Smart Assistive Stick for Visually Impaired People using Sensor Based Feedback

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# 1 Abstract

Navigational challenges faced by visually impaired individuals often hinder their independence, safety, and quality of life. This research focuses on the development of a sensor-integrated smart stick designed to detect a variety of indoor hazards such as physical obstacles, liquid spills, hazardous gases (including methane, butane, and carbon monoxide), flames, and incorrect stick orientation. The system employs multiple ultrasonic sensors for obstacle detection, along with gas, water, flame, and tilt sensors to identify environmental threats. An active buzzer is used to generate distinct beep patterns, each corresponding to a specific hazard or directional cue, thereby providing intuitive feedback to the user. The device operates in real time and is powered by an Arduino Uno R3 microcontroller, ensuring reliable performance and efficient sensor coordination. Unlike many existing solutions, this system is fully standalone, does not require smartphone integration, and offers a robust framework for enhancing indoor mobility and safety. This report presents a comprehensive overview of the system's architecture, hardware integration, programming logic, and performance evaluation. The results demonstrate that the device can significantly improve the ability of visually impaired users to navigate safely within indoor environments, avoiding potential dangers that traditional white canes or single-sensor devices may not detect.

# 2 Introduction

## 2.1 Background

As of 2020, over 298 million people worldwide suffer from moderate to severe visual impairment, with around 43 million being blind [1]. Visually impaired individuals face significant challenges in navigating their environments independently and safely. While traditional tools like white canes are widely used due to their simplicity and affordability, they are limited in functionality. White canes can only detect immediate obstacles that physically come into contact with them and fail to alert users to critical hazards such as uneven surfaces, descending stairs, sharp turns, or airborne dangers like smoke and gas leaks. Furthermore, many indoor environments present a variety of hazards that are not uniformly placed or shaped, making them difficult to detect without enhanced sensory input.

Recent advances in embedded systems, sensors, and microcontrollers have opened new possibilities for assistive technologies. Devices that integrate ultrasonic sensors, gas detectors, water sensors, and orientation modules can detect environmental hazards more accurately and in real-time. However, many existing solutions depend on smartphone connectivity, complex apps, or high-power components like cameras and Wi-Fi modules, which can raise costs and reduce practicality. Hence, there is a growing need for a standalone, sensor-rich navigation aid that is reliable, intuitive, and designed specifically for indoor usage.

## 2.2 Objective

The primary objective of this project is to design and implement a smart assistive stick that enhances the mobility and safety of visually impaired individuals by detecting a broad range of indoor hazards. The smart stick integrates multiple sensors—ultrasonic, gas, water, flame, and tilt—to identify and differentiate between various threats. For instance, ultrasonic sensors provide proximity feedback for obstacles at different heights and directions, gas sensors monitor air quality for potentially harmful substances, water sensors detect spillage, and flame and tilt sensors identify the presence of fire or improper stick orientation respectively.

These sensors work in conjunction to offer real-time alerts using an active buzzer, which emits unique beep patterns to convey different hazard types or navigation guidance such as “turn left” or “turn right.” Unlike many advanced wearable or app-dependent solutions, this system is designed to operate independently, requiring no additional devices for feedback or control. By ensuring that all processing and alerting mechanisms are contained within the stick itself, the project aims to provide a user-friendly and intuitive interface that demands no prior technical knowledge. This makes it suitable for a wide range of visually impaired users, including elderly individuals or those unfamiliar with technology.

## 2.3 Scope

The scope of this project is confined to the development of an assistive navigation tool tailored for indoor environments. Unlike outdoor navigation systems that rely on GPS or mobile connectivity, this stick is designed to detect hazards and obstacles typically found inside residential buildings, such as tables, chairs, beds, staircases, water spills in kitchens or bathrooms, smoke or gas emissions, and even instances where the stick is dropped or not held upright. The inclusion of multiple ultrasonic sensors allows the stick to scan the space ahead, left, and right of the user, while others handle hazard detection close to the ground.

The system uses a single microcontroller board (Arduino Uno R3) to manage all sensor inputs and trigger specific audio alerts via a buzzer. This removes the need for external smartphones or apps, reducing complexity for the user. The solution is designed to be modular, meaning future improvements like adding vibration motors or voice feedback systems can be easily incorporated. Ultimately, the project focuses on practical implementation, real-time performance, and user-centered design, making it an effective tool for indoor navigation and a stepping stone toward more advanced assistive technologies.

