Research Article

Design and Realization of a Low-Cost Smart Walking Aid for Visually Impaired and Blind People

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We have developed an affordable and intelligent walking aid designed to provide visually impaired and blind individuals with alert-based support while navigating both outdoor streets and indoor environments. This innovative smart blind stick offers more than just collision avoidance capabilities; it boasts a range of advantages including cost-effectiveness, rapid responsiveness, minimal power consumption, lightweight design, and water detection features. The smart walking aid utilizes an ultrasonic sensor to detect obstacles in the user's path and promptly notifies them through a combination of buzzer alerts and mechanical vibrations, helping them avoid potential obstacles. Moreover, it can not only identify solid obstructions but can also alert the user to the presence of water using a dedicated water sensing mechanism. We rigorously evaluated the prototype's performance through extensive testing to optimize its accuracy in a variety of scenarios, revealing an impressive maximum obstacle detection range of approximately 2 meters on average.

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1. Introduction

Visually impaired individuals, characterized by their inability to discern fine details with their eyes, face significant challenges in their daily lives. Those with a visual acuity of 6/60 or a horizontal field of vision less than or equal to twenty degrees when both eyes are open are considered visually impaired. In 2011, a survey conducted by the World Health Organization (WHO) highlighted that 1% of the global population grapples with vision-related disabilities. Among them, 10% are afflicted with complete blindness, while the remaining 90% experience varying degrees of visual impairment [1]. A paramount issue faced by the

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visually impaired is their struggle to navigate different environments and routes independently. Many of them rely on constant assistance for guidance. Alarmingly, WHO reports that 10% of visually impaired individuals lack even the most minimal functional eyesight required for safe independent mobility [2]. This paper visualizes this global scenario with a pie chart illustrating the percentage of blind individuals worldwide (referred to Figure 1). The contemporary world boasts an array of technologies that can significantly improve the quality of life for people with visual impairments. Leveraging these technological resources, there have been various attempts by engineers and technologists worldwide over the past two decades to develop devices that aid visually impaired individuals in their indoor and outdoor movements. This section briefly discusses some notable developments in this field. In 2005, Heijden *et al*. introduced a wearable navigation assistance tool for the blind, incorporating a multi-sensory system with components such as stereo vision, acoustic range finding, movement sensors, a warning system, and a tactile human-machine interface [3]. In 2010, Divya *et al*. proposed a theoretical model aimed at providing artificial vision and obstacle detection, offering blind individuals a cost-effective navigation aid with audible directions and information about their environment [4]. In 2013, Mahmud *et al*. unveiled a smart walking stick that utilizes microcontroller-based automation for obstacle detection. The system, featuring a PIC16F690 microcontroller, ping SONAR detector, wetness detector, proximity sensor, GH311 ultrasonic obstacle sensor, and more, stood out for its user-friendly design, low manufacturing cost, low power consumption, and vibratory feedback mechanism [5]. It also incorporated a security code to prevent unauthorized access and could detect muddy, wet, or slippery surfaces. The fingernail controller provided mechanical advantages, and the use of alternative power sources like solar panels for recharging was explored. In 2016, A. Nordrum designed a pothole detection system for the visually impaired, relying on image processing from a video camera capturing 15 frames per second [6]. However, this solution was costly, required substantial storage, and had limitations in terms of detection speed. In 2017, Johnson *et al*. developed a smart stick prototype with infrared (IR), ultrasound, and water sensors to identify obstacles in the path of blind individuals [7]. While it was an innovative approach, the reliance on a buzzer sound as an alert system in noisy outdoor conditions posed challenges. Additionally, it lacked a location identifier or indicator.

