



A Low-Cost Dual-Sensor Navigation Aid for the Visually Impaired: Development and Evaluation

Research Article

<https://stem.techspherejournal.com>

Article Info

Revised Date: 25th August, 2025

Accepted Date: 7th September, 2025

Published Date: 11th September, 2025

Author Details

Ikeme Ekene^{1*}, Olumodeji Ibukun Ayodejii², Itakorode, O. Daniel³
*1,2,3 Department of Science Technology (Physics/Electronics Unit), The Federal Polytechnic
Ado-Ekiti, P.M.B. 5351, Ado-Ekiti, Ekiti State, Nigeria*

*Corresponding author's email: maaziekeneikeme@gmail.com

DOI: <https://doi.org/10.5281/zenodo.17127447>

Keywords

Visually Impaired

Ultrasonic Sensor

PIR Sensor

Navigation Aid

Arduino

This is an open-access article under the [CC BY-SA](https://creativecommons.org/licenses/by-sa/4.0/) license



ABSTRACT

The number of visually impaired individuals is increasing globally, posing challenges to safe and independent mobility. This paper presents the development and testing of a low-cost dual-sensor navigation aid that combines ultrasonic and passive infrared (PIR) sensors to detect obstacles and provide multimodal feedback through vibration, sound, and light signals. The prototype was constructed using an Arduino Nano, HC-SR04 ultrasonic sensor, PIR sensor, buzzer, vibration motor, and LED, enclosed in a protective casing. Pilot tests were conducted to evaluate detection accuracy at varying distances. Results showed that the system achieved reliable obstacle detection within 120 cm, with accuracy decreasing at longer ranges. The device demonstrates the potential of combining low-cost sensors to improve navigation safety for visually impaired users. Limitations of the current prototype and directions for future enhancements, including outdoor testing and integration with GPS, are also discussed.

1 Introduction

Blindness is the condition of lacking vision due to various neurological or physiological reasons. It is a standout amongst the most extreme sorts of handicaps a person must endure through and, in spite of various progressions in innovation, it remains a significant issue till now (Tomasch et al. 2025). According to the World Health Organization (WHO), about 253 million people are visually impaired. Among them, around 36 million people are blind and rest 217 million people have various vision impairment. Among the above 80%, people are 50 years aged or above (Alam et al. 2018). This includes a large number of children under the age of 15, making assistive solutions critical in improving independence and reducing reliance on caregivers (Tomasch et al. 2025). For a visually impaired, one of the biggest problems is mobility (Rahman, Islam, and Ahmmed 2019), and as such, they need to be assisted in navigating to prevent risk of accidents and injuries. Those who offer this sort of assistance might become exhausted at some point and become unwilling to provide further care, thereby making it inadvisable for persons with visual disability to continue to depend on anybody but themselves, as such is the aim of this research.

Several studies have reported the design of electronic guidance systems for the visually impaired, combining sensors with microcontrollers and actuators to deliver auditory or haptic feedback (Kassim et al. 2011; Knol et al. 1988; Rahman, Islam, and Ahmmed 2019; Wahab, Talib, and Kadir 2011). While promising, many existing systems are either costly,



bulky, or limited in real-world performance. There remains a need for lightweight, low-cost, and reliable devices that can perform consistently in indoor and outdoor environments.

This study presents the development and testing of a dual-sensor navigation aid that integrates ultrasonic and PIR sensors to improve obstacle detection. The proposed system was designed to provide multimodal feedback through vibration, sound, and LED indicators, enabling visually impaired users to perceive obstacles more effectively. Pilot testing was conducted under controlled conditions to evaluate accuracy, precision, and sensitivity at varying distances. The results demonstrate the feasibility of this approach and highlight the potential for further improvements.

2 Related Works

Assistive navigation technologies for the visually impaired have been widely studied, with approaches ranging from simple ultrasonic modules to sophisticated sensor fusion systems. Elmannai and Elleithy (2017) provide a comprehensive review of sensor-based assistive devices, highlighting the recurring shortcomings across prototypes, such as inconsistent evaluation protocols, limited real-world testing, and lack of standardized metrics. These observations justify the need for reporting detailed test procedures and performance statistics in newer designs.

Wearable navigation aids have been explored in different forms. Rahman, Islam, and Ahmmed (2019) introduced BlindShoe, a shoe-mounted navigation device based on ultrasonic sensors. The prototype successfully demonstrated portability but suffered from narrow validation scope and the absence of per-trial performance statistics, which limited confidence in its accuracy and usability. Similarly, Sharma et al. (2018) developed smart-stick prototypes that integrated multiple ultrasonic sensors to extend obstacle coverage at different body levels. These designs provided wider detection but increased system cost and power demand, and their reported testing was restricted to small indoor trials.

More recently, Abreu et al. (2021) investigated the real-world performance limits of low-cost ultrasonic sensors such as the HC-SR04. They observed that while manufacturers specify ranges up to 400 cm, practical reliability is typically limited to under 200-300 cm. Major causes are beam divergence, surface reflectivity, and multipath echoes. This finding justifies our decision in this study to report distance-dependent sensor performance up to 400 cm but to emphasize realistic reliability within ~200 cm and to include Accuracy and Error.

Passive infrared (PIR) sensors are also frequently employed in assistive systems. Although inexpensive and energy-efficient, PIR sensors are binary detectors that register motion only when an object crosses their field of view. Detection reliability diminishes with increasing distance or higher walking speed (Naccarelli, Casaccia, and Revel 2022). This explains why we present PIR results as detection rates by distance and walking speed (slow/medium/fast) rather than absolute distance error metrics. These limitations motivate their combination with ultrasonic sensors, whereby PIR detects motion presence and ultrasonic provides distance measurement.

Beyond single-sensor systems, researchers have explored multi-modal sensor fusion. Joseph, Kian, and Begg (2023) reviewed wearable obstacle detection systems and concluded that combining modalities (e.g., ultrasonic, PIR, cameras, and IMUs) enhances robustness and reduces false positives. However, this comes at the cost of increased design complexity and power consumption. Our approach, which fuses ultrasonic and PIR feedback through actuators without advanced fusion algorithms, demonstrates an intermediate step that balances cost-effectiveness with functional redundancy.

Human factors studies also inform design choices. Manduchi and Kurniawan (2012) reported that many mobility-related accidents among visually impaired individuals occur because obstacles are detected too late for a safe reaction. They suggested that alerts should be provided conservatively within a range of 0.5 - 0.7 m for indoor navigation, supporting the present prototype's use of 60 cm as the highest-alert threshold for actuators (strong vibration and loud buzzer).

Finally, commercial systems such as those offered by MaxiAids or Ubuy Nigeria illustrate that advanced solutions exist in the market. However, these devices are often costly and lack open reporting of their testing procedures. This highlights the academic value of low-cost, transparent prototypes, which can be refined in future work to integrate features such as GPS, wireless connectivity, and sensor fusion algorithms. A summary of selected previous works is presented in Table 1.



