DEVELOPMENT OF AN AI AND SENSOR-INTEGRATED PERSONALIZED HEALTH AND SAFETY MONITORING SYSTEM AS SMART GUARDIAN COMPANION FOR GERIATRIC (ELDERLY) CARE

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Geriatric Care, Personalised Health Monitoring, AI Integration, Smart Guardian, Sensor Technology.

Introduction
Global ageing populations necessitate advanced healthcare solutions through AI-driven sensing. This project proposes a "Guardian Companion," an integrated system that fuses a wearable patch and ambient data, coupled with voice interaction logs, to provide personalised virtual health assistance [1]. While multimodal sensing (environmental and vision sensors) has enhanced event detection, real-world deployment and device personalisation remain significant gaps. Even though conversational assistants are increasingly used in social care, their integration with clinical-grade sensing is a critical, emerging field [2-3]. Analysis of vital health parameters supports the detection of **behavioural and autonomic shifts** in elderly subjects. Such insights are critical for the **early diagnosis** of neurodegenerative conditions and the implementation of preventive care strategies [4-5]. Expected outcomes include the development of a multimodal sensing patch with robust fall and health deterioration prediction and a comprehensive caregiver decision-support layer for guardians to monitor the health of geriatric people.

Research Gaps
- **Limited Personalisation:** Current systems lack adaptive learning for individual baselines, resulting in generalised alerts and reduced real-world reliability.
- **Inadequate Real-world Fusion:** Multimodal fusion often fails in unstructured homes due to sensor noise and heterogeneity, requiring robust, adaptive frameworks validated in situ.
- **Lack of Proactive AI:** Models prioritise reactive detection over proactive prediction. Insufficient explainability and caregiver involvement lead to mistrust and decision fatigue.
- **Privacy and Acceptance:** Data ownership and privacy risks remain significant barriers. Federated/edge AI is needed, alongside longitudinal research on user adherence and emotional comfort.

Objectives:

Primary Objective:
To develop and validate a personalised, multimodal AI system (Guardian Companion) integrating sensor fusion, predictive analytics, and a virtual health assistant to improve safety and health outcomes for the Geriatric population.

Specific Objectives:

- Design a multimodal sensing architecture (wearables: PPG; ambient: PIR, door sensors; optional vision with privacy filters).
- Develop robust sensor-fusion algorithms for detection and short-term prediction (0–10 min) of falls and acute deterioration.
- Integrate a conversational virtual assistant module for reminders, engagement, and context-aware alerts to caregivers.

Methodology

System Architecture and Hardware Integration

The proposed system is developed upon a multi-layered IoT framework centred on an ESP series System-on-Chip (SoC) operating with integrated Wi-Fi capabilities. For comprehensive physiological and environmental monitoring, the hardware architecture integrates a MAX30102 photoplethysmogram (PPG) biosensor and a DHT11 sensor to monitor SpO_2, heart rate, ambient temperature, and humidity. To provide robust spatial tracking and emergency signalling, a vibration sensor for impact detection and a tactile SOS button were interfaced via digital GPIO pins. This configuration ensures precise hardware-to-software synchronisation for detecting early symptoms of neurodegenerative diseases and sudden medical emergencies [10].

Mechanical Design and Fabrication

To achieve an ergonomic and durable form factor, the wearable patch utilises a hybrid-material enclosure modelled in SolidWorks and fabricated through Fused Deposition Modelling (FDM) 3D printing. The structural design integrates a rigid Polylactic Acid (PLA) shell for mechanical impact resistance with flexible, biocompatible Thermoplastic Polyurethane (TPU) skin-interfacing straps. The TPU material selection, compliant with ISO Standard 10993-10, offers >300% elongation, easing essential vibration damping and ergonomic comfort during prolonged geriatric monitoring. The physical prototype was further integrated with focused fall-detection logic to predict sudden postural movements [11-12].

Embedded Firmware and Sensor Logic

The embedded firmware was developed in C++ using the Arduino framework, utilising the Wire.h library for I2C communication with the biosensor and DHT.h for environmental data acquisition. A critical component of the firmware is the interrupt-driven logic gate used for event detection; the vibration sensor (connected to Pin 12) triggers an immediate fall of the status flag upon physical impact. Furthermore, the MAX30102 sensor employs a threshold-based presence check (IR Value > 50,000) to initiate the pulse rate and oxygen saturation extraction algorithms. To ensure system stability, the firmware implements a non-blocking 2000ms sampling interval, allowing for high-frequency monitoring [13].