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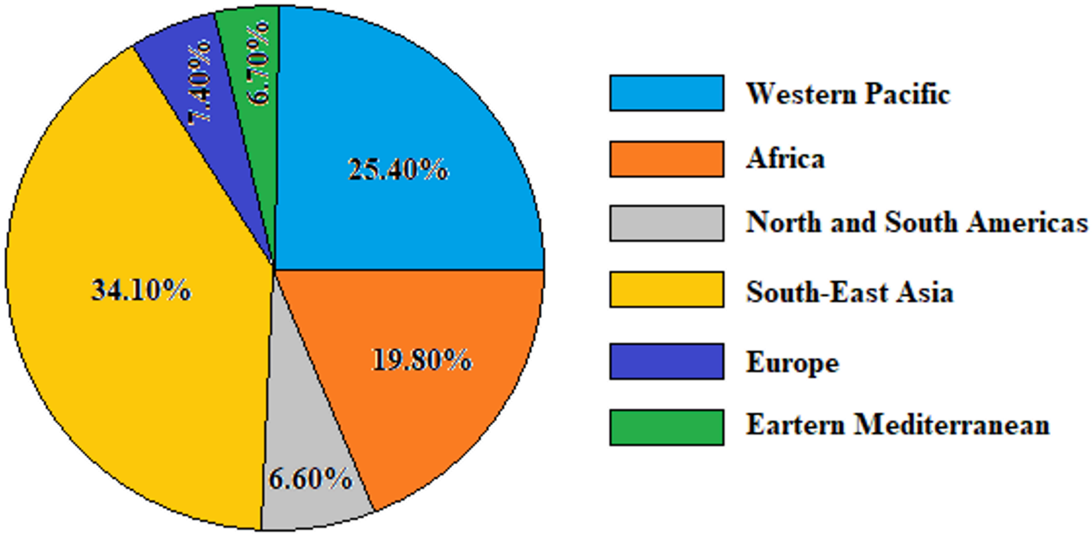

Figure 1. Pie chart showing the percentage of blind people across the world [1].

This paper introduces an advanced smart device designed to be assembled onto a standard walking stick, offering effective assistance and guidance to the visually impaired. The system incorporates an ultrasonic sensor, water sensor, Arduino ATmega 328 microcontroller, vibrator motor, buzzer, and walking stick as its major components. The ultrasonic sensor detects obstacles, with a calibrated range of 20 cm to 2 meters, although the detection distance may vary based on the object's size. A water sensor is employed to identify water on the pathway for easy avoidance. To enhance obstacle recognition, the device provides dual alerts, both in the form of sound and mechanical vibration. Moreover, the device is equipped with a GSM cum GPS module, enabling the transmission of SMS alerts to designated mobile numbers in urgent situations such as accidents. This innovative device represents a significant advancement in aiding visually impaired individuals in their daily lives.

2. Brief Description

The proposed device serves as a crucial aid for visually impaired and blind individuals, enhancing their ability to navigate independently and improving their self-reliance. Its primary function is to effectively address and circumvent a wide range of obstacles, whether static or dynamic, encountered during walking. This device achieves obstacle detection by utilizing ultrasonic sound waves and adopting the principles of sound navigation and ranging (SONAR). Upon identifying obstacles, the sensor transmits the data to the Arduino ATmega 328 microcontroller, which processes the sound wave data in digital

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form. The microcontroller calculates whether the object is within a range of 2 cm to 200 cm. Depending on the obstacle's location, the microcontroller triggers either a buzzer or a vibrator motor. For obstacles located above, detected by the upper ultrasonic sensor attached to the walking stick or wearable goggles, a buzzer sounds. For obstacles situated below, identified by the lower ultrasonic sensor at the base of the walking stick, both a buzzer and a vibration are activated. Additionally, the device incorporates a water sensor at the base, using the same method as the ultrasonic sensor to detect the presence of water and generate an appropriate alert. The device is equipped with a handpiece, functioning as a GSM cum GPS module. It enables the transmission of short messaging service (SMS) alerts to designated mobile numbers in any network in case of urgent situations, such as accidents on the street. The handpiece is connected to the microcontroller unit via a Bluetooth link (2.45 GHz), and the SMS includes the user's current position and the time of the incident, facilitating a prompt response.

Figure 2. Illustration shows the working principle.

From a sociological perspective, this smart stick holds significant implications for meeting the social needs of visually impaired individuals. It empowers them to overcome the challenges they encounter while walking, fostering self-sufficiency. On the economic front, this device is highly affordable, offering

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commendable quality and features within its price range. Moreover, the materials used in the device are environmentally friendly, with most being recyclable, making it environmentally responsible. The power consumption of the device falls within the range of 20 to 30 watts, and it operates using rechargeable Li-ion batteries, which can be recharged using solar power, further enhancing its environmental friendliness. The device's impact extends across social, economic, and environmental dimensions, making it a valuable and sustainable solution for assisting visually impaired individuals in their daily lives. Figure 2 provides a visual representation of the device's working principle, while Figure 3 depicts the schematic diagram of the smart stick, highlighting its various components and dimensions.

