



GUIDED AUDIO-BASED ASSISTIVE YIELD (G.A.B.A.Y): SMART CANE WITH AUDIO NAVIGATION AND CAP SENSOR FOR VISUALLY IMPAIRED MOBILITY

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ABSTRACT

This study aims to design and implement a smart cane with audio navigation and a cap sensor to enhance mobility and safety for visually impaired individuals. The system integrates ultrasonic sensors and a servo motor for obstacle detection, an ESP32 microcontroller for processing, and Bluetooth-enabled audio feedback through earbuds for real-time guidance. The cane handle is wrapped with organic banana fiber to improve grip and absorb sweat, promoting user comfort and sustainability. Performance evaluation focused on distance detection accuracy, direction command precision, and audio response time. Results showed that the smart cane reliably detected obstacles at 20 cm with an average audio response time of 1.48 s (SD = 0.420) across five trials. In comparison, the cap system detected upper hazards at 60 cm with an average response time of 0.106 s (SD = 0.00894). Overall, GABAY demonstrates an accessible and eco-friendly solution for the safe navigation of visually impaired users.

Keywords: smart cane, audio navigation, ultrasonic sensor, visually impaired, banana fiber

INTRODUCTION

Background of the Study

Innovation is most powerful when it restores independence, especially for those whose vision limits their freedom of movement. For years, the traditional cane has been a trusted companion of the visually impaired, guiding each step with reliability. However, its limitations remain. Higher-level obstructions often go undetected, and even the firmest grip can falter when sweaty palms cause the cane to slip, turning safety into uncertainty.

This study takes on that challenge by introducing a dual-function navigation device that not only detects obstacles at ground level but also uses audio alerts to warn against elevated hazards. To further support accessibility, the handle is designed from organic banana fiber, providing natural grip, sweat absorption, and sustainability in one thoughtful material. By blending practicality, affordability, and eco-conscious design, this research aims to create more than just a tool; it offers freedom, security, and inclusion for those navigating the world without sight.

Millions of individuals are affected by blindness and visual impairment, which continue to be serious global public health issues that limit their ability to participate in social, professional, and educational activities fully. According to the World Health Organization (2023), at least 2.2 billion worldwide have a vision impairment or blindness, with a significant portion that could have been treated with proper interventions.

In the Philippines, the World Blind Union–Asia Pacific, citing supplementary reports from the Department of Health (DOH) and the Philippine Statistics Authority (PSA), stated that as of July 2023, there are 592,000 individuals who are blind—most of whom are poor and uneducated—and 2,179,733 individuals with low vision or other related visual impairments. These reports highlight the urgent need

for innovative, reasonably priced, and easily available assistive devices that can enhance the independence and quality of life of blind people.

In connection with this, Aganad et al. (2017), as cited in Gaspay et al. (2024), emphasized that the common challenges faced by blind and visually impaired individuals in their daily lives are not just about their disability but also come from limited accessibility and the lack of inclusive infrastructures that society has failed to address. This includes vehicles left parked that take up space for walking, narrow and crowded sidewalks caused by misuse of public spaces, uneven surfaces on the ground due to poor maintenance, and open manholes and pits.

As a technological response to such barriers, laser-sensing and vision-sensing smart canes have been developed to increase the independence of visually impaired people by offering better navigation support.

Advanced sensing systems in these canes help them sense obstacles and guide users more accurately than the traditional white cane.

However, most existing systems are still limited and need to be improved. Mai et al. (2023) pointed out that although laser and vision-sensing smart canes enhance mobility convenience, a majority of their capabilities are still lacking, especially in terms of precision and dependability. Similarly, Jin et al. (2024) compared conventional canes with secondary electronic mobility aids. They discovered that, even though such devices enhanced object detection and obstacle avoidance, they also led to slower processing times and hesitation on the part of users.

