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RESEARCH ARTICLE

InnoVision: An Advanced Navigation Aid for Visually Impaired Individuals Using GPS, GSM, and Sensor Technologies

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Abstract

Globally, an estimated 285 million people live with significant visual impairments, underscoring a critical need for effective navigation aids that promote independence and safety. Traditional navigation aids, such as white canes and guide dogs, are limited in detecting obstacles and ensuring user safety. This gap highlights the urgent need for innovative solutions that leverage technology to enhance mobility for visually impaired individuals. Consequently, this study aims to develop and evaluate a smart blind stick integrated with GPS, GSM, and sensor technologies. This blind stick was equipped with advanced sensors (i.e., ultrasonic and water level sensors) and modules specifically chosen for their potential to improve navigation and safety for visually impaired users. The research methodology employed Agile Scrum, focusing on iterative development, user-centric design, and continuous evaluation. Three evaluation techniques were used to assess the final product: sensor accuracy assessment, usability testing, and system general performance evaluation. The first assessment aims to measure the accuracy of sensors in estimating the distance between the device and obstacles of varying materials in the simulated environment. The results indicated a high level of accuracy, with an average computed error of 0.04. In the second stage, ten individuals volunteered to utilize the device in the simulated environment, followed by completing a standardized 20-item usability instrument. The outcome showed that the device exhibited a remarkably high level of usability (M=6.17, SD=0.88). The system reached an excellent performance level during the final evaluation, averaging 91.43%. These findings suggest that the proposed smart blind stick is accurate, user-friendly, and effective.

1 | INTRODUCTION

The challenges faced by visually impaired individuals are significant, often necessitating reliance on others for daily tasks. The International Classification of Diseases categorizes vision impairment into two main types: distance vision and near vision [1]. Distance vision is based on visual acuity, with categories ranging from mild to total blindness, depending on the severity. Near vision impairment, on the other hand, is categorized by visual acuity worse than N6 or M.08 at 40cm [2]. Globally, an estimated 285 million people are visually impaired, with 39 million classified as totally blind who rely on external assistance for navigating their surroundings [3]. This reliance underscores the critical role vision plays in human life, as approximately 83% of environmental information is acquired through sight [4]. These statistics highlight the widespread importance of addressing vision impairment on a global scale [5].

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Visually impaired individuals face numerous daily challenges, mainly related to navigation, obstacle detection, safety, and independent living [6], [7]. However, traditional assistance, such as white canes and guide dogs, are limited and costly [8], [9], [10], [11]. Fortunately, advancements in rehabilitation engineering have led to innovative solutions like electronic walking sticks, which leverage cutting-edge technology for improved navigation [12], [13]. These developments capitalize on the rapid progress in both hardware and software, enabling intelligent navigation systems tailored to the needs of visually impaired individuals. Numerous studies have contributed to the evolution of technologies in this area, enhancing safety and mobility for the visually impaired [14]. These efforts underscore a collective commitment to leverage technology to address the navigation challenges faced by the visually challenged community and improve the quality of their lives.

This study aims to address the navigation challenges faced by visually impaired individuals and alleviate the financial burden of conventional navigation aids by designing a smart blind stick with GSM and GPS for real-time location broadcasting, allowing timely alerts to relatives or caretakers. This device aims to address the limitations of traditional aids for visually impaired individuals, offering an innovative solution to enhance independence and safety [15], [16]. It further integrates advanced sensor technologies for accurate obstacle detection with a distance estimator. The target device aims to empower visually impaired individuals through cutting-edge solutions. By combining user-centric design with affordability and real-time communication features, the final device should redefine the landscape of mobility aids [17], [18], [19].

2 | Related Studies

A. *Historical Background of Navigation Aids*

Traditional navigation aids such as white canes and guide dogs have been instrumental for visually impaired individuals. White canes primarily serve as tools for sensory feedback, allowing users to detect obstacles and navigate safely within their environments. Despite their effectiveness, they require extensive training to use effectively and do not provide information about overhead barriers, which limits their functionality [20]. Guide dogs, alternatively, offer dynamic guidance by avoiding obstacles, indicating elevation changes, and navigating through traffic. They enhance the mobility and independence of their users significantly. However, they introduce dependency as they require lifelong care and management, and not all users can quickly adapt to the companionship or responsibilities involved [21], [22].