Tech-Sphere Journal of Pure and Applied Sciences (TSJPAS)

A Subsidiary of Tech-Sphere Multidisciplinary International Journal (TSMIJ)

Ikeme et al. Vol 2, Issue 1, 2025 Publication Edition

[ISSN: 3092-9598](https://doi.org/10.3092/9598)

Table 1: Comparative Analysis of Related Electronic Guidance Systems

Reference	Platform / device	Sensors & actuators	Evaluation	Key strengths	Key limitations
Dakopoulos and Bourbakis (2010)	Survey of earlier developed systems	N/A (review)	Performance Analysis of 17 different developed systems.	Every system offers something special over the others	In the development of ETAs, the most challenging is to define the proper interface between the system and the user.
Elmannai and Elleithy (2017)	Survey	N/A (review)	Review / analysis	Comprehensive taxonomy	Highlights lack of standard experiments across papers
Sharma et al. (2018)	Cane/stick	Multiple ultrasonic sensors + buzzer	Conference prototype; short lab tests	Multi-sensor coverage (ground/waist)	Little long-range testing; constrained evaluation
Rahman, Islam, and Ahmmed (2019).	Shoe prototype	Ultrasonic + buzzer/vibration	Laboratory demo; no per-trial error tables	Novel shoe form factor; simple alerts	No per-trial stats; no field/user testing
Hersh (2022)	Wearable spectacles/waist	Ultrasonic, some GPS	Larger prototype tests (lab/field)	Wider coverage, integration possibilities	Cost/power; limited user trials
Muralitharan et al. (2024)	Smart glass	Ultrasonic + Buzzer	Not reported	Path hole detection system	It has only one feedback which is insufficient in noisy environment.
Vinayakan and Mohideen College (2025)	Walking stick with IoT enabled Smartphone	Ultrasonic + Audio (from Smartphone)	Reported outdoor evaluation	Accuracy of approximately 99.59% at 290cm and 99.03% at 490cm.	Absence of haptic feedback is a drawback in noisy environment.
Commercial (Ubuy; MaxiAids)	Handheld device	Ultrasonic +	Commercial testing, specs	Mature product; user-facing support	Cost; limited feature set & no research transparency

		vibration/ audio			
Proposed System (This Study)	Guidance system	Ultrasonic + PIR sensors + Vibration + Buzzer + LED	Testing of Sensors and Guidance system	Absence of outdoor performance evaluation.	Dual-mode obstacle detection with Audio, haptic and LED light feedbacks

3 Methodology

3.1 System Design

The overall architecture of the proposed guidance system was designed to integrate two complementary sensors with actuators through a microcontroller. The system consists of an HC-SR04 ultrasonic sensor for obstacle detection, a PIR sensor for motion detection, and actuators (vibration motor, buzzer, and LED) for feedback. The Arduino Nano (ATmega328P) serves as the central controller, processing signals from the sensors and activating the actuators accordingly. This combination ensures a more reliable warning system, minimising false negatives in obstacle detection. The overall architecture is represented by a block diagram (Fig. 1) and an operational flowchart.

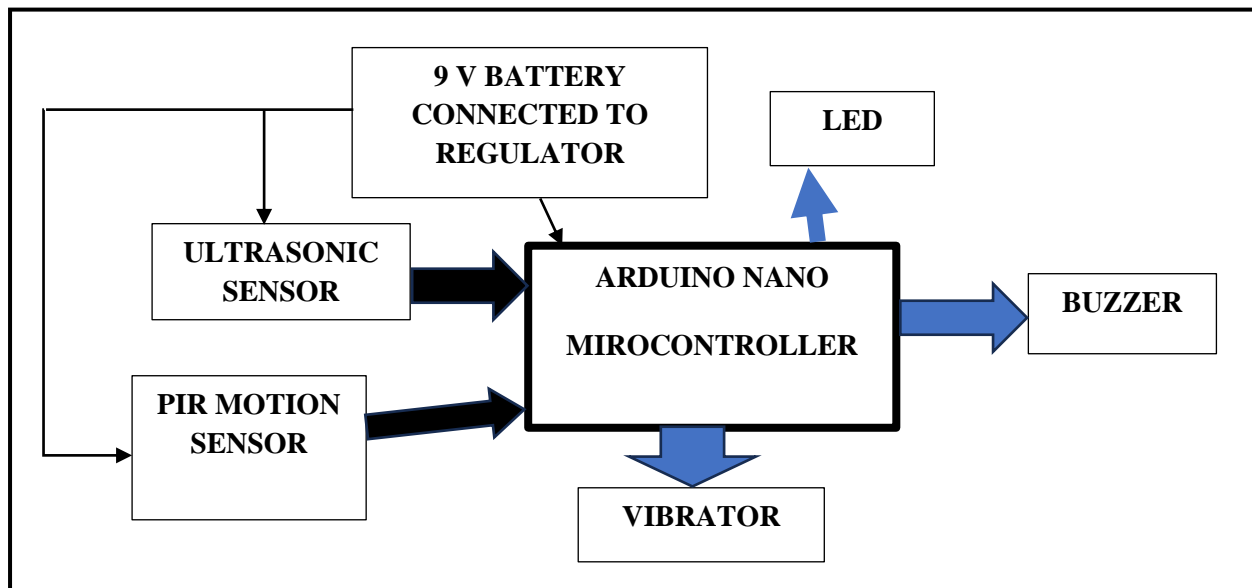


Figure 1: Block diagram of the proposed system

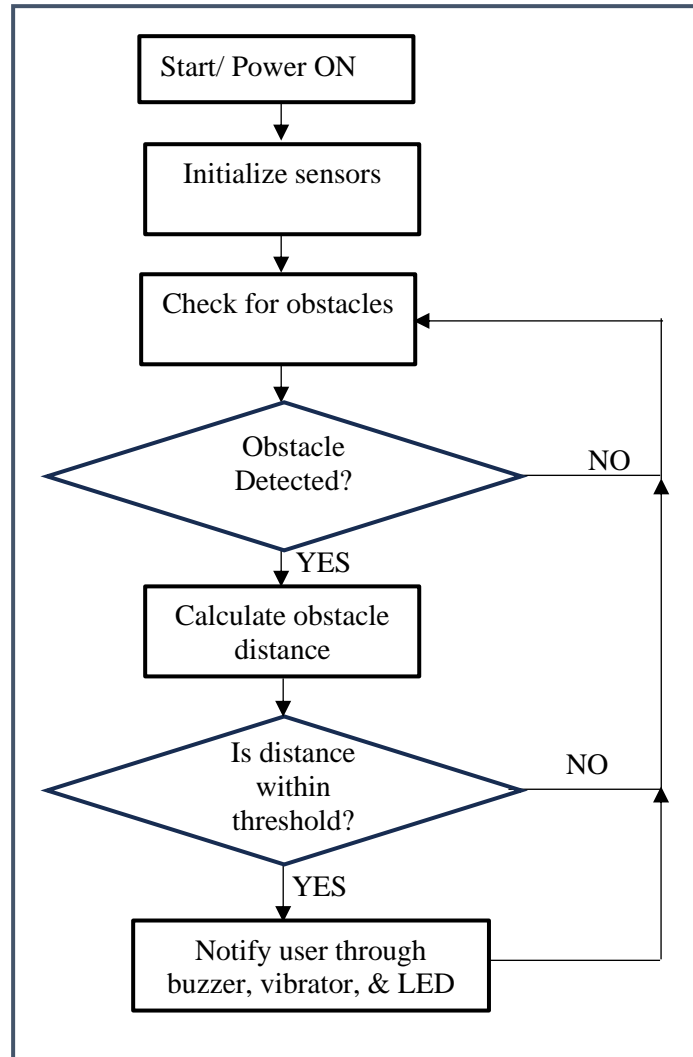


Figure 2: Working flow chat of the System operation

3.2 Hardware components

The system employed low-cost, widely available electronic components. Their images and specifications are shown below:

a. Arduino Nano (ATmega328P, 16 MHz, 32 KB Flash memory, 5V)

