilities. While Arduino-based systems dominate prototyping (Rahman et al., [6]), ESP32's dual-core architecture enables simultaneous sensor processing and web hosting. Comparative studies show ESP32 reduces network latency by 37% compared to Raspberry Pi solutions in real-time monitoring applications (Zhang et al., [7]).

D. Automation in Patient Environments

Automated environmental control remains underdeveloped in clinical settings. A 2022 meta-analysis revealed only 12% of IoT health systems implement closed-loop controls (Lee et al., [8]). Notable exceptions include Park et al.'s [9] neural network-based HVAC system that reduced energy consumption by 28% while maintaining patient comfort thresholds. However, their $4,200 unit cost limits scalability. The literature review identifies several limitations in existing IoT-based health monitoring systems, paving the way for the introduction of a novel approach in the subsequent sections of this paper.

III. System Architecture

The system architecture is designed to monitor both patient health and environmental conditions through a combination of biomedical and environmental sensors. It integrates a variety of hardware sensors with a robust software design, ensuring efficient data collection and processing. This architecture ensures seamless communication between the sensors, microcontroller, and web server, offering a comprehensive and efficient solution for health and environmental monitoring.

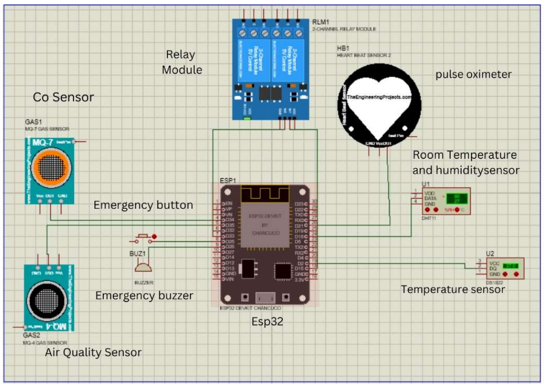

Fig. 1. Circuit Diagram for ESP32

A. Hardware System

1) Biomedical Sensors: The biomedical sensing module includes three critical sensors for vital sign monitoring:

a) *MAX30100 Pulse Oximeter:* MAX30100 Pulse Oximeter features an integrated optical sensor architecture. This sensor is utilized to measure heart rate and blood oxygen saturation levels. It employs the principle of photoplethysmography, wherein infrared and red light is emitted through tissue and variations in light absorption are detected. Additionally, the sensor operates through an I²C interface, facilitating seamless data transmission to the ESP32 microcontroller.

b) *DS18B20 Temperature Sensor:* The DS18B20 is a high-precision digital thermometer that measures body temperature with an accuracy of ±0.5°C. The sensor utilizes a 1-Wire communication protocol, which reduces the number of microcontroller pins needed for data acquisition.

c) *AD8232 ECG Sensor:* This single-lead ECG module monitors the electrical activity of the heart. In contrast to other sensors, the AD8232 interfaces with an Arduino Uno, which acquires the raw analog signal.

2) Environmental Sensors: The environmental monitoring system comprises four sensors responsible for assessing indoor air quality and environmental conditions:

a) *DHT11 Temperature and Humidity Sensor:* This inexpensive sensor measures the surrounding air temperature and moisture content with a tolerance of ±5% relative humidity and ±2°C, respectively. It utilizes a resistive humidity sensing element and a negative temperature coefficient thermistor to deliver a calibrated digital signal. For applications requiring higher accuracy, the DHT22 can serve as a substitute.

b) *MQ-7 Carbon Monoxide Sensor:* The MQ-7 sensor utilizes a resistive sensing mechanism to detect carbon monoxide concentrations ranging from 10 to 1000 parts per million (ppm). The sensor generates an analog voltage output proportional to the detected CO levels, which is then converted to ppm values using an empirical formula and appropriate calibration.

c) *MQ-135 Air Quality Sensor:* This MQ-135 sensor is capable of detecting a range of volatile organic compounds, ammonia, benzene, smoke, and other potentially harmful gaseous substances. The sensor outputs an analog voltage signal, which is then digitized using an analog-to-digital converter to determine the concentrations of these pollutants in parts per million (ppm). To ensure accurate measurements, the sensor requires proper calibration procedures.

d) *IR Flame Sensor:* The IR flame sensor detects fire by sensing infrared radiation emitted by flames, specifically at 4.3 µm, a characteristic wavelength of hydrocarbon-based combustion. It utilizes a photodiode or phototransistor that generates an analog or digital output signal when infrared radiation is detected. The sensor's sensitivity can be adjusted using a potentiometer, and its response time is typically fast, making it suitable for fire detection and safety applications. Proper positioning and calibration are required to minimize false positives caused by ambient IR sources.