Beyond environmental barriers and technological limitations, another challenge arises from physiological conditions that affect from

physiological conditions that affect some users. Excessive hand sweating is a pathological disease known as primary palmar hyperhidrosis (PPH), which negatively affects a patient's social life, career, and mental health (Liu et al., 2022). To address this concern among individuals with excessive palm perspiration, banana fiber (abacá) is incorporated into the handle interface. As stated in Ali (2022), banana fiber possesses good absorbent properties, high breathability, quick-drying ability, and high tensile strength.

Even with the canes being used by people who are blind, they still face struggles due to their vulnerability to accidents. Obstacles that cannot be seen, detected, or anticipated pose a danger to the visually impaired. The existing cane integrates ultrasonic sensors, but these are often limited to detecting obstacles near the feet or knees. This leaves a critical gap as upper-body hazards such as low signboards, hanging branches, or protruding objects remain unaddressed, increasing the risk for users.

In addition to these detection limitations, another concern arises from sweaty palms, which can weaken the user's grip. This may cause the cane to slip or be dropped, creating further danger and leaving an important issue unresolved. Additionally, this research promotes sustainability since all materials to be used in the entire product are eco-friendly, making it not only safer and more functional but also durable, waste-reducing, and environmentally responsible.

Objectives of the Study

This study aims to develop an innovative smart cane with audio navigation and a cap-based sensor system to enhance mobility and safety for visually impaired individuals. (1) To develop a smart cane and cap system with an ultrasonic sensor, obstacle detection, and integrated audio-buzzer alerts for real-time navigation support. (2) To evaluate the accuracy, response speed, distance, and reliability of the system to determine its overall effectiveness.

Literature Review

Smart Cane Technologies for the Visually Impaired

The World Health Organization indicates that about 2.2 billion people across the globe experience vision loss that deeply impacts their daily lives. One of the most used devices among the visually challenged is the white cane, but it is only useful in detecting objects at ground level. It may result in collisions from the failure to see objects at higher levels. Ji et al. (2025) also recognized the drawback of existing intelligent canes regarding power management and power efficiency.

The traditional methods of recharging lead to low battery lives and ineffective functioning, and disrupt the independence of the users. Their DRL-based solution rectified the same, but with the setback of dependence on complex algorithms that might decrease accessibility in resource-poor locations for the users.

In order to help blind people, Kumar et al. (2025) suggested an Internet of Things (IoT) smart cane that uses machine learning and internet connectivity. However, the study's generalizability and reliability are limited by testing on a small number of blinded subjects.

The cane's efficacy in places with inadequate connectivity is further limited by its reliance on dependable internet. Furthermore, its capacity to identify intricate or shifting barriers may be hampered by the use of simple machine learning. Its durability and performance in the real world have not been confirmed because testing was conducted in controlled environments.

Both studies identified the shortcomings of existing intelligent canes. Ji et al. (2025) observed low power management and limited battery

life, and although their DRL-based approach optimized efficiency, it depended on advanced algorithms that limited accessibility. On the other hand, Kumar et al. (2025) found that an IoT-enabled intelligent cane had limited small-scale testing, stable internet dependence, and simple machine learning models that restricted reliability.

Both studies reveal that though intelligent cane technology is developing, it remains impractically unreliable in the field with respect to accessibility and adaptability.

According to Mai et al. (2023), the common cane is widely used as an auxiliary device for the visually impaired for daily travel due to its convenience to carry and use. However, the visually impaired face great travel challenges because of their limitations. By tapping around with the ordinary cane, the visually impaired can only feel the rough spaces, offering limited road information as they walk. Moreover, its detection range is restricted to about one meter, which greatly reduces its effectiveness in ensuring safety.

Additionally, dos Santos et al. (2020) emphasized that despite the help of a white cane for orientation and mobility for the users, its detection range is restricted, and it cannot sense overhead obstacles like hanging tree branches or elevated trash bins.

Both studies highlighted that the traditional white cane, though convenient and widely used, provides only limited spatial feedback within a short range and fails to detect overhead obstacles, leaving users vulnerable to safety risks and navigation challenges.

