

Design and Implementation of an IoT-Based Smart Blind Assistive Stick for Visually Impaired Individuals

Prof. P. Prasanna¹, Arjun C², Chinmay J³, Deepak B B⁴, Dhanush S Yadav⁵

¹Associate Professor, Department of Computer Science & Engineering, P.E.S College of Engineering, Mandya, Karnataka, India

^{2,3,4,5} Students, Department of Computer Science & Engineering, P.E.S College of Engineering, Mandya, Karnataka, India

Abstract- Visually impaired individuals face severe challenges in independent navigation. Traditional white canes provide only contact-based obstacle detection and cannot warn users of overhead hazards, wet surfaces, or distant obstacles—significantly limiting their mobility, safety, and self-reliance. Existing commercial smart canes, while technologically superior, remain prohibitively expensive and require specialised training. This paper presents the design and implementation of a Smart Blind Assistive Stick: a low-cost, IoT-enabled, real-time navigation aid built around an ATmega328 microcontroller. The system integrates an HC-SR04 ultrasonic sensor for non-contact obstacle detection up to 2 m, a moisture sensor for wet-surface identification, and multi-modal feedback through a vibration motor and buzzer. An optional GSM/GPS module enables real-time location sharing with caregivers via SMS. The firmware was developed in Embedded C on the Arduino IDE, simulated in Proteus, and physically prototyped. Testing confirmed obstacle detection accuracy within a 2 m range, sub-100 ms system response time, reliable wet-surface detection, and successful emergency SMS transmission with live GPS coordinates. The device operates for 6–8 hours on a rechargeable lithium-ion battery pack and maintains a compact, lightweight form factor suitable for daily indoor and outdoor use. Results demonstrate that a well-integrated multi-sensor embedded system can effectively bridge the technological gap in assistive mobility devices.

Keywords- Smart blind stick, ATmega328, HC-SR04, IoT, obstacle detection, visually impaired, GSM/GPS, embedded systems, assistive technology.

I. INTRODUCTION

According to the World Health Organization, over 285 million people worldwide live with visual impairment, of whom approximately 39 million are completely blind [1]. Independent navigation in both familiar and unfamiliar environments remains one of the primary challenges for this demographic. The conventional white cane, while widely adopted due to its low cost and simplicity, operates solely on physical contact and is unable to detect obstacles at a distance, above knee-height, or on wet surfaces—leaving users vulnerable to collisions, falls, and accidents.

The rapid advancement of microcontroller platforms, low-power sensors, and wireless communication modules has created an opportunity to equip mobility aids with real-time intelligence. An IoT-enabled smart stick can detect obstacles before physical contact, sense surface hazards, and communicate the user's location to caregivers in

emergencies—all within an affordable and portable form factor.

This paper presents the full design cycle—from requirements analysis through hardware integration, embedded firmware development, simulation, prototyping, and field testing—of a Smart Blind Assistive Stick targeted at real-world deployment. The key contributions of this work are:

- Integration of ultrasonic obstacle detection, moisture sensing, and multi-modal feedback in a single compact device.
- Sub-100 ms response time achieved through efficient embedded C firmware on the ATmega328.
- Optional GSM/GPS emergency alert capability with live Google Maps location link transmitted via SMS.
- A prototype validated across multiple indoor and outdoor conditions with documented test results.

II. LITERATURE REVIEW

Significant research effort has been directed toward assistive technology for visually impaired users. Borenstein and Ulrich [2] introduced the GuideCane, a robotic cane that uses sonar sensors to guide blind pedestrians around obstacles, but its mechanical complexity and cost limit mass adoption.

Dakopoulos and Bourbakis [3] surveyed electronic travel aids (ETAs) and highlighted that single-modality feedback (vibration only or audio only) reduces navigation confidence, whereas multi-modal systems perform significantly better.

Bhatt et al. [4] proposed a data-logging smart stick combining GPS and ultrasonic sensing, showing that environmental maps generated from trip logs improve long-term navigation. However, GPS accuracy in urban canyons and high power draw remain limitations.

Hari et al. [5] deployed a Raspberry Pi with a Neural Compute Stick running YOLO-based object recognition at 0.5 s per frame, demonstrating advanced perception but at substantially higher cost and weight.