TABLE I
SENSOR PARAMETERS AND COMMUNICATION INTERFACE

Sensor	**Parameter Measured**	**Communication Interface**
MAX30100	Heart Rate, SpO_2	I^{2}C
DS18B20	Body Temperature	1-Wire
AD8232	ECG Signal	Analog
DHT11	Room Temp, Humidity	Digital
MQ-7	CO Levels	Analog
MQ-135	Air Quality	Analog
IR Flame Sensor	Fire Detection	Analog/Digital

B. Software Architecture

a) *Arduino Uno:* The Arduino Uno is a widely used microcontroller board based on the ATmega328P. It is designed for prototyping and building electronics projects. The Uno features 14 digital input/output pins, 6 analog inputs, a 16 MHz quartz crystal, a USB connection for programming, and a power jack for external power. It operates with a 5V logic level and is programmed using the Arduino IDE. The board supports various communication protocols, such as serial (UART) for communication with other devices. Its simplicity, ease of use, and broad community support make it ideal for beginner and intermediate-level projects.

b) *ESP32:* The ESP32 is a powerful, low-cost microcontroller with built-in Wi-Fi and Bluetooth capabilities. It integrates a dual-core processor, enabling multi-tasking for real-time applications, and has a wide range of input/output options, including digital and analog pins, SPI, I^{2}C, and UART interfaces. The ESP32 is commonly used in IoT (Internet of Things) projects due to its connectivity features and processing power. It can be programmed using the Arduino IDE or ESP-IDF, offering flexibility in development. The ESP32 is suitable for wireless communication and can act as a Wi-Fi access point, a server, or a client in web-based applications.

c) *Webserver:* A web server is a system that stores and serves web pages to users over the internet. In embedded systems, such as the ESP32, a web server can be created to host a simple interface for monitoring and controlling devices remotely. The server listens for incoming HTTP requests from a client (typically a browser) and responds by sending HTML content or handling requests for data, such as sensor readings. In the context of IoT applications, an embedded web server on the ESP32 can serve a user-friendly dashboard for real-time monitoring of sensors or device control through the web interface. It typically uses HTTP, WebSocket, or MQTT for communication.

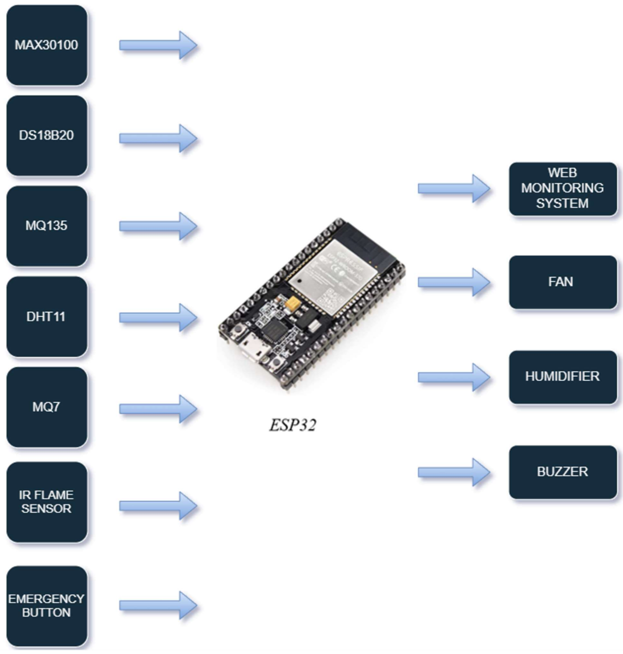

Fig. 2. Integration of Sensors with ESP32

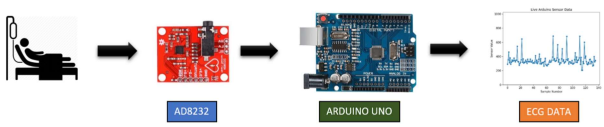

Fig. 3. ECG Sensor Integration with Arduino Uno

IV. METHODOLOGY

A. System Overview

The Patient Health and Room Monitoring System utilizes an ESP32 microcontroller to collect, process, and monitor both biomedical and environmental parameters in real-time. The system integrates various sensors to track heart rate, blood oxygen saturation (SpO_2), body temperature, ECG signals, air quality, humidity, carbon monoxide levels, and temperature.