Dual Detection and Audio Navigation for Safety

According to Okolo et al. (2025), in their study published in the ScienceOpen Journal of Disability Research, the Smart Assistive Navigation System was developed to address these limitations. The system utilizes YOLOv8 object detection alongside ultrasonic sensors and a speaker module to identify both lower-body and upper-body obstacles.

With a reported 91.7% accuracy rate, the device provides real-time voice guidance and demonstrates effective performance in both indoor and outdoor environments. The authors emphasize that multi-sensor integration significantly improves mobility safety for visually impaired users.

Similarly, Simões et al. (2020), in their research featured in the MDPI Sensors Journal, introduced an audio guide system based on stereo vision and musical tones. Their device detects obstacles across a 120° field of view and translates spatial data into auditory cues, including spoken instructions and tonal signals. The use of Kalman filtering enhances indoor positioning accuracy, while the auditory feedback improves users' reaction time and confidence. Simões and colleagues highlight the importance of intuitive sound-based communication in promoting safe and independent navigation.

Both studies underscore the effectiveness of combining visual and ultrasonic detection with audio feedback to create safer mobility experiences. These findings align with the current project's innovation, which integrates a cane for lower-body detection and a cap-earbud system for upper-body hazard recognition and audio alerts. By merging tactile and auditory feedback, the device aims to reduce accidents and empower visually impaired individuals to navigate their environment with greater autonomy.

Besides these results, Ahmed (2023) shows a Smart Assistive Navigation Stick that is built with Arduino. It uses an SD card to keep WAV sound cues and gives voice alerts for different directions, like front, left, and right. Meanwhile, Zare et al. (2022) stress how important it is to have audio feedback in wearable navigation tools. So, adding a microSD card has real benefits—like quick, clear sound

autoplay; simple updates for new content without reflashing firmware; and robust offline performance that complements the sensor and audio strategies reported by Okolo et al. and Simões et al. and makes SD-backed audio well suited for the proposed cane + cap-earbud system.

Baldonado and Faelangca (2024), in Educational Administration Theory and Practice, developed an enhanced Audio-Based Smart Cane featuring object detection, distance measurement, and audio feedback. While generally accurate in obstacle detection, some inconsistencies in distance and audio output were noted. They recommended future upgrades like LiDAR, Bluetooth, and improved processing units.

Meanwhile, Panazan and Dulf (2024), in MDPI Technologies, introduced a smart cane with dual ultrasonic sensors for ground and chest-level obstacle detection. It provides vibration and audio alerts within a 2–400 cm range and connects to a mobile app via Bluetooth for tracking. Their study emphasized user-friendly design and improved safety.

Both studies highlight the value of multi-sensor detection and audio feedback. Baldonado and Faelangca focused on audio navigation, while Panazan and Dulf emphasized dual sensing and real-time alerts. These insights support the current project’s approach—using a cane for ground detection and a cap-earbud system for upper-body hazards and audio guidance—to enhance user confidence and mobility.

In addition to these, Salum et. al (2020) developed a helmet wiper using an SG90 servo motor and emphasized that it is generally used as actuators that require precise rotational positioning. It usually only moves in a certain angle, and for specific purposes, it can be modified to rotate continuously. Meanwhile, Ashari and Faruq (2019), as cited in Khamida et. al (2023), state that the SG90 servo motor provides high accuracy and takes up minimal space due to its tiny circuit. Therefore, both studies show that servo motors are suitable for precise control of position, angle, and movement.

Ergonomic and Sustainable Design Features

Ergonomics is linked to sustainability and eco-friendly design in addition to designing for user comfort and safety. The emerging field of ergoecology highlights how ergonomics supports eco-friendly design through eco-efficiency, eco-productivity, and systematic methods. According to Nacini (2020), sustainable products must be easy to use, and ergonomics provides a structured, user-centered approach that supports both human well-being and environmental responsibility. Integrating ergonomics with sustainability helps improve quality of life while protecting ecosystems in line with global goals like the MDGs and the 2030 Agenda.