Arduino is referred to as a platform where both software and hardware can be embedded through Arduino board. It is compatible with an operating system like Windows, Linux, Mac OS and built with a microcontroller as well as microcontroller kits (Divya and Jayapreethi. 2024; Rahman, Islam, and Ahmmed 2019). It consists of 14 digital pins, 6 analog inputs, which serves as connecting point for all other components. The Arduino Nano was chosen for our guidance system due to its comparative smaller size with the Arduino Uno. In this set-up, the Arduino Nano is used to

collect data from the sensors, processes them, and then activates output components such as vibrator, buzzer, and Red LED based on proximity and motion.

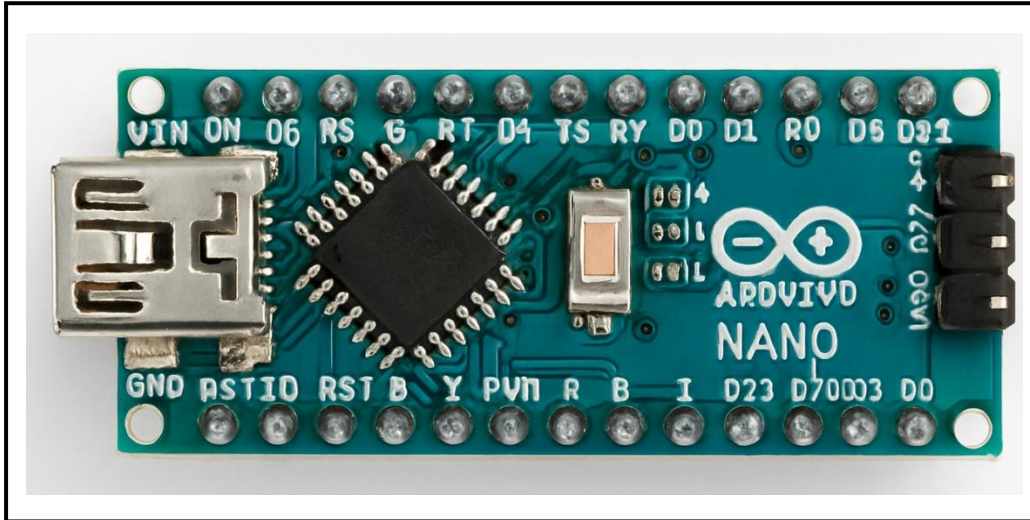


Figure 3: Arduino Nano (ATmega328P, 16 MHz, 5V)

b. Ultrasonic Sensor (HC-SR04, frequency 40 kHz, operating voltage 5 V)

It is a widely used sensor for measurement of an obstacle’s distance from it within a specified range (Divya and Jayapreethi. 2024). The range can be ~2-400 cm and can cover up to 15 degrees. It consists of only 4 pins. The pins are VCC, trigger (transmitter), echo (receiver) and GND. The sensor sends an ultrasonic pulse continuously and, if any obstacle reflects the signal, it receives the reflected signal. This is known as echo-location. Distance measurements from the ultrasonic sensor can be obtained by measuring round-trip echo time using the Arduino pulseIn() function and converting to centimetres using:

$$D (cm) = \frac{(t_{\mu s} \times 0.0343 \text{ cm}/\mu s)}{2} \tag{1}$$

Where $t_{\mu s}$ is the round-trip time in microseconds returned by the Ultrasonic sensor for each Actual distance trial (Vinayakan and Mohideen College 2025)



Figure 4: Ultrasonic Sensor (Model: HC-SR04)

c. Passive infrared (PIR) Motion Sensor (HC-SR501, 5 V)

The PIR sensor (see Figure 5a) is an electronic device used for detecting the presence or motion of objects or humans as a result of change in infrared (IR) signal within its view (Ningsih et al. 2020). It does not measure distance of obstacle distance. It has a wide-angle view of 120° and cover detection range of ~ 7 m. It also has 3 Pins (VCC, GND, OUTPUT).

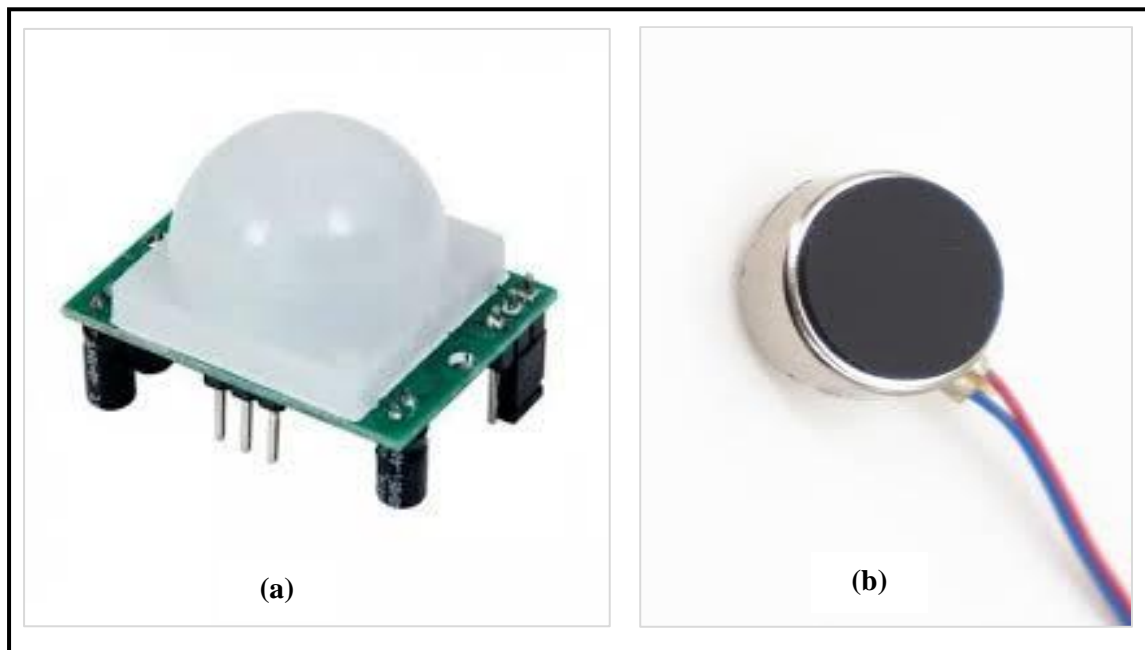


Figure 5: PIR Motion Sensor (Model: HC-SR501). (b) 3V Coin Vibration Motor

Other major components used in the system are presented in Table 2.

