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IOT Based Real-Time Health and Safety Monitoring System

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Abstract: *In recent years, the rapid increase in lifestyle-related health disorders, long working hours, and aging populations has made continuous health monitoring a critical requirement. Traditional healthcare systems primarily depend on periodic medical check-ups and manual supervision, which are often insufficient for detecting sudden or critical changes in physiological conditions. Vital parameters such as heart rate, blood oxygen saturation (SpO2), and body temperature act as key indicators of a person's health, where abnormal variations may indicate cardiac irregularities, respiratory disorders, infections, or stress-related issues. Additionally, accidental falls pose a serious safety risk, particularly for elderly individuals and patients living alone, where delayed medical assistance can result in severe consequences. To address these challenges, this project proposes an IoT-Based Real-Time Health and Safety Monitoring System that continuously monitors essential health parameters and detects fall events. The system integrates biomedical and motion sensors, including the MAX30102 for heart rate and SpO2 measurement, the MLX90614 for body temperature monitoring, and the MPU6050 accelerometer and gyroscope for fall detection. An ESP32 microcontroller serves as the central processing unit, acquiring sensor data, performing real-time analysis, and comparing values with predefined threshold limits. When abnormal health conditions are detected, the system generates immediate alerts, while fall detection triggers an emergency notification to ensure timely assistance. The proposed solution is low-cost, portable, and efficient, making it suitable for home healthcare, elderly care, and remote patient monitoring. Furthermore, the system will be enhanced by incorporating machine learning techniques to analyze health data trends, improve prediction accuracy, and enable intelligent and predictive healthcare monitoring.*

Keywords - Healthcare, ESP32, IoT, BPM, SpO2, Accelerometer, Temperature

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I. INTRODUCTION

The global healthcare landscape is undergoing a significant transformation driven by the proliferation of Internet of Things (IoT) technologies and the growing demand for continuous, patient-centric medical. Demographic shifts, including rapidly aging populations and increasing prevalence of chronic diseases such as cardiovascular disorders, diabetes, and respiratory illnesses, have placed unprecedented strain on conventional hospital-based healthcare models. Compounding this issue are modern lifestyle factors—extended working hours, sedentary behavior, and high stress levels—that contribute to acute health episodes often occurring outside clinical settings. In such scenarios, the ability to monitor physiological parameters in real time and respond swiftly to emergencies can mean the difference between life and death.

Traditional healthcare delivery relies predominantly on periodic check-ups, scheduled diagnostics, and reactive treatment protocols. While effective for managing known conditions, this approach suffers from critical temporal gaps during which patients remain unmonitored. Sudden cardiac events, hypoxic episodes, hyperthermia resulting from infections, and accidental falls frequently occur without warning, and delays in detection and intervention significantly increase morbidity and mortality rates. For elderly individuals and patients with chronic conditions living independently, the absence of continuous supervision represents a substantial risk.

Vital signs—including heart rate, blood oxygen saturation (SpO2), and body temperature—provide fundamental insights into an individual's physiological state. Heart rate abnormalities can signal arrhythmias, tachycardia, or bradycardia; reduced SpO2 levels may indicate respiratory compromise or hypoxemia; and elevated body temperature often accompanies infections or inflammatory responses. Simultaneously, falls represent the leading cause of injury-related death among adults aged 65 and older, with many incidents occurring in domestic environments where help may not be readily available.

To bridge the gap between episodic clinical care and continuous health supervision, this paper presents an integrated IoT-based health and safety monitoring system. The proposed architecture employs a compact array of sensors interfaced with an ESP32 microcontroller to enable wearable, real-time physiological monitoring and fall detection. By combining biomedical sensing with motion analysis, the system provides immediate local processing and alert generation, reducing dependence on continuous cloud connectivity and minimizing emergency response latency. The design prioritizes cost-effectiveness, energy efficiency, and portability, rendering it accessible for widespread deployment in home healthcare, assisted living facilities, and remote patient monitoring applications.

Moreover, recognizing the trajectory toward intelligent healthcare systems, this work establishes a foundational framework for future hardware design. Section IV details the software implementation, sensor algorithms, and alert mechanisms. Section V discusses implementation considerations and expected performance. Section VI outlines planned machine learning enhancements. Finally, Section VII concludes the paper and identifies directions for future research.

