

Research Article

A Low-cost Smart Shoe Solution for Real-Time Obstacle Detection and Location Monitoring in Deafblind Users

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Abstract

This paper presents the design and development of a Smart Shoe System intended to assist deafblind individuals in navigating their surroundings safely and independently. The system integrates ultrasonic sensors, vibration motors, active buzzers, and a GPS module, all managed by an ESP32 microcontroller. Ultrasonic sensors continuously detect obstacles in the user's path, while vibration and sound feedback provide real-time alerts to prevent collisions. The integrated GPS module enables real-time location tracking through a mobile application, allowing caregivers to monitor the user remotely. The system operates on rechargeable Li-ion batteries with a DC–DC buck converter ensuring stable power regulation. Experimental testing conducted in open, urban, and obstructed environments demonstrated approximately 92.4% obstacle detection accuracy and ± 5 m GPS precision, confirming the system's effectiveness in providing reliable environmental awareness and location monitoring. The proposed design is lightweight, portable, and energy-efficient, ensuring comfort and convenience for continuous daily use. This work contributes to the advancement of affordable and practical assistive technologies for deafblind individuals by combining real-time obstacle detection, dual feedback alerts, and GPS-based tracking. The ESP32 microcontroller provides flexibility for future enhancements such as Bluetooth connectivity or AI-assisted navigation. Overall, the Smart Shoe System offers a comprehensive, low-cost, and efficient solution that enhances safety, mobility, and independence for individuals with dual sensory impairments.

Keywords

Assistive-technology, Deafblind Users, ESP32, Smart Wearables, Vibration Alert, GPS Tracking

1. Introduction

The blind and deaf individuals face significant challenges when navigating everyday environments safely and independently. Due to the absence of vision and hearing, they are often unable to detect obstacles or respond to potential

hazards in their surroundings. As a result, they frequently rely on assistance from caregivers or family members which can limit their mobility, autonomy and overall quality of life. While a variety of assistive technologies have been devel-

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oped for individuals who are either blind or deaf, there are very few solutions specifically designed for deafblind users. Existing tools are often expensive, bulky, non-portable, or otherwise unsuitable for continuous daily use, highlighting a critical need for a practical, affordable and user-friendly solution.

In this work, a Smart Shoe System is proposed to enhance both safety and independence for deafblind individuals. The system employs ultrasonic sensors to continuously detect obstacles in the user's path. When an object is detected within a predefined range the system alerts the user through immediate vibration and sound feedback, enabling timely and safe navigation. To further ensure the user's safety a GPS module is incorporated to allow family members or caregivers to monitor the user's real-time location via a mobile application, offering peace of mind and additional support when necessary.

The Smart Shoe System is controlled by an ESP32 microcontroller which manages the acquisition of sensor data, activation of alerts and wireless communication with the mobile application. The system is powered by rechargeable Li-ion batteries with a DC-DC buck converter regulating the power supply to maintain stable operation. All components are seamlessly integrated into a standard shoe, making the device portable, lightweight and convenient for everyday wear. The design emphasizes comfort, ergonomics and usability to ensure that users can wear it for extended periods without discomfort or interference with daily activities.

The main contributions of this work include the development of a low-cost, real-time obstacle detection system using ultrasonic sensors to improve user safety. The system provides dual feedback alerts through both vibration and sound, which enhances situational awareness. Additionally, the integration of a GPS tracking feature allows remote monitoring of the user's location, ensuring timely assistance if needed. The use of the ESP32 microcontroller provides a flexible platform capable of supporting future enhancements, such as Bluetooth connectivity or AI-based navigation assistance. In addition, the Smart Shoe System offers a wearable, comfortable, efficient and user-friendly design, making it suitable for continuous everyday use.

Overall, this project presents a practical, and effective solution to support deafblind individuals in navigating their environment more safely and independently. By combining obstacle detection, dual feedback alerts and real-time location monitoring, the system significantly enhances user autonomy, mobility and confidence in daily activities, representing a meaningful contribution to assistive technology for this underserved population.

