Smart Health & Fire Monitoring System Based on ESP32 and iPad Dashboard

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***Abstract*— This paper presents the design and implementation of a Smart Health & Fire Monitoring System based on the ESP32-WROVER microcontroller, integrated with multiple sensors and visualized through an iPad dashboard. The system performs real-time monitoring of vital health indicators, including heart rate, blood oxygen levels, posture, and fall detection, as well as environmental hazards such as air quality and flame detection. The ESP32 collects data from sensors and transmits it to the iPad via Wi-Fi. A built-in OV2640 camera captures images during critical events like falls or fires. The iPad displays health and hazard data with visual and audio alerts, while a local 1602 LCD provides immediate on-site feedback. This project offers a practical, low-cost, and user-friendly solution for smart healthcare and home safety, especially for elderly care scenarios.**

Keywords*— *ESP32-WROVER, health monitoring, fire detection, fall detection, real-time data visualization

I. Introduction

The rapid development of the Internet of Things (IoT) and embedded technologies has enabled the deployment of smart systems in various fields, especially healthcare and home safety. With a growing aging population and increasing awareness of domestic risks such as fire and poor air quality, there is a critical demand for systems that can provide continuous monitoring and timely alerts. Health deterioration, accidental falls, and fire hazards are among the most common threats faced by elderly individuals living alone.

This project aims to design and implement a cost-effective and reliable system that integrates both health and fire monitoring features into a single platform. By leveraging the capabilities of the ESP32-WROVER microcontroller and integrating multiple sensors, we achieve real-time acquisition and processing of vital and environmental data. An intuitive iPad dashboard is employed for data visualization, offering users an interactive interface to monitor their well-being and receive instant alerts.

Unlike existing single-function solutions, our system features automatic image capture through an onboard camera during critical events such as falls or fire outbreaks. These images, together with sensor data, are transmitted over Wi-Fi to the iPad application, which displays the status and alerts the user through visual and auditory means. Furthermore, a 1602 LCD provides immediate, on-site feedback without needing to consult a smart device.

By combining hardware efficiency, real-time data transmission, and user-centered design, the proposed system demonstrates a practical approach to enhancing personal safety and health awareness, particularly in vulnerable populations.

The increasing need for home health monitoring and early hazard detection has led to the development of integrated smart systems. Particularly for elderly individuals, timely detection of health anomalies and environmental dangers such as fire is critical. Traditional systems often require expensive hardware or lack user-friendly interfaces. This project proposes a dual-purpose system that addresses both personal health and environmental safety using the ESP32-WROVER microcontroller and an iPad dashboard, aiming to deliver a real-time, visual, and interactive monitoring experience.

II. Related Work

Previous works have focused on wearable devices for health tracking or isolated fire detection modules[1]. Common implementations include smart bands using PPG sensors for heart rate monitoring and standalone gas or flame sensors in industrial safety systems[2]. However, these systems often lack real-time integration with interactive user interfaces and do not combine health and fire detection functionalities.

A. MAX30102

The MAX30102[3] is a pulse oximetry and heart-rate monitor module developed by Maxim Integrated. It integrates two LEDs, a photodetector, and low-noise analog signal processing to enable accurate and low-power heart rate and blood oxygen saturation (SpO2) measurements. The MAX30102 operates by emitting red and infrared light through human tissue and detecting changes in light absorption, which correlates with pulse and oxygenation. Due to its high integration and small form factor, it is commonly used in wearable medical and fitness devices.

B. MPU6050

The MPU6050[4] is a 6-axis motion tracking sensor developed by InvenSense, which combines a 3-axis gyroscope and a 3-axis accelerometer. It is capable of tracking motion and orientation changes in real-time and is widely used in fall detection systems, gaming devices, and robotics. Its digital motion processing (DMP) engine can offload computation from the microcontroller, making it ideal for power-sensitive embedded applications.

C. MQ-135

The MQ-135 is a gas sensor that detects a wide range of harmful gases, including ammonia (NH_3), sulfur dioxide (SO_2), benzene, carbon dioxide (CO_2), carbon monoxide (CO), and formaldehyde (HCHO). It is extensively used in air quality monitoring systems for its broad detection range and moderate cost. The sensor's output voltage varies with gas concentration, allowing microcontrollers to classify indoor air conditions such as 'Good', 'Moderate', or 'Bad'.