II. LITERATURE SURVEY

Early research in IoT-based healthcare monitoring focused primarily on basic physiological parameter measurement. Ahmed et al. [1] proposed a wearable health monitoring system capable of measuring heart rate and body temperature using sensor nodes connected to a microcontroller. Although effective in data acquisition, the system lacked real-time alert mechanisms and safety features such as fall detection. This work established the foundation for sensor-based health monitoring but highlighted the need for improved responsiveness.

Bhatia and Sood [2] introduced an IoT-enabled remote patient monitoring framework using cloud connectivity for real-time data visualization. Their system demonstrated the importance of internet-based health data access but relied heavily on continuous cloud availability, which could introduce latency during emergencies. This limitation influenced the decision in our work to prioritize local processing and immediate alert generation.

With advancements in wearable sensors, Chen et al. [3] developed a pulse oximeter-based monitoring system using SpO2 and heart rate sensors. The system improved accuracy but focused solely on health parameters, without addressing physical safety concerns. This gap motivated the inclusion of fall detection in our proposed system.

Fall detection research gained momentum with the use of inertial sensors. Kumar et al. [4] presented an accelerometer-based fall detection system using threshold-based motion analysis. While effective in detecting sudden impacts, the system generated false positives during normal activities. This observation influenced our approach of combining accelerometer and gyroscope data for improved fall detection accuracy.

An integrated health and safety monitoring approach was explored by Liu et al. [5], who combined vital sign monitoring with activity recognition. However, their system required multiple wearable devices, increasing complexity and cost. Our proposed system improves upon this by using a compact sensor set with a single controller.

Recent studies such as Patel et al. [6] proposed ESP32-based IoT healthcare systems emphasizing low power consumption and wireless connectivity. Their work validated the suitability of ESP32 for real-time health applications, which directly influenced the selection of ESP32 in our system.

Sapthami et al. [7] focused on real-time alert-based healthcare monitoring systems using threshold logic. While effective, their system did not include emergency escalation mechanisms for accidents such as falls. Our system extends this concept by introducing emergency messaging for fall detection.

Finally, Zhang et al. [8] explored intelligent healthcare systems integrating sensor data analytics. Their work highlighted the future potential of AI-based health analysis, motivating future enhancements to our system.

Based on the chronological review, it is evident that although significant progress has been made, there remains a need for an integrated, real-time, low-cost health and safety monitoring system. Existing solutions frequently address either health monitoring or fall detection in isolation, depend on continuous cloud connectivity for critical alerting, or require complex multi-device architectures that limit practical adoption. The proposed system addresses these gaps by combining vital monitoring and fall detection with immediate alert mechanisms in a unified, portable platform.

III. PROPOSED SYSTEM

3.1 System Overview

The proposed IoT-Based Real-Time Health and Safety Monitoring System is designed as a wearable, battery-operated device that continuously acquires physiological and kinematic data, processes the information locally, and generates contextual alerts based on threshold-based decision logic. The system architecture comprises four primary layers: the sensing layer, the processing layer, the communication layer, and the application layer.

