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An IoT-Integrated Multi-Sensor Framework for Continuous Vital Monitoring and Fall Detection

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Abstract

This paper introduces a compact, real-time health monitoring system that integrates IoT technology to continuously measure heart rate, SpO_2 (blood oxygen saturation), body temperature, and also detect falls. The design incorporates a MAX30100 pulse oximeter, a thermistor-based temperature sensor, and a three-axis accelerometer, all connected to an ESP32 controller. The data collected is processed locally and sent to the Arduino IoT Cloud for remote monitoring and alert notifications. To minimize noise from ambient temperature fluctuations and variations in sensor-skin contact, a two-step thermal calibration procedure is employed. Tests show that the system provides stable signal acquisition and dependable fall detection capabilities, making it suitable for elderly care, personal health monitoring, and tracking high-risk patients. The prototype developed offers an affordable and scalable option compared to traditional medical monitoring systems.

Keywords: Vital signs, IoT healthcare, MAX30100, Fall detection, ESP32, Temperature monitoring, Wearable system.

1. Introduction

Ongoing monitoring of vital parameters is crucial for the early detection of abnormal physiological states. Heart rate, SpO_2, and body temperature are vital signs for identifying cardiac stress, respiratory problems, and infection-related changes. Falls, especially among the elderly, can lead to serious injuries and often necessitate immediate medical intervention. Conventional monitoring systems used in clinics tend to be bulky, costly, and lack remote connectivity, rendering them impractical for daily use or prolonged personal monitoring. Recent developments in embedded systems and cloud technologies have facilitated the creation of compact, energy-efficient health monitoring devices. This study presents an IoT-integrated multi-sensor framework designed to gather, process, and transmit vital signs in real time. The ESP32 microcontroller interfaces with sensors and ensures secure cloud communication through Wi-Fi. The Arduino IoT Cloud dashboard allows for the visualization of physiological parameters and automated notifications. The key contribution of this work lies in the synthesis of various physiological measurements and fall detection within a single, portable device, enhanced by a tailored calibration algorithm for improved temperature accuracy.

2. System Architecture

The system is powered by a Li-ion battery, which supplies regulated power through a power management board and switch to the ESP32 microcontroller. The ESP32 acts as the central controller, interfacing with multiple sensors. The MAX30100 sensor measures heart rate and SpO_2 levels, the thermistor monitors body temperature, and the 3-axis accelerometer detects motion and fall events. The collected data is processed by the ESP32 and displayed locally on a 16×2 LCD. In case of abnormal conditions or fall detection, a buzzer provides an alert. Simultaneously, all vital parameters and alerts are transmitted to the Arduino IoT Cloud dashboard for remote monitoring.

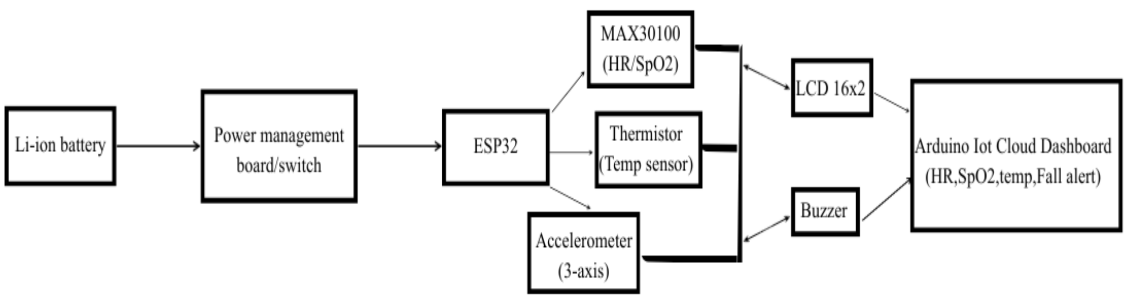

Figure.1. Block Diagram of the System

Figure 1 shows the overall architecture of the proposed system, where a Li-ion battery and power management board supply regulated power to the ESP32 microcontroller. The ESP32 acquires physiological data from the MAX30100 sensor for heart rate and SpO_2 monitoring, a thermistor for body temperature measurement, and a 3-axis accelerometer for fall detection. The processed data are displayed on a 16×2 LCD, alerts are generated using a buzzer, and all vital parameters along with fall alerts are uploaded to the Arduino IoT Cloud dashboard for remote monitoring. Functional Units of the Proposed System as follow,

