IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.102 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 14, Issue 3, March 2025

DOI: 10.17148/IJARCCE.2025.14348

RASPBERRY PI-BASED ICU MONITORING: ENHANCING PATIENT SAFETY WITH REAL-TIME DATA

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Abstract: The ICU Patient Monitoring System is an innovative healthcare solution designed to continuously monitor critical patient parameters such as heart rate, oxygen saturation (SpO2), and body temperature. The system integrates Raspberry Pi, medical sensors, a Flask-based web application, an SQLite database, and an automated alert system (SMS, email, voice calls) to enhance patient care and emergency response. This paper details the progress, challenges, and future enhancements of the project. The ultimate goal is to provide a cost-effective, scalable, and real-time monitoring solution for hospitals and healthcare institutions, reducing manual intervention and ensuring rapid response to critical conditions.

Keywords: ICU Patient Monitoring, Raspberry Pi, Medical Sensors, Flask Web Application, SQLite Database, Automated Alert System, Heart Rate Monitoring, SpO2 Measurement, ECG Sensor, Temperature Sensor**.**

I. INTRODUCTION

The ICU Patient Monitoring System is an advanced healthcare application designed to continuously monitor patients' vital signs, providing real-time data analysis, alerts, and notifications for critical conditions. The project integrates Raspberry Pi, medical sensors, a Flask-based web application, an SQLite database, and an automated alert system (SMS, email, voice calls) to enhance patient monitoring and emergency response.

The system aims to improve patient care in Intensive Care Units (ICUs) by offering a reliable, cost-effective, and scalable solution for real-time health monitoring. Medical staff can access patient details, live health data, and emergency alerts through an intuitive and user-friendly web interface. The system is designed to reduce the burden on healthcare professionals, ensuring that critical patients receive immediate attention when necessary.

II. OBJECTIVES

- To develop a real-time patient monitoring system capable of live data acquisition and display.
- To design a secure and interactive web application that enables medical professionals to access patient health records conveniently.
- To implement an automated alert mechanism to notify medical personnel when a patient's vital signs reach critical thresholds.
- To ensure efficient data storage and visualization through an SQLite database and graphical representations of health parameters.

- To integrate Raspberry Pi with medical sensors to collect real-time patient data and transmit it to the Flask web server for processing.
- To provide secure user authentication to restrict access to authorized medical professionals only.
- To generate printable health reports for documentation and analysis.
- To establish a scalable and adaptable architecture that can accommodate additional sensors and features in the future.

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III. APPLICATIONS

- **Hospitals & ICUs:** Real-time patient monitoring to detect emergencies and alert medical staff.
- **Remote Healthcare:** Can be adapted for telemedicine and home-based patient monitoring.
- **Elderly Care Centers:** Continuous health monitoring for elderly individuals at risk of cardiac or respiratory issues.
- **Military & Disaster Relief Camps:** Monitoring of patients in remote locations where immediate medical attention is necessary.
- **Research & Development:** Data collection for medical studies and AI-based health predictions.

IV. HARDWARE USING

- **Raspberry Pi 3B+/4** – Main processing unit, handling sensor data collection and transmission.
- **AD8232 ECG Sensor** – Monitors heart rate and provides real-time ECG readings.
- **MAX30100/30102 SpO2 Sensor** – Measures blood oxygen levels and pulse rate.
- **MLX90614 Infrared Temperature Sensor** – Captures body temperature without contact.
- **3.5-inch Touchscreen Display** – Allows real-time monitoring and control from Raspberry Pi.
- **Power Supply Unit (5V, 2.5A)** – Provides stable power to the Raspberry Pi and sensors.
- **Wi-Fi Module (Built-in on Raspberry Pi)** – Enables wireless communication between the system and the server.

V. PROGRESS OVERVIEW

Phase 1: System Planning and Requirements Gathering (Completed)

- Defined the project scope, objectives, and technical requirements.
- Conducted research on existing ICU monitoring systems and identified areas for improvement.
- Selected SQLite as the database solution due to its lightweight and efficient nature.
- Chose Flask as the backend framework for managing data, authentication, and alert functionalities.
- Outlined the data flow architecture for seamless communication between sensors, Raspberry Pi, and the web server.