# 3 Literature Review

The development of assistive technologies for visually impaired individuals has undergone a significant transformation, moving from traditional mobility aids such as white canes to sophisticated electronic and AI-based devices. These innovations are designed to improve mobility, safety, and independence for users, especially in indoor environments where obstacles can vary widely and may pose serious hazards if undetected.

## 3.1 Traditional and Emerging Assistive Devices

Assistive tools like the traditional white cane provide limited feedback, as they primarily detect obstacles at ground level through physical contact. To overcome this limitation, researchers and developers introduced Electronic Travel Aids (ETAs). For instance, the **UltraCane** utilizes ultrasonic sensors to detect obstacles and conveys the data through tactile feedback to the user’s hand, allowing detection of hazards beyond physical reach [2].

Similarly, smart canes like **WeWalk** enhance navigational assistance by integrating voice commands, obstacle sensors, and GPS functionality, and linking with smartphones via Bluetooth [3]. These devices not only identify nearby hazards but also provide auditory guidance in real-time, helping users reach their destinations safely and independently.

## 3.2 Wearables and Non-Cane Devices

While smart sticks and canes remain the dominant form factor, wearables have also gained popularity. Devices such as the **Sunu Band**, a sonar-enabled smart band, emit haptic feedback based on distance to obstacles. It enables users to detect head-height or overhead obstacles that are typically out of range of traditional canes [4].

Another example is **OrCam MyEye**, a wearable camera that clips onto any glasses. It reads printed or digital text, recognizes faces, and identifies objects, all in real-time using computer vision. This device is particularly effective for indoor activities like reading labels or identifying people, rather than navigation alone [5].

## 3.3 Integration of AI and Smartphone Technology

Recent research focuses on embedding AI and machine learning in assistive devices. One notable system, **NavCog**, developed by Carnegie Mellon University and IBM, uses AI algorithms and smartphone sensors to provide turn-by-turn audio navigation within indoor spaces [6]. Similarly, the **Horus Device** uses computer vision and deep learning to detect objects, text, and faces, then relays this information through bone-conduction audio [7].

The inclusion of AI significantly improves object classification and user feedback. However, these systems are typically expensive and require a smartphone and high computing power, which limits their accessibility and use in real-time for many users.

## 3.4 Indoor Navigation and Multi-Hazard Detection

Although many systems are optimized for outdoor use, indoor navigation poses its own set of challenges. Projects such as **NavCog** attempt to address indoor environments, but systems that specifically cater to household hazards are limited.

Several researchers have aimed to close this gap by building sensor-based systems. **Singh et al. (2022)** designed a smart cane using ultrasonic sensors for obstacle detection and added audio feedback. While effective for static objects, the system lacked mechanisms for detecting hazards like gas leaks or water [8].

Another work by **Punyashree et al. (2022)** involved integrating GSM and GPS for tracking and obstacle sensing. Their system aimed at outdoor navigation but lacked detection of hazards like fire or user orientation [9].

This gap in the literature highlights the need for **multi-hazard detection**, especially for environments like kitchens and bathrooms where gas, water, or fire could pose a significant threat. Devices must also detect if the stick is held improperly, which could indicate user discomfort or even a fall.

## 3.5 IoT and Remote Monitoring in Smart Canes

The integration of IoT has added another layer of functionality to assistive devices. For example, smart canes can transmit real-time data to caregivers or emergency responders through Wi-Fi, LoRa, or cellular networks. **Apu et al. (2022)** designed a smart cane that uses the Blynk IoT platform to notify caregivers about the user's location and alert status, enhancing remote safety [10].

In indoor environments, where communication modules like LoRa may not be essential, Wi-Fi-enabled boards such as the **Arduino Uno R4 WiFi** can process and relay sensor data effectively. These systems enable modular, non-intrusive, and real-time interaction between the device and other smart home components.

# 4 Methodology

This section outlines the complete design, development, and implementation process of the smart assistive stick for visually impaired individuals. The methodology includes hardware integration, sensor configuration, programming logic, testing, and modifications based on real-time performance. The approach emphasizes real-world utility by ensuring modularity, reusability, and indoor-specific hazard detection using commonly available components.

## 4.1 System Overview

The smart assistive stick is designed to detect indoor obstacles (furniture, walls etc.), environmental hazards (gas leaks, water spillage, fire), and improper orientation (tilt), and to convey this information to the user through distinct buzzer patterns. The system uses a combination of four ultrasonic sensors, a gas sensor (MQ-2), a water sensor, a flame sensor (KY-026), a tilt sensor, and an active buzzer. The entire system can be powered by a 9V battery or USB and runs on an Arduino Uno R3.