Both aids, while beneficial, underscore the limitations and dependencies they impose, highlighting a need for advanced solutions that combine the benefits of both without their respective drawbacks. Innovations such as smart white canes are emerging, incorporating features like obstacle detection and GPS navigation to enhance independence and safety for visually impaired individuals [23]. These developments show the potential of technology in assisting visually impaired individuals in navigating their surroundings.

B. *Technological Advancements in Navigation Aids*

The evolution of navigation aids for the visually impaired has transitioned from traditional methods to modern electronic and sensor-based systems, significantly enhancing mobility and safety. Initially, the visually impaired community relied on simple tools like canes. Still, technological advancements have introduced sophisticated electronic walking sticks and other digital aids, revolutionizing navigation practices.

Electronic walking sticks now incorporate sensors that detect obstacles, providing auditory feedback to the user. This technology improves users' navigation ability and enhances their confidence and independence. Integrating GPS and audio-based guidance systems further supports autonomous navigation, allowing visually impaired individuals to traverse complex urban landscapes without prior knowledge of the area [24], [25]. Moreover, the development of sensor-based systems, which use technologies like ultrasound and microcontrollers, has been crucial in improving the detection of obstacles, thereby reducing navigation difficulties for visually impaired people [26]. These systems facilitate safer and more efficient mobility, especially in unfamiliar settings.

C. *Technologies in Contemporary Navigation Aids*

The integration of GPS, GSM, and sensor technologies has dramatically enhanced the functionalities of navigation aids designed for visually impaired people. These technologies collectively provide accurate location data, real-time environmental feedback, and connectivity, improving users' independence and safety. GPS technology is fundamental for precise localization and routing, enabling visually impaired individuals to navigate familiar and unfamiliar environments confidently. An example of this application is the assistive navigation system that employs GPS to help users identify their location and plot a route to their destination [27]. GSM technology facilitates communication and data transfer over cellular networks, which is crucial for devices that require real-time updates. It also enables devices to send from a central system, thus enhancing user safety and mobility [28].

Sensor technologies, particularly ultrasonic sensors, are used extensively in navigation aids to detect nearby obstacles and alert the user through auditory or tactile signals. These sensors help create a multimodal navigation system that provides real-time environmental feedback [28], [29]. Recent innovations have also focused on combining these technologies to develop comprehensive solutions that address multiple aspects of navigation. For example, an intelligent walking stick equipped with GPS, GSM, and various sensors can provide location tracking, obstacle detection, and emergency communication, significantly enhancing the user's ability to move independently [28].

D. *Evaluation of Existing Technologies*

Evaluating the effectiveness of navigation aids for the visually impaired involves sensor accuracy assessments and usability testing. These evaluations aim to determine the reliability, efficiency, and user-friendliness of the technologies, which are crucial for ensuring the safety and independence of users.

Sensor accuracy is typically assessed through field testing under various environmental conditions to determine the reliability of obstacle detection and environmental feedback mechanisms. For example, integrating GPS with other sensors like odometers and inertial measurement units is evaluated using multi-sensor fusion algorithms to enhance the positioning accuracy of navigation systems [30]. Usability testing is essential to ensure the devices are intuitive and effective for the target user base. Studies often involve real-world testing with visually impaired users to gather feedback on the design and functionality of the devices. For instance, an evaluation of a navigational application using auditory feedback on the Android platform showed that users could use the application with minimal training to maintain a straight walking path in indoor and outdoor environments [31].

Research findings demonstrate that while modern navigation aids significantly enhance mobility for visually impaired individuals, they also have limitations. For example, GPS-based systems may not function effectively in indoor or densely built urban areas with weak satellite signals. Furthermore, the effectiveness of sensor technologies can vary based on the environmental context, affecting the overall reliability of navigation aids [32].