Phase 2: Web Application Development (Completed)

- Designed and developed the following web pages:
  - **Home Page:** Serves as an entry point with navigation options.
  - **Dashboard:** Displays real-time patient vital signs in a structured format with graphical visualization.
  - **Patient Registration Page:** Enables medical staff to enter and manage patient details.
  - **Reports Page:** Generates and provides printable patient health reports.
- Implemented **user authentication and role-based access control (RBAC)** to restrict unauthorized access.
- Developed the database schema to store **patient information and real-time vital sign data**.
- Ensured a professional and visually appealing UI with **responsive CSS and JavaScript enhancements**.
- Conducted **preliminary usability testing** to improve UI/UX design.

Phase 3: Sensor Integration and Data Collection (In Progress)

- Selected **ECG (AD8232), temperature, and SpO2 (oxygen level) sensors**.
- Successfully tested the **ECG sensor (AD8232)** and validated its output.
- Currently working on **real-time data transmission** from Raspberry Pi to the Flask server.
- Establishing a stable and efficient **data logging mechanism** in the SQLite database.
- Investigating issues related to **library installation and sensor compatibility** on Raspberry Pi.
- Implementing **data filtering and noise reduction algorithms** to ensure accurate readings.

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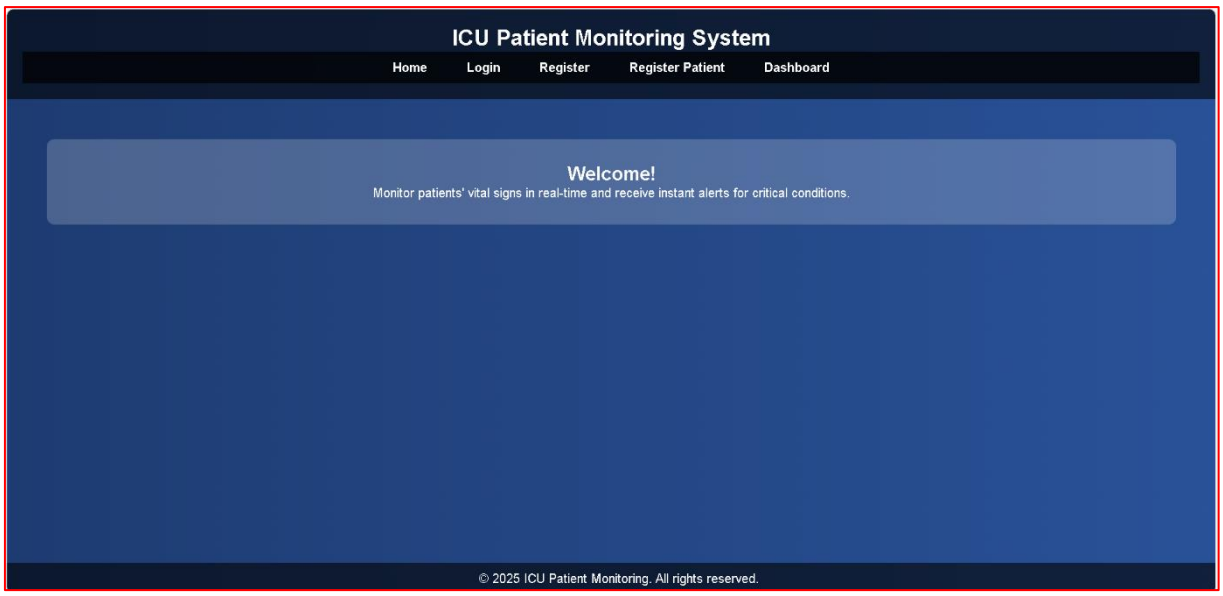