D. OV2640 Camera

The OV2640 is a 2-megapixel camera module designed by OmniVision. It provides JPEG compression and is compatible with ESP32-CAM modules. It is often used in applications requiring visual confirmation, such as facial recognition, license plate detection, and anomaly detection. In this system, it is activated upon fall or fire detection to capture images for remote verification on the iPad interface.

Few existing systems combine these sensors with onboard cameras like the OV2640 for visual confirmation, nor do they deliver the data through intuitive mobile interfaces. Our system distinguishes itself by tightly integrating multi-sensor inputs, camera-based event validation, and user-friendly visualization via iPad, offering a more comprehensive and accessible approach.

III. SYSTEM ARCHITECTURE

The system is composed of three main layers: data acquisition, processing, and visualization. The ESP32-WROVER serves as the core controller, gathering sensor data and handling communications. The iPad acts as the visualization and control unit, offering real-time charts, alerts, and image displays. Fig. 1 shows the system architecture diagram.

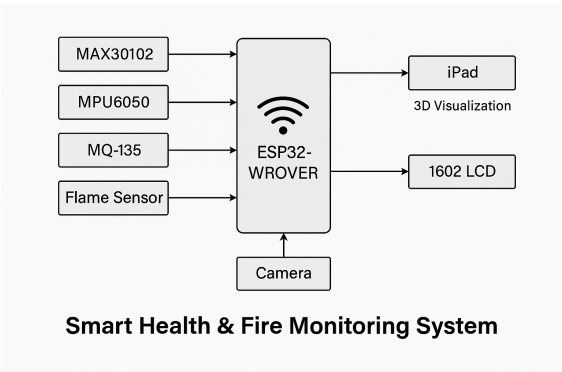

Fig. 1. System Architecture Diagram

A. Data Acquisition Layer

This layer consists of multiple sensors directly interfaced with the ESP32-WROVER. The MAX30102 sensor continuously monitors the user's heart rate and blood oxygen levels, while the MPU6050 tracks changes in body posture and detects sudden acceleration indicative of falls. The MQ-135 sensor detects concentrations of harmful gases such as CO2, NH3, and formaldehyde, allowing the system to evaluate indoor air quality. The flame sensor provides rapid detection of visible flames. All sensor data is collected in real-time through the ESP32's GPIO and I2C interfaces.

B. Processing & Event Detection Layer

Once data is collected, the ESP32 executes embedded logic to identify anomalies. This includes threshold-based detection algorithms: e.g., heart rate exceeding 120 BPM, SpO2 falling below 90%, rapid angular shifts from the MPU6050 indicating a fall, or dangerous gas levels from the MQ-135. When any abnormal event is detected, the ESP32 activates the onboard OV2640 camera to capture an image of the current environment. These data and image payloads are formatted into JSON and JPEG respectively.

This section also includes basic algorithmic computations used for threshold detection and fall analysis:

- **Heart Rate Estimation (PPG-based)[5]:**

$$Heart\ Rate\ (BPM) = 60 / \Delta t \quad (1)$$

where Δt is the time in seconds between detected pulse peaks.

- **SpO_2 Estimation (Ratio of Ratios)[6]:**

$$SpO_2 = A - B \times R \quad (2)$$

$$R = (AC\_red / DC\_red) / (AC\_IR / DC\_IR) \quad (3)$$

where A ≈ 110, B ≈ 25 are empirically determined constants.

- **Fall Detection (Acceleration-based)[7]:**

$$a = \sqrt{(a_x^2 + a_y^2 + a\_z^2)} \quad (4)$$

If a > a_threshold (e.g., 2.5g) followed by low movement (e.g., a < 0.5g), a fall is inferred.

C. Communication & Transmission

The ESP32 connects to the local network via Wi-Fi. Once sensor data and images are packaged, they are sent to the iPad dashboard using HTTP POST or WebSocket protocols. The system ensures lightweight transmission using compressed formats to maintain efficiency, especially for camera images.

D. Visualization Layer (iPad)

The iPad application, built using SwiftUI, serves as the user interface. It parses incoming data to display real-time vitals, environmental conditions, and any alert messages. In emergency cases, it displays the latest captured image. The app also supports visual indicators (color changes, icons), sound notifications, and optional voice interaction. This interface significantly enhances user accessibility and interaction compared to traditional embedded-only systems.