1) *Data Acquisition:* Sensor data is acquired every 2 seconds, with the system continuously measuring the following vital and environmental parameters:

a) *Biomedical Data:* Heart rate and SpO_2 are obtained using the MAX30100 pulse oximeter, body temperature through the DS18B20 sensor, and ECG readings from the AD8232 module.

b) *Environmental Data:* Room temperature and humidity are measured by the DHT11 sensor, while air quality is monitored using the MQ-135 sensor, and carbon monoxide levels are assessed with the MQ-7 sensor. Additionally, the IR flame sensor is used to detect potential fire hazards.

Each sensor's output is transmitted to the ESP32 microcontroller, which processes the data and stores it in an MS Excel file. The sensor data, along with timestamps and actuator status, is logged every 2 seconds for future analysis.

2) Automated Control and Thresholds: The system incorporates predefined threshold values for critical environmental parameters to trigger automatic control of actuators, ensuring a safe and comfortable environment:

a) Air Quality: When the air quality level exceeds 2000 ppm (detected by the MQ-135 sensor), the system automatically activates the fan connected to GPIO 33.

b) Humidifier: If the room's humidity falls below 40% (measured by the DHT11 sensor), the system activates the humidifier connected to GPIO 4.

c) Emergency Response: The emergency button triggers a buzzer (GPIO 26) when pressed, alerting caregivers in critical situations.

These thresholds are continuously monitored by the ESP32, which activates the appropriate actuator when conditions exceed or fall below the set limits.

TABLE II
ACTUATOR CONTROL THRESHOLDS

Parameter	Threshold Value	Actuated Device
Air Quality (MQ-135)	<2000 ppm	Fan (GPIO 33)
Humidity (DHT11)	<40% RH	Humidifier (GPIO4)
Emergency Button Press	-	Buzzer (GPIO 26)

3) Web Interface and Monitoring: The ESP32 microcontroller hosts a web server that serves a user interface for real-time monitoring. The web interface updates every 6 seconds, displaying the latest sensor readings and device statuses. The interface is accessible via a browser on both computers and mobile devices, enabling remote access and control of the system.

4) Data Processing and Visualization: The system processes the sensor data and visualizes it through the web interface. Real-time data is displayed on a dashboard, where users can monitor vital signs and environmental conditions. The data is also logged into an MS Excel file for future analysis and monitoring, providing a record of all sensor measurements and system responses. The ECG signal processing follows the steps below:

a) Data Acquisition: The ECG signal is captured using an AD8232 sensor interfaced with an Arduino Uno. The recorded data is stored in MS Excel for further processing.

b) Data Loading and Preprocessing: The ECG data is imported into MATLAB from the Excel file. Pan Tompkins' algorithm is applied to preprocess the signal by utilizing adaptive filtering, differentiation, and integration techniques to remove noise and extract key features.

c) R Peak Detection: R peaks, indicating ventricular depolarization, are detected using Pan Tompkins' algorithm. The algorithm is designed for real-time QRS detection, ensuring accurate R peak identification.