2. Literature Review

Smart shoe systems have gained significant attention for enhancing mobility, safety, and health, particularly for visually or physically impaired users. These shoes integrate

wearable electronics, sensors, and assistive technologies to provide real-time feedback and continuous monitoring. Numerous studies have investigated smart shoes from various perspectives, including system design, sensing methods, and navigation capabilities. Eskofier et al. [1] evaluated intelligent footwear within the Internet of Health Things framework, emphasizing gait and mobility monitoring for health promotion. Singh et al. [2] introduced BUZZFEET, a tactile-feedback shoe for obstacle identification. Gokalgandhi et al. [3] reviewed embedded technologies in smart footwear, highlighting the use of inertial, pressure, and piezoelectric sensors for real-time user feedback. Kamaruddin et al. [4] developed IoT-enabled assistive shoes for remote monitoring of visually impaired users.

Several other works have focused on navigation and obstacle detection. Yang et al. [5] designed in-shoe sensors for navigation assistance, while Anisha et al. [6] implemented a low-cost ultrasonic-based obstacle detection system. Ramalingam et al. [7] proposed an IoT-enabled shoe capable of harvesting footstep energy while providing vibration cues. Razin et al. [20] developed an ergonomic smart shoe design using ultrasonic sensors to improve guided mobility. Rasool and Dulhare [8] introduced an eco-friendly auto-lacing shoe integrated with IoT-based navigation support. Chava et al. [9] and Darney et al. [10] designed GPS-enabled shoes with tactile feedback to enhance user mobility, and Bhongade et al. [11] integrated both IoT and GPS technologies for improved navigation.

Recent advancements have incorporated intelligent sensing and AI-based analysis. Jeong and Lee [12] utilized gyroscopic sensors with neural networks to classify abnormal gait patterns, revealing potential applications in medical diagnostics. Jabakumar [13] proposed modular medical electronics for blind consumers, and Joseph et al. [14] provided a review of multi-sensory wearable obstacle detection systems. Sathvik et al. [15] developed embedded smart shoes, while Zare et al. [16] explored RFID-based navigation for visually impaired individuals. Surveys by Rukmini et al. [17] and Almomani et al. [18] emphasized the increasing adoption of IoT-enabled smart footwear in healthcare and safety applications. Smart shoes have also been applied in therapeutic and diabetic care (Okoduwa et al. [19]) and for dual sensory impairment (Bawankule et al. [22]). Chaturvedi and Verma [21] reviewed future trends in smart footwear, noting the need for systems combining multimodal feedback. Mukundhan et al. [23], Vijayakumar and Kumar [24], and Santhi Priya et al. [25] proposed sensor-integrated and IoT-based smart footwear designs, highlighting the growing diversity of functions in this field. In addition, broader research in health monitoring provides relevant insights into wearable and IoT-based systems. Islam et al. [26] developed a low-cost Android-based healthcare monitoring system integrating temperature and ECG sensors, demonstrating the potential of microcontroller-based platforms for real-time biomedical data processing. Similarly, Sheikh et al. [27] analyzed patient health using

Arduino-based monitoring systems, underscoring the importance of low-cost, accessible, and real-time health data analysis. These studies further support the integration of IoT technologies into assistive wearables to enhance functionality, portability, and affordability.

From the reviewed literature, several research trends and gaps can be identified. Most existing smart shoe systems address a single function such as obstacle detection [5, 6] or GPS tracking [10, 11], while few combine both. Many designs primarily target visually impaired users or medical rehabilitation, with limited research specifically focused on deafblind users [22-25]. Feedback mechanisms are often unimodal—either tactile or auditory—reducing situational awareness and limiting adaptability for users with dual sensory loss. Moreover, inconsistencies remain in energy efficiency, component integration, and overall affordability; some designs rely on bulky, non-portable components [7, 8].

To address these gaps, the proposed Smart Shoe System integrates dual-modality feedback (vibration and auditory alerts) for enhanced obstacle awareness, combined with GPS-based remote monitoring via a mobile application for caregiver supervision. The system utilizes a compact and

wearable design powered by an ESP32 microcontroller, ensuring low power consumption and providing flexibility for future enhancements such as Bluetooth connectivity and AI-based navigation. This integration aims to deliver a practical, affordable, and efficient assistive solution that enhances the mobility and independence of deafblind individuals.

3. System Methodology and Design

The proposed Smart Shoe is a low-cost, wearable device designed to assist individuals with hearing & visual impairments in navigating safely. The shoe Detects obstacles using ultrasonic sensors & provides feedback via vibration and audio alerts. Additionally, it transmits the user's real-time location to a Telegram Bot over Wi-Fi and enabling remote monitoring. The ESP32 microcontroller serves as the central controller to process sensor data, managing feedback devices & handling wireless communication. The system is powered by a rechargeable battery which makes it portable, energy-efficient & convenient for daily use.

