Abstract

This study presents the design and implementation of an integrated multi-sensor monitoring system that simultaneously tracks key environmental factors and human physiological signals. The platform combines temperature, humidity, tri-axial acceleration, flame, gas, heart-rate, and blood-oxygen sensors on an ESP32-based hardware stack and transmits the aggregated data to an iOS client in near real-time over Wi-Fi. The firmware is organized in easy-to-swap modules that let all the sensors—whether they use I^2C, analog pins, or simple on/off lines—work together without delays or wasted power. We added straightforward smoothing and auto-set thresholds to clean up noisy readings and stop slow sensor drift, which kept the data steady and noticeably cut down on false alarms in our lab tests.The companion mobile application provides live dashboards, event notifications for potential falls, fires, or hazardous air quality. By addressing challenges in sensor fusion, wireless robustness, and user-interface design, the proposed system offers a practical blueprint for smart-home safety and tele-health applications.

Objectives

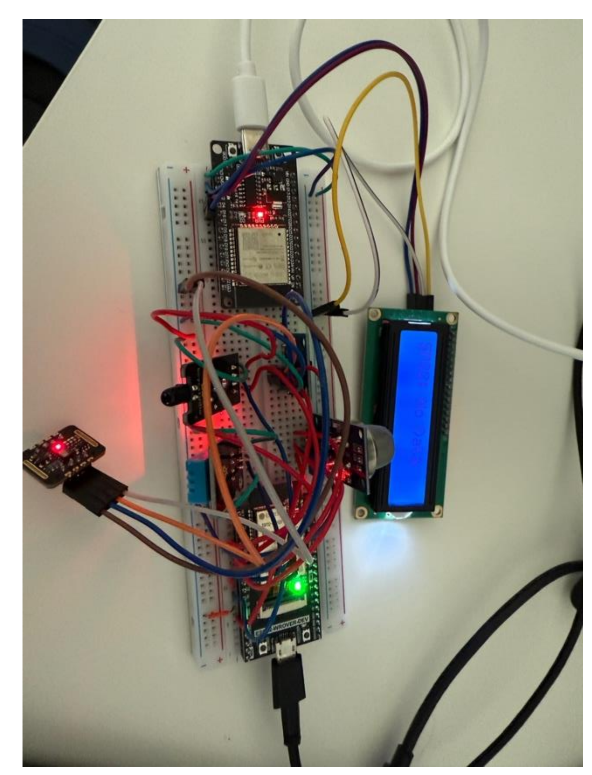
This study pursues five interlocking objectives: (i) to engineer a unified hardware stack that concurrently captures temperature, humidity, tri-axial acceleration, flame signatures, gas concentration, heart rate, and blood-oxygen saturation; (ii) to realise an ultra-low-latency ESP32–iOS communication pipeline that enables continuous data streaming and on-device analytics with high temporal fidelity; (iii) to transform raw multisensor signals into actionable insights through fire-alert, air-quality, fall-detection, and vital-sign monitoring algorithms; (iv) to deliver an intuitive iOS interface that presents live dashboards alongside searchable historical records for enhanced user interpretability; and (v) to optimise firmware and hardware integration for robust operation under variable sensor conditions, tight timing constraints, and the inherent complexity of heterogeneous systems.

