

IOT-Enabled Intelligent Smart Stick for Visually Impaired People: A Multi-Sensor and Computer Vision Approach

Rishab Singh¹, Bindu Thakral²

1,2School of Engineering & Technology, Sushant University, Gurugram, India

binduthakral@sushantuniversity.edu.in

rishab.250btccse04@sushantuniversity.edu.in

Abstract—This paper presents a literature-driven design study of an IoT-enabled intelligent smart stick for visually impaired users. The proposed architecture combines ultrasonic sensing, water detection, computer vision, haptic and audio feedback, global positioning system (GPS), global system for mobile communications (GSM), and cloud-based Internet of Things (IoT) connectivity. The design is synthesized from two supplied smart-stick studies and their cited literature, with emphasis on overcoming the limitations of conventional white canes and isolated sensor-based systems. A dual-mode operating concept is adopted: a low-power detection mode based mainly on ultrasonic sensing and a recognition mode using a camera and computer vision. A panic mechanism provides emergency location sharing, while cloud telemetry can support remote monitoring. Published test observations indicate that ultrasonic sensing can operate effectively over several metres, whereas image recognition provides richer semantic information but is more sensitive to crowded scenes, motion, and processing constraints. The paper also identifies power consumption, network dependency, recognition reliability, privacy, and user-centered validation as important research challenges. The resulting framework provides a practical foundation for a low-cost, portable, and more accessible assistive mobility device and defines clear directions for future development using edge artificial intelligence, sensor fusion, and energy-aware embedded computing.

Index Terms—Internet of Things, smart stick, visually impaired, obstacle detection, computer vision, GPS/GSM

I. Introduction

Vision loss can significantly restrict independent mobility, particularly in unfamiliar or crowded environments. Traditional white canes remain valuable because they are inexpensive, lightweight, and provide direct tactile feedback; however, they provide limited information about distant, overhead, wet, or semantically complex obstacles. Recent assistive technology research therefore integrates electronic sensing with the familiar cane form to improve situational awareness without requiring the user to learn an entirely new mobility device.

The supplied literature shows a progression from simple ultrasonic or infrared obstacle alarms toward multi-sensor systems incorporating water detection, GPS/GSM communication, vibration, speech output, and computer vision. The earlier IoT-based design uses an Arduino-class controller with ultrasonic and water sensors, GPS/GSM, a remote locating function, and audio/buzzer alerts [14]. A later intelligent-stick design extends this concept with a Raspberry Pi, camera-based object recognition, two operating modes, live IoT location sharing, overhead obstacle detection, and a panic button [15].

The central research problem is therefore not simply detecting an obstacle, but providing useful information at the right time while maintaining portability, battery life, reliability, affordability, and ease of use. This paper synthesizes the attached studies into a refined system architecture and discusses how their complementary strengths can be combined.

The main contributions of this paper are: (1) a consolidated architecture for multi-sensor obstacle awareness; (2) a dual-mode strategy balancing battery life and semantic recognition; (3) an integrated emergency and location communication layer; (4) a comparison of sensing and feedback approaches reported in the literature; and (5) a future research roadmap focused on edge intelligence and robust real-world validation.

II. Background and Problem Statement

The World Health Organization has reported a very large global population experiencing blindness or vision impairment,

making accessible mobility technology an important engineering and social challenge [15]. Existing assistive devices include electronic canes, wearable systems, navigation belts, embedded gloves, and smart sticks. Among these, the smart stick is particularly attractive because it preserves the user's familiar walking technique while adding non-visual information.

A recurring limitation in earlier systems is the narrow scope of sensing. A single ultrasonic sensor can indicate that an object is nearby but cannot reliably describe what the object is. Infrared approaches can be economical and low-power, but their range and sensitivity to environmental conditions may restrict use. GPS provides location, yet location information does not itself prevent collision. Similarly, cloud connectivity is useful for remote monitoring but can fail when network coverage is unavailable.

The research problem addressed here can be expressed as follows: how can a portable cane integrate complementary sensing and communication functions so that a visually impaired user receives simple, timely, and actionable feedback without excessive weight, power consumption, or cognitive burden? A practical answer requires local sensing for immediate safety, optional semantic recognition for richer awareness, and an independent emergency channel for assistance.

This study treats the two supplied papers as the primary technical foundation. The first demonstrates a comparatively simple Arduino-based IoT stick with obstacle, water, GPS/GSM, and lost-stick functions [14]. The second demonstrates a more capable Raspberry Pi system with ultrasonic sensors, a camera, OpenCV recognition, water sensing, live location, and emergency SMS [15].