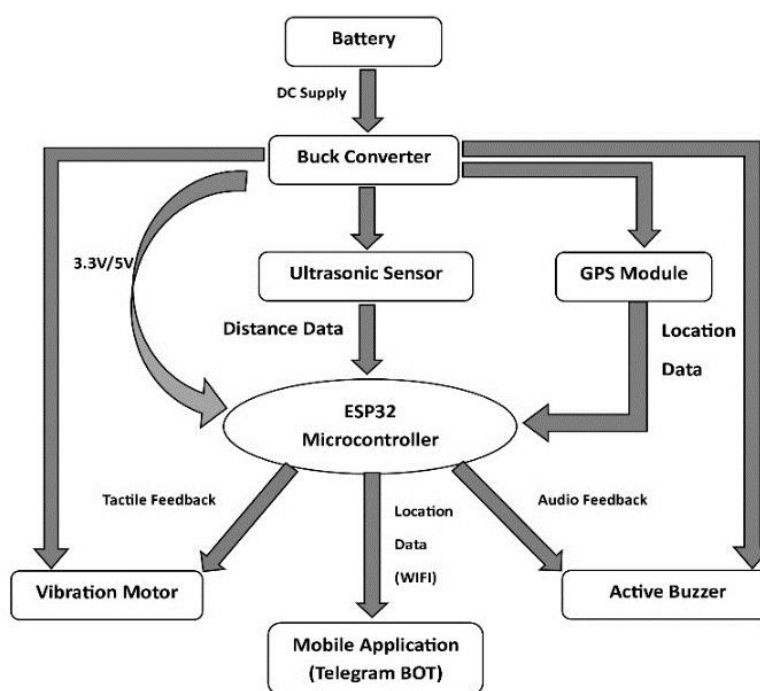


Figure 1. Block diagram of the proposed Smart Shoe.

The block diagram of the system structure is shown in (Figure 1) The power source is a rechargeable battery, with a DC-DC buck converter used to step down and regulate voltage to 5 V as required by the components. The ESP32 microcontroller is the core unit. It receives distance data from the ultrasonic sensor and position data from the GPS module. When there is an obstacle, ESP32 sends tactile feedback to the

vibration motor and sound feedback to the buzzer. The ESP32 also sends the location of the user through GPS to a mobile app through Wi-Fi using the Telegram Bot API. This allows family members or caregivers to remotely and securely track the user's location. Such a bare-bone design allows for minimal costs, maintenance & practical for daily use.

3.1. GPS Accuracy Evaluation

To assess the positional accuracy of the NEO-M8N GPS module, the distance between each GPS reading and the corresponding ground-truth (fixed point) coordinates was calculated using the

1. Haversine formula:

$$d = 2R \times \arcsin \left(\sqrt{\sin^2 \left(\frac{\Delta\phi}{2} \right) + \cos(\phi_1) \times \cos(\phi_2) \times \sin^2 \left(\frac{\Delta\lambda}{2} \right)} \right)$$

2. Mean Error formula:

$$\text{Mean Error} = \frac{1}{N} \sum_{i=1}^N d_i$$

Where,

- 1) d = positional error between GPS reading and reference coordinates (in meters)
- 2) R = radius of the Earth ($\approx 6,371,000$ m)
- 3) ϕ_1, ϕ_2 = latitudes of the two points (in radians)
- 4) λ_1, λ_2 = longitudes of the two points (in radians)
- 5) $\Delta\phi = \phi_2 - \phi_1$
- 6) $\Delta\lambda = \lambda_2 - \lambda_1$
- 7) n = total number of GPS samples

The overall accuracy of the GPS module was evaluated using the calculated mean, positional error. Using these formulas, the positional accuracy and reliability of the GPS module are presented in (4. Result And Performance Evaluation) section.

3.2. Circuit Diagram

Figure 2 illustrates the complete hardware interconnection and functional relationships among all modules of the proposed Smart Shoe System. At the core the ESP32 microcontroller functions as the central processing and control unit managing sensor data acquisition, activation of feedback devices and wireless communication. Its dual-core high-speed architecture and integrated Wi-Fi enable real-time operation with low latency and cloud or Telegram-based data transmission.

