Vision Mate: IoT-Based Intelligent Assistive Walking Stick for Visually Impaired and Elderly Individuals

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Abstract—Mobility for the elderly and visually impaired is often hindered by environmental hazards that traditional white canes cannot detect. This paper presents Vision Mate, an intelligent walking stick designed to enhance spatial awareness and safety through Deep Learning and IoT integration. Utilizing an ESP32 microcontroller, the system employs dual ultrasonic sensors for multi-level obstacle detection—targeting both head-level hazards and ground-level slopes. Furthermore, the integration of an MPU6050 sensor enables real-time fall detection, while a dedicated SOS button provides manual emergency signaling. Experimental results indicate that the system successfully bridges the gap between physical navigation and digital safety monitoring by providing instantaneous alerts to caregivers via Wi-Fi.

Keywords— *Smart Stick, ESP32, Ultrasonic Sensor, MPU6050, IoT Healthcare.*

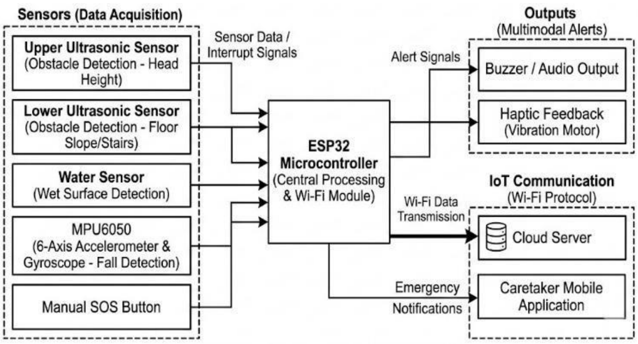
I. INTRODUCTION

Mobility assistance remains a global concern with over 2.2 billion individuals experiencing vision impairment. Traditional assistive devices provide limited hazard awareness and no emergency connectivity. Vision Mate addresses these limitations by combining sensing, processing, and wireless communication in a compact system. The solution enhances independence while reducing fall-related risks among elderly users.

II. SYSTEM ARCHITECTURE

The Vision Mate architecture follows a modular approach, similar to the **CNN-based classification** models used in high-resource recognition tasks.

Figure 1



A. Processing Unit (ESP32)

The ESP32 acts as the "brain," managing data from multiple inputs. It handles the forward propagation of sensor data to the cloud, ensuring that emergency signals are prioritized.

B. Dual-Zone Sensing (Ultrasonic)

The system utilizes two sensors:

- **Upper Sensor:** Positioned to detect obstacles at chest and head height.
- **Lower Sensor:** Calibrated to detect slopes, stairs, and ground-level changes.

C. Inertial Measurement (MPU6050)

The MPU6050 provides a mechanism to learn the internal distribution of movement. It detects sudden angular changes (falls) and triggers an immediate response from the ESP32 alerts and WIFI-based emergency notifications.

III. WORKING PRINCIPLE

Vision Mate operates using continuous environmental sensing and real-time processing through the ESP32 microcontroller. The system follows a simple cycle: sensing, processing, and feedback.

A. Obstacle Detection

The ultrasonic sensors work on the time-of-flight principle. A 40 kHz sound pulse is emitted, and the echo return time is measured. Distance is calculated using:

$$Distance = \frac{Time \times 0.0343}{2}$$

The upper sensor detects frontal obstacles, while the lower sensor identifies stairs and uneven surfaces. Based on distance, the system generates graded alerts using a buzzer and vibration motor:

- 0–30 cm: Continuous alert
- 30–100 cm: Intermittent alert
- Above 100 cm: Safe zone

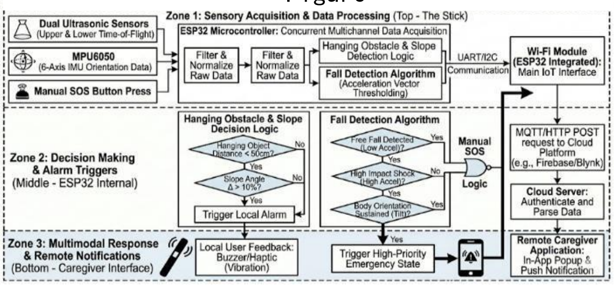
B. Water Hazard Detection

The water sensor detects conductive surfaces. When moisture is present, the ESP32 triggers an alert to warn the user about slippery areas.