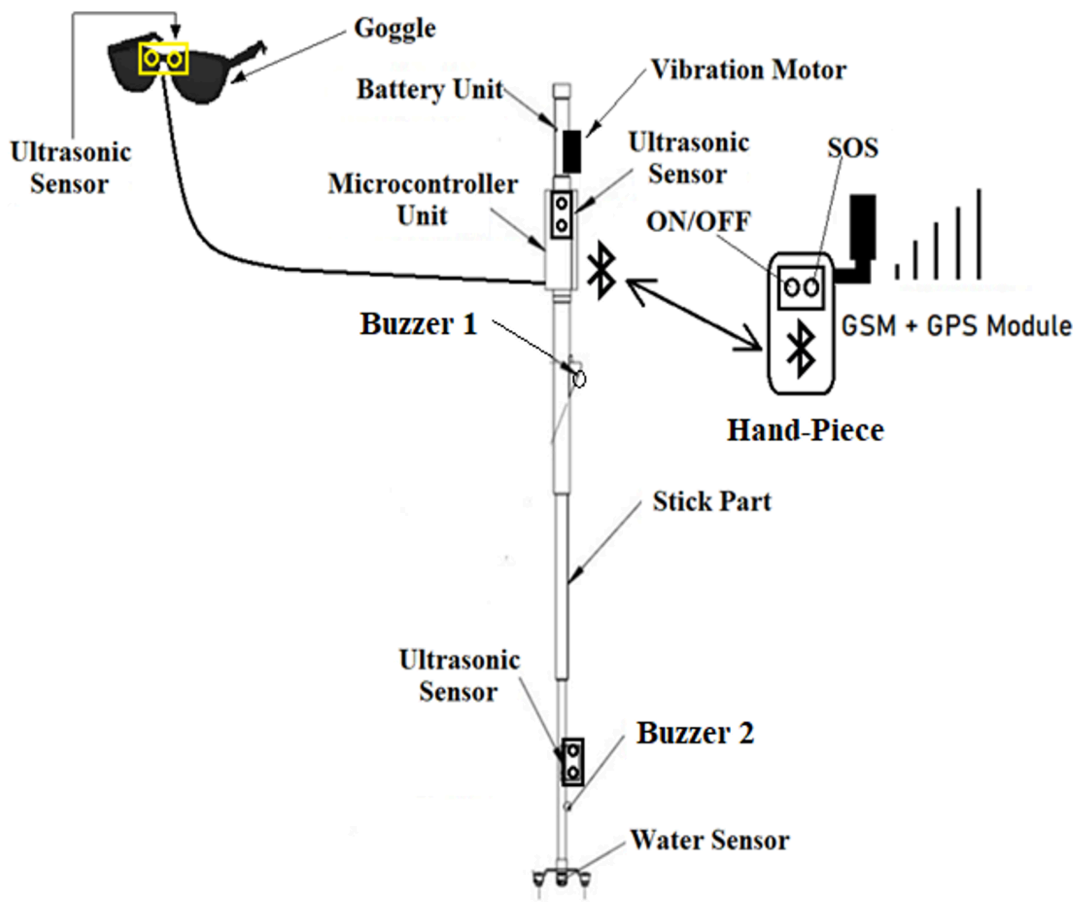

Figure 3. Schematic diagram of the smart stick with different components.

3. Design and Realization

The core of the system is the Arduino ATmega 328 microcontroller, meticulously programmed to process digitized data generated by the ultrasonic sensor – the reflected ultrasound waves in digital format. This data processing facilitates the calculation of the distance between the device and any object encountered. When the object falls within the range of 20 cm to 2 m, the microcontroller takes action by signalling both a buzzer and a vibrator motor to generate an alert. To convey the object's position to the user, the microcontroller activates the buzzer for upper-side obstacles and triggers both the buzzer and vibrator motor for lower-side obstacles near the ground surface. This dual-alert approach is crucial for enabling blind users to avoid collisions with obstacles. Furthermore, in the presence of water at ground level, the water sensor sends an interrupt signal to the microcontroller, prompting it to sound a different-toned buzzer.