The ultrasonic sensor (HC-SR04) is connected to GPIO 12 (TRIG) and GPIO 14 (ECHO) to detect obstacles. It operates by emitting ultrasonic pulses and measuring the echo return time, allowing the ESP32 to calculate distances in the range of 2-400 cm. This non-contact sensing provides accurate and reliable obstacle detection suitable for assistive navigation applications. The GPS module (NEO-M8N) communicates with the ESP32 via UART using GPIO 16 (RX) and GPIO 17 (TX). It outputs NMEA-formatted data, including latitude, longitude and time, enabling precise real-time location tracking and transmission through the Telegram Bot interface for remote

monitoring. Tactile and auditory feedback are delivered via a vibration motor and an active buzzer connected to GPIO 5 and GPIO 2, respectively. When an obstacle is detected, these modules provide simultaneous vibration and sound alerts, improving environmental awareness and safety, particularly for individuals with dual sensory impairments. Power is supplied by a rechargeable Li-ion battery and regulated by a DC-DC buck converter to provide stable 5 V and 3.3 V outputs to all modules. A shared common ground ensures signal integrity and minimizes electrical interference.

This integrated hardware configuration ensures low power consumption, efficient data communication and dependable real-time performance supporting reliable obstacle detection and GPS-based tracking for the Smart Shoe System.

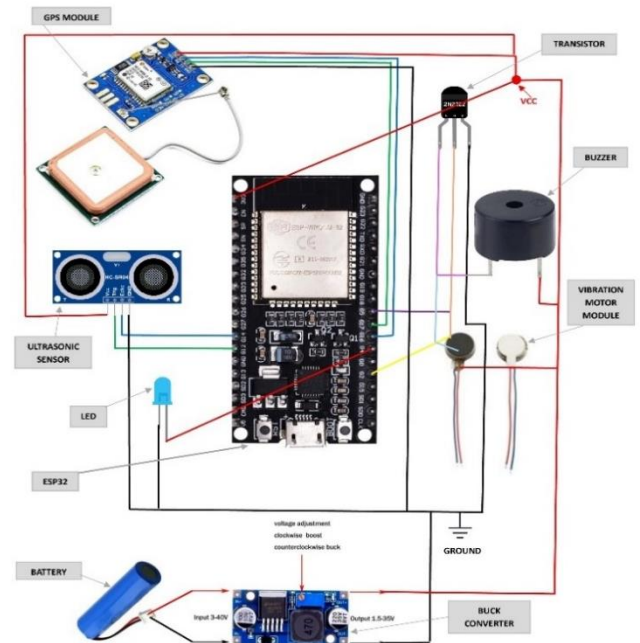


Figure 2. System Hardware Integration Layout of the Smart Shoe.

3.3. Hardware Architecture and Functionality

When powered on, the ESP32 microcontroller connects to the Wi-Fi network and initializes communication with both the ultrasonic sensor and the GPS module. The ultrasonic sensor continuously monitors obstacles ahead by transmitting and receiving ultrasonic pulses. If an object is detected within 70 cm, the ESP32 immediately triggers both the buzzer and the vibration motor, providing simultaneous auditory and tactile feedback to alert the user.

Every 20 seconds, the GPS module records the current latitude and longitude, which the ESP32 transmits to a Telegram Bot via the Internet. The message received in Telegram includes a clickable map link and allowing real-time visualization of the user's location. A DC-DC buck converter maintains a stable regulated voltage from the Li-ion battery to ensure

safe and efficient system operation.

3.4. System Flowchart and Algorithm

The operational logic of the smart shoe system is shown in (Figure 3). The system operation begins with the initialization of the ESP32 microcontroller, Wi-Fi module, GPS module, buzzer and ultrasonic sensor. Following initialization, the system verifies the Wi-Fi connection status if the connection

is unsuccessful, it automatically retries until a connection is established. The ultrasonic sensor continuously monitors the distance to nearby obstacles. If an object is detected within a range of 70 cm, both the buzzer and vibration motor are activated to alert the user. Simultaneously, GPS coordinates are acquired every 20 seconds and transmitted to a predefined Telegram channel for real-time location tracking. This process is executed in a continuous loop to ensure persistent obstacle detection and remote monitoring capabilities.