3 | METHODOLOGY

A. Software Development Life Cycle

This study employed the Agile Scrum methodology to develop the target device, as illustrated in Figure 1. This methodology is divided into seven phases: Planning, Design, Develop, Test, Deploy, Review, and Launch.

1. **Planning:** This initial phase sets the groundwork for the project by establishing clear goals, deliverables, and timelines, including stakeholder requirements, scope, and detailed roadmap.
2. **Design:** During this phase, the team focused on creating the architectural blueprint of the system, including the design of the user interface, system architecture, and database schemas.
3. **Develop:** The developers wrote code based on this phase's defined specifications and designs.
4. **Test**: Testing was conducted concurrently with development to ensure early detection and resolution of issues, including various types of testing, such as unit, integration, and system testing.
5. **Deploy:** This phase involves releasing the system into a live environment, including setting up the production environment, deploying the system components, and conducting final pre-launch checks.
6. **Review:** This phase includes gathering feedback from end-users and stakeholders, assessing user satisfaction, and measuring performance metrics.
7. **Launch:** The final phase focused on rolling out the system across the user base and ensuring it was fully operational. Training sessions, user manuals, and support were provided to facilitate a smooth transition.

Figure 1. Agile Scrum Methodology.

B. Ethical Considerations

Recognizing the potential risks and ethical implications of involving visually impaired individuals directly, this study opted for an alternative approach to simulate the experience of visual impairment. It was achieved by blindfolding participants, thereby eliminating direct physical stress on visually impaired individuals while gaining valuable insights into the usability and effectiveness of the developed device.

Before the commencement of the project, the research proposal was submitted to the college's ethics review committee for a thorough evaluation. This rigorous review aimed to ethically scrutinize the research methods and objectives to ensure they met the required standards. The committee's approval to proceed was contingent on the project's adherence to ethical research practices.

Central to this project's ethical conduct was the informed consent process. Participants were fully informed about the nature of the research, the procedures involved, potential risks, and their right to withdraw from the study at any point without any repercussions. The researchers committed to upholding the highest levels of integrity and impartiality throughout the study. Furthermore, this study adhered strictly to all applicable laws and regulations.

C. Participants and Usability Testing

Ten participants were recruited to participate in the evaluation process. Although not visually impaired themselves, they were selected for their ability to understand and simulate the challenges faced by visually impaired individuals using traditional navigation aids. The group consisted of a diverse mix of ages and backgrounds, providing a broad perspective on the usability and functionality of the smart blind stick.

Before the commencement of the experiment, each participant received comprehensive training about the device's features and functionality. This orientation session was designed to familiarize them with the device's technological enhancements and operational mechanics. The testing environment was meticulously prepared to simulate real-world settings. A 10-meter testing area was created, as shown in Figure 2, with various obstacles commonly found in everyday environments, such as curbs, steps, and barriers. This controlled setting allowed a detailed observation of how effectively the device guided the blindfolded participants around obstacles.

Figure 2. System Accuracy for Obstacle Detection.

During the experiment, participants were blindfolded to simulate visual impairment, ensuring the findings closely reflect the experiences of visually impaired individuals. The participants were then asked to navigate the obstacle course using the device. The objective was to assess the device's responsiveness, ergonomic design, and the intuitiveness of its navigational cues. The researchers closely monitored and recorded how participants interacted with the device. After completing the course, the participants were asked to provide feedback on their experience, including their thoughts or opinions regarding the device's functionality. Then, each participant completed the usability survey instrument.

D. Instrument

This study used the Computer System Usability Questionnaire (CSUQ) developed by Lewis [33]. This standardized instrument is highly regarded in usability research for its robustness and reliability in capturing user satisfaction with system interfaces, particularly in IoT-based projects [34][35]. The CSUQ consists of 19 statements encompassing various usability aspects, such as satisfaction, effectiveness, and efficiency. Each statement is designed to probe the users' experiences and perceptions while interacting with the device. Participants respond to each statement using a 7-point Likert scale, where 1 indicates strong disagreement, and 7 indicates strong agreement. The granularity of the CSUQ allows researchers to delve into specific areas of a system's usability, providing a detailed picture of user experience.

