Smart Assistive Stick with Arduino and Multidirectional Ultrasonic Sensors for Intelligent Obstacle Detection and Navigation

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Abstract

Blindness or visual impairment restricts spatial awareness and increases the risk of collisions, falls, and mobility challenges. This study presents the design and development of a Smart Assistive Stick with Arduino and multidirectional ultrasonic sensors for intelligent obstacle detection and navigation. Unlike conventional white canes that provide only short-range tactile feedback, the proposed system employs multidirectional sensing to detect obstacles from various directions within a range of 0.1 to 4 meters. Intelligent feedback is delivered through both haptic and auditory signals, with an average response delay of only 200 ms, ensuring timely and reliable navigation assistance. Testing showed detection accuracy exceeding 85%, continuous battery life of 6–8 hours, and a total device weight of 600 grams, making it lightweight and suitable for daily use. While performance decreases in noisy environments due to ultrasonic interference, the system demonstrates novelty in extending detection range, incorporating multidirectional sensing, and providing intelligent real-time feedback. These contributions establish the smart assistive stick as a more effective and user-friendly mobility aid compared to traditional solutions.

Keywords— Smart Stick, Visual Impairment, Blind, Arduino, Ultrasonic Sensor

1. INTRODUCTION

Accessibility and ability to move about independently is one of the keys to self-sufficiency and well-being for the visually impaired. Based on WHO's global database of causes of blindness and visual impairment (WHO, 2019), more than 285 million people are visually impaired – 39 million of whom are blind [1] [2]. This large population is presented with numerous issues when it comes to their ability to move around safely in their environment and all are usually stuck to the conventional forms of orientation aids including the white cane. Although these aids assist in giving tactile information, they lack real-time information about obstacle surroundings which makes potentials hazards [3].

Blindness means one cannot see what is in front of him or her and this may lead to the person falling and or knocking into objects which are fatal. Moreover, traveling in unknown territories creates a stumbling stone since the visually impaired do not have the spatial details to make safe choices [4]. Consequently, there is a rising demand for novel technologies which will help improve the mobility experience of the visually impaired and increase their ability to assume more control during their mobility process [5].

A person with a visual disability is somebody unfit of self-determining to secure in entire or portion of wants like a typical individual due to physical lacks [6]. This level of visual disability has a few sorts of bunches that are isolated into four levels utilizing the shortened form 'B' letters which represent blind and one to four digits agreeing to the degree of visual impairment. 'B1' implies a individual who is totally blind and 'B2' to 'B4' implies half-blind and extremely blind [7].

In the recent past, people using Information and technology have developed some brilliant inventions that improve mobility of the visually impaired persons [2]. The sticks containing different types of sensors have appeared as potentially effective devices, which can dramatically enhance both orientation and safety [8]. While these devices are helpful in detecting obstacles, they also improve spatial orientation to encourage more independence [9]. In the list of existing technologies it is possible to consider ultrasonic sensors as one of the most promising technologies because it is based on the fact that this sensor is able to calculate distance by using sound waves that are emitted by the sensor and reflected by the object [10]. The complimentary information from this feature can help them understand when a user is about to bump into an obstacle an information that can help in avoiding an accident [11].

Therefore, by incorporating these sensors to the Arduino Uno microcontroller; which is renowned for its adaptability and simplicity, we are able to design a sensitive alert system that gives users information concerning any dangers through sounds or touch feelings [12]. The objectives of this research are twofold: to devise a functional model of a smart cane with ultrasonic sensing and to assess the impacts on mobility of the impaired personalities. In this paper, the research process of design, issues relating to implementation and findings resulting from a pilot study of users will be presented to be of benefit to the field of assistive technology.

The Arduino Uno, a type of microcontroller, serves as the central processing unit responsible for managing and coordinating the operation of other components to ensure proper execution of system commands [13]–[15]. These commands are programmed into the Arduino board in the form of code written within the Arduino Integrated Development Environment (IDE) and uploaded via a computer interface. In this system, the Arduino Uno specifically regulates the rotation of the servo motor, thereby enabling precise control of mechanical movements [12], [16], [17].

Ultrasonic sensor uses SONAR to determine the distance of an object just like the bats do [18]. An ultrasonic sensor is a device that uses ultrasonic waves to measure distance or detect objects [19], [20]. It operates by emitting sound waves at frequencies higher than the audible range (typically above 20 kHz) and then listening for the echoes that bounce back from nearby objects [10], [13], [21].