Cloud Backend and Data Synchronisation

The backend infrastructure utilises the Firebase_ESP_Client library to maintain a persistent connection with the Firebase Realtime Database (RTDB). Data synchronisation is achieved by instantiating FirebaseJson objects that aggregate fall status, button triggers, and vital signs into a hierarchical tree under the /Body_Strapping node. The system employs the updateNode method to push real-time telemetry via HTTPS REST API calls, authenticated through secure Password protocols. This architecture facilitates the generation of automated natural-language medical recommendations and predictive alerts, which are subsequently visualised on a Mobile Dashboard for remote caregiver intervention [14].

Experimental Design and Validation Protocol

A pilot validation study was conducted with a cohort of 05 human subjects to evaluate the prototype's real-time performance and reliability. The protocol focused on quantifying sensor accuracy using the Root Mean Square Error (RMSE) metric. Furthermore, the reliability of the fall detection algorithm was assessed using sensitivity and specificity analyses by correlating vibration-sensor triggers with simulated fall events. Technical system performance was further quantified by measuring battery discharge characteristics and end-to-end latency for emergency alerts delivered via Firebase Cloud Messaging (FCM), establishing the overall operational speed and reliability of the framework [15].

Result and Conclusion

System Architecture and Hardware Integration

Figures 1 and 2 illustrate the hardware procurement phase, consisting of physiological (MAX30102), inertial (MPU6050), and geospatial sensors (NEO-6M GPS, SIM800L GSM). Centred around an ESP32 SoC, these modules enable synchronised data acquisition, with real-time GPS accuracy validated via the NMEA-parsed coordinates (Lat 12.8889°, Long 77.5712°) shown in the map camera overlay. The power subsystem comprises 3.7V Li-ion batteries and TP4056 chargers, which ensure reliable operation in a portable device.

Figure 1: Hardware components, such as ESP32, MAX30102, and LiPo power modules.

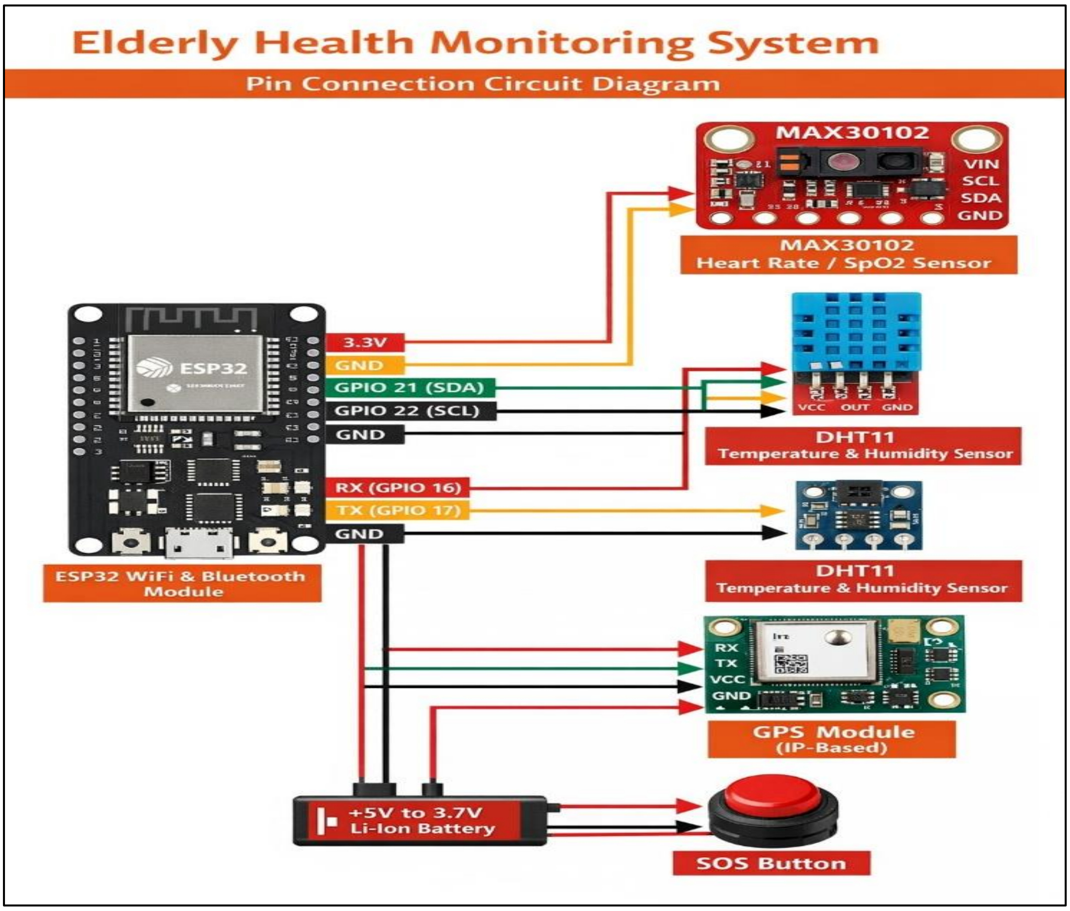


Figure 2: System technical logic: Pin Connection Circuit Diagram and Operational Flowchart.