## 4.2 Hardware Components and Configuration

**4.2.1 Microconroller : Arduino Uno R3**

The entire system is built using the **Arduino Uno R3** microcontroller. This board was selected due to its affordability, widespread availability, ease of use, and compatibility with a wide range of sensors. It features 14 digital I/O pins and 6 analog input pins, which allowed the integration of multiple sensors after careful pin planning.

Despite some limitations in available I/O pins, we managed to connect all the required sensors—ultrasonic, gas, flame, water, and tilt—along with the buzzer by optimizing pin assignments and using analog input pins efficiently. Though the use of an I/O expander or an Arduino with more pins (like Mega) was considered, we ultimately stayed with the Uno R3 to keep the system compact and manageable for prototyping and testing.

The microcontroller was programmed via the Arduino IDE using C/C++, and the logic was structured for real-time sensing and prioritized alerting using if conditions and switch statements.

**4.2.2 Ultrasonic Sensors (HC-SR04)**

Four ultrasonic sensors were used:

* *Front-bottom sensor (D10 and D9) : Detects objects near ground level in front of the user.*
* *Middle-front sensor (D5 and D6) : Detects objects at body level (e.g., tables, beds).*
* *Left sensor (D3 and D2) : Detects obstacles to the left side.*
* *Right sensor (D7 and D8) : Detects obstacles to the right side.*

Each ultrasonic sensor's TRIG and ECHO pins were connected to digital pins on the Arduino.

**4.2.3 Gas Sensor (MQ-2)**

The MQ-2 sensor was used in *analog mode*(for better control over sensitivity**)** to detect combustible gases and smoke. Its analog output was connected to analog pin A5. Thresholds were set based on experimental calibration (e.g., values above 70 indicating gas presence). The sensor was tested with incense sticks to simulate smoke.

**4.2.4 Water Sensor**

A water sensor was attached near the base of the stick in a *vertical position* to detect puddles and spills. Since the sensor gives analog readings based on conductivity, values above 40 were considered indicative of water contact. The sensor was carefully positioned to avoid friction with the floor. It was interfaced via analog pin A3.

**4.2.5 Flame Sensor (KY-026)**

A 4-pin analog flame sensor connected to A0 was used to detect fire. The sensor outputs high values by default and drops significantly in the presence of a flame. A threshold value of 650 was set to detect fire accurately in indoor conditions.

**4.2.6 Tilt Sensor**

A *simple ball-in-cylinder tilt sensor (3-pin digital sensor)*was connected to pin D4. It outputs HIGH when tilted and LOW when held vertically. This is useful to detect potential falls or if the user is not holding the stick correctly. Debounce logic was used to avoid false triggers due to micro-movements

**4.2.7 Active Buzzer (Low Level Trigger)**

A *3-pin active buzzer module (low level trigger)* was used to generate distinct beep patterns for different hazard alerts. Digital pin 12 was used to control the buzzer using both *digitalWrite()* and *delay()* functions. Unique patterns were written for gas, flame, tilt, obstacle, and water alerts.

**4.2.8 Power Supply**

Initially powered through a USB cable from the laptop, the device was later powered using a 9V battery and adapter. However, the 9V battery caused erratic behavior with gas sensor. Switching to a power bank via USB cable offered stable performance, though it required the user to manually plug it in (a usability compromise).

## 4.3 Programming Logic and Structure

The code was developed using the Arduino IDE with a focus on:

1. *Efficient sensing*
2. *Prioritized alerting*
3. *Hazard-specific beep patterns*

Each sensor reading is processed using appropriate thresholds and logic. The buzzer generates alerts based on real-time conditions, and only the highest priority hazard is addressed at any time using AlertType enum and a switch statement.

**4.3.1 Sensor Data Acquisition**

Sensor data is acquired through analog or digital reads:

* *analogRead() is used for the gas, water, and flame sensors.*
* *digitalRead() is used for the tilt sensor.*
* *Ultrasonic sensors use digitalWrite() for TRIG and pulseIn() for ECHO.*

The readDistance() function handles the ultrasonic logic with short pulses (2 µs LOW, 10 µs HIGH) to ensure accurate distance measurement.

**4.3.2 Priority based Alerts**

The program evaluates sensor readings in a strict order of priority:

1. *Gas*
2. *Flame*
3. *Water*
4. *Tilt*
5. *Obstacle (front sensors)*

If a high-priority hazard (like gas or flame) is detected, other sensors are ignored in that iteration. This is managed using an enum AlertType and a switch(currentAlert) block.