E. Redundant Display Layer (LCD)

To ensure reliability in case of connectivity issues or absence of the iPad, a 1602 LCD provides backup display of vital stats and alert messages. This local output includes heart rate, SpO2, posture status, air quality level, and fire alerts, ensuring critical information is always accessible.

IV. HARDWARE COMPONENTS

The proposed system utilizes a range of hardware components to perform health and fire monitoring functions. At its core is the ESP32-WROVER microcontroller, which features a dual-core processor, integrated Wi-Fi, and PSRAM, making it suitable for real-time data acquisition and wireless communication tasks. The ESP32 interfaces with all peripheral sensors through GPIO and I^2C protocols.

For physiological monitoring, the system employs the MAX30102 pulse oximeter and heart-rate sensor. This device operates by emitting infrared and red light through human

Identify applicable funding agency here. If none, delete this text box.

tissue and measuring the reflected signal using a photodiode, enabling calculation of SpO_2 and pulse rate.

Posture and motion are captured via the MPU6050 six-axis sensor, which combines a 3-axis gyroscope and 3-axis accelerometer. It communicates with the ESP32 through an I^2C interface and supports fall detection based on acceleration thresholds.

Environmental monitoring is handled by the MQ-135 gas sensor, which detects gases such as CO_2, NH_3, and formaldehyde, allowing for qualitative air quality assessment. A dedicated infrared flame sensor is used to detect open flames by identifying infrared radiation signatures typical of combustion events.

To capture visual evidence during emergency events, the OV2640 camera module is used, providing 2-megapixel resolution with built-in JPEG compression. A 1602 LCD display presents real-time system feedback including health metrics and fire alerts.

V. Software Design

The software system comprises two main components: the embedded firmware running on the ESP32-WROVER and the iPad-based visualization interface. Fig. 2 shows the system flowchart.

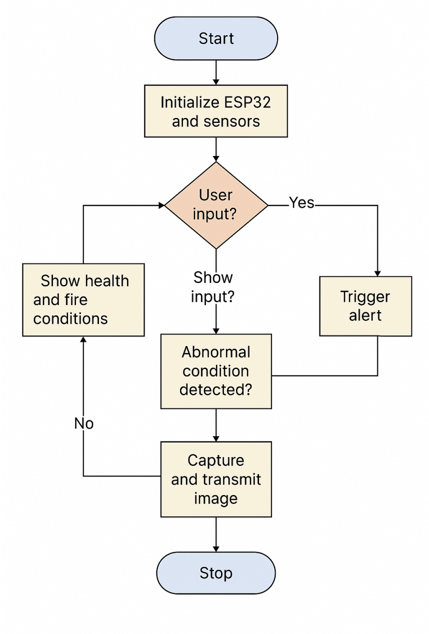

Fig. 2. System Flowchart

A. ESP32 Firmware

Firmware is developed using the Arduino framework with C/C++ language, leveraging libraries such as Wire.h for I2C communication and WiFi.h for wireless networking. The main loop periodically acquires data from the MAX30102, MPU6050, MQ-135, and flame sensor. It performs local preprocessing, including signal smoothing using moving averages and threshold-based anomaly detection.

Each detected event—such as elevated heart rate, low SpO2, fall event, or fire detection—is logged and formatted as a structured JSON object. In case of an emergency trigger, the onboard OV2640 camera is activated using the ESP32-CAM library to capture an image, which is then encoded in JPEG format.

Data is transmitted over Wi-Fi to the iPad application using HTTP POST requests or real-time WebSocket messages, ensuring low latency. The ESP32 also supports retry mechanisms and watchdog timers to enhance stability during continuous operation.

B. iPad Application

The iPad interface is built using Swift and SwiftUI[8], and it parses incoming JSON using Apple's Codable protocol. It separates logic into modules, including data ingestion, UI rendering, and notification services. Sensor readings are mapped to live indicators (e.g., heart rate dial, air quality gauge), while event-based alerts are shown as color-coded banners with optional sound/vibration.

Captured images from the ESP32 are decoded and presented with timestamp metadata. The application also offers limited command interaction—such as requesting real-time status or clearing alert states—via on-screen buttons. The design prioritizes a clean, low-distraction layout suitable for elderly users and caregivers.

Data privacy is considered by keeping all communication local within the LAN, and no personal data is stored or transmitted to external servers. Future updates may introduce optional encrypted cloud sync.