The operational algorithm of the system is visually depicted in Figure 4. The device has been meticulously designed to ensure cost-effectiveness, which serves as its primary motivation. Other essential attributes include rapid responsiveness, low power consumption, lightweight construction, and user-friendly operation. The key hardware components necessary for the prototype include:

i. HC-SR04 ultrasonic sensor,

ii. Arduino ATmega 328 microcontroller,

iii. Walking stick,

iv. REES52 water sensor,

v. Vibrator motor,

vi. Piezo buzzer, and

vii. SIM808 GPS/GSM shield.

To enhance comprehension, photographs of each of these components are provided in Figure 5.

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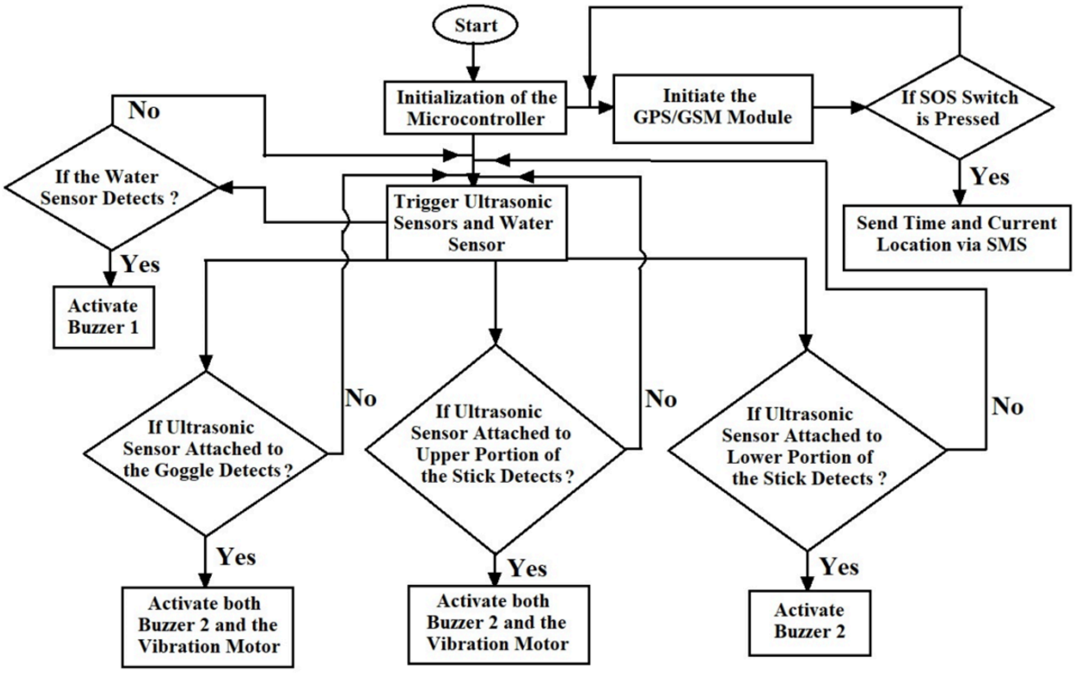

Figure 4. Flowchart of the algorithm.

Two ultrasonic sensors have been employed for obstacle detection, with the upper sensor responsible for detecting upper obstacles and the lower sensor for lower obstacles, as depicted in Figure 3. The ultrasonic sensor emits ultrasound waves, with a frequency exceeding human hearing capabilities (f > 20 KHz). The Ultrasonic Ranging Module HC-SR04, shown in Figure 5 (a), consists of a transmitter and a receiver. The transmitter emits the ultrasonic sound signal, and the receiver detects the reflected sound signal from any object within a range of 2 cm to 4 m. However, with suitable calibration, the sensor's range is limited to 20 cm to 2 m. The distance is calculated using the formula $D = (v_S T)/2$, where vs represents the speed of sound in the air medium (~340 m/s). The Arduino ATmega 328 microcontroller, depicted in Figure 5 (b), features 20 pins. The water sensor, equipped with multiple probes, is situated at the base of the smart blind stick, as seen in Figure 3. When the probes come into contact with water or a similar liquid, the sensor promptly sends an interrupt signal to the microcontroller, prompting the buzzer to produce an alert sound. The vibrator motor, a compact coreless DC motor, serves to alert the user silently, and it is activated solely when a lower-side obstacle near the ground surface is detected. The GPS/GPRS/GSM shield plays a pivotal role in sending SMS messages to predefined phone numbers in emergency situations, such as accidents. To trigger the SMS transmission, the user needs to press a push-button

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switch, which conveys essential information, including the time and the current location's latitude and longitude. A piezo buzzer has been integrated into the system to sound alerts when the ultrasonic sensor identifies obstacles on either the upper or lower side. The customized program code was developed using the Arduino IDE. A photograph of the prototype can be found in Figure 6, providing a visual representation of the realized device.