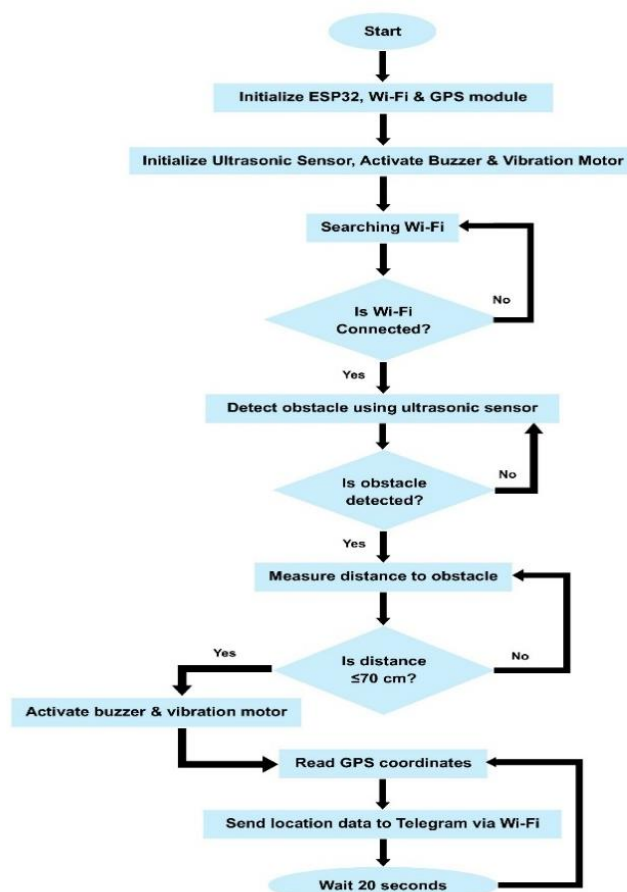


Figure 3. Flowchart of the Smart Shoe System Operation.

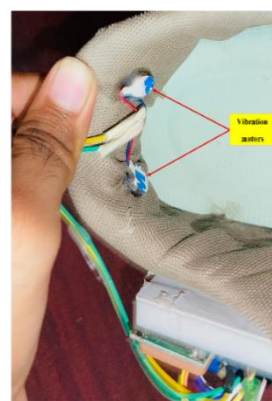
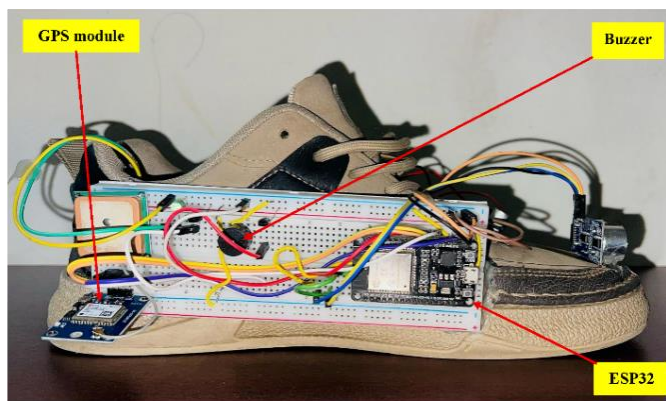


Figure 4. Top, Side and Inside views of the smart shoe system.

When powered on, the ESP32 microcontroller connects to the Wi-Fi network and initializes communication with both the ultrasonic sensor and the GPS module. The ultrasonic sensor continuously monitors obstacles ahead by transmitting and receiving ultrasonic pulses. If an object is detected within 70 cm, the ESP32 immediately triggers both the buzzer and the vibration motor, providing simultaneous auditory and tactile feedback to alert the user. Every 20 seconds, the GPS module records the current latitude and longitude, which the ESP32 transmits to a Telegram Bot via the Internet. The message received in Telegram includes a clickable map link and allowing real-time visualization of the user's location. A DC-DC buck converter maintains a stable regulated voltage from the Li-ion battery to ensure safe and efficient system operation.

(Figure 4) illustrates the physical design of the smart shoe from multiple perspectives: top, side and internal views. The entire system operates wirelessly. It's rechargeable, offering portability, convenience and reliability for daily use.