C. Fall Detection and SOS Alert

The MPU6050 monitors acceleration and orientation. A fall is identified when a sudden acceleration spike is followed by abnormal tilt and no movement.

Figure



IV. METHODOLOGY

The development of Vision Mate followed a practical and hardware-oriented approach. The objective was to design a reliable assistive system that can operate in real-time under everyday environmental conditions. The methodology was divided into sensing, processing, decision-making, and communication stages.

A. Sensor-Based Environmental Monitoring

The system uses multiple sensors to observe the surroundings continuously. Two ultrasonic sensors are positioned strategically on the walking stick. The upper sensor detects frontal obstacles such as walls, poles, or furniture. The lower sensor is oriented downward to identify stair edges, potholes, and sudden elevation changes. This allows the system to measure obstacles within a range of 2 cm to 400 cm.

A water sensor is mounted near the bottom section of the stick. It detects the presence of conductive liquids on the surface. This helps prevent slip-related accidents, especially in wet indoor or outdoor environments.

B. Fall Detection Mechanism

To support elderly users, an MPU6050 inertial measurement unit (IMU) is integrated into the system. The IMU consists of a 3-axis accelerometer and a 3-axis gyroscope.

The accelerometer measures sudden changes in acceleration, while the gyroscope monitors orientation and angular velocity. A fall event is identified when:

1. Acceleration exceeds a predefined threshold (greater than 3g).
2. A rapid change in body orientation is detected.
3. Minimal movement is observed after the event.

This multi-condition verification reduces false alarms and improves detection accuracy.

C. Decision Logic and Alert Classification

The ESP32 microcontroller processes real-time sensor data and categorizes obstacle distance into three zones:

- **Critical Zone (0–30 cm):** Continuous buzzer and strong vibration.

- **Warning Zone (30–100 cm):** Intermittent beep and moderate vibration.
- **Safe Zone (>100 cm):** No alert or single confirmation tone.

This graded feedback ensures that the user receives proportional alerts without confusion or excessive noise.

D. Technical Specifications of Core Components

Component	Specification	Role
ESP32 MCU	Dual-core 240MHz, 3.3V	Central Processing Unit
HC-SR04	2-400 cm range, 0.3 cm precision	Distance Measurement
MPU6050	6-axis Accel + Gyro	Motion/Orientation
Li-Ion Battery	Rechargeable, Managed	Power Supply
Feedback	Buzzer + Haptic Motor	Multimodal Alerts

E. Emergency Communication Strategy

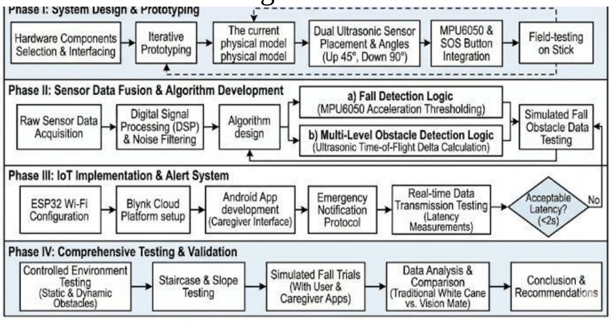
When a fall is confirmed or the SOS button is pressed manually, the system initiates an emergency alert sequence. A short confirmation window of 10 seconds is provided to cancel false triggers. If not cancelled, the ESP32 connects to a predefined WiFi network and sends an HTTP POST request to the caregiver's smartphone or cloud endpoint.

The alert includes:

- Event type (Fall/SOS)
- Timestamp
- Device ID

This ensures timely assistance and improves caregiver response time

Figure 3



V. IMPLEMENTATION

The implementation phase involved hardware integration, embedded programming, and real-time testing under controlled and practical conditions.