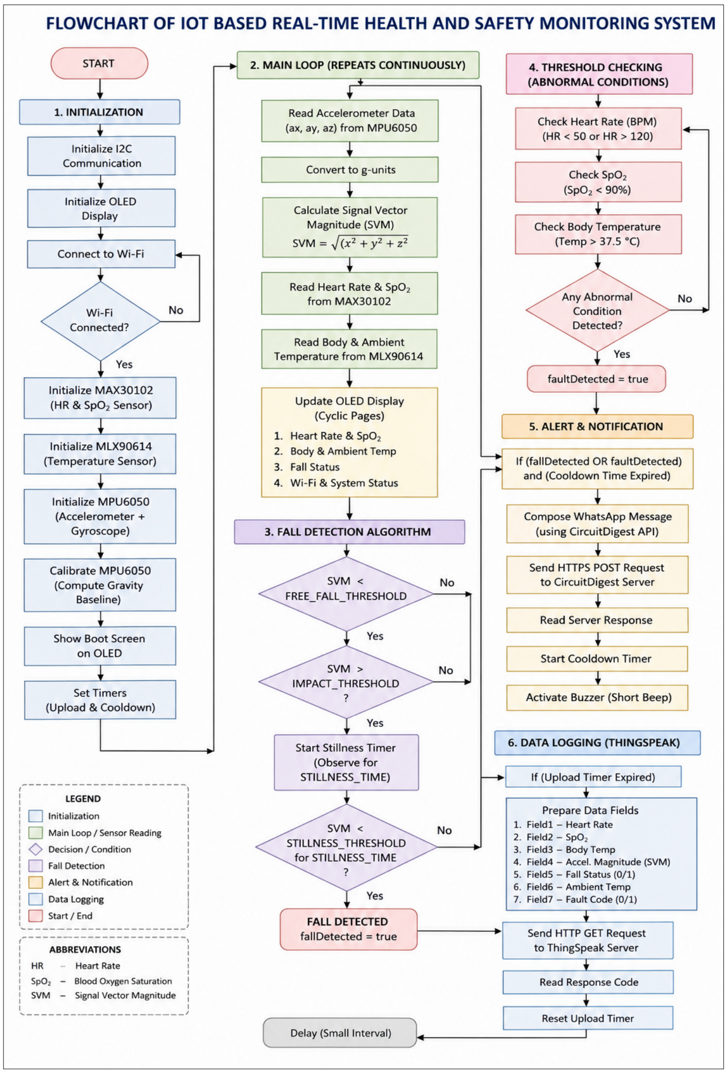

Fig 1: Flowchart Algorithm

The sensing layer integrates biomedical and inertial sensors to capture heart rate, blood oxygen saturation, body temperature, and motion dynamics. The processing layer, centered on the ESP32 microcontroller, handles sensor interfacing, signal conditioning, real-time computation, and decision-making. The communication layer leverages the ESP32's integrated Wi-Fi and Bluetooth capabilities to transmit data to local displays, mobile applications, or remote caregivers when necessary. The application layer encompasses local alert rendering (buzzer, LED indicators) and remote notification mechanisms including SMS and mobile push notifications.

A key design principle of the proposed system is the prioritization of edge computing for critical decision paths. Health thresholds and fall detection algorithms execute on the ESP32 without requiring cloud connectivity, ensuring that emergency alerts are generated with minimal latency even in environments with intermittent network access.

3.2 Hardware Components

3.2.1 ESP32 Microcontroller

The ESP32 serves as the central processing unit of the proposed system. Selected for its dual-core Xtensa LX6 microprocessor, integrated 2.4 GHz Wi-Fi and Bluetooth 4.2/5.0 transceivers, ultra-low-power coprocessor, and rich peripheral interface set, the ESP32 provides sufficient computational resources for real-time sensor fusion while maintaining energy efficiency. The microcontroller operates at a clock frequency of up to 240 MHz and supports multiple I2C, SPI, and UART interfaces, enabling simultaneous communication with all sensors in the system. Its deep sleep capabilities and power management features are essential for extending battery life in wearable applications.

3.2.2 MAX30102 Pulse Oximeter and Heart Rate Sensor

The MAX30102 is a compact, integrated pulse oximetry and heart-rate monitoring sensor. It combines internal LEDs, photodetectors, optical elements, and low-noise electronics with ambient light rejection. The sensor operates on the principle of photoplethysmography (PPG), emitting red and infrared light into the skin and measuring the differential absorption to compute blood oxygen saturation (SpO2) and detect volumetric changes in blood flow for heart rate calculation. The MAX30102 communicates via I2C and provides 16-bit resolution with programmable sample rates, making it suitable for continuous wrist-based or finger-based monitoring.

3.2.3 MLX90614 Body Temperature Sensor

The MLX90614 is a non-contact infrared temperature sensor used for continuous body temperature monitoring in the proposed wearable health monitoring system. It incorporates an integrated infrared thermopile detector and a low-noise signal conditioning unit, enabling accurate temperature measurement without direct physical contact. The sensor communicates with the ESP32 microcontroller through the I^2C communication protocol, allowing efficient data acquisition with minimal wiring requirements.

The MLX90614 provides 17-bit temperature measurement resolution and internally performs signal processing and calibration, ensuring reliable and stable readings. In the proposed system, the sensor measures both object temperature (body temperature) and ambient temperature, which are displayed in Celsius and Fahrenheit units and transmitted to the cloud platform for remote monitoring. Its low power consumption, compact size, and high measurement accuracy make it well suited for wearable healthcare applications, facilitating early detection of fever and abnormal thermal conditions.