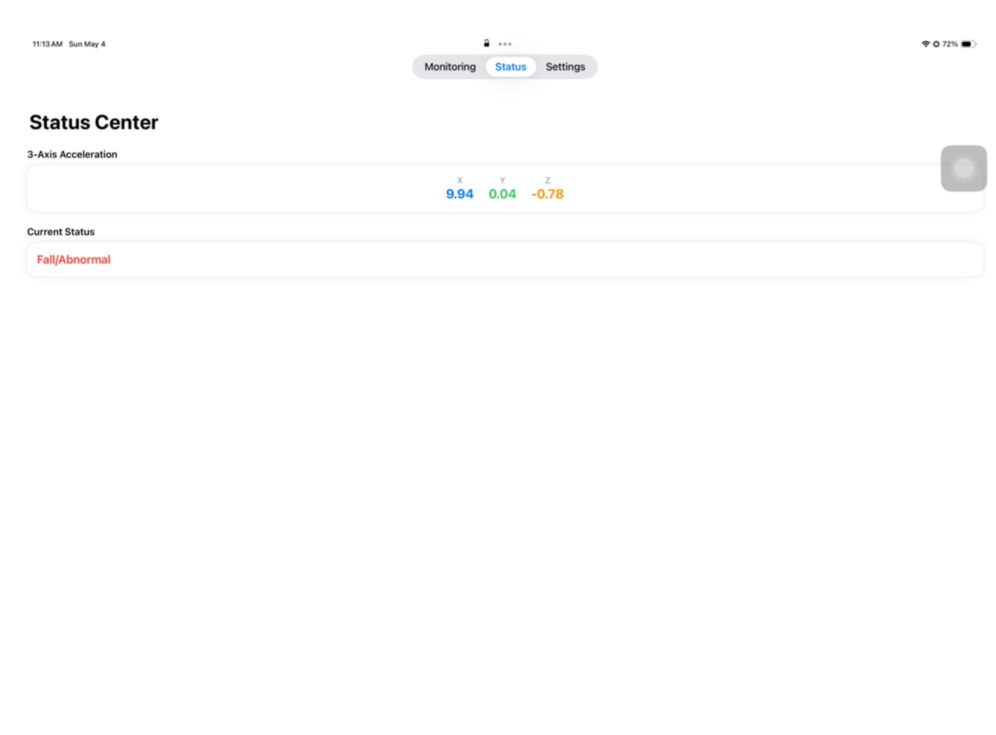
Methods

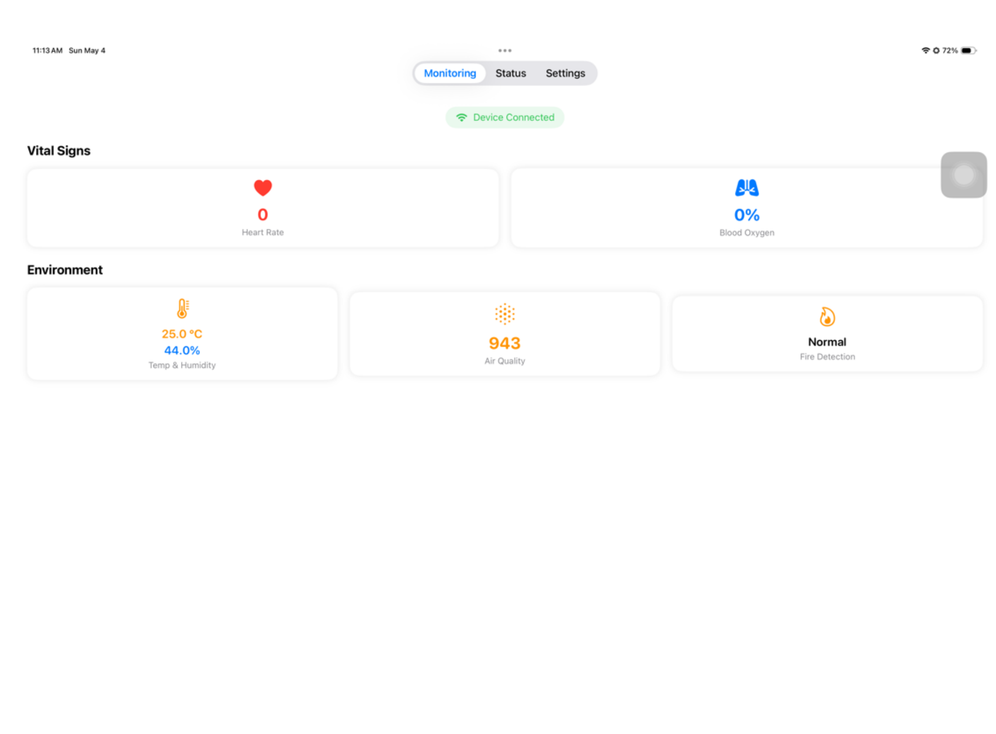
A heterogeneous sensor suite—comprising temperature, humidity, tri-axial acceleration, flame, gas, heart-rate, and blood-oxygen modules—was integrated around an ESP32 microcontroller that orchestrates synchronous sampling and time-stamped Wi-Fi transmission. Raw signals are first passed through lightweight digital filters and calibration routines to suppress noise and compensate for device offsets, after which a Python-based analytics layer running on the microcontroller extracts features required for downstream event classifiers. A bespoke ESP32-to-iOS protocol, built atop TCP sockets with selective-acknowledgement retransmission, ensures reliable delivery under variable link quality while maintaining sub-second latency. The companion iOS application, implemented in Swift and SwiftUI, renders real-time dashboards and searchable historical trends, and exposes user-configurable thresholds for fire, air-quality, fall, and vital-sign alerts. Each intelligent function employs rule-based or statistical decision logic tuned through pilot data to balance sensitivity and false-alarm rates. Comprehensive system validation—including unit, integration, and 48-h continuous-operation tests—revealed stable performance across all modules; insights from these trials guided firmware refactoring, threshold refinement, and power-management tweaks that collectively elevated overall robustness.