Furthermore, Ivascu et al. (2021) explained that products created through manufacturing connect with workers, business owners, communities, and consumers both directly and indirectly at all stages of their life cycles. This is particularly evident during reverse logistics like recycling and reuse. Because of this, ergonomics plays a key role in checking these interactions to ensure products are useful, safe, and centered on user needs.

Ergonomics focuses on humans. It works alongside areas like engineering, design, production, transport management, and eco-friendliness to boost how well organizations work as they move towards sustainable development.

Therefore, when ergonomics and sustainability come together, they make sure that products are easy to use, safe, and good for the environment. By thinking about every stage of a product's life—from making it to reusing it—this method not only makes life better but also helps meet worldwide goals for sustainability.

As explained in the study of Kavya and Kavitha (2025), hypoallergenic banana sweat pads have been developed as a natural, gentle, and eco-friendly alternative in response to the issues caused by traditional sweat pads, which usually contain synthetic materials, chemicals, or adhesives that can lead to allergic reactions, discomfort, or environmental problems. Made from banana fibers, these eco-friendly pads offer absorbency and breathability while also being soft on the skin. Its hypoallergenic properties give a skin-friendly experience, free from harsh chemicals, which make them helpful to those with allergies and sensitivity, providing effective sweat absorption without causing irritation. At the same time, its biodegradable properties make it an environmentally responsible choice.

Moreover, based on the study of Islam et. al (2019), cited in Rajput and Khot (2022), banana fiber is a natural bast fiber that comes from the pseudo-stem of a banana plant. Research indicates that billions of tons of banana plant stems are wasted every year. After harvesting the fruit, farmers typically throw this waste into rivers, lakes, or burn it, which can be highly harmful to the environment if not managed properly.

According to Ebisike et. al (2013), cited in Rajput and Khot (2022), the banana tree must be disposed of after yielding the fruit since it cannot produce fruit again. With the growing population, the demand for bananas will rise, which leads to an increase in banana tree plantations. Moreover, this consequently produces more waste each year. Therefore, efforts should be made to turn this waste into a valuable resource.

Therefore, this concludes that hypoallergenic banana fiber can not only benefit the user by being an effective, natural, and eco-friendly sweat absorbent pad that is gentle, chemical-free, and highly absorbent. It can also benefit the earth by providing a sustainable way to turn banana waste into something useful that lessens the potential harm to the environment.

Theoretical Framework

Feedback systems, originally developed for industrial regulation, have evolved into adaptive models that underpin many intelligent technologies. According to Mayr (1975), cited in Lipnevich and Panadero (2021), these systems operate by monitoring input, comparing it against predefined thresholds, and adjusting output accordingly. This principle is embedded in the device’s decision-making loop. Ultrasonic sensors detect obstacles, and specific audio cues are triggered based on the user's environment. This continuous feedback mechanism ensures safe and efficient navigation by dynamically responding to real-time changes, aligning with the core tenets of adaptive system design.

According to Epstein et al. (2017), the brain builds a visual representation of the environment’s space, also called a ‘cognitive map’, supporting the memory and providing guidance. For four decades, studies on rodents have shown that special neurons in the hippocampus and surrounding regions, known as place, grid, border, and head direction cells, are the physical basis for the brain's internal "cognitive maps".

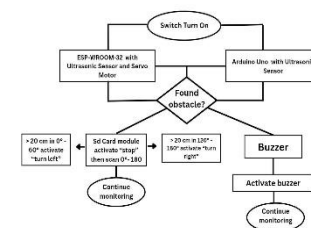


Figure 1. Conceptual Framework of the study

Scope and Limitations

This study focuses on designing, developing, and evaluating a smart cane with audio navigation and a cap sensor system powered by an ESP32 with built-in Wi-Fi and Bluetooth. Ultrasonic sensors are used to detect low and high obstacles, while Bluetooth earbuds deliver real-time audio guidance. The cane also features an organic banana-fiber handle to improve grip, absorb sweat, and support sustainability. The scope includes testing the accuracy of distance detection and direction commands to ensure safe and reliable navigation for visually impaired users.