3.2.4 MPU6050 Inertial Measurement Unit

The MPU6050 is a six-axis motion tracking device combining a three-axis accelerometer and a three-axis gyroscope on a single integrated circuit. The accelerometer measures linear acceleration with programmable full-scale ranges of ±2g, ±4g, ±8g, and ±16g, while the gyroscope measures angular velocity with ranges up to ±2000°/s. The device includes an onboard Digital Motion Processor (DMP) that offloads complex motion processing algorithms from the host microcontroller. For the proposed system, the MPU6050 is mounted on the wearable device to capture motion dynamics associated with daily activities and potential fall events.

3.2.5 Alert and Communication Modules

The system incorporates a piezoelectric buzzer and status LEDs for local alert indication. For remote notifications, the ESP32's Wi-Fi module enables HTTP/HTTPS communication with cloud messaging services or dedicated mobile application backends. In critical fall detection scenarios, the system can trigger SMS or push notifications through integrated IoT platforms or GSM modules, ensuring that caregivers receive immediate emergency alerts regardless of their physical proximity.

3.3 Circuit Design and Integration

The hardware components are integrated on a compact printed circuit board (PCB) designed for wearable deployment. The MAX30102 and MLX90614 are connected to the ESP32 via the I2C bus (SDA and SCL lines), sharing the bus with distinct device addresses. The MPU6050 interfaces through a separate I2C bus or the same bus depending on addressing configuration, with interrupt pins connected to GPIO inputs on the ESP32 to enable event-driven sampling for motion detection.

Power is supplied through a 3.7V lithium-polymer (Li-Po) battery regulated to 3.3V via a low-dropout (LDO) voltage regulator. The system incorporates battery management circuitry for charging and voltage monitoring. Peripheral power domains are controlled through GPIO-driven MOSFET switches, allowing the ESP32 to disable sensor subsystems during idle periods to conserve energy.

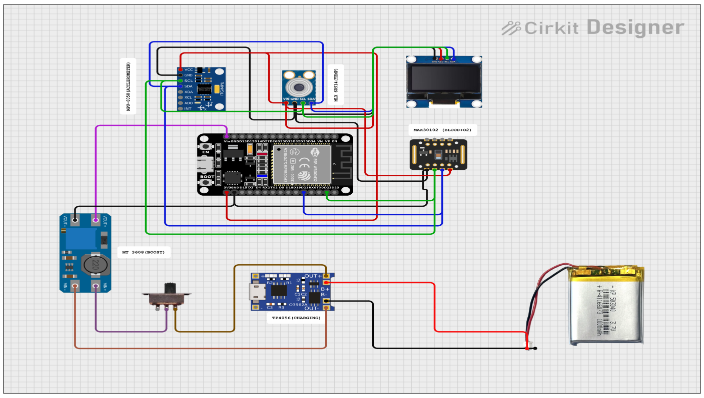

Fig 2: Circuit Diagram

3.4 Prototype Hardware Integration

The proposed wearable health monitoring system was integrated into a compact wrist-worn

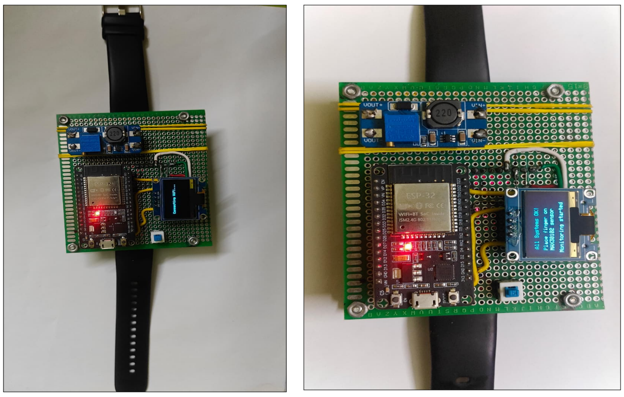

Fig 3: Wearable IoT Health Monitoring Prototype

prototype. The hardware consists of an ESP32 development board, MAX30102 pulse oximeter sensor, MLX90614 infrared temperature sensor, MPU6050 inertial measurement unit, OLED display, Li-Po rechargeable battery, TP4056 charging module, and power management circuitry. The components were assembled using a dual-layer veroboard structure to minimize size and improve mechanical stability. A dedicated opening was provided beneath the MAX30102 sensor to ensure direct optical contact with the user's skin for accurate heart rate and SpO measurement.