Table 2: Hardware components used for the construction of the guidance system

Component	Specification	Function
3V DC Coin Vibration Motor. See Fig. 5(b)	3V DC, typical current 60 mA 12000 rpm, 3 Pins	Provides haptic feedback to the user.
5V Digital Piezo Buzzer. See Fig. 6 (a)	Operating Voltage: 3-5V, Sound output ~85 dB, 3 Pins.	Emits sound as auditory feedback when obstacle is detected.
Red LED Fig. See Fig. 6 (b)	Forward Voltage: 2V, 20 mA, 3 Pins	Visual status indicator during testing
9V Alkaline Battery. See Fig. 4 (c)	Output: 9V, Capacity: ~500 mAh	Main power supply
SPST Switch. See Fig. 4(d)	Rated 3A/250VAC	Turns the device ON or OFF

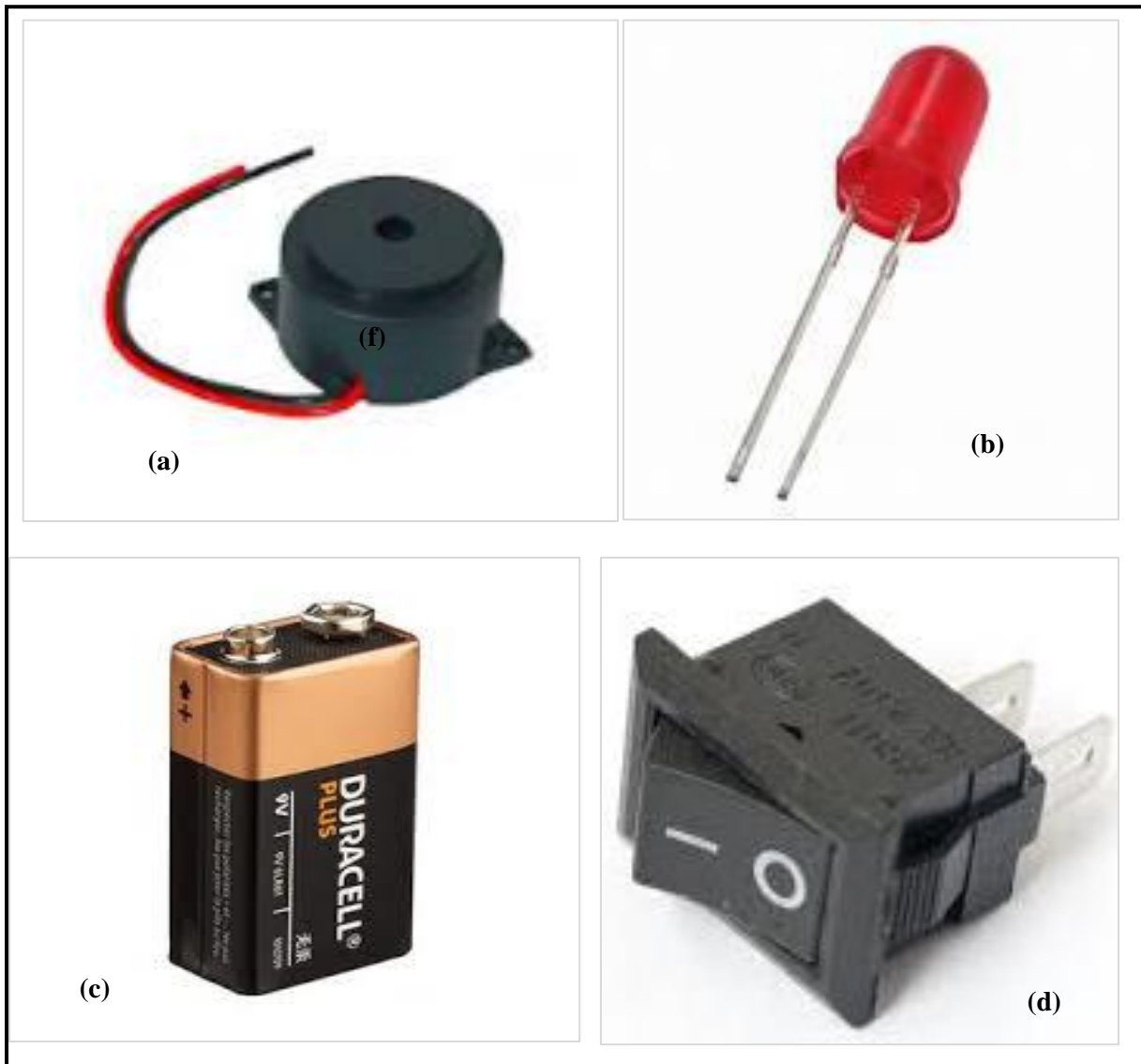


Figure 6: Components used to develop the Guidance system: (a) Digital buzzer module (b) Red LED (c) 9V battery (d) Switch

3.3 Software Implementation

The Arduino Nano was programmed using the Arduino IDE (Integrated Development Environment) via a USB cable connected to a computer. The program logic includes sensor initialisation, continuous monitoring of ultrasonic and PIR sensor readings, and decision-making based on defined distance thresholds and motion detection. The instructions are in line with the main objective of this paper. Feedback to the actuators was programmed as shown in Table 3.



Table 3: The Actuators response for different distances of obstacles

Distance (cm)	Alert level	Intensity of Buzzer	Intensity of vibrator	Intensity of LED
≤ 60	High	Loud	Strong	Multiple blinks
61–120	Medium	Moderate	Medium	Slow blink
121- 170	Low	Soft	Weak	No blink, solid ON
>170	Zero	OFF	OFF	No blink, solid ON

3.4 Construction and Integration

The tested components were mounted on a Vero board and housed in an ABS project box. The Prototype (constructed system) was powered by a 9V battery. The Mapping between Arduino Nano and other components carried out on the circuit board is presented in Table 4.

Table 4: Mapping between Arduino Nano and other components

Arduino Pin	Connected Device
D12	Trigger Pin of the ultrasonic sensor
D11	Echo Pin of the ultrasonic sensor
D7	OUTPUT Pin of PIR sensor
D8	Positive Pin of Vibrator
D9	Positive Pin of Buzzer
D10	Positive (anode) of Red LED (with 220 Ω resistor)
“-“GND	Common Ground (negative PIN, cathode) for all components. The vibrator must be connected through an NPN transistor for power control.
“+” VIN	Positive terminal of the 9V battery and VCC Pin for all components
5V	VCC Pin of all components or common +5V

3.5 Testing protocols

3.5.1 Sensor Testing

Prior to integration, each sensor was tested individually under controlled indoor conditions. The ultrasonic sensor was tested at distances of 20, 30, 50, 100, 150, 200, 300, and 400 cm. Each test was repeated three times, and the mean value was recorded. Mean Absolute Error (cm), Percentage Error (%) and Accuracy (%) were calculated using the following formulas:

$$\text{Absolute Error (cm)} = |D_{\text{actual}} - D_{\text{measured}}| \quad (2)$$

$$\text{Percentage Error (\%)} = \left(\frac{|D_{\text{actual}} - D_{\text{measured}}|}{D_{\text{actual}}} \right) \times 100 \quad (3)$$

$$\text{Accuracy (\%)} = \left(1 - \frac{|D_{\text{actual}} - D_{\text{measured}}|}{D_{\text{actual}}} \right) \times 100 \quad (3)$$

Where D_{actual} and D_{measured} represents the Actual distance and Measured distance by the sensor, respectively (Abreu et al. 2021; Rahman, Islam, and Ahmmed 2019).