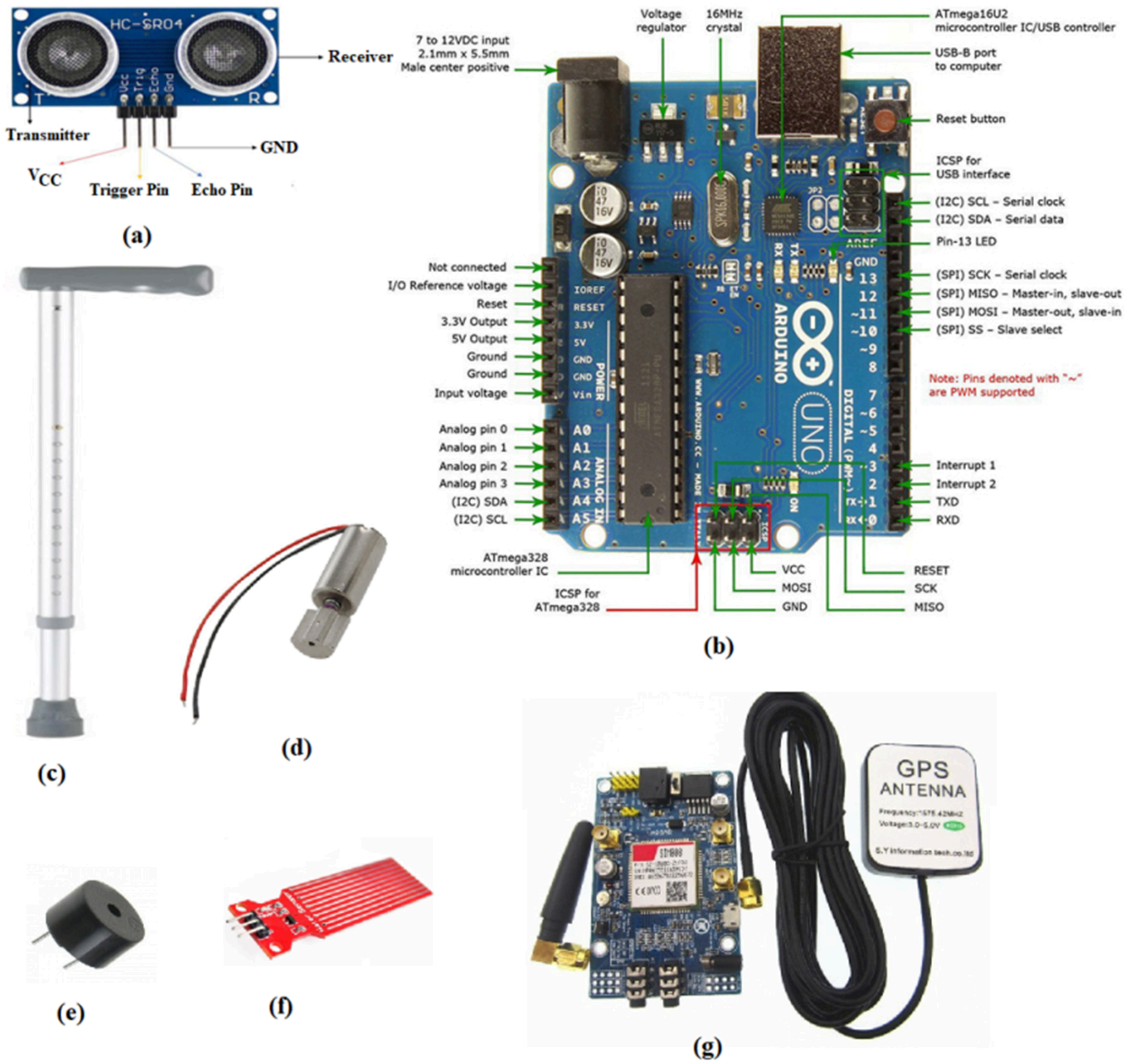

Figure 5. The components and modules required for the smart stick, such as (a) HC-SR04 ultrasonic sensor, (b) Arduino ATmega 328 microcontroller, (c) walking stick, (d) vibrator motor, (e) piezo buzzer, (f) REES52 water sensor, and (g) SIM808 GPS/ GSM shield.