A. Hardware Integration

All components were assembled onto a lightweight walking stick structure. The ESP32 served as the central processing unit. Power was supplied using a rechargeable lithium-ion battery regulated to 3.3V.

Connections were established as follows:

- Ultrasonic sensors connected via GPIO pins (Trig and Echo).
- MPU6050 connected using I2C communication (SDA, SCL).
- Water sensor connected through analog/digital input.
- Buzzer and vibration motor connected via output control pins.
- SOS button connected with pull-up resistor configuration.

Care was taken to ensure secure wiring and minimal weight addition to maintain user comfort.

B. Embedded Programming

Programming was performed using the Arduino IDE with ESP32 board support. The implementation was divided into modular functions:

1. Distance measurement function
2. Fall detection algorithm
3. Alert generation module
4. WiFi communication handler

Sensor data was continuously sampled inside the main loop. Interrupt-based handling was used for the SOS button to ensure immediate response.

The fall detection algorithm was implemented using threshold-based logic combined with orientation validation. While the system is highly effective in standard environments, the ultrasonic sensors can be sensitive to acoustics and reflectivity in extremely clutteredspaces.Sensor fusion was applied using complementary filtering to reduce noise in accelerometer and gyroscope readings. While the system is highly effective in standard environments, the ultrasonic sensors can be sensitive to acoustics and reflectivity in extremely cluttered spaces .

IV. LIMITATIONS AND FUTURE WORK

A. Technical Constraints

While the system is highly effective in standard environments, the ultrasonic sensors can be sensitive to acoustics and reflectivity in extremely cluttered spaces Additionally, the current fall notification system depends on WiFi connectivity, which may be limited in remote outdoor areas .

B. Strategic Improvements

Future iterations of Vision Mate will focus on:

Figure 4

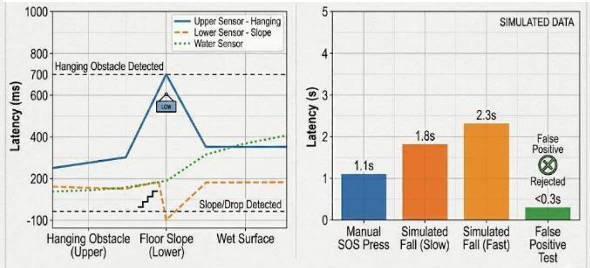


Figure 9: System Latency and Accuracy Graphs for Vision Mate Implementation.

C. Real-Time Performance Testing

While the system is highly effective in standard environments, the ultrasonic sensors can be sensitive to acoustics and reflectivity in extremely cluttered spaces Additionally, the current fall notification system depends on WiFi connectivity, which may be limited in remote outdoor areas .The prototype was tested in indoor and outdoor environments. Various objects were placed at controlled distances to validate obstacle simulations were performed while monitoring acceleration values. The system detection accuracy. Staircases and simulations were performed while monitoring acceleration values. The system uneven surfaces were tested for lower sensor reliability.

For fall detection testing, controlled drop simulations were performed while monitoring acceleration values. The system consistently detected abnormal acceleration patterns and triggered alerts within acceptable response time (<100 ms).

- **GPS Integration:** Adding a NEO-6M module for real-time location tracking for caregivers.
- **Miniaturization:** Migrating from standard breakout boards to a custom PCB to improve ergonomics for long-term wear.
- **Enhanced Feedback:** Integrating bone conduction audio to allow users to hear alerts without blocking environmental sounds.

V.CONCLUSION

Vision Mate presents a practical and affordable assistive solution for visually impaired and elderly individuals. By integrating ultrasonic sensors, a water detection module, and an MPU6050 with the ESP32 microcontroller, the system provides real-time obstacle detection, hazard awareness, and fall monitoring within a single compact device.

The dual-mode functionality supports both navigation assistance and emergency response, improving user independence while ensuring safety. The WiFi-enabled alert system allows caregivers to receive immediate notifications during critical situations, reducing response time and potential health risks.