However, the study does not cover external factors such as weather conditions, battery lifespan, or durability when dropped or struck. The cane detects obstacles at around 20 cm, while the cap detects up to about 60 cm because the cane is held diagonally, placing its sensor farther forward. The system is also unsuitable for users who are both blind and deaf, as it relies solely on audio feedback, and alerts may be less noticeable in noisy environments. The banana-fiber handle may weaken after 4–6 months due to natural decomposition (Mehta et al., 2020).

Other limitations include the fixed detection range of the cap, which reduces effectiveness in wider or dynamic environments. The study does not cover long-term maintenance such as sensor cleaning, recalibration, or component replacement, nor integration with GPS or mobile navigation apps. Performance under extreme lighting conditions is also excluded from the scope.

METHODOLOGY

Research Design

This study employs a non-iterative developmental design. According to Wynn and Maier (2022), this approach follows a linear, step-by-step process that minimizes revisions, costs, and uncertainties, making it suitable for projects with stable requirements and limited resources (Bianchi & Suganthan, 2020).

This design is appropriate due to the study's defined scope and time constraints. The objective is to develop a single, functional prototype of the G.A.B.A.Y smart cane rather than undergo multiple redesign cycles, which are not feasible within the given timeframe. Although the project involves a user-centered assistive device, risks are minimized by using established technologies such as ESP32, ultrasonic sensors, and Bluetooth audio feedback with predictable performance. Therefore, a non-iterative approach enables efficient development and evaluation of the prototype while still addressing the essential needs of the intended users.

Materials and Equipment

The smart cane materials include an ultrasonic sensor, ESP32 WROOM32, Bluetooth earbuds, SG90 servo motor, 4AA battery, SD card module, bamboo stick, battery holder, and Y dupont wire. The cap materials consist of an Arduino Uno, ultrasonic sensor, active buzzer, 9V battery, wires, and a cap insert safety helmet for storing and protecting the components. The banana fiber handle materials include resin, sandpaper, cane body, fresh water, and fresh banana pseudostem. The equipment used in the study includes a soldering iron, soldering wire, wire stripper, cutter, and glue gun.

Procedure for making the GABAY smart cane for lower hazards

The cane's handle is wrapped with banana fibers to enhance grip, sweat absorption, and user comfort. An ultrasonic sensor is mounted on an SG90 servo motor and secured using adhesive to allow controlled tilting for scanning purposes. The assembled unit is then attached to the upper section of the cane.

Audio commands (“left,” “right,” and “stop”) are stored in an SD

card and integrated through an SD card module to enable feedback. The ESP32 microcontroller is configured to read the stored data and establish a connection with Bluetooth earbuds for audio output.

The system operates in two modes. In the first mode, the servo is maintained within a limited range of 70° to 110° to detect obstacles at a distance of up to 20 cm. In the second mode, the servo rotates from 0° to 180° to scan and determine the clearest path.

All components, including the sensor, servo, and SD card module, are connected to the ESP32 using a common ground and powered by an external battery. The circuitry is enclosed within the cane and secured with protective materials. The device is then tested in different environments to evaluate its reliability and performance.

Procedure for Making the Cap with Buzzer for Upper Hazards

The process of making the cap with a buzzer for detecting upper hazards begins by gathering all the necessary materials, including an Arduino Nano, an ultrasonic sensor, an active buzzer, a 9V battery, connecting wires, and a cap with a safety helmet insert. Next, the ultrasonic sensor is attached to the cap at an upward angle so it can effectively detect upper-level obstacles such as signboards or branches. After securing the sensor, it is connected to the Arduino Nano and programmed to activate the active buzzer whenever an obstacle is detected within a distance of 50 centimeters. Finally, the Arduino Nano, active buzzer, and 9V battery are placed securely inside the cap's safety helmet insert to ensure that the system remains discreet, lightweight, and comfortable for the user.