**4.3.3 Obstacle Navigation Logic**

If an object is detected (distance less than 35 cm) in front (by either front-bottom or middle-front sensor), the buzzer emits a long beep. Then, distances from the left and right sensors are compared. The stick suggests turning in the direction where the obstacle is farther using distinct short (turn right) or double (turn left) beeps.

**4.3.4 Alert Patterns**

Custom beep patterns are assigned:

* *Gas: Two sets of three quick beeps*
* *Water: Two beeps with wave-like timing*
* *Flame: Long-short-long beep pattern*
* *Tilt: Two pairs of quick beeps*
* *Obstacle: Long beep followed by left/right cue*

**4.3.5 Real-Time Feedback and State Tracking**

* A flag for water ensures the alert only triggers once until the sensor resets.
* Tilt sensor timing logic uses millis() to avoid false alerts from slight movement.
* Serial.print() outputs the state of all sensors for real-time debugging.

## 4.4 Challenges Faced and Solutions

* *Power Instability*

When using a 9V battery, the gas sensor gave false readings. Switching to a power bank resolved this issue, offering a more stable current and longer runtime.

* *Tilt Sensor Noise*

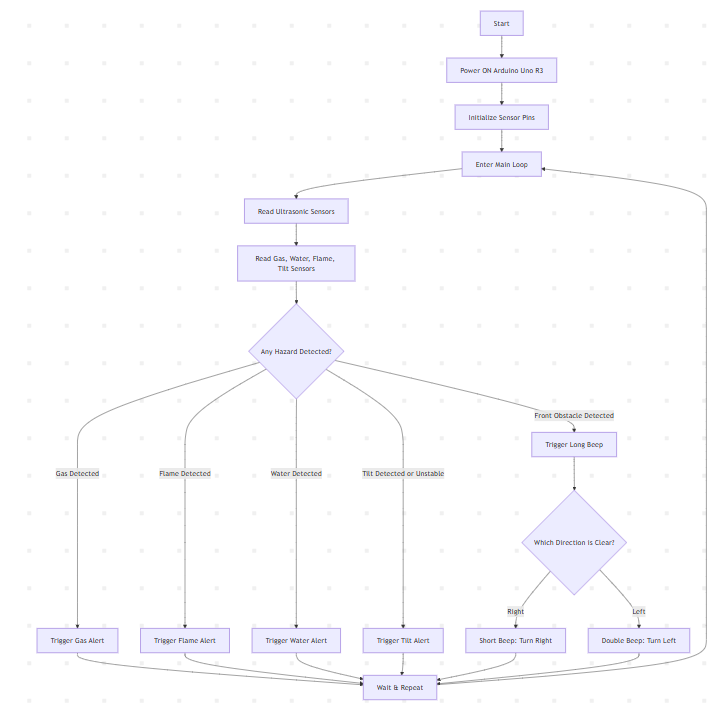
The tilt sensor frequently oscillated between HIGH and LOW even when stationary. We introduced a tiltLowStartTime and tiltAlertActive flags with a 1-second debounce logic to differentiate between stable and unstable positions.

* *Water Sensor Repitition*

Once the water sensor touched moisture, it continued to beep. A static waterAlertActive flag was used to ensure the alert only played once until the sensor returned below threshold.

* *Obstacle Overlap*

The front-bottom and front-middle ultrasonic sensors could both detect the same obstacle, leading to overlapping alerts. A flag isHandlingObstacle prevents re-triggering during the obstacle-handling routine.



# 5 Result

The developed smart assistive stick was tested in various controlled indoor scenarios to evaluate its effectiveness in real-time hazard detection and user feedback. The tests focused on evaluating the accuracy of the sensors, the clarity of feedback from the buzzer, the prioritization logic of the system, and the system's responsiveness during multiple simultaneous events.