Table 1 serves as a comprehensive interpretation guide for the responses gathered from the CSUQ, enabling an evaluation of the system's usability. By categorizing the range of scores into distinct levels of usability, ranging from excellent to poor, the table offers a structured framework for assessing the system's performance based on user feedback. This clear delineation facilitates the conversion of raw scores into actionable insights, guiding subsequent development and refinement efforts.

TABLE 1. System's Usability Evaluation.

Range (%)	**Interpretation** *The system is perceived as…*
6.14 - 7.00	very useful
5.29 - 6.14	useful
4.43 - 5.29	moderately useful
3.57 - 4.43	fairly useful
2.71 - 3.57	neither useful nor not useful
1.86 - 2.71	not very useful
1.00 - 1.86	not useful

Once collected, the CSUQ data were subjected to rigorous statistical analysis to identify patterns and trends. The results were reported in aggregate form, with individual scores anonymized to maintain participant confidentiality. The analysis focused on areas with lower scores to identify usability challenges and on areas with higher scores to recognize the system's strengths.

E. Research Procedure

The research procedure for developing the smart blind stick is a comprehensive process encompassing several critical phases according to the Agile Scrum methodology, as illustrated in Figure 1. The process begins with a thorough needs assessment to understand visually impaired individuals' specific requirements and preferences concerning navigation aids. This stage involves direct consultations with visually impaired individuals through interviews and focus groups to gain firsthand insights into their daily navigation challenges and preferences. With a clear understanding of the requirements, the next step involves creating a tangible design and plan, including developing a comprehensive system architecture that integrates necessary electronic components, sensors, GSM, and GPS technologies. Then, a functional prototype is built to simulate the smart blind stick's interface and capabilities, allowing for iterative testing and refinement. A multi-tiered testing strategy was implemented, which involves sensor accuracy assessment, usability testing, and system general performance evaluation. During the sensor accuracy assessment, the researchers measured the accuracy of sensors in estimating the distance between the device and obstacles of varying materials (i.e., metal, wood, plastic, and stone).

F. Analysis

During the system performance evaluation, the researchers assigned a performance rate to each system feature created based on the data gathered after each test. The researchers used Equation (1) to calculate the performance rates of each system parameter under test:

$$\boldsymbol{P_r}(\%) = \frac{\boldsymbol{N_S - N_F}}{\boldsymbol{N_R}} \times \mathbf{100} \quad (1)$$

where,
P_T → *Percentage performance rate;*
N_S → *Estimated proportion of success;*
N_F → *Estimated proportion of failure; and*
NR → *Total number of trials.*

The overall system average performance rate was calculated using Equation (2).

$$\boldsymbol{AV_{PR}}(\%) = \frac{\sum \boldsymbol{P_R}}{\boldsymbol{N}} \quad (2)$$

where,
P_R → *Summation of performance rates; and*
N → *Total number of tests performed.*

G. Overall Data Flow

Algorithm 1 shows the pseudocode of the sensor function, which commences by retrieving data from the surroundings through the sensors. In the event of a direct obstacle detection, an alert is triggered by activating a buzzer. Depending on the SMS, the system either transfers control of the device to a designated guardian or instigates procedures for locating the user. This operational sequence perpetuates indefinitely to continually monitor sensors' data and execute requisite actions in response to detected conditions and objects from the surroundings.

Algorithm 1: Sensor Function.

Input: Distance and Water Level
Output: Action

```
DetectGound = Sensor.read()
DetectWater = Sensor.read()
DetectObstacle = Sensor.read()
if ObstacleDetected() then
    return triggerBuzzer()
end if
if GroundDetected() then
    // do nothing
end if
if WaterDetected() then
    return isLost()
end if
```

Algorithm 2 shows the system's SMS and Geolocation function triggered by a buzzer click, facilitating remote control of the device and the user's location tracking. It sends predefined messages to relatives or guardians and waits for their responses. Control is transferred to the designated guardian upon receiving a "switch" response. A "locate" reply, on the other hand, prompts the system to retrieve and send the user's current location.