Process on making Organic Banana Fiber as sweat absorbent

The process for making the GABAY cane and cap-based audio navigation system, focusing on the organic banana fiber handle, begins with collecting raw banana (abacá) stalks. Mature banana or abacá plants with thick stalks are selected to ensure stronger fibers. The outer layers of the stalk are then stripped using a sharp knife or stripping tool to expose the inner fiber bundles. These fibers are extracted by pulling or scraping along the length of the stalk, separating long strands of natural banana fiber. The extracted fibers are thoroughly washed in clean water to remove plant sap, dirt, and impurities that may cause odor or stickiness. After washing, the fibers are boiled in water mixed with a small amount of natural soap or sodium bicarbonate to soften them, remove excess gum, and improve absorbency. The fibers are then dried under direct sunlight for several hours until they become completely dry, lightweight, and flexible.

Once dried, the fibers are combed or brushed to straighten them and remove coarse particles, resulting in a smoother texture suitable for wrapping. The prepared fibers are then twisted or woven into thin ropes or flat strips, depending on the handle design, to improve strength and grip. These fiber strips are tightly wrapped around the cane handle, overlapping slightly to ensure even coverage, and secured with eco-friendly adhesive at the start and end points. Finally, the absorbency of the fiber-wrapped handle is tested by lightly wetting it; the banana fiber should quickly absorb moisture, preventing slippage when held with sweaty hands.

Procedure for testing the dual detection system: distance accuracy, command response, and real-time audio navigation

The dual detection system was evaluated by first powering on the smart cane and verifying that the ESP32 system, ultrasonic sensors, servo motor, and Bluetooth earbuds were functioning properly. The servo's default sweep range of 70°–110° and its ability to transition to a full sweep of 0°–180° upon obstacle detection were also confirmed. A participant was then instructed to hold the cane naturally while walking within a marked indoor testing area, with Bluetooth earbuds connected to receive real-time audio feedback.

Obstacles were positioned at predetermined distances in 20 cm

increments, including placements directly in front, to the left, to the right, and across multiple angles. Both upper-level hazards, such as branches or signboards, and lower-level hazards, such as stairs or potholes, were incorporated to simulate real-world conditions. During each trial, an obstacle was introduced within the detection range while the participant was in motion. Response time was measured from the moment the obstacle entered the sensor's range until the correct audio feedback was delivered.

System performance was assessed by comparing the detected distance with the actual obstacle distance, as well as verifying the accuracy of navigation commands such as "turn left," "turn right," "stop," or hazard alerts. The responsiveness of the servo in shifting between default and full sweep modes was also observed. Each testing scenario was repeated multiple times, with slight variations in obstacle angles, to ensure consistency and robustness of detection and response.

All relevant data, including actual distance, system response, and measured response time, were recorded for each trial. Any delays, missed detections, or inconsistencies in audio feedback were documented. The collected data were then summarized through the calculation of average response times, accuracy rates, and command correctness to evaluate the overall reliability and effectiveness of the dual detection system.

Procedure for testing the cap with buzzer for upper hazards

The cap system was powered on, and the functionality of the Arduino Uno, ultrasonic sensor, and buzzer was verified prior to testing. The participant was instructed to wear the cap naturally while ensuring proper sensor orientation. System performance was first evaluated by placing an obstacle at a fixed distance of 60 cm.

A timer was started once the obstacle entered the detection range and stopped upon activation of the buzzer. This procedure was repeated five times, and the average, minimum, and maximum response times were recorded.

To assess height-based detection performance, obstacles were introduced at varying elevations ranging from 10 cm to 60 cm to simulate upper hazards.

The system was expected to trigger the buzzer at or within 60 cm and remain inactive beyond this threshold. Each distance condition was tested at least five times to determine the maximum reliable detection range, defined as the farthest distance at which successful detection occurred in at least two out of three trials.

Controlled directional scenarios were then conducted, including obstacles positioned directly overhead, slightly to the left, and slightly to the right of the participant. During each scenario, the participant walked naturally while obstacles were introduced into the detection field. Buzzer responses were observed to ensure correct activation within the 60 cm range and the absence of false activations beyond it.