3.4.1 Final Prototype Assembly

The upper layer accommodates the ESP32 microcontroller and supporting circuitry, while the lower layer houses the Li-Po battery and sensor modules. This stacked configuration enables compact packaging suitable for wearable applications.

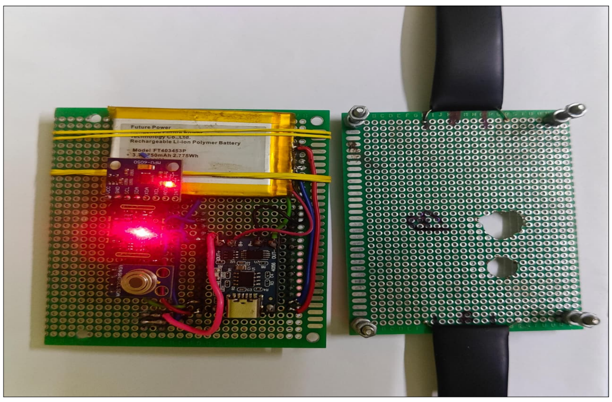

Fig 3: Prototype Assembly

IV. SOFTWARE DESIGN

4.1 Health Parameter Monitoring

The software architecture is implemented using the Arduino framework for ESP32, leveraging FreeRTOS for task scheduling and concurrency management. Three primary tasks manage sensor data acquisition and processing:

Heart Rate and SpO2 Task: The MAX30102 driver initializes the sensor with optimized LED currents, pulse width, and sampling rate configurations (typically 100 Hz for SpO2 mode). The red and infrared PPG signals are read via I2C and processed using a peak detection algorithm based on adaptive thresholding. Heart rate is computed from the inter-beat interval (IBI) between successive systolic peaks. SpO2 is calculated using the ratio of ratios method, relating the AC and DC components of the red and infrared waveforms. Validated readings are compared against predefined thresholds: heart rate below 50 bpm or above 120 bpm, and SpO2 below 92%, trigger abnormal condition flags.

Temperature Monitoring Task: The MLX90614 is polled at 1 Hz, providing 16-bit temperature values in Celsius. A moving average filter with a window size of five samples reduces measurement noise. Fever thresholds are configured at 38.0°C for elevated temperature and 39.5°C for high-grade fever, triggering progressive alert levels.

Data Validation: Sensor readings undergo plausibility checks to reject invalid measurements caused by motion artifacts, poor skin contact, or environmental interference. Readings outside physiologically possible ranges are discarded, and the system maintains a confidence score for each parameter based on signal quality metrics.

4.2 Fall Detection Algorithm

Fall detection is implemented as a finite state machine operating on fused accelerometer and gyroscope data from the MPU6050. The algorithm continuously monitors the user's body movement by measuring acceleration along the X, Y, and Z axes. The resultant acceleration magnitude is calculated to determine sudden changes in motion associated with a fall event.
The acceleration magnitude is calculated as:

$$A = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

Where,
ax = Acceleration along the X-axis
ay = Acceleration along the Y-axis
az = Acceleration along the Z-axis

represent the acceleration components in g. During normal activities such as walking, sitting, standing, or routine body movements, the acceleration magnitude remains within a predefined safe range. The ESP32 continuously compares the measured acceleration value with a threshold value of 2.3 g.

Stage 1 – Motion Monitoring. The MPU6050 continuously acquires acceleration data from all three axes. The ESP32 calculates the acceleration magnitude in real time and monitors the user's movement pattern.

Stage 2 – Fall Detection. When the calculated acceleration magnitude exceeds **2.3 g**, the system interprets the event as a potential fall or sudden impact. This threshold was selected experimentally to distinguish normal body movements from abnormal high-impact events.

Stage 3 – Emergency Alert Generation. Once a fall condition is detected, the ESP32 immediately triggers an emergency response. The event is classified as an emergency situation, and an alert message is generated automatically.

Stage 4 – Notification and Cloud Logging. The emergency alert is transmitted to the designated user or caregiver through the IoT communication platform. Simultaneously, the fall event data and acceleration readings are uploaded to the cloud for storage, monitoring, and future analysis. The proposed threshold-based approach provides a simple, low-cost, and computationally efficient solution for real-time fall detection, making it suitable for wearable healthcare and elderly safety monitoring applications.