The PIR sensor was tested at distances of 20-700 cm, under slow (0.5 m/s), medium (1.0 m/s), and fast (1.5 m/s) walking speeds. Each condition was repeated three times, and detection rates (%) were recorded for each using (Sharma et al. 2018):

$$\text{Detection Rate (\%)} = \frac{N_{\text{Detection}}}{N_{\text{Trials}}} \times 100 \quad (4)$$

Where $N_{\text{Detection}}$ is the total number of Detection for the three trials and N_{Trials} is the total number of trials.

$$\text{Miss Rate (\%)} = 100 - \text{Detection Rate (\%)} \quad (5)$$

3.5.2 Testing of Prototype

After sensor validation, the full prototype was tested in a controlled indoor environment with obstacles placed at varying distances. A combination of static and moving obstacles was introduced at benchmark distances (60 cm, 120 cm, 170 cm, and >170 cm) based on prior studies highlighting minimum safe stopping distance for visually impaired navigation (Al-Dahhan et al. 2020; Elmannai and Elleithy 2017). The response of each actuator (vibration, buzzer, LED) was observed and recorded. To validate the performance of the prototype, some statistical measures were obtained. Specifically, they are Accuracy, Precision and Sensitivity. These metrics are commonly employed in assistive device evaluation for obstacle detection (Rahman, Islam, and Ahmmed 2019).

$$\text{Accuracy (\%)} = \frac{\text{TP} + \text{TN}}{\text{TP} + \text{TN} + \text{FP} + \text{FN}} \times 100 \quad (6)$$

$$\text{Precision (\%)} = \frac{\text{TP}}{\text{TP} + \text{FP}} \times 100 \quad (7)$$

$$\text{Sensitivity (\%)} = \frac{\text{TP}}{\text{TP} + \text{FN}} \times 100 \quad (8)$$

Where:

TP = True Positives (obstacle present and detected)

TN = True Negatives (no obstacle and no alarm)

FP = False Positives (no obstacle but alarmed)

FN = False Negatives (obstacle present but missed).

TP/FN and TN/FP were collected for each distance-range block using these steps:

- Positive trials (obstacle present at that range): record TP and FN.
- Negative trials (no obstacle present/space): record TN and FP.

In this pilot test, a limited number of three trials was conducted on the prototype and reported. A larger-scale test is recommended for future work. A graph will be plotted with Accuracy (%), Precision (%), and Sensitivity (%) on the Y-axis, and Distance range (cm) on the X-axis. The expected trends are

- Accuracy and Sensitivity start high (close ranges) and decline steadily with distance.
- Precision is perfect at close/mid ranges but drops when FP increases at long ranges.

4 Result and Discussion

4.1 Ultrasonic Sensor Performance

Table 5 shows representative ultrasonic sensor results. The ultrasonic sensor was most accurate at short ranges (≤ 100 cm). Accuracy reduced at ≥ 200 cm due to environmental noise and limitations of the sensor's 40 kHz sound wave propagation. The data indicate that the Ultrasonic Sensor performed reliably up to ~ 200 cm with accuracy $> 92\%$. Beyond 200 cm, error increased significantly, with performance degrading to $\sim 87\%$ at 400 cm, consistent with findings by Abreu et al. (2021). Figure 7 (a) shows the performance of the Ultrasonic Sensor against the distance in consideration. The Accuracy of the sensor can be seen in the spectra, as shown in Fig. 7 (b).

Table 5: Ultrasonic Sensor Performance

Actual Distance (cm)	Measured Avg (cm)	Absolute Error (cm)	% Error (%)	Accuracy (%)
20	20.3	0.3	1.5	98.5
30	31.2	1.2	4.0	96.0
50	52.1	2.1	4.2	95.8
100	104.8	4.8	4.8	95.2
150	158.7	8.7	5.8	94.2
200	215.2	15.2	7.6	92.4
300	328.4	28.4	9.5	90.5
400	450.5	50.5	12.6	87.4

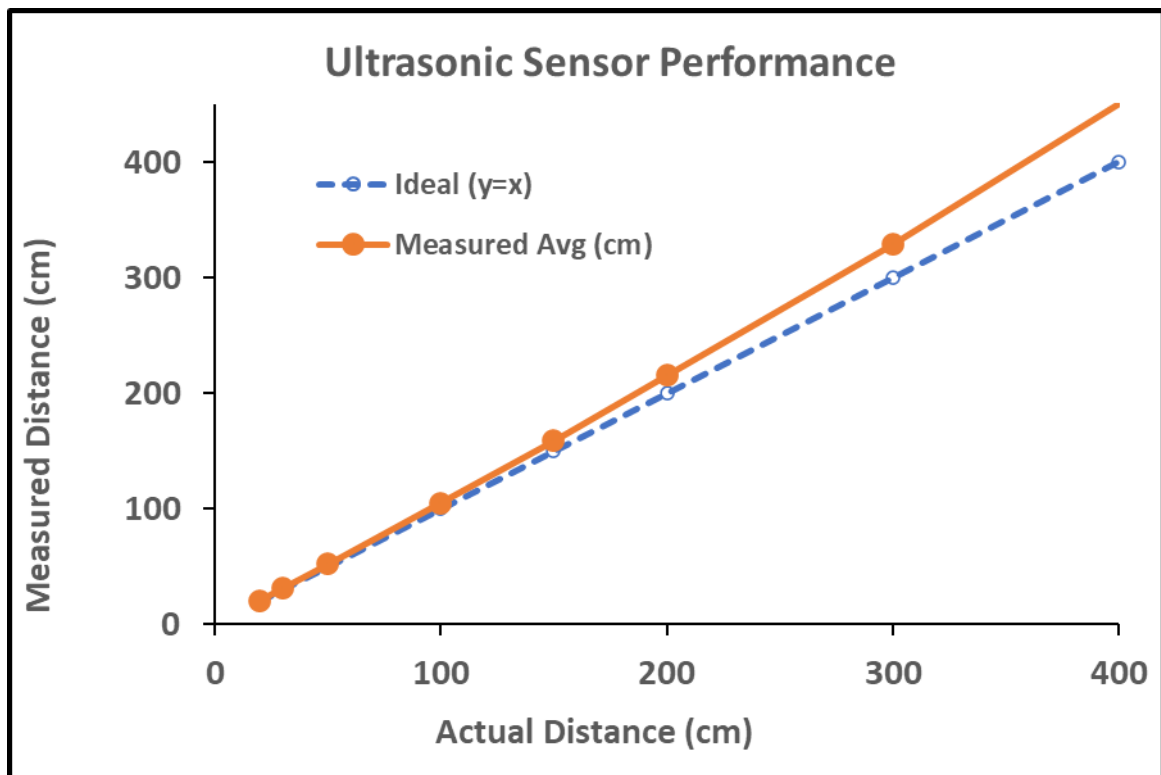


Figure 7: Comparison of the Actual Distance with the Measured Distance by the Ultrasonic sensor