1. Physiological Sensing Unit
2. Processing Unit
3. Local Display Unit
4. Alerting Unit
5. Cloud Monitoring Unit

2.1. Hardware Components

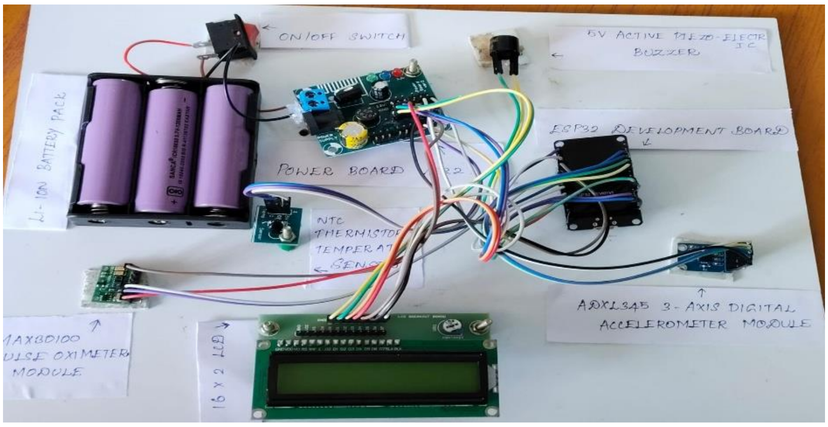

Figure.2. Prototype Hardware Setup of the Proposed System

Figure 2 Shows the complete hardware prototype is shown, consisting of the ESP32 development board, MAX30100 pulse oximeter, NTC thermistor, ADXL345 accelerometer, 16×2 LCD, buzzer, and Li-ion battery module. The setup validates successful integration of multiple sensors for continuous health monitoring and falls detection.

1. ESP32 Development Board
2. MAX30100 Pulse Oximeter Module
3. NTC Thermistor Temperature Sensor
4. 16×2 LCD
5. Li-ion battery pack along with power management board

6. On/off switch and supporting circuitry
7. ADXL345 3-Axis Digital Accelerometer Module
8. 5V Active piezoelectric Buzzer

3. Methodology

3.1. Measurement of Heart Rate and SpO_2

The MAX30100 sensor employs red and infrared LEDs in conjunction with a photodiode to identify volumetric changes in blood vessels. The processed pulses undergo analysis using the Pulse Oximeter library to calculate:

- Heart Rate (in beats per minute)
- SpO_2 (percent of oxygenated hemoglobin)

Noise reduction is accomplished by selecting an optimal LED current and conducting periodic sampling.

3.2 Temperature Measurement and Calibration

A thermistor, connected via a voltage divider, detects temperature fluctuations. A two-phase calibration procedure is utilized:

Phase 1 – Ambient Calibration

The system collects 50 ADC samples without skin contact to establish the baseline resistance in the ambient environment.

Phase 2 – Human Contact Calibration

When the user touches the sensor, the system gathers 30 samples to determine the body surface temperature. The discrepancy between the expected human temperature (~36.5°C) and the measured value is applied to correct future readings.

3.3. Fall Detection Logic

The ESP32 processes analog-scaled data from the accelerometer's three axes. Abrupt changes in vector magnitude suggest a potential fall. A straightforward threshold-based logic is incorporated into this prototype, triggering the buzzer when a fall is detected and transmitting the event to the cloud simultaneously.