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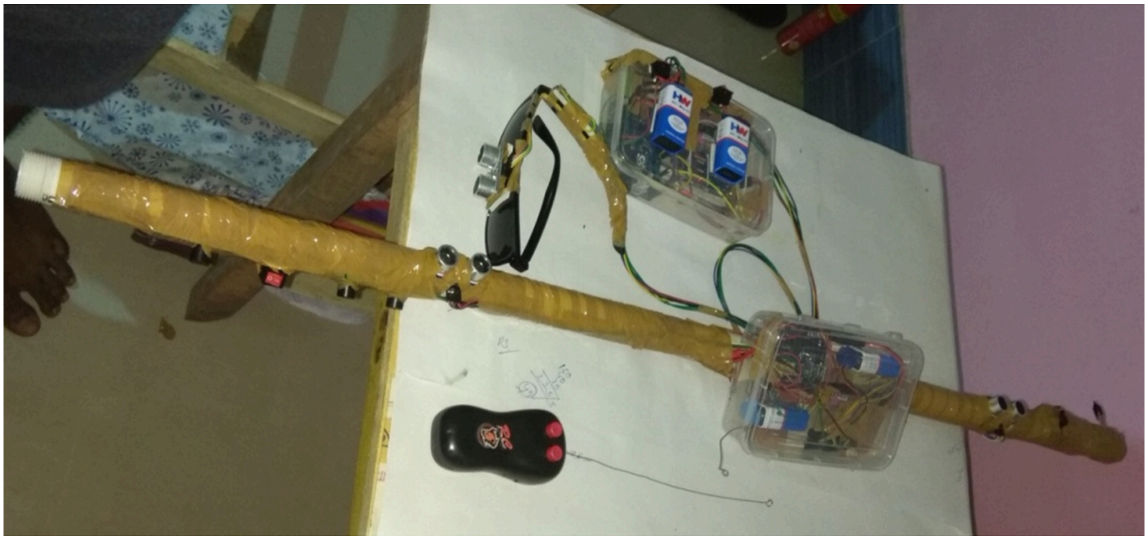

Figure 6. Prototype of the smart stick for blind people.

4. Performance Evaluation

The performance evaluation of the smart stick involved rigorous testing under various conditions, encompassing assessments of both the ultrasonic sensor system and the water sensor system to ascertain their accuracy in detecting obstacles at different distances from the sensors and sensing water at varying heights relative to the flat ground surface. To quantify the performance, the percentage of error (POE) was calculated by tallying the number of false alarms within a specific number of experiments conducted for a given obstacle distance (D). The formula employed for calculating the POE is as follows: POE = (Number of false alarms)/(Number of experiments for a particular distance)×100%. Twenty detection experiments were performed for each distance, ranging from 20 cm to 200 cm, and the count of false detections was recorded. This procedure was repeated five times, resulting in five trials. The POE versus D plots for these five trials are presented in Figure 7 (a). Notably, the sensor demonstrated higher accuracy for shorter distances. However, the POE remained within the range of 2% to 8% throughout the 20 cm to 200 cm distance range, signifying a highly commendable level of performance.

The accuracy of the water sensor system was assessed using the same experimental method. In this case, the POEs were computed for different water heights (h) concerning the flat ground surface. Variations in the POE associated with the water sensor in five separate trials are visualized in Figure 7 (b). A compelling observation is that the accuracy of the water sensor system increases, as indicated by a decrease in POE, with an augmentation in water height, which aligns with expectations. Nevertheless, the POE remained limited to a range of 2% to 2.5% across the spectrum of h variations from 1 mm to 46 mm. This consistent low level of POE underscores the system's exceptional performance in accurately detecting water at diverse heights above the ground surface.