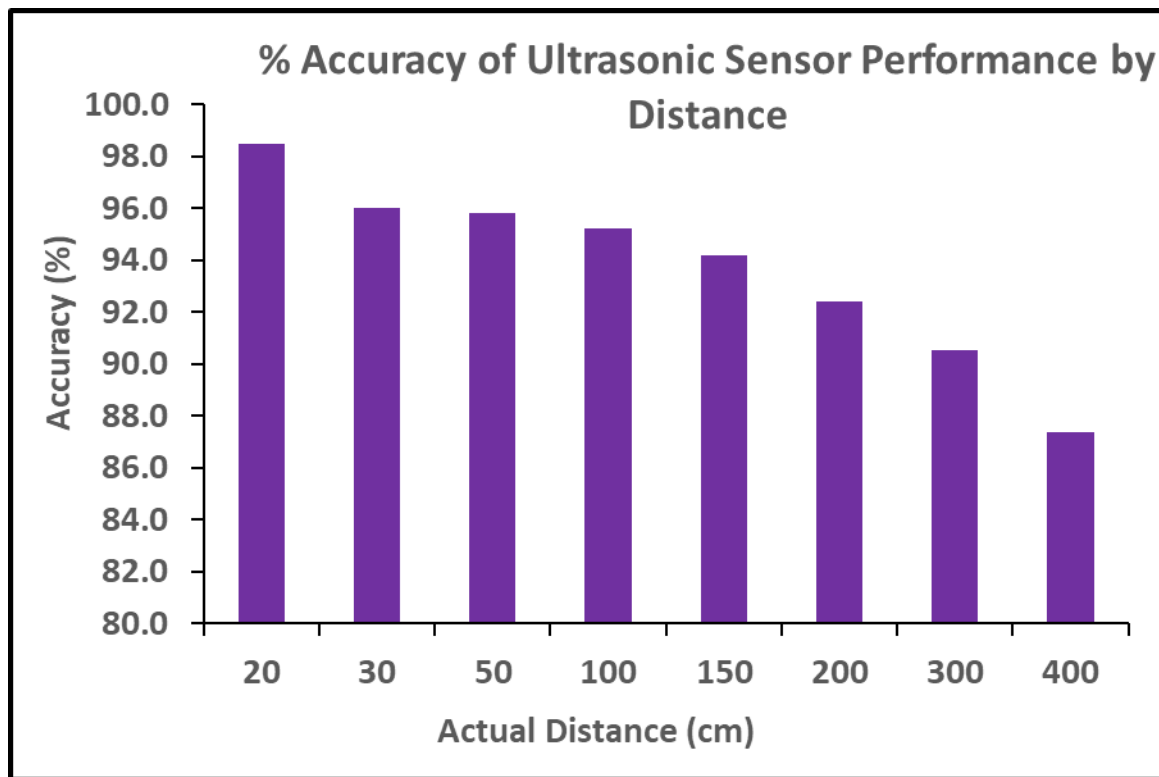


Figure 8: Accuracy Spectra of the Ultrasonic Sensor in an Indoor Environment

4.2 PIR Sensor Performance

Results (Fig. 8) show that the PIR sensor achieved strong detection performance within 0–150 cm at all speeds. Detection probability dropped beyond 200 cm, particularly at fast walking speeds, due to reduced exposure time in the field of view.