Algorithm 2: SMS and Geolocation Function

Input: Buzzer Clicked
Output: Location via SMS

```
sendSMS(message)
waitSMSResponse()
if SMSReceived() then
    if message = "switch" then
        return transferControl(Guardian)
    else if message = "locate" then
        return location()
    end if
end if
```

H. *Software Architecture*

Algorithm 3 presents the operational process for programming sensors within the device, designed to detect obstacles and alert the designated guardian as needed. The device utilizes ultrasonic sensors to measure the distance to nearby objects. This is done by monitoring the time delay between each pulse emitted and its echo return, allowing precise calculation of the obstacle's distance. The water sensor measures the size of water droplets intercepted along a series of parallel lines exposed on the sensor's surface.

The system triggers an alert when the sensors detect objects or water within specific pre-programmed value ranges. This response is twofold: The buzzer is activated to emit intermittent buzzing sounds. Simultaneously, the vibrator is activated to provide physical feedback, alerting the user to nearby obstacles through discontinuous vibrations. Suppose the sensors detect a high density of obstacles, causing the buzzer to emit a continuous beep or the vibrator to maintain constant vibration (or both). In that case, it indicates an unusually cluttered pathway that may require immediate attention or alternative routing.

Users can press a toggle switch when navigation becomes challenging to alert relatives or guardians. Alternatively, the device can initiate an audio call with the guardian, allowing immediate verbal communication in an emergency.

Algorithm 3: Programmed Sensors Function.

Input: Ultrasonic Pulse
Output: Location and Buzzer Mechanism

```
sendSMS(message)
waitSMSResponse()
if SMSReceived() then
    if message = "switch" then
        return transferControl(Guardian)
    else if message = "locate" then
        return location()
    end if
end if
```

I. *Circuit Diagram*

Figure 3 outlines the Arduino Blind Stick Circuit, detailing a structured workflow for its multiple functionalities that enhance navigation and safety for visually impaired users.

The HC-SR04 Ultrasonic Sensor sends ultrasonic pulses and receives them upon reflection from nearby objects. If an object is detected within a predetermined range, the circuit triggers audible alerts via a Buzzer and tactile feedback through a Vibration Motor. The GPS module continuously tracks the user's location or coordinates for an emergency.

User inputs are managed through a Push Button that enables users to interact with the device according to their needs. A simple press can initiate various programmed actions, such as sending messages, making emergency calls, or other features relevant to user safety. The battery powered the device, ensuring sustained functionality without frequent recharges. Communication capabilities are handled by a GSM module, which facilitates sending text messages and making phone calls, providing a critical link between the user and external assistance. The system operates under a continuous monitoring approach, where sensors continually scan the environment. The Arduino processor analyzes sensor data to determine the appropriate alerts and cues.

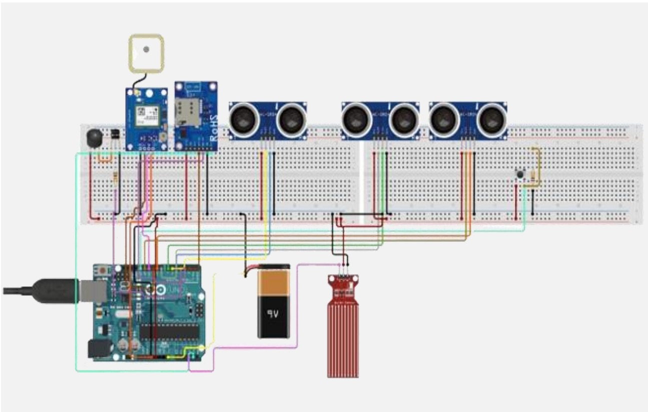

Figure 3. Circuit Diagram.

J. *External Communication Requirements*

Figure 4 illustrates the external communication requirements for the target device, highlighting the strategic arrangement of sensor modules for comprehensive obstacle detection. The device is programmed to scan specific environmental ranges at equivalent angles, ensuring thorough coverage and precise localization of obstacles. The mounted modules are strategically positioned on the device to eliminate blind spots, guaranteeing that no areas remain undetected within the device's operational range.