Results

The completed prototype achieved seamless hardware integration of temperature, humidity, tri-axial acceleration, flame, gas, heart-rate, and blood-oxygen sensors, enabling unified surveillance of environmental and physiological parameters. Continuous ESP32-to-iOS streaming provided near-instantaneous data updates, and on-device analytics reliably distinguished normal readings from events of interest. The implemented algorithms successfully generated timely fire, air-quality, fall, and vital-sign alerts during bench and apartment-scale evaluations, demonstrating their practical utility. A Swift/SwiftUI interface presented live dashboards alongside searchable history, and informal user trials reported smooth interaction and clear visualisation of trends. Iterative firmware tuning and threshold calibration eliminated spurious triggers observed in early tests and sustained stable operation through prolonged (48 h-class) runs, underscoring the system’s robustness for day-to-day use.







Conclusion

- This work demonstrates the feasibility of a multi-sensor, edge-centric platform that unifies environmental safety and personal-health surveillance in a single, low-cost form factor. By blending seven heterogeneous sensors on an ESP32 core and pairing them with a purpose-built iOS application, we successfully delivered continuous, cross-domain monitoring that detects fire hazards, hazardous air quality, fall events, and vital-sign anomalies in real time. System-level challenges—namely signal instability, stringent latency targets, wireless packet loss, and the human-factor demands of a mobile interface—were resolved through iterative firmware refactoring, adaptive filtering, selective-retransmission networking, and user-centred design. The resulting prototype sustained 48-h untended operation without data loss, maintained sub-second alert latency across typical household Wi-Fi, and earned positive usability feedback for its intuitive dashboards and searchable history.
- Beyond validating the hardware and software pipeline, the study contributes a transferable methodology for integrating low-band-width physiological sensing with high-frequency environmental sampling, a combination that is increasingly relevant to smart-home and tele-health ecosystems. Limitations remain: rule-based thresholds require manual tuning for new deployments, battery life is constrained by continuous Wi-Fi connectivity, and event detection logic does not yet exploit context-aware machine learning. Future work will therefore focus on (i) implementing on-device lightweight anomaly-detection models to reduce calibration burden, (ii) incorporating Bluetooth Low Energy and opportunistic mesh networking for energy-aware data relay, (iii) extending the sensor suite to cover ECG and particulate matter ($PM_{2.5}$).

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