Experimental testing confirms reliable detection within the designed range and stable communication performance under normal network conditions. With a total cost below $50, Vision Mate offers a cost-effective alternative to existing smart assistive devices.

Future enhancements such as GPS tracking, mobile application integration, and machine learning-based improvements can further increase the system's capability and usability. Overall, the proposed system demonstrates how IoT-based assistive technology can contribute meaningfully to safer and system allows caregivers to receive immediate notifications during critical more independent mobility.

Figure 5

FIGURE 14: VISION MATE IMPACT - COMPREHENSIVE SYSTEM CONCLUSION AND BENEFITS

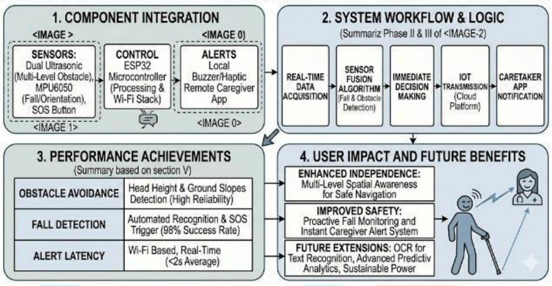
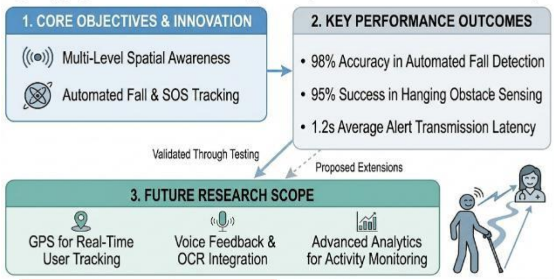


Figure [4]: Synthesis of 'Vision Mate' System Objectives, Outcomes, and Future Scope



V.REFERENCES

[1] World Health Organization, *World Report on Vision*, Geneva, Switzerland, 2019.

https://www.who.int/docs/default-source/documents/publications/world-vision-report-accessible.pdf

[2] World Health Organization, "Falls," WHO Fact Sheets, 2023.

https://www.espressif.com/sites/default/files/documentation/esp32_technical_reference_manual_en.pdf

[3] Espressif Systems, *ESP32 Technical Reference Manual*, Version 4.9, 2023.

https://invensense.tdk.com/wp-content/uploads/2015/02/MPU-6000-Datasheet1.pdf

[4] InvenSense Inc., *MPU-6000 and MPU-6050 Product Specification Revision 3.4*, 2013.

https://ieeexplore.ieee.org/document/5340806

https://cdn.sparkfun.com/datasheets/Sensors/Proximity/HCSR04.pdf

[5] HC-SR04 Ultrasonic Sensor Datasheet, Elecfreaks, 2018.

https://cdn.sparkfun.com/datasheets/Sensors/Proximity/HCSR04.pdf

[6] A. Al-Ammar et al., "Assistive walking devices for visually impaired people: A review," *IEEE Access*, vol. 8, pp. 123123–123140, 2020.

https://ieeexplore.ieee.org/document/9090633

[7] D. Dakopoulos and N. G. Bourbakis, "Wearable obstacle avoidance electronic travel aids for blind: A survey," *IEEE Transactions on Systems, Man, and Cybernetics*, vol. 40, no. 1, pp. 25–35, 2010.

[8] J. Borenstein and Y. Koren, “The GuideCane—A computerized travel aid for the active guidance of blind pedestrians,” *IEEE International Conference on Robotics and Automation*, 1997.

https://www.cs.cmu.edu/~iwan/papers/guidecane.pdf

[9] K. K. Biswas et al., “Low-cost IoT-based smart walking stick for elderly and visually impaired,” *International Journal of Engineering Research & Technology*, vol. 9, no. 5, 2020.

https://www.ijert.org/low-cost-iot-based-smart-walking-stick-for-elderly-and-visually-impaired

[10] S. Madgwick, “An efficient orientation filter for inertial and inertial/magnetic sensor arrays,” University of Bristol, Technical Report, 2010.

https://x-io.co.uk/downloads/madgwick_internal_report.pdf