The proponents have employed three methods for obstacle detection to enhance navigational safety and efficiency: Overhead, front, and side obstacle detections. Each method targets different spatial zones around the user, thus providing a multi-dimensional safeguard against potential hazards. Additionally, this approach allows for early warning signals and more accurate navigation adjustments, significantly improving the user's ability to maneuver in complex environments.

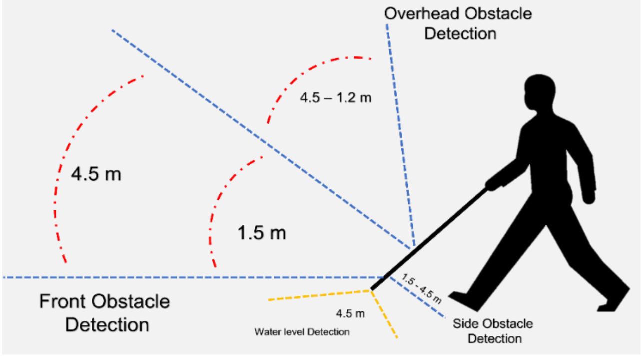

Figure 4. External Communication Requirements.

After the prototype was completed, its performance was assessed in a simulated environment, focusing on the top, right, and left sensors' line of sight measurements. The upper sensor, positioned to detect obstructions within a line of sight 50cm from the user's upper torso, was employed to identify obstacles at higher levels. Additionally, right and left sensors, with a 20cm line of sight from the right and left body, were utilized to detect ground impediments and other obstacles. The assessment involved placing various obstacles of varying materials and shapes at different distances.

K. Overall System Design

Figure 5 presents the structural design of the target device, including its components and parts.

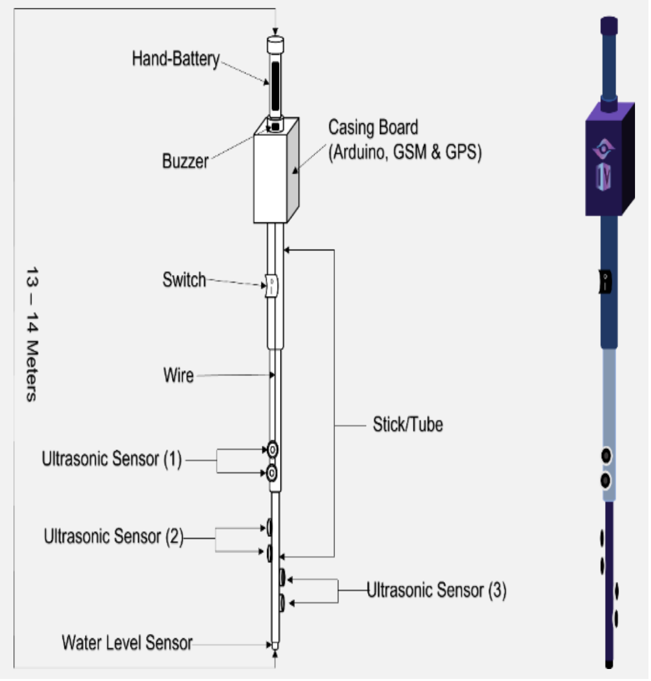

Figure 5. Structural Design.