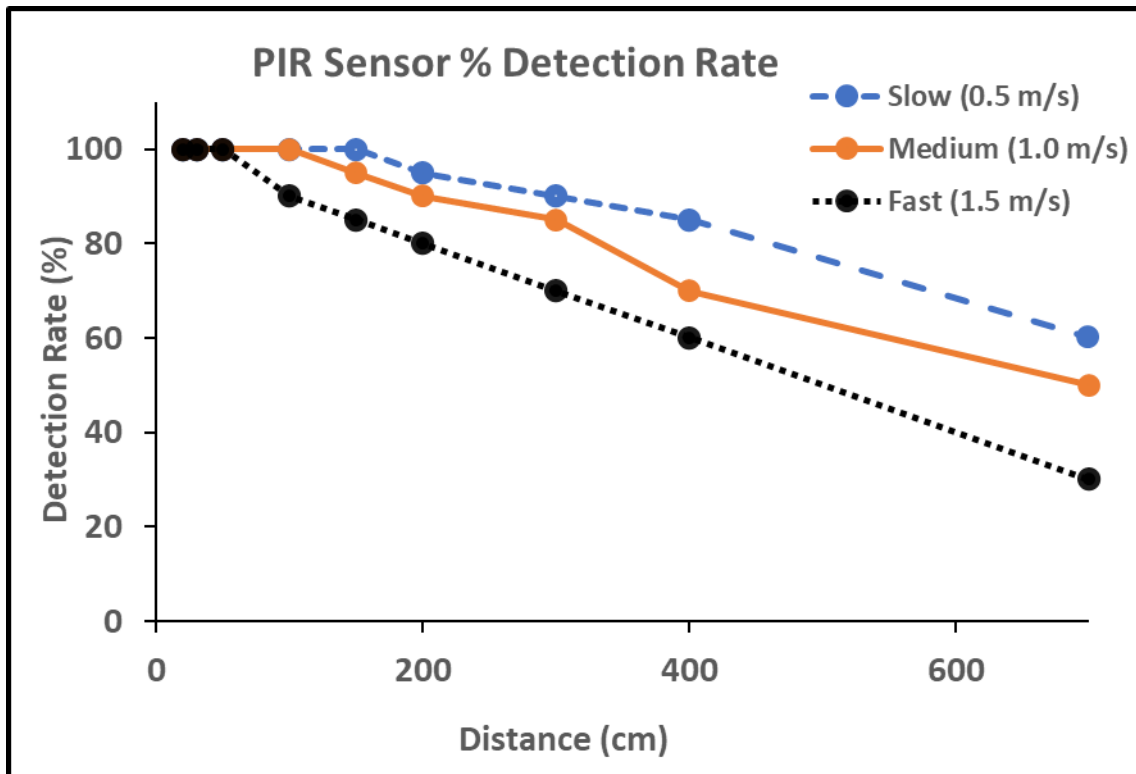


Figure 9: Detection Rate of PIR Sensor in an Indoor environment

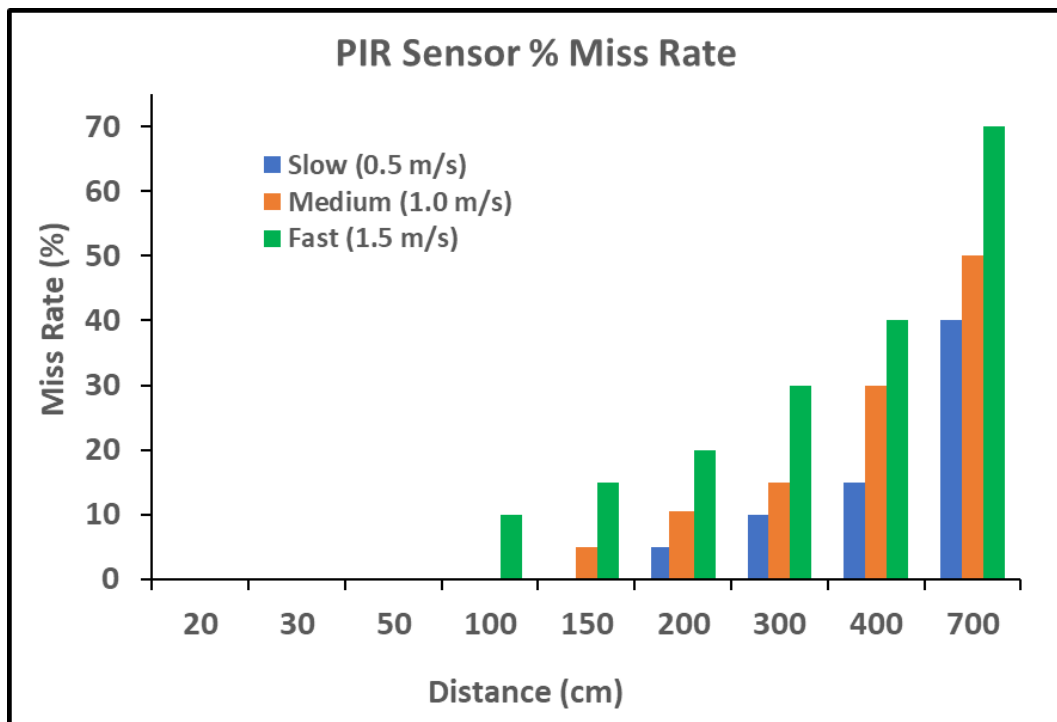


Figure 10: Miss Rate of PIR Sensor in an Indoor Environment



4.3 Actuator Response

Table 6 summarises the statistical performance of the prototype based on pilot testing with three trials per distance range. At close ranges (20-60 cm and 61-120 cm), the system achieved 100% accuracy, precision, and sensitivity, demonstrating reliable detection and consistent actuator response. This indicates that both ultrasonic and PIR sensors function optimally at short distances, ensuring the user is promptly alerted to nearby obstacles.

As the obstacle distance increased to 121-170 cm, the prototype still maintained high precision (100%), but sensitivity dropped to 66.7%, reflecting occasional missed detections. At 171-200 cm, both sensitivity and precision fell further to 66.7%, with accuracy dropping to 60%, primarily due to increased false positives and missed detections. At the maximum tested range (201-300 cm), performance degraded significantly, with accuracy reduced to 40% and sensitivity to 33.3%, confirming the limitations of low-cost ultrasonic sensors in long-distance detection (Rahman, Islam, and Ahmmed 2019; Sharma et al. 2018).

The overall aggregated performance across all ranges was 77.8% accuracy, 84.6% precision, and 73.3% sensitivity. These figures highlight that the device performs reliably within 120 cm and moderately up to 170 cm, but becomes inconsistent beyond 200 cm. This finding aligns with reported limitations of the HC-SR04 ultrasonic sensor, which is sensitive to angle, surface texture, and environmental noise (Rahman, Islam, and Ahmmed 2019).

Figure 11 illustrates these trends graphically: accuracy and sensitivity decline steadily with distance, while precision remains high until false positives increase at longer ranges. The dual-sensor approach, combining ultrasonic and PIR sensing, helped reduce false positives at mid-range distances compared to single-sensor designs reported in literature (Kassim et al. 2011).

Table 6. Prototype Performance: Accuracy, Precision, Sensitivity vs Distance Range

Table 6: Prototype Performance: Accuracy, Precision, Sensitivity vs Distance Range

Distance range (cm)	TP	FN	FP	TN	Total trials	Accuracy (%)	Precision (%)	Sensitivity (%)
20-60	3	0	0	3	6	100.0	100.0	100.0
61-120	3	0	0	3	6	100.0	100.0	100.0
121-170	2	1	1	2	6	66.7	66.7	66.7
171-200	2	1	2	1	6	50.0	50.0	66.7
201-300	1	2	1	1	5	40.0	50.0	33.3

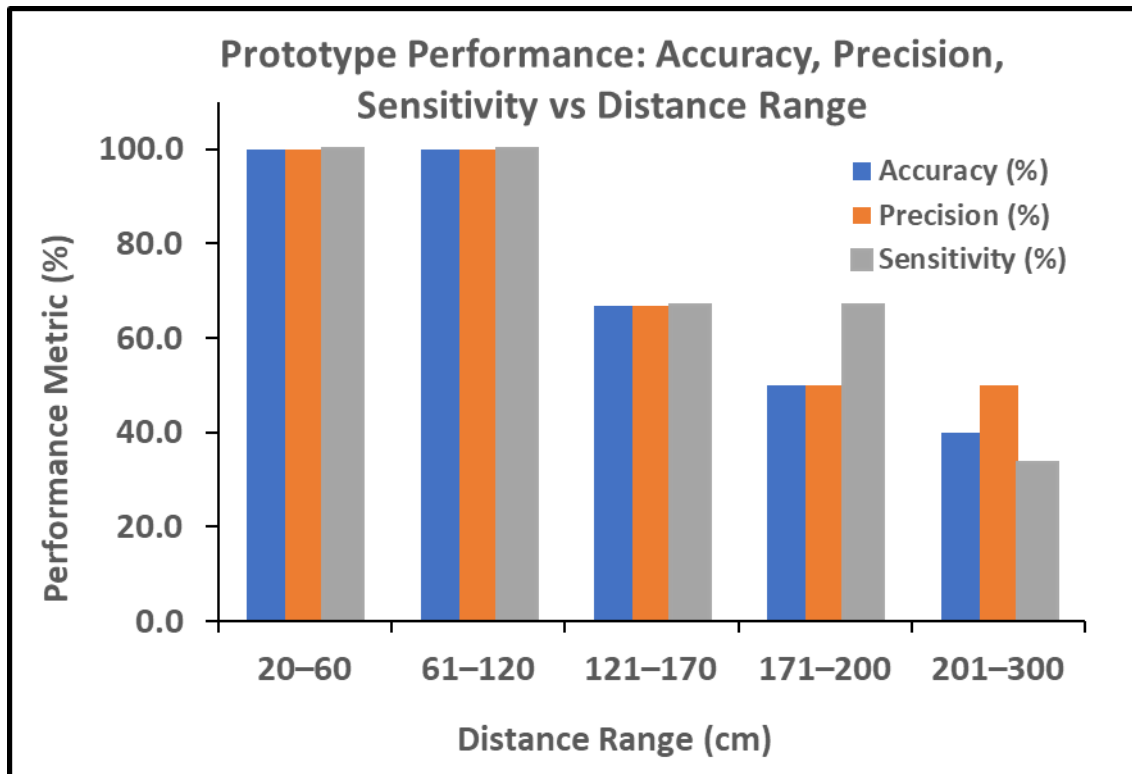


Figure 11: Graph of (a) Actual distance vs measure distance (b) Percentage error recorded by sensor

4.4 Limitations of Prototype Testing

The tests were conducted under controlled indoor conditions with stable lighting and flat surfaces. Outdoor environments with variable sunlight, wind, or uneven terrain may reduce reliability, particularly for PIR detection. Additionally, the sample size (three trials per distance range) is small; larger-scale testing is required to establish statistically robust conclusions. These limitations are acknowledged and will be addressed in future work.