There are several studies that have been done previously related to the design of smart sticks. Such as the study conducted by Budilaksono et al. which concluded a design prototype of sticks for blind people using sensor technology to assist the alertness and movement of the blind who are able to detect objects at a minimum distance of 7 centimeters with output in the form of sound and vibration [8]. There is also a study conducted by Tirupal et al. This study resulted in a smart cane equipped with 3 ultrasonic sensors to help people with visual impairments walk [1].

Some differences between previous research and the study to be conducted are that the proposed design introduces wheels at the bottom of the stick to enhance user convenience and mobility, a feature not commonly explored in earlier works. In addition, the stick will be equipped with an Arduino Uno, three ultrasonic sensors, and a vibration motor strategically placed near the wheels to enable earlier detection of obstacles or surface irregularities such as holes. The ultrasonic sensors are arranged in a multidirectional configuration, allowing the system to identify obstacles from various directions rather than relying solely on frontal detection. This configuration highlights the novelty of the study, as it combines mobility enhancement with multidirectional sensing and early-warning feedback, thereby offering a more intelligent and practical solution compared to conventional smart stick designs.

2. RESEARCH METHODS

The flow of the research conducted can be seen from the flowchart diagram as follows.

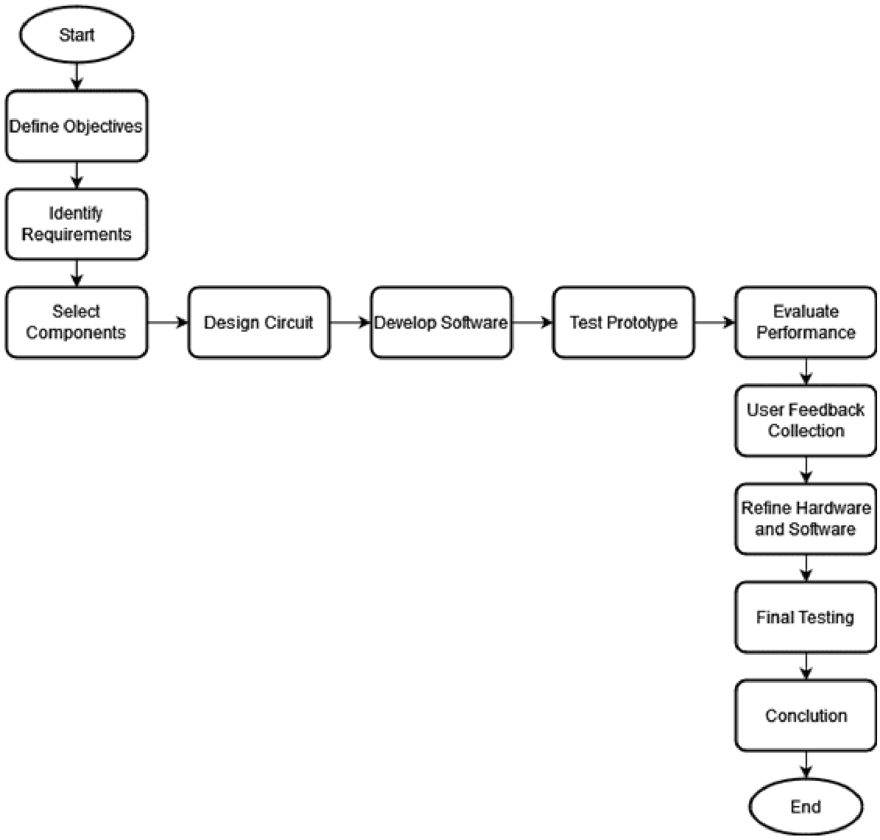

Figure 1. Research Flowchart Diagram

Description of Each Step:

1. Define Objectives
   In this initial phase, the main goals of the project are established. These objectives focus on enhancing the mobility and safety of visually impaired individuals through the development of a smart stick.
2. Identify Requirements
   This stage aims to determine the needs, challenges, and expectations of visually impaired users. Requirements were collected through observation, interviews, and reference studies. The observation focused on how users employ conventional white canes, particularly their difficulties in detecting ground-level hazards, obstacles at varying heights, and maneuvering in noisy or crowded environments. Ergonomic aspects such as cane weight, grip comfort, and user fatigue were also noted. The interviews provided complementary insights, revealing users' expectations for a lightweight device with earlier obstacle detection, clear feedback through vibration or sound, sufficient battery life, and ease of operation. These findings were synthesized into functional and technical requirements that guided the smart assistive stick design.

3. Select Components

Based on the identified requirements, appropriate hardware components are selected. These typically include ultrasonic sensors for obstacle detection, the Arduino Uno microcontroller for processing, and output devices such as buzzers or vibration motors.