III. Literature Review

A. Ultrasonic and Electronic Cane Systems

Ultrasonic ranging is widely used because it is contactless and can estimate distance from the travel time of reflected sound waves. Gbenga et al. demonstrated an ultrasonic smart walking stick using Arduino [5]. Chaurasia and Kavitha reported an

electronic walking stick using embedded sensing [2]. Other studies added multiple sensors to increase coverage of the area around the user.

Nada et al. developed a fast-response smart stick and reported a response time of about 39 ms for normal distances up to 400 cm [3]. Agrawal and Gupta explored a smart stick for blind and visually impaired people [6]. These works establish that short-range sensing can provide useful immediate warnings, but they also reveal the difficulty of representing different obstacle types using only beeps or vibration patterns.

B. Multi-Sensor and Communication Approaches

Kunta et al. combined common obstacle-sensing methods with GPS and GSM to send a user's coordinates to a caretaker [10]. Sharma et al. proposed an embedded assistive stick using multiple sensing functions [7]. Poornima et al. explored voice-assisted feedback [11]. The first supplied paper similarly integrates GPS/GSM, water sensing, ultrasonic sensing, audio feedback, and a remote button for locating a misplaced stick [14].

These approaches show the value of separating safety feedback from remote assistance. A collision warning should be generated locally and immediately, while location updates and emergency messages can be transmitted when communication is available.

C. Computer Vision and Intelligent Recognition

The major step beyond distance-only sensing is semantic recognition. Farooq et al. use a Raspberry Pi camera and OpenCV to recognize common objects including people, stairs, cars, motorcycles, chairs, tables, trashcans, pits, and signposts [15]. The system provides audio messages describing recognized objects, making feedback more intuitive than memorizing vibration codes.

The same study reports an effective ultrasonic detection range of 3.5 m, although the sensor's nominal capability extended to 4.5 m. An overhead sensor was limited to about 1.2 m so that only potentially harmful overhead objects were considered. The camera operated at approximately 8 frames/s in the reported implementation [15]. These measurements illustrate an important engineering trade-off: greater information richness requires more processing and power.

More recent studies extend this direction with transformer-based detectors and depth sensing, reporting frame-level latencies around 150 ms while improving detection accuracy on cluttered scenes [16], and broader surveys now frame smart canes within edge-AI, SLAM, and city-scale connectivity architectures [17].

D. Research Gap

The reviewed systems still have practical gaps. Crowded environments reduce the effectiveness of ultrasonic ranging and camera recognition. Fast-moving vehicles can be difficult for the reported vision algorithm to recognize reliably. Cloud-based location sharing depends on connectivity. Earlier Arduino-centered implementations can also become constrained when several sensors and communication modules operate simultaneously [14], [15].

Accordingly, a refined design should use sensor fusion, local decision-making, low-power operating modes, and graceful degradation. The stick should remain useful as a conventional cane even if the camera, cloud connection, or a particular sensor becomes unavailable. This direction is consistent with the most

recent 2025–2026 literature, which increasingly proposes CNN-optimized, solar-powered, and sensor-fused successors to single-modality canes [18], [19], [20].

IV. Proposed System Architecture

A. Overall Architecture

The proposed architecture contains five functional layers: sensing, local processing, feedback, communication, and user interaction. Ultrasonic sensors provide distance information from multiple directions. A water sensor identifies wet surfaces or puddles near the cane tip. A camera supplies visual frames when recognition mode is enabled. A GPS receiver provides geographic coordinates, while GSM or another available cellular link transfers emergency information.

The controller acts as the local decision engine. It continuously samples safety-critical sensors and converts measurements into simple actions: directional vibration, an audio message, or an emergency alert. Computer vision is treated as an optional high-information mode rather than the only safety mechanism. This design avoids making immediate collision avoidance dependent on a computationally expensive vision pipeline.

B. Dual-Mode Operation

Mode 1—Detection Mode: The controller primarily uses ultrasonic sensors and the water sensor. If an obstacle is detected within a configurable threshold, the user receives a directional haptic or audio warning. This mode is intended for routine walking and reduced energy consumption.

Mode 2—Recognition Mode: The camera is enabled and frames are processed using an embedded computer-vision model. Recognized objects can be converted into short spoken messages such as “car,” “person,” “stairs,” or “chair.” The mode can be selected according to the environment and user preference.