Each scenario was repeated five times to evaluate consistency. All observations, including correct activations, missed detections, and false activations, were recorded.

The collected data were summarized by computing average response times, accuracy rates across different distances, and overall system reliability to assess the effectiveness of the cap-based upper hazard detection system.

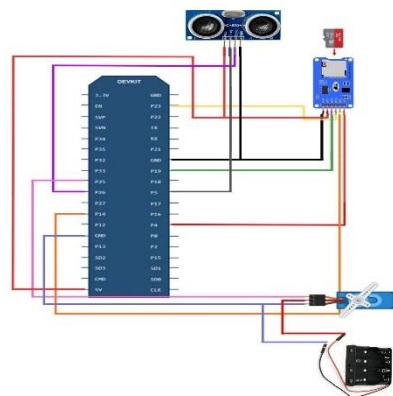


Figure 2. Physical connection of the G.A.B.A.Y cane

Figure 2 shows the wiring of the GABAY cane prototype. The ESP32 WROOM32 microcontroller collects data from the ultrasonic sensor, which detects the distance of obstacles. The SD card module provides the audio files to the ESP32, determining which audio should play. Meanwhile, the servo motor controls the angle, helping the system indicate the correct direction, either left or right.

Research Instrument

For this study, the researchers used a researcher-made observation sheet as the main instrument. The sheet was designed to record the Smart Cane's distance accuracy, direction command accuracy, and audio response accuracy, as well as the cap's detection accuracy. It includes spaces for actual and measured values, system outputs, classifications, accuracy rates, detection or precision rates, and response delays across multiple trials.

Statistical Treatment

The study used descriptive statistical treatments to analyze the data gathered through the researcher-made observation sheet. Descriptive statistics refers to a collection of techniques used to organize, summarize, and present data in a clear, systematic way, often through tables, charts, and numerical measures (Bhandari, 2020; VisionLearning, n.d.). Key measures include the mean, which is the arithmetic average of the data points, and the standard deviation, which quantifies how spread out the values are from that mean (VisionLearning, n.d.; UW Quantitative Analysis, n.d.).

The mean measurement was computed to determine the average speed recorded by the system's sensor across all trials. This provided the researchers with a general estimate of the system's typical output at each set distance, allowing for a clearer assessment of its overall reading behavior.

Standard deviation was used to determine the consistency of the system's performance. A low SD indicated stable results, while a high SD signaled variability across trials.

Ethical Considerations

In this study, safety is prioritized by conducting all tests of the smart cane and cap system in controlled, low-risk environments. Before every trial, the researchers inspected all components—including sensors, buzzer, wiring, and power supply—to ensure proper function and prevent risks such as overheating or loose connections. Testing was stopped immediately if any irregularities were observed, keeping the process safe throughout.

No external participants were involved in the testing; only the researchers operated and evaluated the device, eliminating any risk to

human subjects.

Integrity and transparency were also upheld. All results, observations, and limitations were recorded accurately based on actual device performance, without modification or exaggeration. Only data necessary for evaluating the system's functionality were collected, ensuring responsible and ethical use of technology. Through these practices, the study maintained fairness, honesty, and safety in the development and evaluation of the prototype.

RESULTS AND DISCUSSION

This chapter presents the results of the Smart Cane System and demonstrates that the device performed successfully across all conducted trials. Throughout the tests, the cane consistently detected obstacles and generated the correct direction commands without failure. The audio feedback was activated each time promptly, showing stable responsiveness across repeated trials. These outcomes indicate that the system is not only functioning as intended—it is also dependable and consistent under real-use conditions, proving its reliability as an assistive navigation tool.

Table 1. Smart Cane System Trial

Trial No.	Direction Command Accuracy (Yes/No)	Audio Response Speed (in seconds)
1	Yes	1.4
2	Yes	1.5
3	Yes	0.91
4	Yes	1.5
5	Yes	2.09
Mean		1.48
SD		0.420

Across all five trials, the smart cane consistently detected the obstacle at 20 cm and correctly recognized the direction command every time. The audio response times ranged from 0.91 to 2.09 seconds, showing generally prompt feedback with small variations. Overall, the results demonstrate stable detection accuracy and reliable system responsiveness throughout the test.