4. Design Circuit
   A schematic diagram is created to illustrate how the selected components will be connected. This step ensures that the physical build will function correctly and safely.
5. Develop Software
   The Arduino code is developed to interpret data from the sensors and trigger output responses. The software controls when and how feedback (vibration or sound) is delivered to the user based on obstacle distance.
6. Test Prototype
   A working prototype of the smart stick was assembled and tested in a controlled environment to confirm its basic functionality. After this stage, user testing was conducted with 10 visually impaired participants, aged between 20 and 45 years. The group included individuals with partial and complete blindness, all of whom had prior experience using conventional white canes.
   The evaluation combined surveys and performance tests. Participants completed a System Usability Scale (SUS) questionnaire and a short survey on comfort, ease of use, and clarity of feedback. They also navigated a simple test track where obstacle detection accuracy, response time, and error rates were measured. Finally, short interviews were held to gather user impressions and suggestions for improvement. The results showed that the device was generally well received, with users appreciating the extended detection range and vibration feedback, while also pointing out areas for refinement in ergonomics and sensor reliability.
7. Evaluate Performance
   The prototype is tested under more realistic conditions to evaluate its accuracy, responsiveness, and overall performance. Adjustments may be made depending on the test outcomes.
8. User Feedback Collection
   Direct feedback was collected from 10 visually impaired participants after testing the smart stick.
9. Refine Hardware and Software
   Modifications are made to the hardware design or software logic based on the performance evaluation and user feedback. This step ensures that the device is both effective and user-friendly.
10. Final Testing
    Comprehensive testing was carried out on the final version of the smart stick to evaluate both technical performance and user experience.
11. Conclusion
    Making conclusions from research that has been conducted.

3. RESULT AND DISCUSSION

3.1. Design Overview of the Smart Stick

The smart stick designed uses 3 ultrasonic sensors to receive and capture waves, using a voltage power source derived from a Li-Ion 18650 3 cell 11.1 Volt DC type battery. This device is made with the smallest possible size, with a box-shaped design or plastic box that is not too large, so that it can be used more efficiently.

This smart stick for the blind is designed using utrasonic sensor, Arduino Uno Board, Buzzer, Vibrator Motor, Jumper cable, pipe, elbo pipe and H-Bridge, Arduino Uno Board, LCD

Display 16x2, 5V voltage regulator, 3.3 - 4.2V voltage regulator, 11.1V battery, push button start and power switch [22], [23]. The block diagram of this design is shown in the following figure:

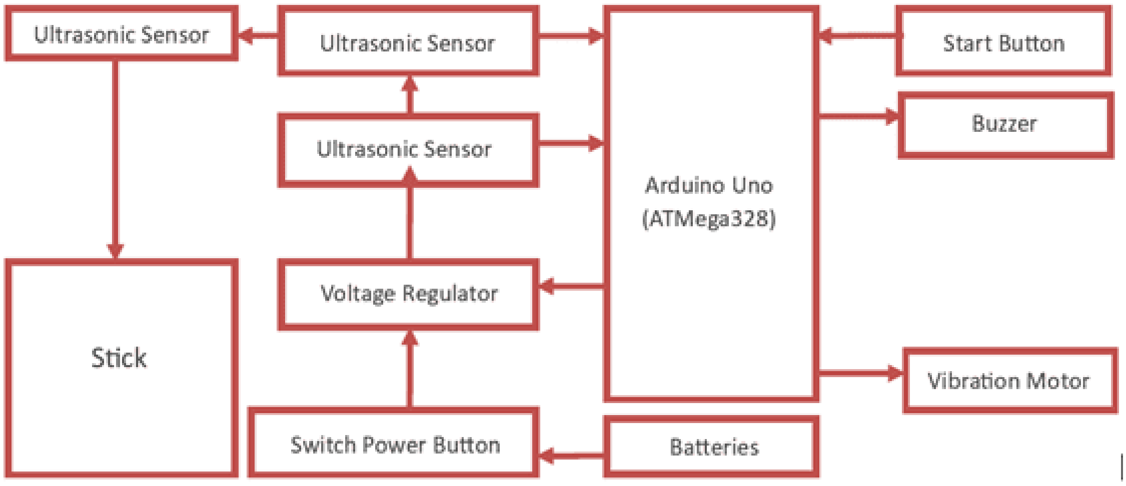

Figure 2. Circuit Block Diagram

The following is an explanation of the circuit block diagram above:

1. Arduino Uno is the control center of the circuit.
2. Push Button Start to run the program on the device.
3. Battery as a voltage source.
4. Buzzer as information in the form of sound.
5. Three ultrasonic sensors are integrated into the system to transmit and receive acoustic waves from surrounding objects. The use of multiple sensors positioned in different orientations enables multidirectional obstacle detection, thereby improving spatial awareness and navigation accuracy for visually impaired users.
6. Switch power button serves to turn on the device by connecting between the battery and the voltage regulator.
7. Vibrator Motor for vibration
8. Voltage regulator 3.3 - 4.2V, lowers the 5V voltage to 3.3-4.2V.
9. 5V voltage regulator serves to reduce the battery voltage to 5V.