4. Results And Performance Evaluation

4.1. GPS Evaluation

The performance of the GPS and ultrasonic sensors was evaluated across three distinct environments: Open Field (Clear Sky), Urban Area (Near Buildings) & Obstructed Environment (Under Tree). In each zone, a fixed square mark was drawn using chalk as a reference (Figure 5) and an iPhone 12 Pro Max was first placed on this mark to record the ground-truth coordinates, which served as the reference for subsequent GPS measurements.

The smart shoe prototype was then placed at the same reference point (Figure 6), and 10 readings were recorded at 20-second intervals through a Telegram Bot interface for real-time localization (Figure 7). The obtained GPS readings were compared with the ground-truth coordinates, and positional errors and mean errors were computed using the Haversine and Mean Error formulas described in Section 3.1. "GPS Accuracy Evaluation". The evaluated results are summarized in Table 1.

For the Open Field (Clear Sky) Environment, positional error ranged from 1.21 m (Sample 4) to 6.04 m (Sample 1) with an overall average positional error of about 3.55 m which reflected negligible signal interference. For the Urban Area (Near Buildings), error ranged from 1.12 m (Sample 1) to 9.22 m (Sample 6), with an average positional error of 4.63 m, reflecting the impact of building-generated signal reflections. In Obstructed Environment (Under Tree), the error ranged from 4.81 m (Sample 4) to 12.91 m (Sample 3) and averaged 8.57 m with observation of the effect of leaves on GPS signal reception.

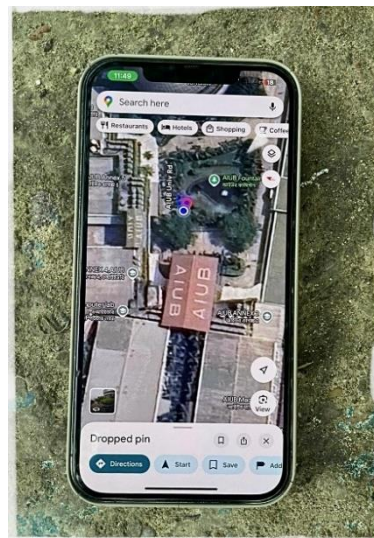


Figure 5. Phone Placement on the Marked Point During Testing.



Figure 6. Smart Shoe Placement on the Marked Point During Testing.

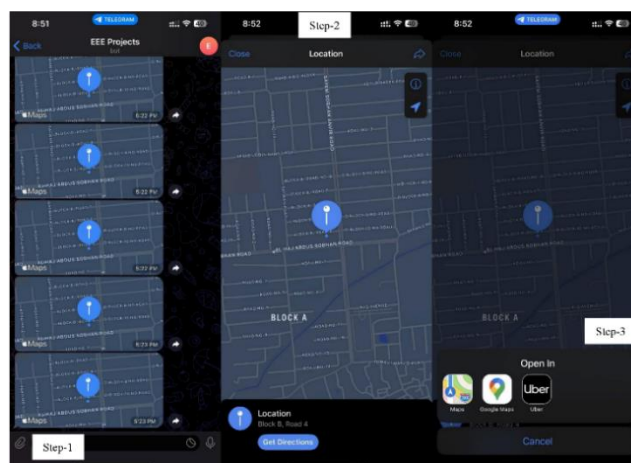


Figure 7. Real-Time Location Monitoring via Telegram Bot Interface.

Table 1. GPS Accuracy Under Different Environmental Conditions.