3.4. IoT Cloud Integration

a) The Arduino IoT Cloud is utilized for
b) Data logging
c) Real-time visualization
d) Status updates (Normal, Keep Finger, Abnormal, Fall Detected)
e) Cloud variables are refreshed every second. Dashboard widgets represent
f) Heart Rate
g) SpO_2
h) Body Temperature
i) Status updates

4. Literature Review

4.1 IoT in Healthcare Monitoring

The implementation of Internet of Things (IoT) technology in the healthcare sector has facilitated ongoing observation of patient health outside of clinical settings. By linking sensors, embedded controllers, and cloud services, IoT-based healthcare systems enable real-time data collection and remote access, which enhances patient monitoring and diminishes reliance on hospital facilities.

4.2. Remote Monitoring of Physiological Parameters

Numerous research initiatives have investigated the use of embedded systems to monitor critical physiological metrics such as heart rate, oxygen saturation, and body temperature. An IoT-driven remote patient monitoring framework discussed in the latest literature illustrates the practicality of wirelessly transmitting vital health information for distant evaluation and medical oversight, especially benefiting older adults and patients needing prolonged care.

4.3. Sensor-Based Measurement Techniques

Non-invasive optical sensors are frequently used for measuring heart rate and SpO_2 due to their ease of use and dependability. Temperature measurement using thermistor-based devices continues to be favored in portable monitoring applications due to their affordability and satisfactory accuracy. When matched with appropriate calibration methods, these sensors can deliver consistent readings for ongoing monitoring use.

4.4. Motion Analysis for Fall Detection

Falls pose significant dangers for elderly and mobility-impaired individuals. Approaches that utilize motion sensors, specifically accelerometers, detect falls by recognizing sudden shifts in acceleration patterns. Algorithms based on thresholds are commonly used because of their minimal computational demands and their capacity to provide quick responses in real-time systems.

4.5. Identified Limitations in Existing Systems

Although current healthcare monitoring solutions effectively target separate parameters, many do not offer a holistic integration of vital sign tracking, fall detection, and alert functionalities within a unified system. Moreover, there has been a lack of focus on enhancing temperature accuracy under assorted environmental circumstances. The proposed work intends to address these issues by introducing a comprehensive, calibrated, and cloud-connected health monitoring framework.

5. Results And Discussion

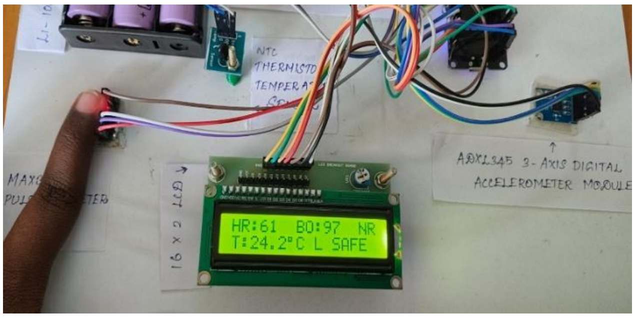

Figure.3. Image Showing the Working of the Proposed System

Figure 3 shows the model that monitors heart rate, blood oxygen level, body temperature, and movement using sensors. The measured values are processed by a microcontroller and displayed on a 16×2 LCD to indicate the user's health status. The system was evaluated for signal stability and cloud connectivity.

5.1. Heart Rate and SpO_2

Consistent readings were achieved when the user maintained correct finger placement. The device categorized the signals as follows:

1. Normal: HR 60–100 bpm and $SpO_2 > 95\%$
2. Abnormal: Values beyond this range

3. Keep Finger: In cases of Inadequate signal quality

5.2. Temperature Response

The calibration algorithm markedly diminished measurement drift. Following calibration, the deviation from a medical infrared thermometer was maintained within ±0.3°C during the testing phase.