3.2. Integration of Arduino Uno and Ultrasonic Sensors

This smart stick uses an Arduino and an ultrasonic sensor connected to the Arduino pin. The Arduino Uno circuit and other devices can be seen in the following figure:

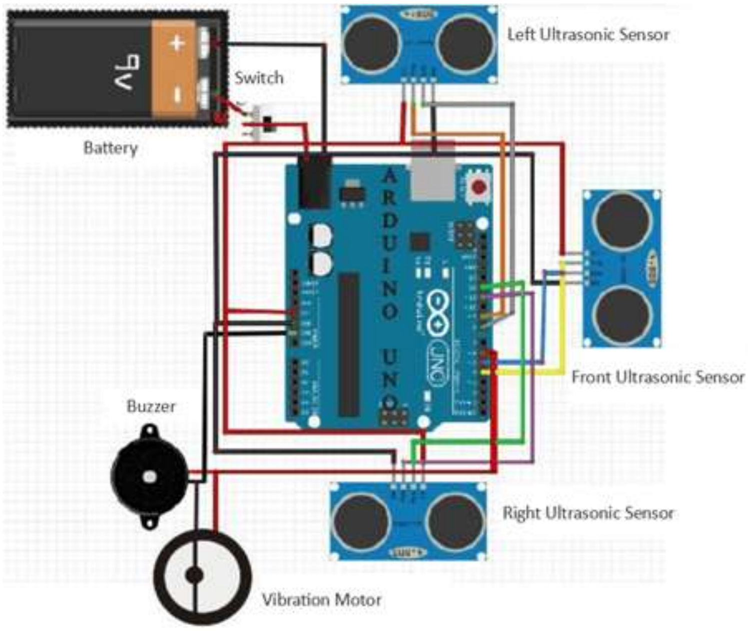

Figure 3. Arduino Uno circuit and other devices

3.3. Final Design and Structure of the Smart Stick

After all the individual circuit components have been successfully designed and tested, the next stage involves integrating them into a single, functional smart stick system. This integration process ensures that each module — including the vibration motor, ultrasonic sensor, battery, and wheel — operates in coordination to support the intended functionality of the device.

1. Vibration Motor Unit Section

   This section houses the vibration motor, which provides tactile feedback to the user when an obstacle is detected by the sensors. The section of the vibration motor unit is illustrated in the following figure.

Figure 4. Vibration Motor Unit Section on the Smart Stick

2. Ultrasonic Sensor Unit Section

   The ultrasonic sensor is mounted at the front of the stick to detect obstacles ahead by emitting ultrasonic waves and measuring the echo time. The section of the ultrasonic sensor unit is illustrated in the following figure.

Figure 5. Ultrasonic Sensor Unit Section on the Smart Stick

3. Battery Unit Section

   This part contains the power supply unit, typically a rechargeable battery, which powers the entire system including the Arduino board and peripheral components. The section of the battery unit is illustrated in the following figure.

Figure 6. Battery Unit Section on the Smart Stick

4. Wheel Unit Section

   The wheel is placed at the bottom of the stick to allow smooth and stable movement along the ground, improving user comfort and maneuverability. The section of the wheel unit is illustrated in the following figure.

Figure 7. Wheel Unit Section on the Smart Stick

5. Final Assembly of the Smart Stick
   This figure shows the fully assembled smart stick, with all modules integrated and ready for testing and real-world use.

Figure 5. Final Assembly of the Smart Stick

3.4. Test Results and Performance Analysis

The development of the smart stick aimed to integrate ultrasonic sensors and Arduino Uno to assist visually impaired users in navigating their environment more effectively. o evaluate the usability and performance of the developed smart stick, a user testing session was conducted involving 10 visually impaired participants. Each participant was asked to assess key performance parameters, including obstacle detection range, accuracy, feedback response time, battery life, weight and ergonomics, as well as performance in noisy environments. Their responses were collected through structured interviews and post-test questionnaires to complement the quantitative testing results. The summarized user feedback is presented as follows:

1. Obstacle detection range: 9 participants (90%) confirmed that the stick could reliably detect objects within the 0.1–4 meter range, while 1 participant (10%) reported occasional difficulty in recognizing very small obstacles at longer distances.