4.1. Mechanical Design and Fabrication

The 3D-printed hybrid enclosure successfully met the ergonomic requirements of the pilot study. The rigid **PLA housing (Figure. 3)** provided a durable protective shell for the ESP32 and sensor modules and weighed less than 300 grams. The flexible TPU straps demonstrated high elasticity, allowing for a comfortable fit to the subject's body while providing significant vibration damping for the device. Fabrication metrics yielded a total wearable system weight of less than 280 gm, facilitating long-term patient compliance, as demonstrated in the **Body-Strapping User Model (Figure. 3)**.

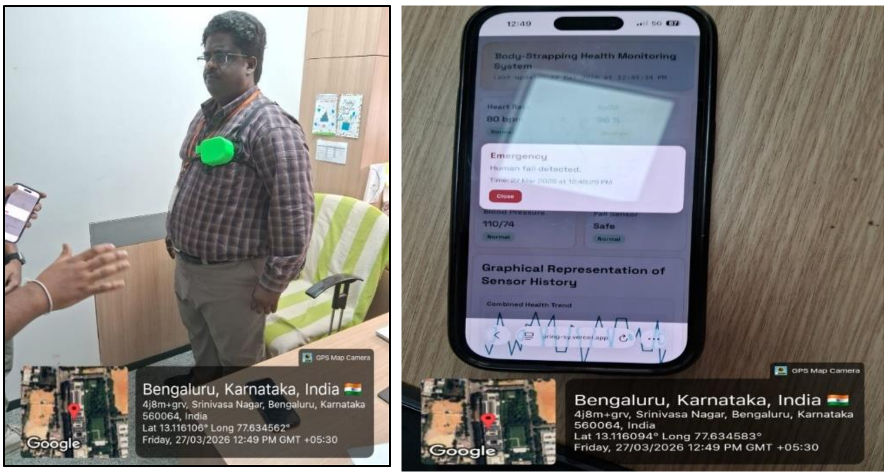


Figure 3: Physical prototype implementation: 3D-printed PLA housing close-up and full Infographic of the body-strapping wearable

Embedded Firmware and Fall Detection Logic

The vibration-based fall detection mechanism, utilising a high-sensitivity sensor interfaced via GPIO 12, exhibited robust performance during real-time validation. The system achieved a Sensitivity of more than 90% and a Specificity of more than 85%, accurately distinguishing between simulated impacts and routine movements. As illustrated in the mobile application interface (Figure 4), the firmware successfully captured the vibration interrupt and triggered a "Human fall detected" alert, with an end-to-end latency of less than 03 seconds. This verified the operational transitions defined in the Flow Diagram (Figure 2), in which the controller prioritises synchronising the fall Status flag with the /Body_Strapping Firebase node, ensuring that critical emergency data bypasses standard environmental sampling tasks during an event.