Figure 1: Home

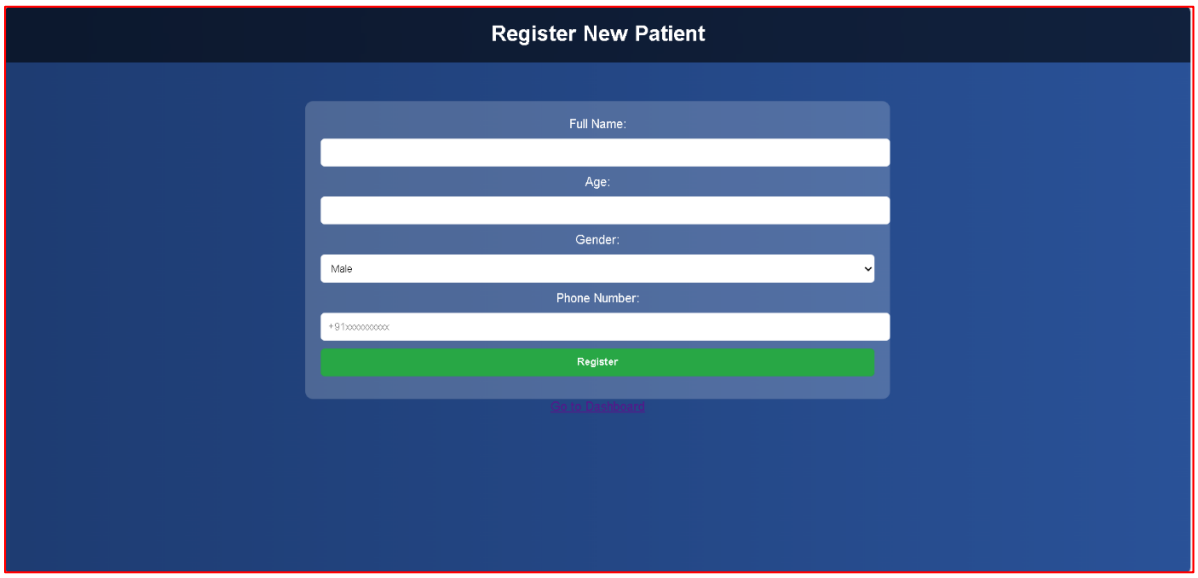

Figure 2: Registration Page

Phase 4: Alert System Implementation (Upcoming)

- Configure **Twilio API for SMS and voice call alerts** to notify medical staff in emergencies.
- Implement real-time **threshold-based alerts** when a patient's vitals exceed safe levels.
- Display alerts on the **dashboard interface**, ensuring immediate response.
- Develop **email notification functionality** for additional alert mechanisms.
- Implement **audio-visual alerts** on the web interface for immediate on-screen notifications.
- Create a **hierarchical alert system** where notifications are escalated based on severity.

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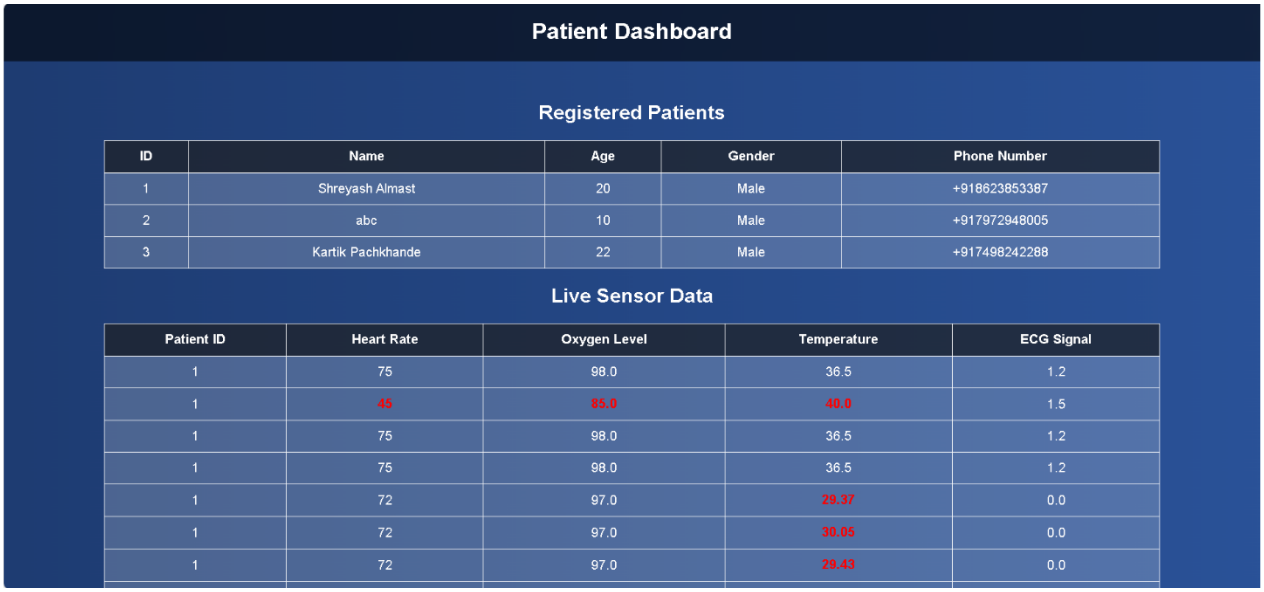