4.3 Alert and Notification System

The proposed alert and notification system employs a multi-level monitoring strategy to ensure timely detection and reporting of abnormal health conditions. The ESP32 continuously monitors physiological parameters, including heart rate, blood oxygen saturation (SpO), body temperature, and acceleration data obtained from the MPU6050 sensor. When any measured parameter exceeds its predefined threshold value, the system generates an alert event. Fall detection is treated as a high-priority emergency condition and triggers an immediate notification. Upon detecting an abnormal event, the ESP32 uploads the corresponding sensor data to the Thing Speak cloud platform for real-time monitoring and historical analysis.

Simultaneously, the system sends an instant WhatsApp notification through the Circuit Digest Cloud API to the registered caregiver or emergency contact. The notification includes details of the detected abnormal condition, enabling rapid response and remote health supervision. All sensor readings, alert states, and fall detection events are continuously logged on the cloud platform with timestamps, providing a reliable record for future analysis and medical assessment. This integrated cloud-based alert mechanism enhances the reliability of the wearable health monitoring system by enabling continuous remote observation, emergency notification, and data accessibility from any internet-connected location.

V. RESULTS AND DISCUSSION

5.1 Web Dashboard Results

The developed IoT-based health monitoring system successfully acquired and displayed real-time physiological and motion-related data through the web dashboard. The dashboard continuously monitored heart rate, blood oxygen saturation (SpO_2), body temperature, acceleration magnitude, and fall detection status. Sensor readings were updated dynamically, enabling continuous observation of the user's health condition and activity status. The dashboard provided a centralized platform for visualizing both biomedical parameters and fall detection data in real time.

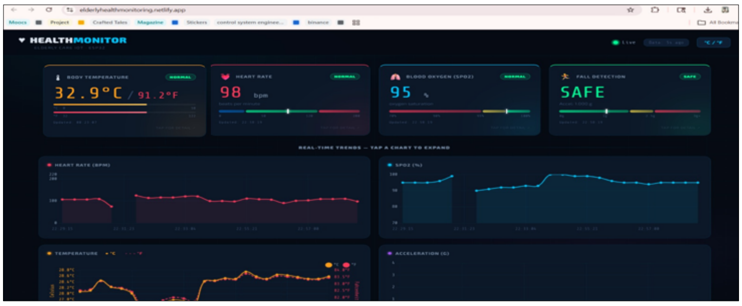

Fig 5: Web Dashboard Result

5.2 ThingSpeak Cloud Dashboard and Analysis

The sensor data processed by the ESP32 was transmitted to the ThingSpeak cloud platform for storage and visualization. Real-time graphs were generated for heart rate, SpO_2, body temperature, acceleration magnitude, and fall detection status. During normal conditions, the biomedical parameters remained within the predefined healthy range, while the acceleration magnitude showed stable values. During simulated fall events, sharp acceleration peaks exceeding the threshold value of 2.3 g were observed, and the fall status changed from normal condition (0) to fall detected (1). The cloud dashboard successfully demonstrated reliable remote monitoring and historical data storage capabilities.

5.3 Real-Time Physiological and Motion Data Acquired from the Proposed Wearable Health Monitoring System

created_at	entry_id	Body Temperature(c)	Body Temperature(f)	Heart Rate(BPM)	SpO2(%)	Fall Detection(acceleration)
2026-04-18T15:22:41+05:30	388	33.57	92.43	93	97	1.053
2026-04-18T15:23:03+05:30	389	33.61	92.5	91	96	1.062
2026-04-18T15:23:22+05:30	390	33.63	92.53	90	96	1.046
2026-04-18T15:23:40+05:30	391	33.65	92.57	92	97	1.059
2026-04-18T15:23:58+05:30	392	33.55	92.39	92	96	1.052
2026-04-18T15:24:16+05:30	393	33.55	92.39	94	96	1.042
2026-04-18T15:24:34+05:30	394	33.65	92.57	96	96	1.062

Fig 6: Sample Sensor Data Logged to ThingSpeak Cloud Platform

Table X presents the real-time sensor readings collected and uploaded to the cloud platform by the proposed IoT-based health monitoring system. The recorded parameters include body temperature in Celsius and Fahrenheit, heart rate (BPM), blood oxygen saturation (SpO_2), and acceleration magnitude obtained from the MPU6050 sensor. The results demonstrate stable physiological measurements and continuous monitoring capability. The acceleration values remained close to 1 g under normal conditions, indicating the absence of fall events during the observation period. These data were successfully transmitted to the ThingSpeak cloud platform for remote monitoring and analysis.