The obtained response times are consistent with findings from related studies, such as Sustainability: Evaluation of Bluetooth Detectors in Travel Time Estimation, which emphasizes that assistive navigation devices relying on wireless communication often experience slight delays due to signal transmission and processing (Krit Jedwanna & Saroch Boonsiripant, 2022). In comparison, Bluetooth-based systems typically operate within approximately 0.7 to 0.95 seconds, while the developed system showed a slightly higher range of 0.91 to 2.09 seconds. This indicates that although the system performs reliably, further optimization in communication and processing could reduce latency and improve real-time responsiveness in practical navigation scenarios.

Table 2. Cap System Trial

Trial No.	Buzzer Accuracy (Pass/Fail)	Audio Response Speed (in seconds)
1	Pass	0.10
2	Pass	0.11
3	Pass	0.10
4	Pass	0.12
5	Pass	0.10
Mean		0.106
SD		0.00894

The data shows that the sensor consistently detects the obstacle within 60 cm across all five trials and uses the buzzer as a response. In every test, the buzzer's detection time remained constant at 0.10 seconds for all trials. This indicates that the cap system functions with high accuracy and fast response time regardless of repeated testing.

The cap system consistently detected obstacles at 60 cm with an average response time of 0.106 seconds. These results align with benchmarks reported by Joseph, Kian, & Begg (2023), who note that wearable obstacle detection systems are effective when detection occurs within 50–60 cm and response times are below 0.2 seconds. Thus, our system demonstrates high accuracy and faster responsiveness than the minimum standards established in current literature.

CONCLUSION

This research focused on creating a Smart Cane with audio navigation and a cap sensor system designed to improve mobility and environmental awareness for visually impaired individuals. After conducting systematic testing and performance assessment, the following conclusions were established.

The smart cane and cap sensor system was successfully developed, with all major components such as the ultrasonic sensors, components such as the ultrasonic sensors, servo motor, SD card module, ESP32 for the cane, buzzer, Arduino Uno, and the cap-mounted ultrasonic sensor properly integrated. Minor wiring adjustments were needed to stabilize the connections. However, the system ultimately worked as intended, providing real-time obstacle detection, clear audio feedback, and improved comfort through the banana-fiber-wrapped handle.

The cane consistently detected obstacles at the 20 cm threshold in every trial, demonstrating reliable range measurement. Directional audio commands were accurately delivered, and with response times ranging from 0.91 to 2.09 seconds, the system provided prompt and effective guidance for real-time navigation.

The cap also showed consistent and precise performance across all tests. Obstacle detection remained accurate at 60 cm, and the buzzer responded reliably within the designated range. With a response speed of 0.10 to 0.12 seconds, the system reacted quickly and effectively to detected obstacles.

The banana-fiber-wrapped handle fulfilled its intended purpose, improving grip stability and natural moisture absorption. Under simulated sweaty-hand conditions, the material demonstrated enhanced comfort and secure handling during extended use.

Recommendation

Based on the study's results showing reliable obstacle detection, fast response times, and stable performance of the smart cane and cap system, the following improvements are recommended: (1) Adjust and evaluate multiple detection distances for the front, left, and right sensors to establish optimal range settings for diverse walking environments. (2) Integrate lighter and more durable materials to improve structural longevity and reduce user fatigue during extended use. (3) Test and select more stable and compatible earbuds or audio devices to ensure consistent and uninterrupted auditory guidance. (4) Expand the cap's sensing system by incorporating additional sensor modalities or head-tracking technology to enable detection of a wider

range of obstacles.

Future studies are recommended to adopt an iterative developmental approach to improve the G.A.B.A.Y smart cane. This would allow continuous user testing and refinement, which is essential for assistive technologies. With fewer time constraints, multiple design cycles can enhance usability, performance, and overall effectiveness.

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