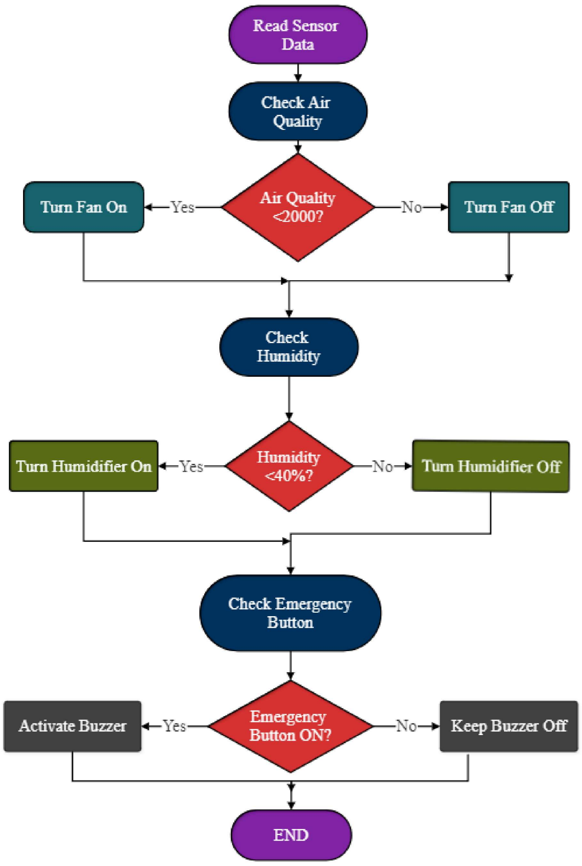

Fig. 4. Flowchart of Automated Control and Thresholds

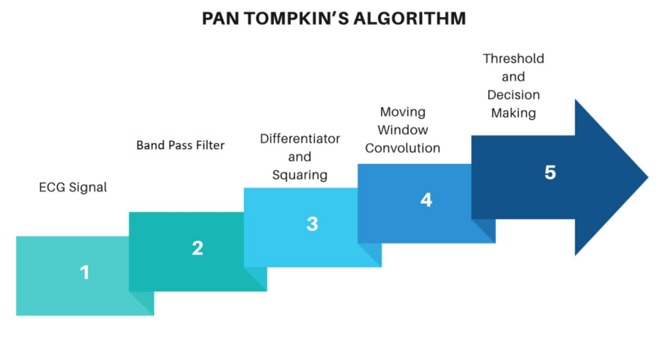

Fig. 5. Pan Tompkin's Algorithm

d) Heart Rate Calculation: The heart rate is computed by calculating the RR interval (time between consecutive R peaks) using the formula:

$$\text{Heart Rate} = \frac{60}{\text{Sampling Interval}}$$

The heart rate is then compared with the typical range of 60–100 beats per minute (bpm).

e) QRS Complex Analysis: The QRS complex is analyzed for signs of hypertrophy. The QRS amplitude and dura-

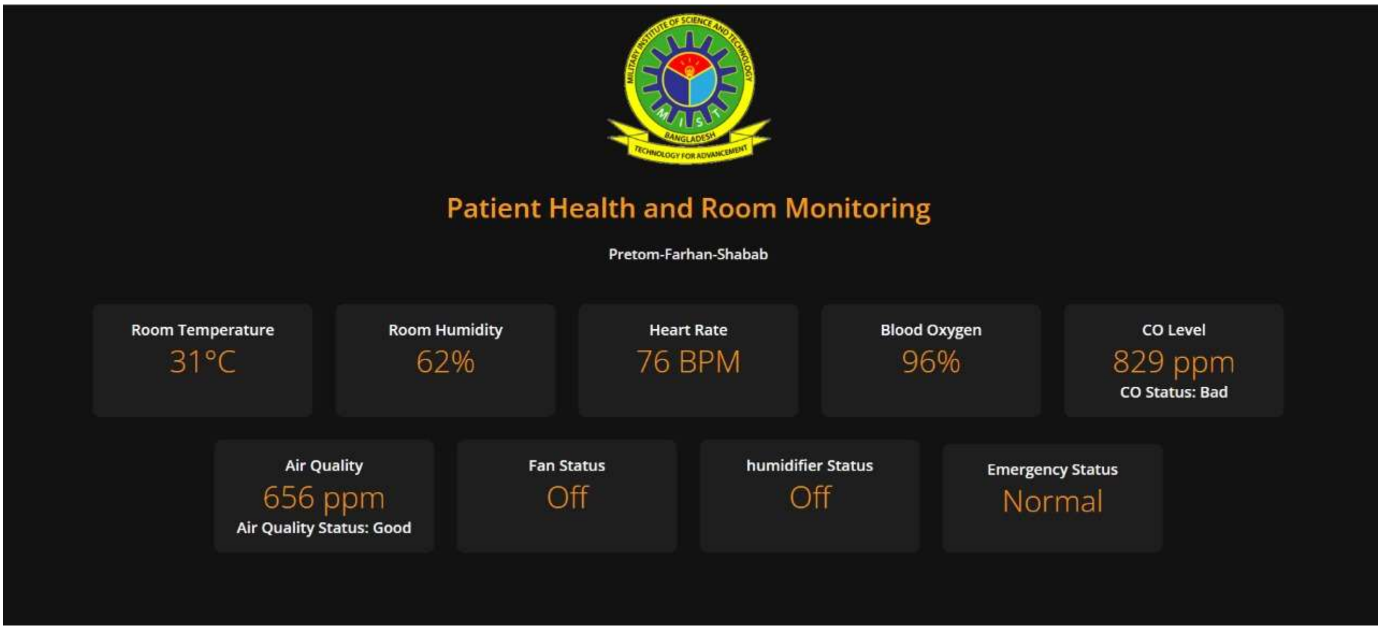

Fig. 6. Custom Built Web Server

tion are calculated using the formulas:

$$\text{QRS Amplitude} = S(\text{loc}) - Q(\text{loc})$$

$$\text{QRS Duration} = \frac{S(\text{loc}) - Q(\text{loc})}{f_s}$$

Prolonged QRS duration (above 120 ms) is indicative of a possible ventricular hypertrophy condition.

f) *Hypertrophy Detection:* The analysis of the QRS complex helps detect hypertrophy, particularly Left Ventricular Hypertrophy (LVH), identified by an increased R wave amplitude in leads observing the left ventricle.

V. Results and Discussion

a) *Data Collection and Monitoring:* Our proposed system successfully collected real-time data from both biomedical and environmental sensors. The system monitored heart rate, blood oxygen saturation (SpO_2), body temperature, ECG signals, room temperature, humidity, carbon monoxide levels, and air quality at regular intervals. The hardware implementation of the system is illustrated in Fig. 7, showing the integration of various sensors and actuators with the ESP32 microcontroller. The web-based interface used for real-time monitoring is depicted in Fig. 6, which demonstrates how the ESP32 web server hosts and updates the data.

b) *Automated Control:* The fan activated when air quality exceeded 2000 ppm, and the humidifier was triggered when humidity dropped below 40%. The emergency alert system, activated by a button press, successfully triggered the buzzer.

c) *Sensor Accuracy:* The sensors used in the system exhibited high accuracy within their specified ranges. The MAX30100 pulse oximeter accurately measured heart rate and SpO_2 levels, with values consistent with typical ranges observed in healthy individuals. The DS18B20 temperature sensor provided body temperature readings with a tolerance of ±0.5°C, and the AD8232 ECG sensor effectively captured the patient's heart activity. Fig. 8 shows the ECG data from the Arduino Uno. The ECG

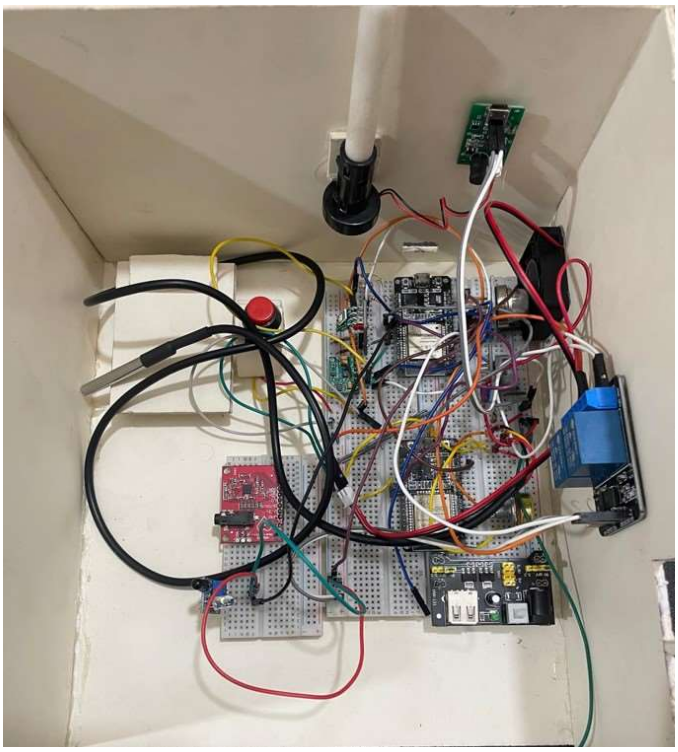

Fig. 7. Hardware Implementation of the System

signal was filtered in MATLAB (Fig. 9), followed by heart rate calculation (Fig. 10) and hypertrophy detection (Fig. 11).