## 5.1 Sensor Performance and Responsiveness

Each sensor module was individually tested to assess its ability to detect relevant hazards:

* ***Ultrasonic Sensors****: The four ultrasonic sensors consistently measured distances with a tolerance of ±2 cm. The* ***front-bottom sensor*** *successfully detected low-lying obstacles, while the* ***middle-front sensor*** *was effective in identifying taller furniture such as tables and cabinets. The* ***left and right sensors*** *correctly identified side obstacles, helping to suggest safe directional movement. The switch logic between front and side sensors worked reliably, avoiding redundant alerts.*
* ***Gas Sensor (MQ-2)****: The MQ-2 sensor was tested using incense sticks and lighter gas. It showed a steady rise in analog values when exposed to gas. The alert was triggered when the values exceeded the threshold (70), and the buzzer emitted the designated pattern. No false alarms were triggered in a clean environment.*
* ***Water Sensor****: Placed vertically at the bottom, the sensor accurately detected wet floor conditions caused by small spills. The system used a state flag (waterAlertActive) to ensure the alert triggered only once per detection cycle, avoiding continuous beeping due to residual moisture.*
* ***Flame Sensor****: When exposed to a candle or flame at a distance of about 10-30 cm, the flame sensor rapidly dropped below the defined threshold (650), triggering the correct beep pattern. The flame detection was stable and did not respond to standard lighting or reflections, confirming its reliability.*
* ***Tilt Sensor****: The digital tilt sensor was extremely responsive. A custom logic was implemented to suppress minor fluctuations using time-based checks with millis(). Alerts were triggered only when the stick was not held upright or if it returned from a vertical position in less than one second—indicating user instability or mishandling.*

## 5.2 Alert System Evaluation

The buzzer-based feedback system was evaluated for its clarity and differentiation of tones. Each event generated a distinct beep pattern:

* ***Short Beep****: Turn right*
* ***Double Beep****: Turn left*
* ***Long Beep****: Obstacle in front*
* ***Gas Alert****: Quick triple beeps repeated twice*
* ***Water Alert****: Two beeps with pause*
* ***Tilt Alert****: Four quick alternating beeps*
* ***Flame Alert****: Long-short-long beeps*

During testing, users were able to identify and distinguish between the alerts consistently. This suggests that the beep patterns are intuitive and provide an effective audio interface for the user.

## 5.3 Prioritization and Conflict Handling

One of the main achievements of the system was its ability to prioritize events. If multiple hazards occurred at the same time, the system evaluated them in the following order: **Gas > Flame > Water > Tilt > Obstacle**.

This ensured that critical hazards such as gas leaks or fire were not overridden by low-priority events like an obstacle or slight tilt. The use of an enum and switch case block allowed structured logic, and static flags prevented false retriggers.

Simultaneous tests—such as placing the stick near a wet patch while also placing a flame—demonstrated that only the flame alert was played, in line with the designed priority.

## 5.4 Real-Time Behavior and Delay Tolerance

The system operated in real-time with minimal latency. The delay(500) in the loop provided a good balance between sensor stability and responsiveness. All sensor readings were printed to the serial monitor to verify accuracy, and the output was consistent with real-world conditions.

## 5.5 Practical Limitations Observed

* *The 9V battery did not provide sufficient current for consistent sensor performance, especially the gas sensor. This was mitigated by switching to a power bank.*
* *Sensor wires and breadboard connections required careful handling during testing and may need to be soldered or mounted on a PCB for better durability.*
* *The system currently uses only audio feedback, which may not be suitable in noisy environments. Future versions could explore haptic (vibration) output as an additional modality.*

# 6 Conclusion

This project has been an exploration not just into assistive technology, but into how simplicity and function can converge to make everyday life safer and more navigable for individuals with visual impairments. The journey of building the smart stick involved multiple iterations, careful component integration, and practical problem-solving—all rooted in the real-world needs of its intended users. It became increasingly clear during development that the challenges faced by visually impaired people in indoor environments are often overlooked in favor of outdoor navigation solutions. By shifting focus indoors, this project fills a critical gap, targeting hazards that are more subtle but equally dangerous—such as water spills, gas leaks, and flame exposure.

More than just assembling sensors and writing code, the process demanded design thinking—understanding how alerts should feel, how quickly users need feedback, and how to prioritize warnings in chaotic environments. Each component had to serve a clear purpose without overwhelming the user with information. Furthermore, implementing the logic to manage sensor conflicts, debounce erratic signals (like from the tilt sensor), and ensure consistent behavior under varying power conditions was a key learning experience.

Beyond the technical aspects, this project highlights the importance of accessibility-driven design. Rather than adding complexity, the goal was to build a device that was easy to power, operate, and interpret, even for those unfamiliar with modern technology. No external apps, no interfaces—just direct, sensory cues.

The smart assistive stick is not the final solution, but it is a foundation. With future improvements like GPS, vibration motors, machine learning-based object classification, or wireless data logging, it can evolve into a comprehensive navigation assistant. Most importantly, it stands as a reminder that impactful technology doesn’t always require advanced AI or expensive hardware—sometimes, it’s about solving the right problem with the right intent.

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