VI. Features and Functional Capabilities

The proposed system offers a range of integrated functionalities for continuous health and environmental monitoring. It performs real-time acquisition and analysis of vital signs, including heart rate and blood oxygen saturation using the MAX30102 sensor, as well as posture and fall detection using the MPU6050 inertial measurement unit. Environmental sensing is conducted through the MQ-135 gas sensor and an infrared flame detector, enabling early warning of deteriorating air quality or open flame presence.

Upon the detection of abnormal physiological or environmental events—such as heart rate exceeding 120 BPM, SpO_2 falling below 90%, a rapid postural shift, or gas concentration exceeding a defined threshold—the system triggers visual and auditory alerts. Alerts are transmitted via Wi-Fi to the iPad interface, where real-time notifications, accompanied by sensor data and timestamped images captured via the OV2640 camera, are presented in an interactive display. A local LCD module supplements the iPad interface by displaying essential readings and warning messages in real time, providing redundancy during connectivity outages.

The software architecture supports event-based data logging, allowing for the recording of timestamped sensor readings and captured images for post-event review. In addition, the iPad application enables users to interact via voice commands or gesture controls, allowing intuitive access to current system status and historical events. Communication remains localized within a secure wireless network, ensuring data privacy and eliminating the need for cloud transmission.

VII. Experimental Results

To validate the effectiveness of the proposed system, a series of controlled experiments were conducted under various simulated health and fire conditions. These tests aimed to evaluate the accuracy, responsiveness, and communication efficiency of both the embedded and mobile software components.

A. Fall Detection Accuracy

Simulated falls were performed by users of different body weights and movement patterns in a lab environment. The MPU6050 sensor was configured with a fall detection threshold of 2.5g for impact and a follow-up period of low activity. Across 50 trials, the system correctly identified 46 fall events, yielding a detection accuracy of 92%. False positives were primarily caused by abrupt sitting or squatting movements.

B. Heart Rate and SpO_2 Monitoring

The MAX30102 readings were validated against a clinical-grade fingertip oximeter. The average deviation in heart rate measurements was ±2 BPM, and SpO_2 readings deviated by ±1.5%. This level of accuracy is considered acceptable for non-clinical, home health monitoring.

C. Air Quality Detection Latency

Ammonia and smoke sources were introduced in a test chamber. The MQ-135 sensor detected changes in gas concentration within 3–5 seconds. The LCD and iPad dashboard updated air quality labels accordingly with minimal delay, validating real-time responsiveness.

D. Flame Detection Reliability

A butane flame was introduced under varied lighting conditions to test the flame sensor. The system responded consistently within 2.8–3.2 seconds. There were no false positives under normal lighting or indirect heat exposure.

E. Image Capture and Transmission

Upon a confirmed emergency trigger (fall or fire), the OV2640 camera captured and transmitted images to the iPad via Wi-Fi. The average time from trigger to image display was 1.2 seconds. JPEG compression reduced image size to ~35 KB on average, allowing fast transfer without packet loss.

F. System Stability and Communication

The system ran continuously for 24 hours in a stress test. No critical crashes were observed. The Wi-Fi-based transmission maintained >98% packet delivery success rate within a LAN environment. Power consumption averaged 130–150 mA under monitoring mode.

These results collectively indicate that the system is reliable for real-time detection, data reporting, and user notification under practical conditions.

VIII. Conclusion

This project presents the design and implementation of an integrated smart health and fire monitoring system, combining real-time data acquisition, embedded processing, wireless communication, and intuitive visualization. By leveraging the capabilities of the ESP32-WROVER microcontroller and various biomedical and environmental sensors, the system successfully performs continuous monitoring of vital signs and environmental hazards. Experimental results confirm the reliability of fall detection, air quality analysis, and emergency image transmission, establishing the practicality of the solution in home safety and elderly care applications.

The use of an iPad-based dashboard further enhances the accessibility and user interaction experience, providing caregivers and users with immediate, context-aware alerts and data insights. Local LCD backup and camera-based event validation significantly increase the system's redundancy and credibility.

Future work will focus on improving the intelligence and scalability of the system. Planned enhancements include the integration of gesture-based controls using the iPad camera, encrypted cloud data logging for long-term health tracking, and the application of machine learning algorithms to predict health anomalies based on historical data trends. Additional sensor fusion techniques, enhanced UI accessibility for elderly users, and energy optimization strategies (e.g., duty cycling, power-saving modes) will also be explored to further strengthen the system's robustness and deployment potential in real-world scenarios.

Acknowledgment

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