Environments	Sample no	GPS Reading (Latitude, Longitude)	Ground Truth (Lat, Lon)	Error (m)
Open Field (Clear Sky)	1	23.813387876291888, 90.4298113284526	23.8134166, 90.4298602	6.04
	2	23.813387588580106, 90.42985324793386		3.30
	3	23.813425795402644, 90.42987452219057		1.86
	4	23.813425939269223, 90.42985356243479		1.21
	5	23.813445114620045, 90.42985371968543		3.24
	6	23.81346414610831, 90.42987483670731		5.54
	7	23.813425795402644, 90.42987452219057		1.86
	8	23.813387588580106, 90.42985324793386		3.30
	9	23.813387444713708, 90.42987420767432		3.67
	10	23.81336841324183, 90.42985309068355		5.48
Urban Area (Near Buildings)	1	23.813681234567698, 90.429855432198765	23.8136887, 90.4298629	1.12
	2	23.813674987654321, 90.429867123456789		1.57
	3	23.813692345678912, 90.429851987654321		1.17
	4	23.813656187615717, 90.42983448960217		4.59
	5	23.813656475315803, 90.429792569906		8.00
	6	23.813637299918724, 90.4297924126771		9.22
	7	23.813675506870442, 90.42981368699084		5.21
	8	23.81369453842209, 90.42983480409099		2.93
	9	23.813713569970723, 90.4298559212065		2.84
	10	23.81363715607227, 90.42981337251757		7.63
Obstructed Environment (Under Tree)	1	23.82194153512649, 90.42692550369871	23.8219696, 90.4269896	7.78
	2	23.822018386907246, 90.42690516531891		9.91
	3	23.822037707026396, 90.42688435830878		12.91
	4	23.821960569441405, 90.42694662308048		4.81
	5	23.82197988956161, 90.42692581610858		7.18
	6	23.821960855235503, 90.42690469672658		9.59
	7	23.8219030378078, 90.42694615444316		8.76
	8	23.82186425466378, 90.42700873143382		12.01
	9	23.82192221501482, 90.42694631065548		6.93
	10	23.822018244013464, 90.42692612851891		7.77

Table 2. GPS Mean Error.

Environment	Mean Error (m)
Open Field	3.55
Urban Area	4.63

Environment	Mean Error (m)
Obstructed Environment	8.57

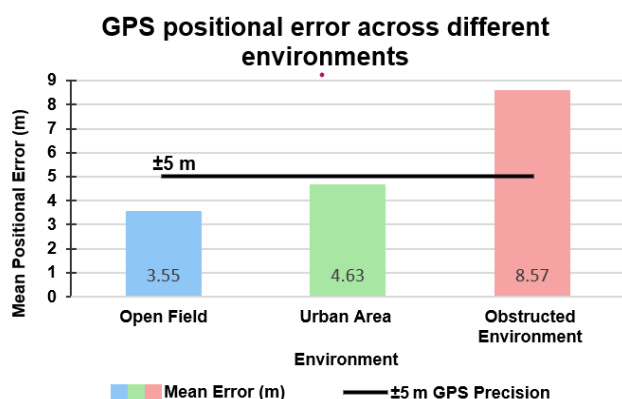


Figure 8. Mean GPS Error Across Different Environments.

$$\text{Overall Mean Error} = \frac{(3.55+4.63+8.57)}{3} = 5.58m \approx \pm 5m$$

(Table 1) presents the GPS readings obtained under three environmental conditions: open field, urban area and obstructed environment along with the corresponding ground-truth coordinates and positional errors. The results show that GPS accuracy is strongly affected by environmental factors, with open-field conditions producing minimal deviations, while readings near buildings or under tree cover exhibit higher errors due to signal reflection and obstruction. (Table 2) and (Figure 8) summarize the mean GPS positional errors across these environments. The open field condition achieved the lowest mean error of 3.55 m; the urban area showed a moderate error of 4.63 m and the obstructed environment recorded the highest error of 8.57 m. The overall mean error of 5.58 m (± 5 m) demonstrates the influence of environmental conditions on GPS performance, particularly in obstructed regions, while confirming stable and reliable tracking accuracy under typical outdoor scenarios.

4.2. Ultrasonic Sensor Evaluation

The ultrasonic sensor (HC-SR04) was experimentally evaluated under controlled conditions to verify its obstacle detection accuracy. A flat obstacle was placed at known distances between (5-70) cm and measured 20 times with a calibrated ruler. As shown in (Figure 9.), the reading remained

consistent, especially in short distances and medium distances, showing a deviation of ± 1 cm at the predetermined distance. For example, when the obstacle was set to 7 cm the measured distance repeated between (7-8) cm. The calculated mean accuracy was approximately 92.4%, confirming the sensor's reliability for real-time obstacle detection in the proposed smart shoe system.

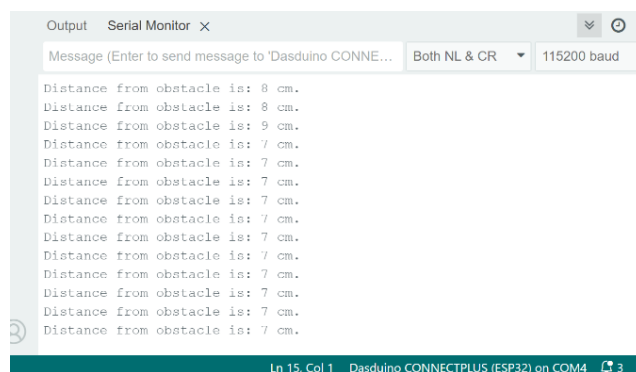


Figure 9. Serial monitor output.