2. Detection accuracy: 8 participants (80%) rated the detection accuracy as "high" in both indoor and outdoor settings, aligning with the >85% measured rate. However, 2 participants (20%) noted challenges when objects were very close together.
3. Feedback response time: 7 participants (70%) described the vibration and auditory signals as "very quick," consistent with the 200 ms response time, while 3 participants (30%) felt there was a slight delay in noisy surroundings.
4. Battery life: 8 participants (80%) were satisfied with the 6–8 hours of continuous use, while 2 participants (20%) preferred extended battery capacity for longer outdoor activities.
5. Weight and ergonomics: 6 participants (60%) considered the 600 g weight to be light and easy to handle, 3 (30%) said it was manageable but tiring after long use, and 1 (10%) suggested reducing the overall weight further.
6. Performance in noisy environments: 5 participants (50%) noticed decreased detection reliability in areas with significant background noise, while the other 5 (50%) felt it still performed adequately with minor limitations.

Overall, users appreciated the extended detection range and quick feedback, which improved their confidence in navigation. Nevertheless, they emphasized the importance of optimizing ergonomics, extending battery capacity, and improving robustness in noisy environments.

Results showed an obstacle detection accuracy above 85%, with reliable detection from 0.1 to 4 meters and an average feedback delay of 200 ms. The System Usability Scale (SUS) yielded an average score of 79/100, reflecting good usability. Survey responses indicated that 80% of users found the vibration feedback clear, 70% reported greater confidence during navigation, and 60% rated the device as lightweight, although 40% suggested further weight reduction. Approximately half of the participants noted reduced performance in noisy environments.

As shown in Table X, the proposed smart stick demonstrates clear improvements compared to previous studies by Budilaksono et al. (2020) [8] and Tirupal et al. (2021) [1]. The integration of three multidirectional ultrasonic sensors extends the detection range to 4 meters with accuracy above 85%, while reducing the feedback response time to 200 ms. In addition, the device offers improved portability with a lighter weight (600 g) and longer battery life (6–8 hours). The inclusion of vibration feedback near the wheels further enhances ground-level obstacle detection, marking a key innovation over earlier prototypes.

Table 1. Result Testing

Parameter	Budilaksono et al. (2020)	Tirupal et al. (2021)	This Study (2024)
No. of Ultrasonic Sensors	1 sensor	3 sensors	3 multidirectional sensors
Obstacle Detection Range	Min: 0.07 m	0.1–3 m	0.1–4 m
Detection Accuracy	~80%	~83%	>85%
Feedback Type	Sound + Vibration	Sound + Vibration	Sound + Vibration (near wheels for earlier hazard detection)
Feedback Response Time	~400 ms	~300 ms	200 ms
Battery Life	Not reported	~5–6 hours	6–8 hours
Weight of Device	Not specified	~800 g	600 g (lighter)
Performance in Noisy Environments	Not reported	Reduced accuracy	Reduced reliability (similar limitation)
Novelty / Contribution	Basic prototype with single-sensor detection	Multi-sensor obstacle detection	Multidirectional sensor placement + early ground-level hazard detection via vibration near wheels

4. CONCLUSION

This study successfully developed a smart stick to support the mobility of individuals with visual impairments. The device integrates an Arduino Uno microcontroller, three multidirectional ultrasonic sensors, vibration motors, and a Li-ion battery into a lightweight structure with wheels, designed for ease of use. Experimental results demonstrated reliable obstacle detection within a range of 0.1–4 meters with an accuracy exceeding 85%, and an average response time of 200 ms. The auditory and haptic feedback system was found to enhance user awareness of nearby hazards, while the operational duration of 6–8 hours per charge was considered adequate for daily mobility.

Nonetheless, some limitations were identified, including the lack of waterproofing, which reduces usability in outdoor environments, and the limited battery endurance for extended daily use. To address these constraints, future work will focus on enhancing the robustness and functionality of the device. Potential directions include waterproofing the design for all-weather reliability, integrating GPS-based navigation to provide route guidance and location awareness, and incorporating artificial intelligence algorithms for obstacle classification and intelligent navigation support. Furthermore, optimizing power consumption to extend operational time and improving ergonomic design to reduce weight will also be prioritized. These advancements are expected to transform the smart stick from a basic obstacle detection aid into a more comprehensive assistive system capable of delivering safer, more intelligent, and user-friendly navigation for individuals with visual impairments.

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