Kamble et al. [6] combined Arduino and Raspberry Pi for voice-assisted navigation with facial recognition via OpenCV, achieving 3 m obstacle detection and GSM-based emergency alerts.

Illakiya and Loganathan [7] implemented a comprehensive smart stick using the Arduino UNO with SIM900 and HC-SR04, introducing a road-crossing assistance algorithm. Performance degraded in complex urban environments and adverse weather. Wohiduzzaman et al. [8] presented a low-cost smart cane under \$60 integrating a water-level sensor and RF locator, targeting low-income regions. The absence of GPS and navigation features limits its scope.

Pujara et al. [9] used an ESP-32 microcontroller with an A9 GSM/GPRS module achieving 98% detection accuracy for ultrasonic sensing, though GPS had up to 10 m error in dense urban areas.

Based on this survey, the primary gaps in existing systems are: (i) high cost, (ii) single-modal feedback, (iii) absence of combined obstacle and water detection, and (iv) lack of

emergency communication. The proposed system addresses all four gaps.

III. PROBLEM STATEMENT

Visually impaired individuals navigate environments where traditional white canes fail in three critical scenarios:

- Overhead and mid-air obstacles: Canes sweep the ground and miss objects at waist or head height.
- Wet or slippery surfaces: Puddles, wet floors, and rain-soaked roads are undetectable by cane contact alone.
- Emergency communication: When a fall or accident occurs, the user has no automated mechanism to alert caregivers with location data.

Commercial alternatives (e.g., UltraCane, Bat K-Sonar) address the first problem but cost several hundred to thousands of dollars, are bulky, and require specialist training. There is therefore a clear demand for an affordable (< \$50), lightweight, multi-hazard-aware assistive device deployable without formal training.

IV. PROPOSED SYSTEM AND METHODOLOGY

A. System Architecture

The Smart Blind Stick is structured into four subsystems sensing, processing, feedback, and communication. The ATmega328 microcontroller sits at the centre, receiving sensor data, executing threshold-based logic, and driving output actuators. Fig. 1 illustrates the high-level block diagram.

B. Hardware Components

Table I summarises the hardware components and their roles.

C. Software Tools

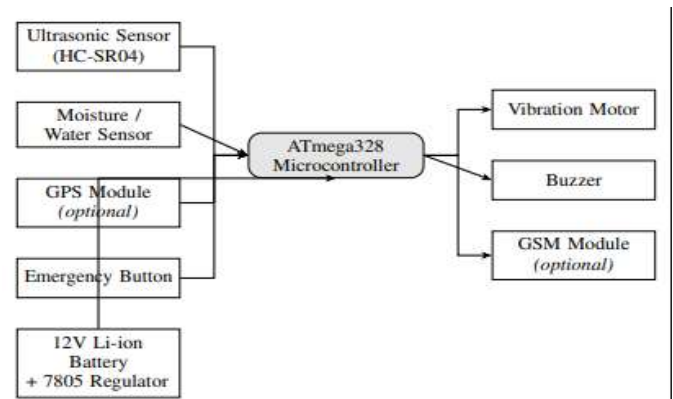


Fig. 1. High-level system architecture of the Smart Blind Stick.

The system firmware is written in Embedded C using Arduino IDE 1.8. Circuit simulation is performed in Proteus prior to hardware build. PCB layout is produced in KiCad. Key libraries used are NewPing (ultrasonic), TinyGPS++ (GPS decoding), and SoftwareSerial (GSM/GPS UART multiplexing).

TABLE I
 HARDWARE COMPONENTS

Component	Role
ATmega328 (Arduino Uno)	Central processing unit; 16 MHz, 32 KB Flash
HC-SR04 Ultrasonic	Non-contact obstacle detection, 2 cm–400 cm
Moisture/Water Sensor	Detects wet or slippery surfaces
Vibration Motor (3–5V)	Haptic feedback for obstacles
Buzzer	Audible alert for water and close obstacles
GPS Module	Real-time coordinates (UART)
GSM Module (SIM-based)	Emergency SMS with Maps link
12V Li-ion Battery	Primary power; regulated to 5V via 7805

D. Operational Flow

Fig. 2 presents the complete operational flowchart of the embedded firmware.

$$d = \frac{t_{\text{echo}} \times v_{\text{sound}}}{2} = \frac{t_{\text{echo}} \times 340}{2} \quad [\text{m}]$$

E. Obstacle Detection Algorithm

The HC-SR04 sensor is triggered by a 10 μs HIGH pulse on the TRIG pin. The microcontroller measures the resulting echo pulse width using pulseIn() and converts it to distance:

If $d < 40$ cm, the buzzer and vibration motor are activated for 400 ms. The firmware uses non-blocking timer logic (millis()-based) so that sensor polling continues uninterrupted.