L. General Features

1. **Advanced Sensors.** The device incorporates advanced ultrasonic sensors to detect obstacles, providing real-time distance measurements. These sensors offer accurate and immediate feedback on obstacle proximity, enhancing user awareness and enabling confident navigation in diverse environments.
2. **User-friendly Interfaces and Operations.** The target device features intuitive controls that cater to users with varying levels of training, ensuring accessibility without the need for advanced technical skills. This user-friendly interface promotes independent navigation for visually impaired individuals, aligning with the project's goal of enhancing mobility and well-being.
3. **Cost-Effective Components.** The device utilizes cost-effective materials and technologies, overcoming financial barriers and increasing accessibility for visually impaired individuals. This approach ensures affordability compared to alternative solutions like trained dogs or expensive navigation devices.
4. **GSM Technology.** This feature is for immediate communication, enabling users to alert relatives or caregivers during emergencies quickly. Leveraging mobile networks, GSM ensures broad coverage and connectivity, vital in urgent situations. This feature enhances the safety of visually impaired individuals, offering a reliable means to seek assistance or convey crucial information.
5. **GPS Integration.** This feature enables accurate location tracking for visually impaired individuals using InnoVision. This real-time information enhances safety and independence by allowing users and caregivers to monitor their position precisely. GPS contributes to navigation, providing reassurance and connectivity in diverse environments, addressing a fundamental need for individuals with visual impairments.
6. **Emergency Assistance.** The integration of GSM technology enables swift communication during distress situations, enhancing the safety of visually impaired users. This feature allows users to seek assistance, quickly facilitating a rapid emergency response. It provides a sense of security and ensures help is readily available when needed, prioritizing the well-being of visually impaired individuals in critical moments.
7. **User-Centric Feedback.** InnoVision's auditory and haptic feedback features enhance the user experience during navigation, prioritizing user-centric design. Utilizing a buzzer and a vibrator, these mechanisms provide essential cues about obstacles, terrain changes, and directions. This intuitive feedback system increases users' understanding of their surroundings, promoting confidence and autonomy in navigation.

4 | RESULTS AND DISCUSSION

A. Sensors Accuracy Assessment

One of the primary requirements of this study was obstacle distance estimation by ultrasonic sensors, especially with varying obstacle materials [36]. As shown in Table 2, the results indicate that the developed device is highly accurate in distance estimation, regardless of materials.

TABLE 2. Experimental Results of Selected Materials.

S/No	Selected Material	Obstacle Position Range (cm)	Mean Distance Measured (cm)	Calculated Margin Error
1	Human	50	45	0.05
2	Metal	100	97	0.03
3	Wood	120	113	0.07
4	Plastic	150	147	0.03
5	Stone	170	168	0.02

The calculated margin of error implies that the ultrasonic sensors are reliable and consistent in obstacle detection. Although the estimated distance is always lower than the actual distance, as shown in Figure 6, the computed margin errors remain relatively low, underscoring the system's effectiveness in accurately detecting the obstacle and estimating its distance from the user [37].

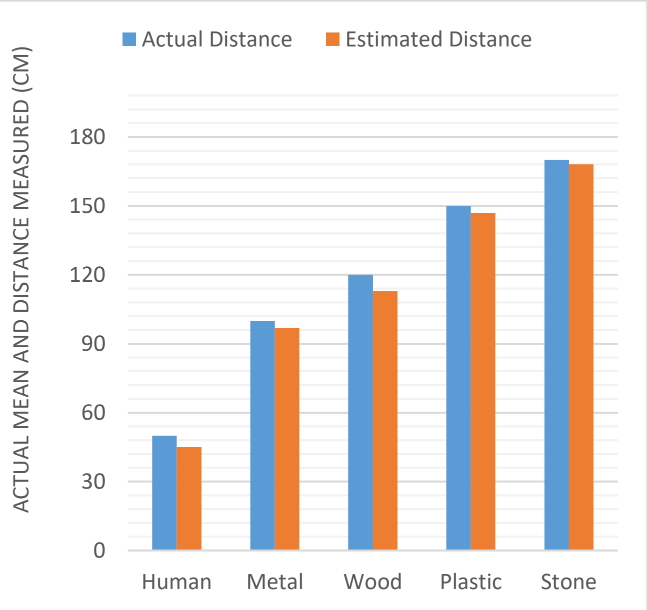

Figure 6. Actual vs Estimated Distance.

B. *Usability Evaluation*

Table 3 shows the users' response time, performance, and feedback during the usability evaluation. The results suggest that most participants demonstrated familiarity with the warning signals, effectively utilizing the device to navigate the obstacle course and avoid the planted obstacles. Overall, the device exhibited commendable performance, surpassing the expectations of most participants. Furthermore, participants playing as guardians during the simulation found it easy to track their partner's (playing the visually impaired user) location using the device.