Figure.4. On-Device Display Under Normal Operating Condition

Figure 4 shows the LCD output when the monitored parameters remain within acceptable limits. The screen displays heart rate, SpO_2, and temperature values along with a safe status message, demonstrating correct sensor calibration and proper functioning of the embedded processing unit.

5.3. Fall Detection

The prototype consistently activated alerts during simulated falls by implementing significant instantaneous variations in acceleration. The buzzer and IoT dashboard indicated the occurrence within one second.

Figure.5. On-Device Display During Fall Detection

Figure 5 indicates a fall alert triggered during a simulated fall scenario. The immediate change in the displayed message confirms successful detection of sudden motion variations and timely activation of local alert mechanisms such as the buzzer and display.

5.4. Cloud Visualization

Sensor data was transmitted continuously to the Arduino IoT Cloud without interruptions. Real-time visualization of vital parameters confirmed stable Wi-Fi connectivity and dependable cloud performance.

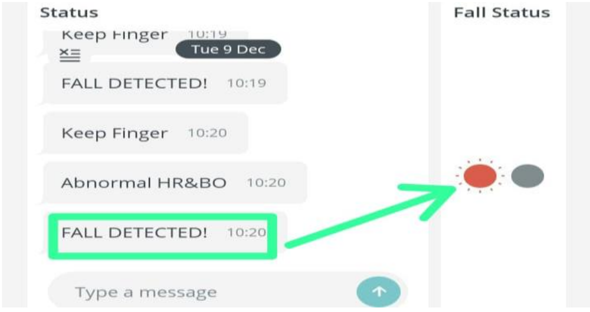

Figure.6. Cloud-Based Emergency Alert Display

This figure 6 presents the alert notifications generated on the IoT cloud when a fall event occurs. The system instantly updates the status with a fall warning message along with time information. A change in the visual indicator emphasizes the emergency condition, confirming fast data transmission and reliable cloud responsiveness.

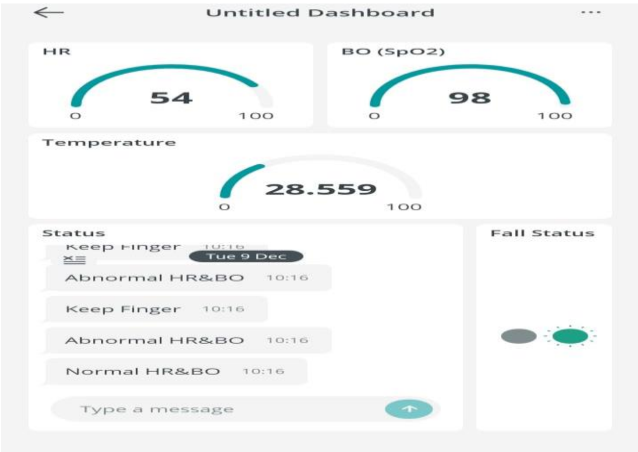

Figure.7. Live Monitoring Dashboard of Vital Signs

The dashboard in figure 7 illustrates continuous real-time measurement of heart rate, oxygen saturation (SpO_2), and body temperature. The displayed gauges reflect current sensor readings, while the status panel categorizes them into normal, abnormal, or signal insufficient states, verifying accurate data acquisition and effective cloud visualization.

6. Conclusion

The proposed system demonstrates an effective IoT-based approach for continuous monitoring of vital physiological parameters combined with reliable fall detection. By integrating multiple sensors with an ESP32 microcontroller and cloud connectivity, the device enables real-time health supervision and rapid alert generation. Experimental evaluation confirms accurate measurement of heart rate, SpO_2, and body temperature, along with prompt detection of fall events. The system offers a low-cost and portable alternative to conventional medical monitoring solutions and holds potential for future enhancements such as wearable integration and intelligent data analytics.

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Conflict of Interest/Competing Interests
No conflict of interest.

Data Availability
The raw data supporting the findings of this research paper will be made available by the authors upon a reasonable request.

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