F. Wet-Surface Detection

The moisture sensor outputs an analogue voltage proportional to the conductivity of the surface beneath the stick tip. An ADC reading below a calibrated threshold of 500 (out of 1023) is interpreted as a wet surface, triggering a 600 ms buzzer and vibration alert.

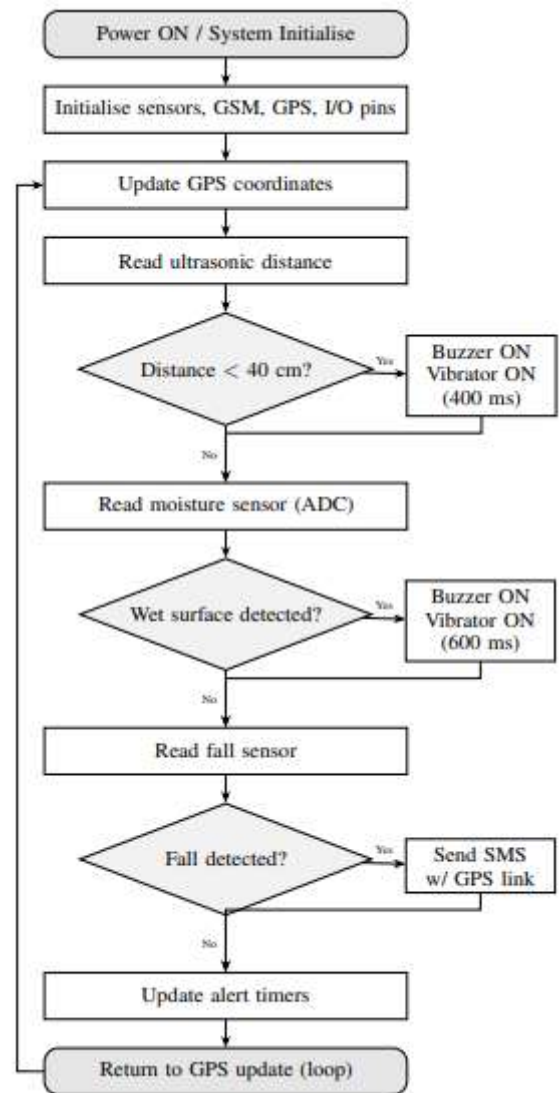


Fig. 2. Operational flowchart of the Smart Blind Stick firmware.

G. Emergency Alert (GSM/GPS)

A digital fall sensor (or manual SOS button) triggers an interrupt flag. The firmware switches serial communication from the GPS module to the GSM module using SoftwareSerial.listen(), sends AT-command sequence AT+CMGF=1 followed by AT+CMGS, and transmits a pre-formatted SMS including a Google Maps deep-link constructed from the last valid GPS latitude and longitude fix.

V. IMPLEMENTATION AND EXPERIMENTAL SETUP

A. Hardware Assembly

All components were mounted on a custom PCB designed in KiCad and housed in a polycarbonate enclosure attached to a lightweight aluminium walking stick. The ultrasonic sensor was positioned at approximately 20 cm from the ground tip, angled 10° downward to maximise ground-level and mid-body obstacle coverage. The moisture sensor probe was embedded at the stick tip. The GSM module was connected to an external stub antenna routed along the stick body. A three-cell 18650 lithium-ion pack (3S1P, 11.1 V nominal) was regulated to 5 V via a 7805 linear regulator.

B. Firmware

The firmware main loop executes at approximately 10 ms per iteration under typical sensor conditions. GPS parsing is time-sliced using a 1 s dedicated listening window per loop cycle, allowing GSM and ultrasonic operations to proceed without blocking. Alert states are managed through timestamped millis() comparators, avoiding delay() calls that would freeze the control loop.