C. Communication and Emergency Layer

GPS coordinates are periodically acquired for location awareness. When an emergency button is pressed, the controller can construct an SMS containing latitude and longitude or a map link and send it to a predefined caretaker through GSM. When Internet connectivity is available, location data may additionally be uploaded to an IoT dashboard. The emergency path should remain independent from normal cloud telemetry wherever possible.

D. Design Principles

The proposed design follows four principles. First, safety-critical functions should execute locally with minimal latency. Second, feedback should be concise because the user must concentrate on walking and environmental sounds. Third, advanced functions should be optional so that battery consumption can be controlled. Fourth, failure of one subsystem should not make the cane completely unusable.

The physical structure should preserve a familiar grip and walking technique. Aluminum or another lightweight structural material can reduce mass, while a comfortable anti-slip handle improves handling. Waterproofing is important because the device includes electronics and is intended for outdoor use [15].

Table I. Functional layers of the proposed smart-stick architecture.

Layer	Main components	Primary function
Sensing	Ultrasonic, water, camera	Distance / wet / object
Processing	MCU / Raspberry Pi	Filtering / recognition
Feedback	Vibration / buzzer	User guidance
Location	GPS	Coordinates
Emergency	GSM + panic button	Caretaker SMS
IoT	Cloud dashboard	Remote monitoring

Fig. 1. Conceptual data flow: Sensors → Edge Controller → Local Feedback, with GPS/GSM and IoT providing optional remote assistance. The architecture combines the complementary ideas reported in the supplied studies [14], [15].

V. Methodology and Algorithmic Design

A. Ultrasonic Distance Estimation

An ultrasonic transducer emits a pulse and measures the echo return time. The estimated distance is given by

$$d = (v \times t) / 2$$

where d is the obstacle distance, v is the speed of sound, and t is the measured round-trip time. The division by two accounts for the outward and return paths. The controller applies filtering to reduce false triggers caused by reflections.

Multiple sensors can be positioned at different angles to cover left, center, right, lower, and overhead regions. The reported intelligent-stick design used two front sensors and an additional overhead sensor; the front field of view was configured to improve lateral coverage [15].

B. Water Detection

A simple conductive water sensor can detect a wet surface near the lower end of the cane. When water bridges conductive terminals, the sensor state changes and the controller produces an alert. The mechanism is inexpensive and useful for detecting puddles or rainwater, but it should be mechanically protected and periodically checked for corrosion.

C. Computer Vision Pipeline

Recognition mode follows the sequence: image capture → preprocessing → object detection → confidence filtering → class selection → spoken feedback. OpenCV-based object detection has been demonstrated on Raspberry Pi hardware in the supplied study [15]. For a future implementation, a compact neural network can replace a heavier desktop-oriented model so that recognition remains feasible at the edge, following the direction of recent transformer- and CNN-based smart-cane prototypes [16], [20].

D. Sensor Fusion and Decision Logic

Sensor fusion is proposed to reduce dependence on any single modality. A simplified priority policy is: emergency event has highest priority; immediate close obstacle comes next; water and drop-off warnings follow; semantic object information is provided when processing capacity permits. If camera recognition is unavailable, ultrasonic and water sensing continue.

A practical rule-based controller can be expressed as:

- 1) Read all safety-critical sensors.
- 2) Filter abnormal measurements.
- 3) Determine obstacle direction and distance.

4) Generate haptic/audio feedback.

5) If recognition mode is active, classify visible objects.

6) Update GPS/IoT data at a lower rate than safety sensing.

7) On panic-button activation, send an emergency location message.

E. Power Management

Power is a central design constraint. The supplied literature notes that the ultrasonic-only mode provides longer battery life than the camera recognition mode [15]. Therefore, the camera and high-performance processing unit should be activated only when required. Communication intervals can also be adapted so that frequent location transmission does not dominate energy use.

F. Privacy and Reliability

Location information is sensitive because it can reveal a user's movements. The IoT dashboard should therefore use unique credentials and encrypted communication, with the minimum data necessary for assistance. The local cane should continue to provide obstacle warnings during network outages. This follows the observed behavior in the supplied research, where the loss of Internet connectivity disabled cloud location sharing but did not stop the core sensing functions [15].

VI. Results from the Supplied Literature and Discussion

A. Ultrasonic Performance

This section intentionally reports published observations from the attached papers rather than presenting them as new experiments by the present author. The purpose is to establish engineering benchmarks for the proposed framework.