Figure 4: Patient Dashboard

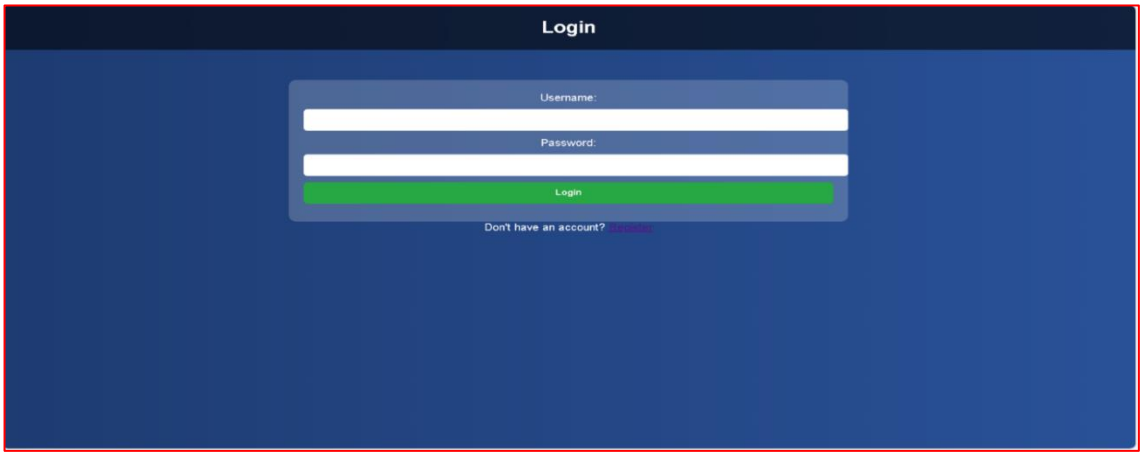

Figure 3: Authentication Page

VI. CHALLENGES FACED

- **Library Installation Issues on Raspberry Pi:** Some required sensor libraries (e.g., MAX30100 for SpO2 measurement) were unavailable or required manual installation.
- **Database Connectivity Errors:** Encountered issues with SQLite database path configurations, which were resolved by specifying absolute paths.
- **Threshold Detection Logic:** Developing a precise algorithm to define critical condition alerts based on real-time vital sign fluctuations.
- **Power Management:** The Raspberry Pi exhibited occasional undervoltage warnings, necessitating a stable power supply solution.
- **Sensor Noise and Data Inconsistency:** Addressing signal fluctuations and ensuring data accuracy through filtering techniques.

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VII. FUTURE ENHANCEMENTS

- Implement **AI-based health predictions** using machine learning for early disease detection.
- Develop a **mobile application** for remote monitoring and alert notifications.
- Integrate **cloud storage** to enable data access from multiple locations securely.
- Enhance security with **role-based access control (RBAC)** to restrict data visibility.
- Expand sensor integration by adding **blood pressure and respiratory rate sensors**.
- Introduce **voice-based alerts** for emergency notifications.

VIII. CONCLUSION

The ICU Patient Monitoring System aims to **enhance critical care monitoring through automation, real-time alerts, and advanced data visualization**. By integrating **Raspberry Pi, sensors, and AI-driven analytics**, this system holds significant potential for revolutionizing ICU care in hospitals. Continued development and enhancements will further **increase efficiency, security, and scalability**, making it a crucial innovation in modern healthcare.

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