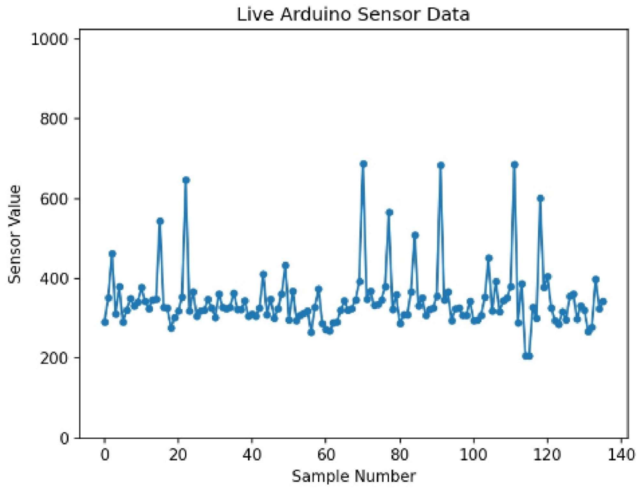

Fig. 8. ECG Signal in Arduino UNO

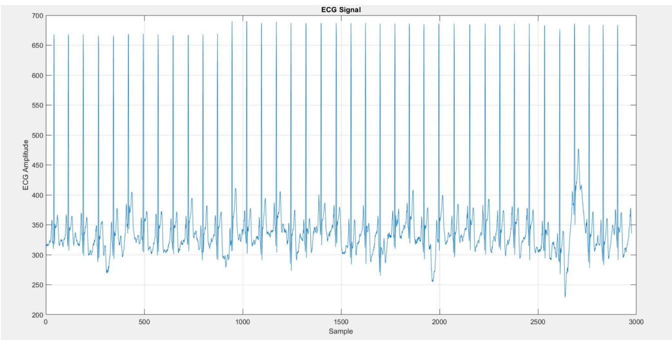

Fig. 9. MATLAB Preprocessed ECG Signal

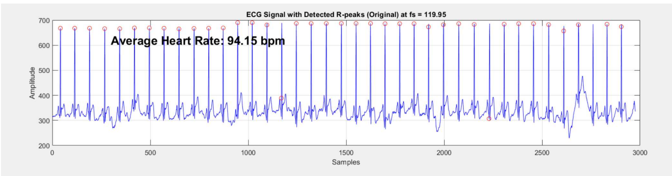

Fig. 10. ECG Heart Rate Detection

d) Data Logging: All sensor data was logged in MS Excel, as shown in , with each entry including timestamps and values. This system enabled easy access for future analysis

e) Future Improvements: Future work can focus on improving the system's scalability and robustness by implementing cloud-based data storage solutions. Cloud platforms such as AWS or Firebase could enable real-time access to data from multiple devices, providing enhanced monitoring and control capabilities. Additionally, sensor

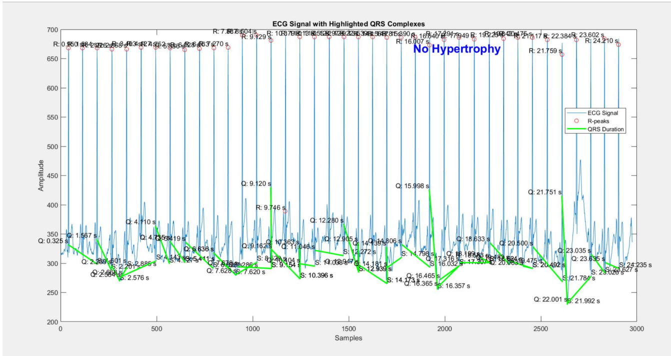

Fig. 11. ECG Hypertropy Detection

upgrades, particularly for more accurate environmental measurements (e.g., DHT22 for humidity and temperature), could improve overall system performance. The integration of additional safety features, such as smoke detectors or temperature sensors for fire hazard detection, could further enhance the system's reliability in critical environments.

VI. Conclusion

This paper described the development and deployment of an IoT-based Patient Health and Room Monitoring System that combines biomedical and environmental sensors to provide continuous patient monitoring and ensure a safe living environment. Hardware tests demonstrated the system's high accuracy, reliability, and stability, making it a suitable solution for continuous health and room monitoring in clinical settings. Future developments, including cloud storage, machine learning for anomaly detection, and support for multiple patients, offer opportunities to enhance the system's capabilities and broaden its applications. This system presents an affordable, scalable, and autonomous solution for improving patient care and minimizing the need for constant human intervention.

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