Notably, the participants completed the 20-meter obstacle course within an average of three minutes and 13 seconds. However, several participants encountered difficulties interpreting the warning signals. These difficulties are attributed to the low learnability of the design; that is, the device requires ample time for the users to thoroughly memorize the association between warning signals and environmental information. Thus, future designs should simplify warning signals and make them easier to learn or recognize.

TABLE 3. Usability Assessment Results.

User	ATC (mins)	EN	EC	ASMS	ATGM
1	4:32s	Yes	Yes	Yes	Yes
2	5:10s	Yes	Yes	Yes	Yes
3	4:15s	**No**	Yes	Yes	Yes
4	4:43s	Yes	Yes	**No**	Yes
5	6:43s	Yes	Yes	Yes	Yes
6	5.11s	Yes	Yes	Yes	Yes
7	7.10s	Yes	Yes	Yes	**No**
8	4.33s	Yes	Yes	**No**	**No**
9	4.37s	Yes	Yes	Yes	Yes
10	5.43s	Yes	Yes	Yes	Yes

ATC = Average time to complete (mins); EN = Easy to navigate; EC = Encounter collusion; ASMS = Ability to use SMS; ATGM = Ability to track Google Maps.

The summary result of CSUQ shows that the smart blind stick is highly usable (M=6.17, SD=0.88). It implies that, on average, participants rated their satisfaction with the system's usability favorably. This score suggests that most users felt the system met their needs well, was easy to use, and efficient. They likely experienced fewer usability issues and felt optimistic about their interactions with the system.

Table 3 further shows that the sensors recognized various barriers within the defined ranges; however, subtle issues were observed. For instance, since the water detection sensor was placed near the base of the stick, it returned mostly a false positive for a small accumulation of water on the ground, such as a puddle. Meanwhile, the device's GPS and SMS services performed accordingly. Furthermore, the warning systems responded to each sensor correctly and consistently.

C. *System General Performance Evaluation*

The proponents examined the device's performance based on Equation (1) and Equation (2), where every module was evaluated $\mathbf{N_T}$ number of trials. The number of trials was adapted from [34].

TABLE 4. General Performance Evaluation Results.

S/No	SPUT (10)	N_T
1	GPS Coordinates	5
2	SMS Feature	5
3	Ultrasonic Sensor 1 (Left Detection)	10
4	Ultrasonic Sensor 2 (Frontal Detection)	10
5	Ultrasonic Sensor 3 (Right Detection)	10
6	Water Detection	5
7	Buzzer	10
System Average Performance		**91.43%**

SPUT = System Parameter Under Test (10); N_T = Number of Trials; R = Remarks; P_R (%) = Performance Rate

The system's general performance was 91.43%, indicating that the system is excellent in assisting visually impaired users in navigating the simulated obstacle course. According to [39], any device with high-performance scores (greater than 90%) has higher-quality features. In other words, there is a high level of efficiency and effectiveness in the functioning of a system. In addition, the system is reliable and consistently performs near its optimal capacity. Users and stakeholders can depend on the system to function well under various conditions without frequent failures or significant issues.

5 | Conclusion and Future Works

This study introduced a smart navigation stick for visually impaired individuals, which was evaluated based on its utility and operational mechanisms. The device incorporated GPS, GSM, and sensor technologies. This study has three key findings: First, the sensors used in this study are highly accurate in detecting obstacles regardless of materials and estimating the distance between the user and the obstacles. Second, the developed device is highly usable, promising high user satisfaction. Lastly, in terms of general performance, the system is considered excellent in assisting visually impaired users across a complex obstacle course.

Despite these valuable findings, the study recognizes several limitations and areas for future development. First, the proponents are planning to replace the buzzer with a more intuitive human voice guidance system to offer more precise direction to users. Second, future designs will include advanced cameras capable of motion detection to identify and react to moving objects at various speeds, such as vehicles. These improvements aim to reduce user stress and increase the utility of the final product that provides comprehensive support to visually impaired users.

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