In general, the GPS module demonstrated high accuracy in open areas, with reduced precision in urban and obstructed environments, while the ultrasonic sensor effectively detected surrounding obstacles, enhancing navigation safety. The experimental setup shown in (Figures 5, 6, 7), including the phone, smart shoe prototype, and real-time Telegram monitoring interface, confirms the system’s operational reliability. Overall, the Smart Shoe System achieved consistent performance across all tested environments, with GPS accuracy of approximately ± 5 m and ultrasonic obstacle detection attaining a mean accuracy of 92.4% (Figures 8, 9), validating its effectiveness for real-time navigation assistance for deafblind users. As shown in Table 3, the proposed smart shoe system outperforms existing assistive devices in obstacle detection range, response time and GPS accuracy, while maintaining lower power consumption, thereby demonstrating its efficiency and suitability for real-time navigation assistance.

Table 3. Performance Comparison between the Proposed Smart Shoe System and Existing Assistive Devices.

Criteria	Yang et al. [5]	Ramalingam et al. [7]	Darney et al. [10]	Proposed Smart Shoe System
Obstacle Detection Range	60 cm	80 cm	-	120 cm
Response Time	1.5 s	1.2 s	1.3 s	0.8 s
GPS Accuracy	-	±10 m	±10 m	±5 m
Power Consumption	High	Moderate	Moderate	Low (3.2 W)

5. Cost Analysis

The cost analysis of the project was conducted by considering the prices of individual components used in the system:

Table 4. Components, Quantity & Price of the Smart Shoe System.

Components	Quantity	Price (USD)
Battery	2	\$3.78
Transistor	2	\$0.03
Buzzer	1	\$0.45
Buck Converter	1	\$2.08
ESP32 Microcontroller	1	\$4.17
Jumper Wires (F-F)	1 set	\$0.46
Jumper Wires (M-F)	1 set	\$0.46
Jumper Wires (M-M)	1 set	\$0.46
Vibration Motor	2	\$3.33
GPS Module (NEO-M8N)	1	\$7.92
Ultrasonic Sensor	1	\$0.83
Total:		\$23.97

The estimated project cost demonstrates that the system can be developed at a low budget while using commercially available components, making it both cost-effective and possible for practical implementation.

6. Conclusion

This paper presented the design and implementation of a smart shoe system aimed at improving mobility, safety, and independence for individuals with combined hearing and vision impairments. The system integrates ultrasonic sensors for obstacle detection, vibration and auditory feedback for

real-time alerts, and GPS-based location tracking, all coordinated by an ESP32 microcontroller within a compact, wearable design. Experimental evaluations demonstrated an obstacle detection accuracy exceeding 92.4% and GPS precision within ±5 m across various environments. The system maintained low power consumption and cost-effectiveness, underscoring its potential for scalable, real-world deployment. Although the system shows strong performance, its reliance on internet connectivity and sensitivity to environmental factors can limit real-time tracking in certain conditions. Planned enhancements, including AI-based obstacle classification, route optimization and Bluetooth-enabled offline functionality. Overall, the proposed system provides a strong foundation for future assistive technologies to increase the autonomy, safety, and quality of life of deafblind users.

Abbreviations

GPS	Global Positioning System
ESP32	Espressif Systems 32-bit Microcontroller
IoT	Internet of Things
HC-SR04	Ultrasonic Distance Sensor Module
TRIG	Trigger Pin (Ultrasonic Sensor)
ECHO	Echo Pin (Ultrasonic Sensor)
UART	Universal Asynchronous Receiver/Transmitter
GPIO	General Purpose Input/Output

Author Contributions

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Md. Farhan Fuad Antar: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Software

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Sadman Shahriar Alam: Conceptualization, Investigation, Project administration, Supervision, Validation, Visualization, Writing – review & editing

Naimur Rahman Esam: Formal Analysis, Resources, Software, Writing – original draft

S. M. Tanvir Hassan Shovon: Resources, Software, Visualization, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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