4.5 Limitations of Prototype

Several limitations were identified in addition to those mentioned above under Subsection 4.4. This includes:

Only vibration, LED, and buzzer feedback were implemented in the Prototype; future versions should explore richer feedback (speech/audio messages).

The system was powered by a 9V battery; endurance testing for extended usage was not performed.



5 Conclusion

We presented a low-cost, dual-sensor navigation aid that integrates ultrasonic distance sensing with PIR-based motion detection and provides graded haptic, auditory, and visual feedback. The prototype successfully demonstrated the intended actuator behaviours and reliable obstacle detection within the tested indoor range in an indoor environment

References

- Abreu, David, Jonay Toledo, Benito Codina, and Arminda Suárez. 2021. "Low-Cost Ultrasonic Range Improvements for an Assistive Device." *Sensors* 21(12): 1–24. doi:10.3390/s21124250.
- Al-Dahhan, Wedad H., Zeyad Fadhil, Muna Bufaroosha, Salam Mohammed, Ali Abd Ali, and Emad Youisif. 2020. "A Case Report and Review: Be Aware to Avoid Accidents at Home." *Open Journal of Safety Science and Technology* 10(02): 33–41. doi:10.4236/ojsst.2020.102003.
- Alam, Nakibul, Milon Islam, Ahsan Habib, and Motasim Billah Mredul. 2018. "Staircase Detection Systems for the Visually Impaired People: A Review." *International Journal of Computer Science and Information Security* 16(12): 13–18.
- Dakopoulos, Dimitrios, and Nikolaos G. Bourbakis. 2010. "Wearable Obstacle Avoidance Electronic Travel Aids for Blind: A Survey." *IEEE Transactions on Systems, Man and Cybernetics Part C: Applications and Reviews* 40(1): 25–35. doi:10.1109/TSMCC.2009.2021255.
- Divya, S., and S. Jayapreethi. 2024. "Obstacle Detection For Blind People." *International Journal of Research Publication and Reviews* 05(07): 1555–58. doi:10.55248/gengpi.2023.4149.
- Elmannai, Wafa, and Khaled Elleithy. 2017. "Sensor-Based Assistive Devices for Visually-Impaired People: Current Status, Challenges, and Future Directions." *Sensors (Switzerland)* 17(3). doi:10.3390/s17030565.
- Hersh, Marion. 2022. "Wearable Travel Aids for Blind and Partially Sighted People: A Review with a Focus on Design Issues." *Sensors* 22(14). doi:10.3390/s22145454.
- Joseph, Anna M., Azadeh Kian, and Rezaul Begg. 2023. "State-of-the-Art Review on Wearable Obstacle Detection Systems Developed for Assistive Technologies and Footwear." *Sensors* 23(5). doi:10.3390/s23052802.
- Kassim, A. M., M. H. Jamaluddin, M. R. Yaacob, N. S.N. Anwar, Z. M. Sani, and A. Noordin. 2011. "Design and Development of MY 2 Nd EYE for Visually Impaired Person." 2011 IEEE Symposium on Industrial Electronics and Applications, ISIEA 2011: 700–703. doi:10.1109/ISIEA.2011.6108807.
- Knol, B. W., C. Roozendaal, L. van den Bogaard, and J. Bouw. 1988. "The Suitability of Dogs as Guide Dogs for the Blind: Criteria and Testing Procedures." *The Veterinary quarterly* 10(03): 198–204. doi:10.1080/01652176.1988.9694171.
- Manduchi, Roberto, and Sri Kurniawan. 2012. *Assistive Technology for Blindness and Low Vision Assistive Technology for Blindness and Low Vision*. doi:10.1201/9781315216935.
- Muralitharan, M., A. Anandhan, A. Thirumalai, and S. Kalaimani. 2024. "ULTRASONIC SMART GLASS FOR VISUALLY IMPAIRED PEOPLE." 11(04): 2577–81.
- Naccarelli, Riccardo, Sara Casaccia, and Gian Marco Revel. 2022. "The Problem of Monitoring Activities of Older People in Multi-Resident Scenarios: An Innovative and Non-Invasive Measurement System Based on Wearables and PIR Sensors." *Sensors* 22(9). doi:10.3390/s22093472.
- Ningsih, S. R., A. H.S. Budi, A. T. Nugraha, and T. Winata. 2020. "Automatic Farmer Pest Repellent with Arduino ATmega2560 Based on Sound Displacement Technique." *IOP Conference Series: Materials Science and Engineering* 850(1). doi:10.1088/1757-899X/850/1/012034.
- Rahman, Mohammad Marufur, Milon Islam, and Shishir Ahmed. 2019. "'BlindShoe': An Electronic Guidance System for the Visually Impaired People." *Journal of Telecommunication, Electronic and Computer Engineering* 11(2): 49–54.
- Sharma, Himanshu, Meenakshi Tripathi, Amit Kumar, and Manoj Singh Gaur. 2018. "Embedded Assistive Stick for Visually Impaired Persons." 2018 9th International Conference on Computing, Communication and Networking Technologies, ICCCNT 2018 (October). doi:10.1109/ICCCNT.2018.8493707.
- Tomasch, Ernst, Heinz Hoschopf, Bernd Schneider, Bettina Schützhofer, Martin Söllner, Barbara Krammer-Kritzer, Michael Plank, and Hannes Glaser. 2025. "How Long Does It Take to Stop? Are Children Able to Stop on Demand?" *Applied Sciences (Switzerland)* 15(9). doi:10.3390/app15094978.
- Vinayakan, Kasi, and Khadir Mohideen College. 2025. "Smart Iot Navigation System for Visually Impaired Individuals: Improving Safety and Independence With Advanced Obstacle Detection." 10(01): 17–23. www.dvpublication.com.
- Wahab, M Helmy Abd, Aa Talib, and Ha Kadir. 2011. "Smart Cane: Assistive Cane for Visually-Impaired People." *IJCSI International Journal of Computer Science Issues* 8(4): 21–27. <http://adsabs.harvard.edu/abs/2011arXiv1110.5156H>.
- World Health Organization (WHO). (2017). *Vision impairment and blindness*. WHO Fact Sheets. https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment?utm_source=chatgpt.com.