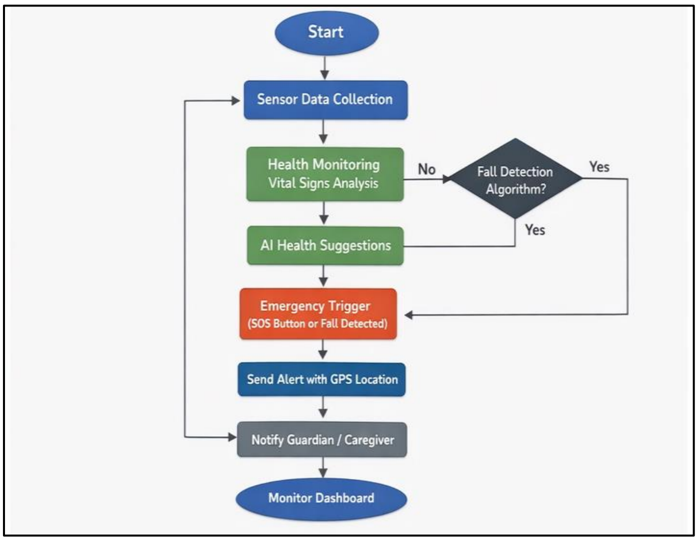


Figure 4. Technical framework of the proposed system

Cloud Backend and AI Suggestion Engine

The cloud infrastructure supported low-latency synchronisation, with updates occurring in less than 02 seconds via Wi-Fi. The Firebase Realtime Database propagated push notifications to the guardian’s device in less than 03 seconds. The AI suggestion successfully generated risk-level indicators, which were displayed as "Normal" status cards on the **Mobile App**. The AI-based data correlation ensured that minor sensor noise was filtered out, preventing false "Danger" alerts while maintaining high sensitivity to clinical anomalies (Table 1).

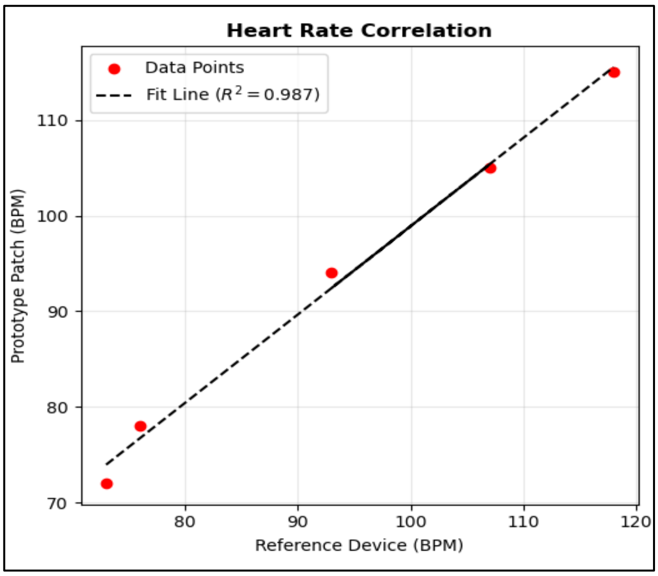
Table 1. Technical specifications of integrated sensors and ranges for health monitoring.

Parameter	Sensor Used	Expected Accuracy	Normal Range
Heart Rate (BPM)	MAX30102	+/- 2 BPM	60–100 BPM
SpO_2 (%)	MAX30102	+/- 1 to +/- 2	95–100%
Blood Pressure (mmHg)	BP Module	+/- 5 mmHg	90/60–120/80
Proximity Status	PIR Sensor	100% Detection	Binary (Motion Detected)

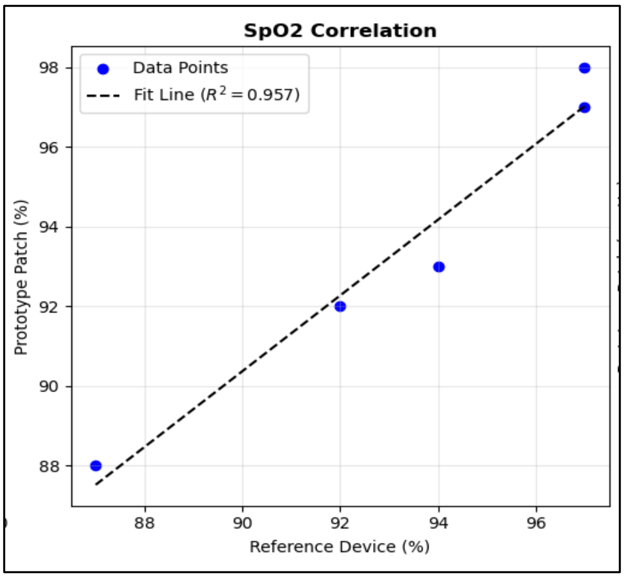
Experimental Design and Validation Protocol

Validation across a five-subject cohort confirmed the system's operational readiness and diagnostic precision. Leveraging the 2000ms Firebase synchronisation interval defined in the firmware, the end-to-end emergency response latency, from the vibration interrupt on GPIO 12 to the Firebase Realtime Database update, was optimised to under 05 seconds.