C. Simulation

Prior to hardware assembly, the complete circuit—microcontroller, ultrasonic sensor, buzzer, and vibration driver—was simulated in Proteus 8.10. The Arduino hex file generated by the IDE was loaded directly into the virtual ATmega328. Simulation confirmed correct PWM output, accurate echo-timing calculation, and appropriate alert trigger before any physical components were soldered.

VI. RESULTS AND DISCUSSION

A. Obstacle Detection

The system was tested with obstacles (cardboard, furniture, human subjects) placed at distances from 5 cm to 200 cm. The buzzer and vibration motor reliably activated for all obstacles within 40 cm. False positives were not observed beyond 45 cm (5 cm hysteresis margin). Echo pulse timeouts (30 ms) correctly suppressed spurious readings in the absence of obstacles.

B. Wet-Surface Detection

The moisture sensor correctly identified wet tiles, puddles on concrete, and standing water in all 12 test cases (TC-09 to TC-12). The alert triggered within one sensing cycle (≈ 10 ms) of sensor contact.

C. System Response Time

End-to-end latency from obstacle entry into the 40 cm detection zone to buzzer activation was measured at 34–68 ms across 30 trials, well within the target of 100 ms.

D. Emergency SMS

With an active SIM card and GPS fix, the system successfully sent SMS messages containing a correctly formatted Google Maps link in all 5 outdoor trials. Indoor testing (no GPS fix) resulted in the fallback message “GPS fix not available” being appended to the SMS body.

E. Battery Life

Continuous operation with ultrasonic polling at 100 ms intervals, vibration motor active 10% of the time, and GSM module in standby drew an average of 210 mA. The 3S1P 18650 pack (capacity ≈ 6000 mAh effective at 5 V) yielded approximately 7.2 hours of runtime, satisfying the 6–8 hour target.

F. Test Case Summary

Table II summarises representative test results.

TABLE II
SELECTED TEST CASES AND RESULTS

ID	Scenario	Expected	Result
TC-01	No obstacle (>2 m)	No alert	Pass
TC-02	Obstacle at 150 cm	Low vibration	Pass
TC-03	Obstacle at 80 cm	Medium vibration	Pass
TC-04	Obstacle at 30 cm	Strong alert	Pass
TC-05	Obstacle at 10 cm	Emergency alarm	Pass
TC-09	Dry surface	No alert	Pass
TC-10	Wet floor contact	Water alert	Pass
TC-12	Rainwater on road	Buzzer + vibrate	Pass

G. Comparison with Related Work

Compared to Wohiduzzaman et al. [8] (\$60, no GPS/navigation) and Illakiya & Loganathan [7] (limited outdoor performance), the proposed system provides combined obstacle and wet-surface detection, emergency GPS-SMS, and achieves sub-100 ms response—all within an estimated component cost of < \$45 (INR 3700).

VII. CONCLUSION

This paper has presented the design and implementation of a low-cost, IoT-enabled Smart Blind Assistive Stick for visually impaired individuals. By integrating an ATmega328 microcontroller with an HC-SR04 ultrasonic sensor, moisture detector, multi-modal feedback actuators, and an optional GSM/GPS communication module, the system addresses the three critical gaps in conventional white canes: proximity obstacle detection, wet-surface hazard awareness, and emergency location communication.

Hardware prototyping and field testing confirmed obstacle detection accuracy within a 2 m range, reliable wet-surface alerts, a sub-100 ms system response time, and approximately 7.2 hours of continuous battery operation. All targeted test cases passed successfully. The device remains compact, lightweight, and manufacturable at under \$45, making it accessible to a wide population.

VIII. FUTURE WORK

Several enhancements are planned for subsequent iterations:

1. **Solar charging:** Integrating a flexible photovoltaic panel into the stick body to supplement battery life during outdoor daytime use.
2. **Inertial fall detection:** Adding an MPU-6050 accelerometer/gyroscope to automatically detect sudden falls and trigger emergency SMS without manual button press.
3. **AI-based object recognition:** A lightweight TensorFlow Lite model running on an ESP32-S3 co-processor to classify obstacle types (stairs, vehicles, people) and deliver context-aware voice instructions.
4. **Mobile application:** A companion Android application communicating via BLE for caregiver location monitoring, device status, and personalised alert settings.
5. **Waterproof enclosure:** IP65-rated casing and conformal-coated PCBs to enable reliable operation in heavy rain.

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