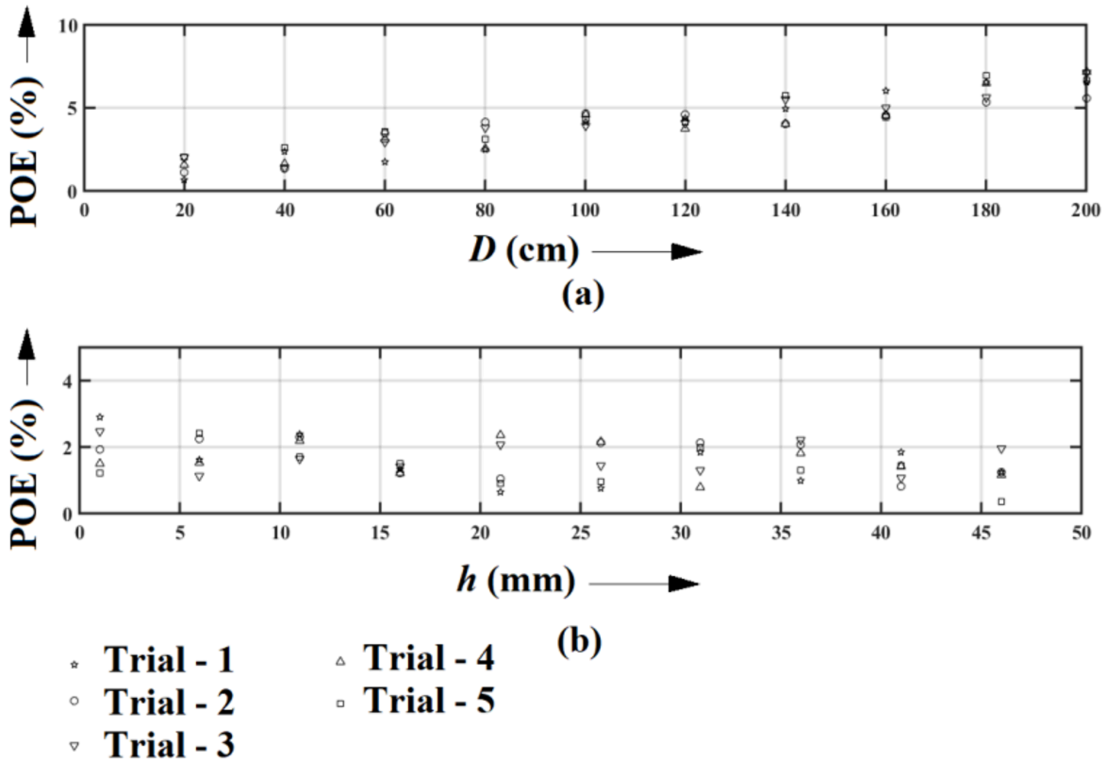

Figure 7. Variations of percentage of errors in detection of (a) obstacle by ultrasonic sensor with distance, and (b) presence of water by water sensor with height of water.

5. Conclusion

In conclusion, we have successfully designed and implemented a smart stick that offers crucial alert-based assistance to visually impaired individuals when navigating streets, and it is equally suited for both indoor and outdoor usage. Our paramount consideration during the development process was ensuring that this device remains affordable, making it accessible to the middle-class and economically disadvantaged populations in India. The smart blind stick we have introduced boasts several distinctive features, including its cost-effectiveness, swift response time, minimal power consumption, lightweight construction, and the ability to detect the presence of water along the user's path. Utilizing an ultrasonic sensor, it effectively identifies obstacles in the path of the user, promptly delivering alerts through a combination of buzzer sounds and mechanical vibrations to facilitate obstacle avoidance. Importantly, it excels not only at detecting solid obstacles but also at warning users of the presence of water, thanks to a dedicated water-sensing mechanism. Our comprehensive performance evaluations, conducted through a series of meticulous experiments, have consistently demonstrated its reliability, with an average maximum obstacle detection range of approximately 2 meters. Looking ahead, our future endeavours will involve a complete redesign of the system, transitioning it into an Internet of Things (IoT) based solution. This IoT-based control will significantly enhance remote accessibility to the smart walking aid, especially in emergency situations requiring immediate assistance. Additionally, we plan to introduce voice-based alert systems in conjunction with the existing buzzer and vibration alert mechanisms, further enriching the user experience and improving the device's overall functionality. These enhancements reflect our commitment to continually advancing the capabilities of this smart stick to better serve the needs of visually impaired individuals, promoting their safety, autonomy, and quality of life.

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Conflict of Interest

All authors declare no conflicts of interest in this paper.

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Declarations

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