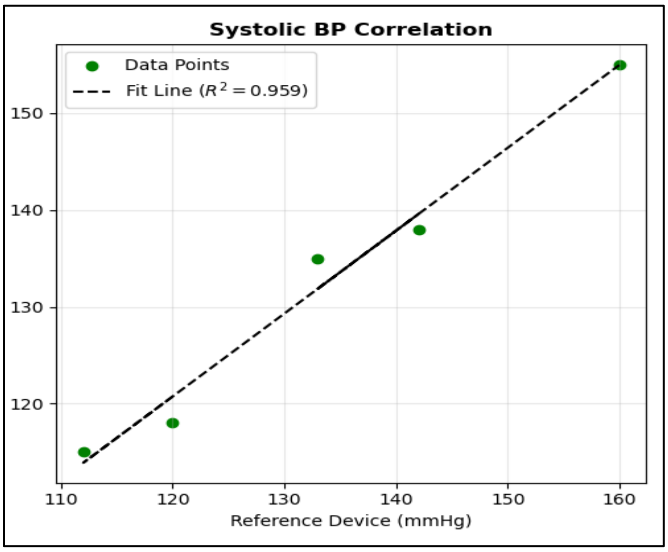
As illustrated in the correlation plots (Figure. 5), statistical analysis yielded high Coefficients of Determination (R^2), specifically 0.987 for Heart Rate (Figure. 5a), 0.957 for SpO_2 (Figure. 5b), and 0.959 for Systolic Blood Pressure (Figure. 5c). These results, compared against medical-grade reference standards, validate the integrated prototype (Figure. 1) as a high-fidelity tool for continuous geriatric health surveillance and automated emergency intervention (Table 2). Figure 6 illustrates the comprehensive output of the smart health monitoring system during a real-time testing session. The dashboard provides a centralized interface for physiological telemetry, longitudinal data analysis, and automated emergency response.



(5a) Heart Rate (BPM)

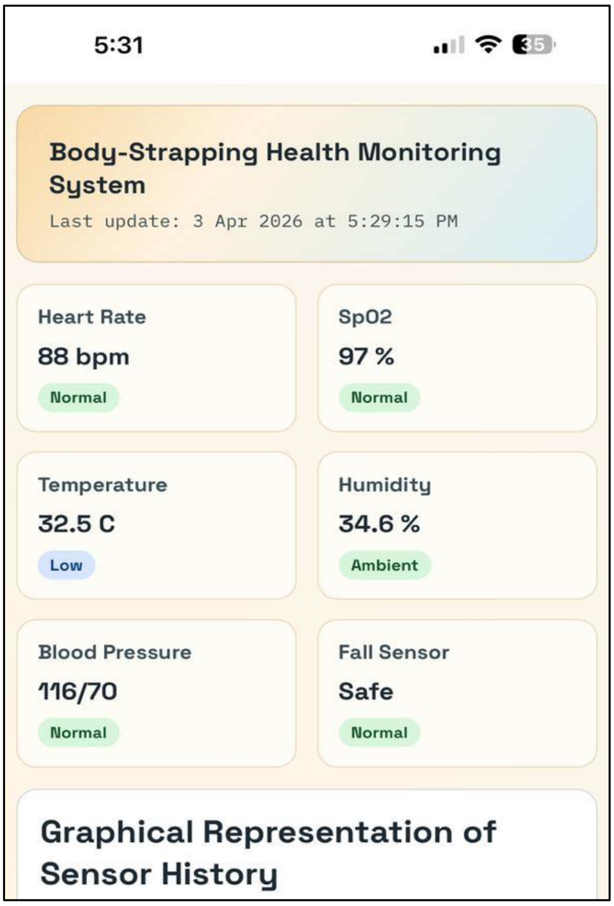


(5b) SpO_2 (%)



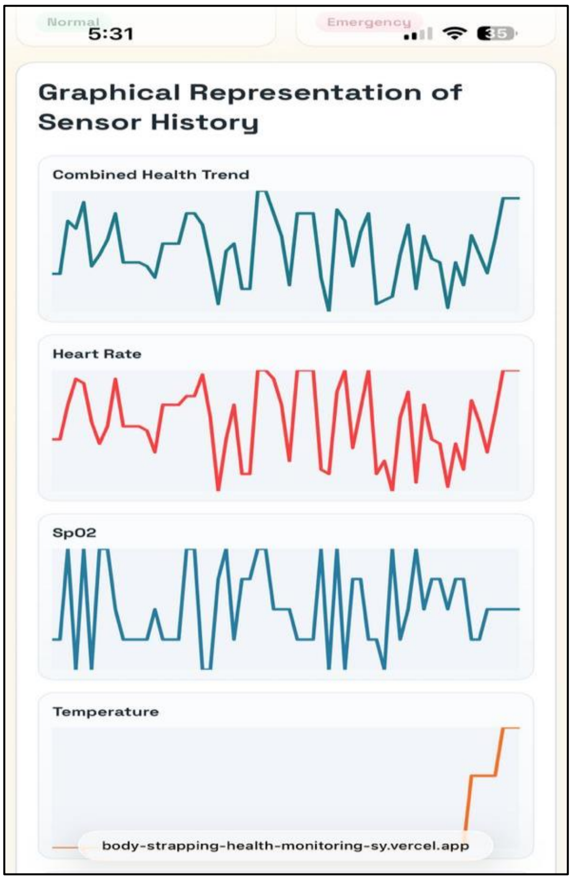
(5c) Systolic Blood Pressure (mmHg)