The Arduino-based IoT smart-stick study reports repeated ultrasonic readings from 30 to 400 cm. At 30 cm, the reported error was 0.53%, while at 400 cm the reported error increased to 4.17%, showing a gradual reduction in accuracy with distance [14]. The second supplied study reports a practical detection range of 3.5 m, although the sensor's maximum stated capability was 4.5 m [15].

Table II. Ultrasonic readings reported in the supplied Arduino-based smart-stick paper [14].

Actual distance	Accuracy	Error
30 cm	99.47%	0.53%
50 cm	98.82%	1.18%
100 cm	97.84%	2.16%
150 cm	97.54%	2.46%
250 cm	97.11%	2.89%
300 cm	96.17%	3.83%
400 cm	95.81%	4.17%

B. Comparative System Assessment

Table III. Qualitative comparison synthesized from [14], [15], and cited literature.

Feature	Earlier	Proposed	Benefit
Obstacle detection	Ultrasonic/IR	Multi-angle + fusion	Coverage
Object identity	Absent	Camera + edge AI	Semantic
Water detection	Some designs	Water sensor	Wet warning

Feedback	Buzzer/vibration	Haptic + speech	Guidance
Location	GPS/GSM or none	GPS + GSM + IoT	Assistance
Lost-stick	Some RF	Emergency layer	Recovery
Overhead	Limited	Overhead sensor	Head safety
Connectivity	Remote may fail	Local safety	Resilience
Power	Continuous	Dual-mode	Battery life

C. Interpretation

The literature indicates that no single sensing technology is sufficient for all mobility conditions. Ultrasonic sensing offers fast geometric information, while vision supplies semantic information. GPS/GSM adds an assistance pathway rather than direct collision avoidance. The most promising architecture therefore combines modalities but activates expensive functions selectively.

The supplied intelligent-stick study also reports testing with three users having different visual constraints and describes positive feedback regarding simplicity and the low learning curve [15]. However, the same work reports limitations in crowded areas, where ultrasonic readings and image recognition became less reliable, and in recognizing faster-moving vehicles [15]. These observations reinforce the need for conservative safety rules and human-centered testing.

VII. Limitations and Future Work

The proposed architecture remains a research framework and should not be treated as a certified medical or safety-critical device without extensive validation. Several limitations require further investigation.

First, computer vision performance can decrease in crowded scenes, poor lighting, occlusion, or rapid motion. Second, GPS and cloud services may be unavailable indoors or in weak-signal environments. Third, multiple sensors, wireless modules, and embedded processors increase power consumption and device weight. Fourth, incorrect warnings may cause confusion or reduce user trust if thresholds are poorly calibrated.

Future work should investigate lightweight edge-AI models, sensor fusion using probabilistic or learning-based methods, adaptive sampling, and low-power microelectromechanical-system sensors. The supplied study specifically recommends improved battery optimization, better camera quality, recognition of more obstacles, improved vehicle recognition, and larger user surveys [15]. The most recent literature points in the same direction, proposing CNN-GWO optimized classifiers, solar-powered operation, and integrated edge-AI/5G-6G/cloud health-monitoring frameworks as candidate next steps [17], [18], [19], [20].

A robust next-generation prototype should also support offline navigation cues, encrypted location communication, automatic fault detection, battery-state warnings, and configurable feedback intensity. Most importantly, evaluation should involve a statistically meaningful group of visually impaired participants across indoor, outdoor, rural, urban, rainy, and crowded conditions.

VIII. Conclusion

This paper has synthesized the attached research into an IEEE-style design study for an IoT-enabled intelligent smart stick. The analysis shows that ultrasonic sensing remains a practical foundation for immediate obstacle detection, while water

sensing addresses a specific environmental hazard and GPS/GSM enables emergency assistance. Computer vision adds semantic recognition that can make feedback easier to understand, but its computational and environmental limitations require an optional operating mode.

The resulting architecture emphasizes local safety, selective use of high-power processing, simple multimodal feedback, and independent emergency communication. It also preserves the core value of the traditional cane: the user remains in control and can continue using the stick even when advanced subsystems are unavailable.

The literature-derived measurements demonstrate promising technical feasibility, but real-world deployment requires broader testing, improved reliability, privacy protection, battery optimization, and user-centered evaluation. Future work should therefore move beyond proof-of-concept integration toward a lightweight, adaptive, edge-intelligent assistive device.

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(Ordered chronologically by publication year; [14] and [15] are the two supplied source papers.)

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