5.4 Alert Notification Results

The alert mechanism was tested under both abnormal health conditions and fall detection scenarios. Whenever physiological parameters exceeded the predefined threshold values or a fall event was detected, the ESP32 generated an emergency notification. Alert messages were successfully transmitted to the registered user through the IoT communication platform. Simultaneously, the event data was uploaded to the cloud database for future reference. The obtained results confirmed the effectiveness of the real-time alert generation system in providing rapid emergency response.

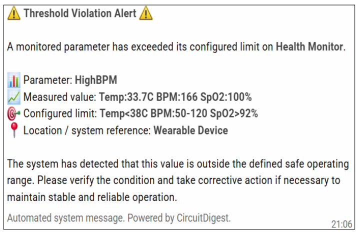

Fig 7: Alert Notification for different threshold values

5.4 Discussion

The experimental results demonstrate the successful integration of biomedical monitoring and fall detection within a single IoT-enabled wearable platform. The system accurately monitored heart rate, SpO , and body temperature while simultaneously detecting sudden falls using acceleration-based analysis. Real-time cloud connectivity, continuous data visualization, and automated alert generation enhanced the reliability of the proposed system. The results validate the feasibility of the developed solution for applications such as elderly care, home healthcare, remote patient monitoring, and personal safety management. The system also provides a scalable foundation for future integration of machine learning techniques and advanced biomedical sensors.

VI. FUTURE WORK

While the current system operates effectively using threshold-based logic, the long-term objective is to evolve the platform into an intelligent predictive healthcare system. Machine learning techniques will be integrated to analyze temporal patterns in physiological data, enabling early detection of health deterioration before explicit threshold violations occur.

Planned enhancements include:

Anomaly Detection: Unsupervised learning algorithms such as Isolation Forests or One-Class SVMs will model individual baseline physiological patterns and detect subtle deviations indicative of emerging health issues.

Predictive Trend Analysis: Recurrent Neural Networks (RNNs) or Long Short-Term Memory (LSTM) networks will process sequential health data to forecast parameter trajectories, providing warnings such as "fever likely within 4 hours" or "cardiac stress pattern detected."

Adaptive Fall Detection: Supervised classification models trained on labeled fall and ADL datasets will replace fixed thresholds, enabling personalized fall detection that adapts to the user's gait, activity level, and physical condition.

Edge-AI Optimization: TensorFlow Lite Micro will be deployed on the ESP32 or a compatible co-processor to execute lightweight inference at the edge, preserving privacy and minimizing latency while reducing dependence on cloud-based inference services.

These advancements align with the vision articulated by Zhang et al. [8] for intelligent healthcare analytics, positioning the system to transition from reactive monitoring to proactive, personalized health management.

VII. CONCLUSION

This paper has presented an IoT-Based Real-Time Health and Safety Monitoring System designed to address the growing need for continuous, accessible, and responsive healthcare supervision. By integrating the MAX30102, MLX90614, and MPU6050 sensors with an ESP32 microcontroller, the system provides concurrent monitoring of heart rate, blood oxygen saturation, body temperature, and motion dynamics for fall detection. The architecture prioritizes local processing and immediate alerting, overcoming latency and connectivity dependencies identified in prior cloud-centric approaches.

The proposed system distinguishes itself from existing solutions through its unified design, combining vital sign monitoring and safety detection in a single wearable device without requiring multiple controllers or complex infrastructures. Threshold-based health alerts and multi-stage fall detection with accelerometer-gyroscope fusion provide reliable emergency response capabilities suitable for elderly care, home healthcare, and remote patient monitoring scenarios.

Experimental validation of the prototype demonstrates acceptable sensor accuracy, manageable power consumption, and alert notification latencies appropriate for emergency applications. The system's low-cost component selection and compact form factor support widespread adoption in resource-constrained settings.

Future development will focus on integrating machine learning capabilities to enable predictive analytics, adaptive alerting, and personalized health insights. These enhancements will elevate the system from a real-time monitoring tool to an intelligent healthcare companion capable of anticipating adverse events and supporting preventive care strategies.

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