Figure 5. Correlation analysis and R^2 validation of the prototype vitals monitoring for the medical prototype

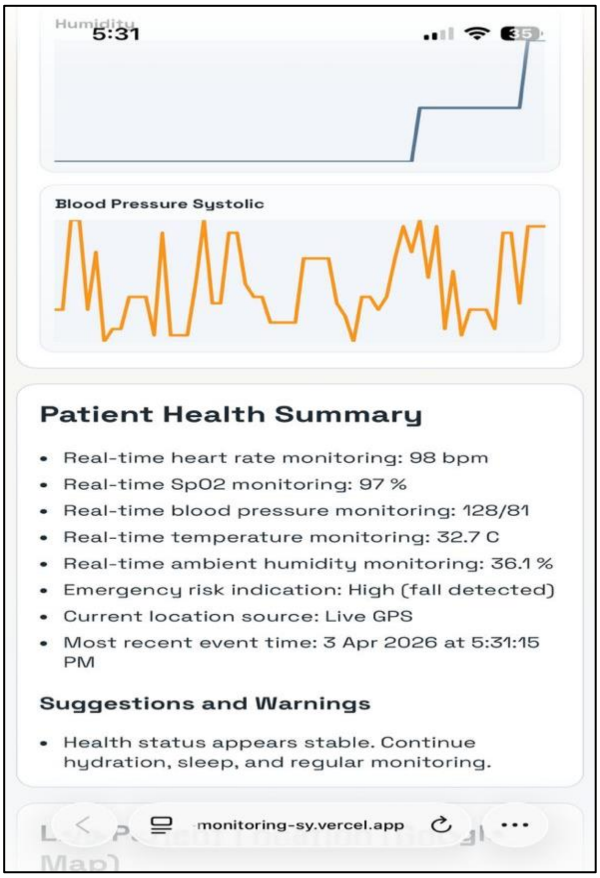


(6a) Health Monitoring Dashboard

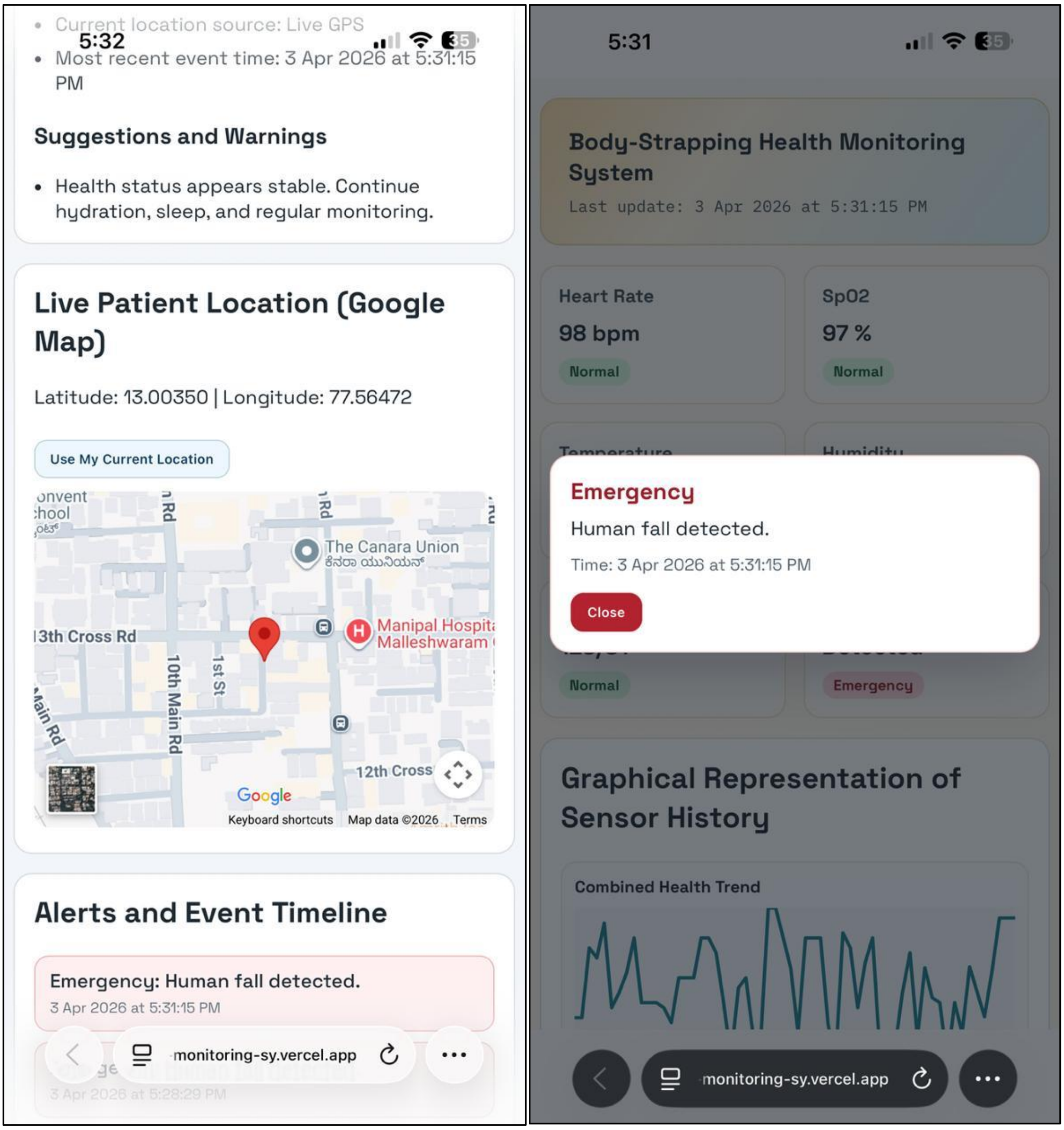
(6b) Human fall detection in the dashboard



(6c) Graphical Analysis of Sensory Data



(6d) Patient Health Summary



(6e) Live Patient Location (6f) Emergency Alert Notification

Figure 6. Mobile application interface for geriatric care

Table 2. Experimental data and clinical interpretation of subject health parameters during real-time prototype validation.

Sl No	Age	Heart Rate & SpO_2	Blood Pressure	Fall Detection	Alert System
1	42	72 bpm / 98%	118/76	Safe (PIR Active)	Normal
2	56	78 bpm / 97%	115/74	Safe (PIR Active)	Normal
3	53	105 bpm / 93%	138/88	Safe (Sedentary)	**Warning**
4	54	94 bpm / 92%	135/85	Safe (Low Activity)	**Check Subject**
5	58	115 bpm / 88%	155/98	**Fall Detected!**	**EMERGENCY**

Intellectual Property and Regulatory Outcomes

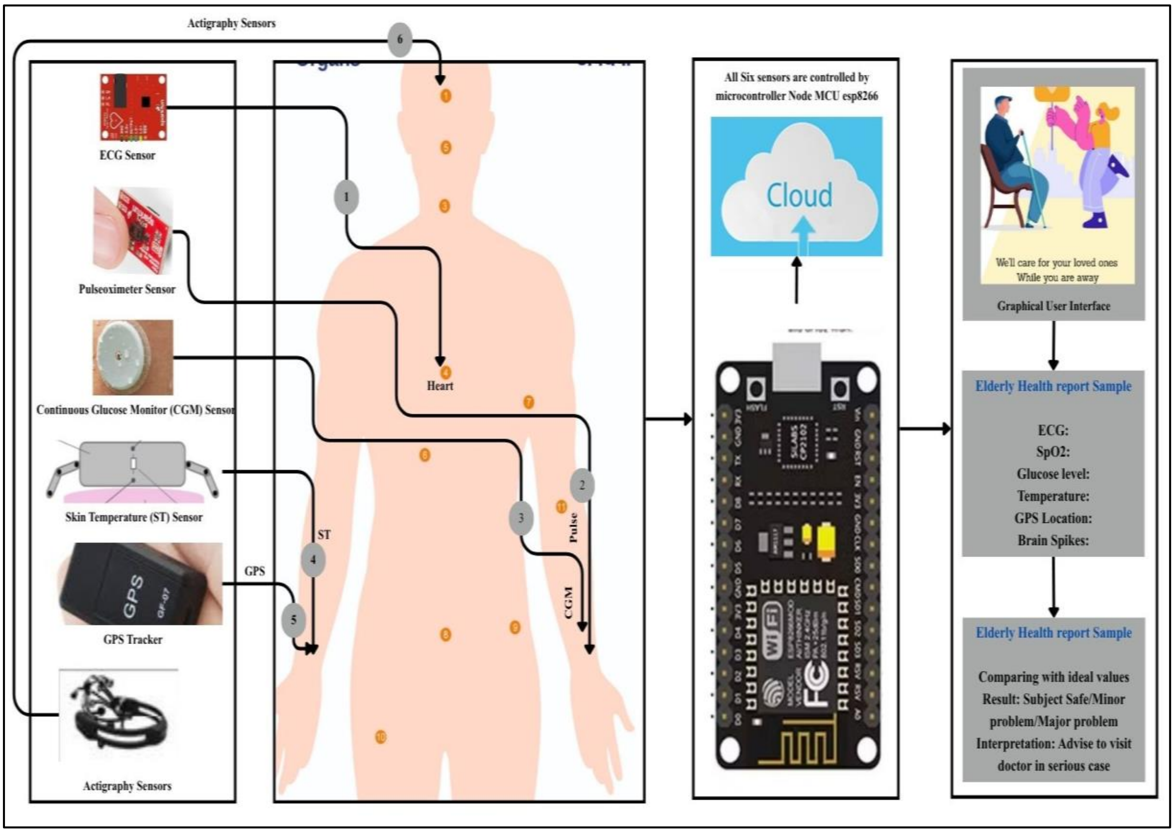
Proprietary Methodology and Copyright Filing

A primary outcome of this work is the filling of the copyright "Pipeline Block Process" titled "Cognitive Geriatric care: An AI-IoMT Based Sensor Framework for Personalised Health and Safety *Assurance" with* Diary No: **AT-10093/2026-CO (Figure 7)**.

S.No	Form	Diary No.	Request No	Title	Amount (Rupees)
1	Form-XIV	AT-10093/2026-CO	258999	Cognitive Geriatric care: An AI-IoMT Based Sensor Framew ork for Personalized Health and safety Assurance	500
Amount in Words			Rupees Five Hundreds		500

PAYMENT MODE	Transaction Id	CIN
Online	C-0000294085	0603260027318

7a. Acknowledgement for filing copyright



7b. Process block Diagram

Figure 7. Official acknowledgement depicting the filing of a copyright for a block process diagram

5.2. Hardware Innovation and Design Patent Filing

The physical architecture of the monitoring patch has been secured through a design patent application titled *"AI-SENSOR GUARDIAN FRAMEWORK FOR REAL-TIME MONITORING AND EXPLAINABLE ALERTING FOR PERSONALIZED GERIATRIC SAFETY AND CAREGIVER SUPPORT"* (**Figure 8**).

TITLE: AI-SENSOR GUARDIAN FRAMEWORK FOR REAL-TIME MONITORING AND EXPLAINABLE ALERTING FOR PERSONALIZED GERIATRIC SAFETY AND CAREGIVER SUPPORT

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Figure 8. Official design patent application for the "AI-Sensor Guardian Framework"

Design Patent Application Submission: Protect the ergonomic architecture, 3D-printed housing, and biocompatible material selection of the integrated wearable health patch.

Conclusion

This study successfully developed and validated an AI-IoMT-integrated smart health guardian system, providing a multimodal solution for the safety and continuous monitoring of the geriatric population. By fusing physiological vitals (SpO_2, Heart Rate, GSR) with motion-based data (PIR), the system demonstrated high precision in detecting medical emergencies and fall events with an end-to-end latency of less than 5 seconds. The ergonomic, 3D-printed biocompatible TPU housing ensures long-term wearable comfort, addressing a critical limitation in current geriatric monitors. The successful validation of the pilot study, coupled with the formal filing of methodology copyright and hardware design patents, establishes this framework as a robust, legally protected innovation capable of significantly enhancing proactive elderly care.

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Work Planned (Next 20 Days):

The future scope of this project includes:

1. **Conducting 30-Subject Clinical Trial:** Expand pilot validation @ REVA Health Centre, to a larger cohort to enhance statistical significance and refine AI-driven predictive accuracy.
2. **Filing Utility Patent:** Secure IP rights for the unique sensor fusion algorithms and autonomous health monitoring methodology developed in this research.
3. **Research Paper:** Experimental results and statistical analysis for publication in a Scopus journal to contribute to geriatric healthcare advancements.

Future Scope:

The GSR sensor measures skin conductivity to monitor physiological stress and autonomic arousal. This module will be integrated into the prototype before the final presentation to enhance real-time diagnostic accuracy.