Jurnal Penelitian Politeknik Penerbangan Surabaya
Vol 11, No 2, Agustus, 2026
p-ISSN: 1978-6832
e-ISSN: 2622-5948

Development of an ESP32-Based IoT Smart Cane for Multi-Directional Obstacle Detection and Real-Time Monitoring

[1]Raja Satria Ernovrianto Sirait, [2]Uvi Desi Fatmawati, [3]Azhari Diansyah Putra Sinaga, [4]Muhammad Rikfi Fahriza, [5]Guntur Ramadan, [6]Annisa Siregar, [7]Yosephine Lubis
[1,2,3,4,5,6,7] Department of Electrical Engineering, Faculty of Engineering and Défense Technology, Republic of Indonesia Defense University
Email: [1]*rajasatria312@gmail.com*, [2]*Uvi.fatmawati@idu.ac.id* , [3]*swanggisentul@gmail.com*, [4]*muhammadrifkifakhriza@gmail.com*, [5]*gunturramadhan258@gmail.com*, [6]*parwinparwin39@gmail.com*,[7]*yosephinelubis8@gmail.com*
corresponding: Uvi.fatmawati@idu.ac.id

DOI : https://doi.org/10.46491/jp.v11i2.2621

Abstract

Visual impairment limits independent mobility due to difficulties in recognizing obstacles and environmental conditions. This study aims to develop an ESP32-based Internet of Things (IoT) smart cane to improve navigation safety and real-time monitoring for visually impaired users. The proposed system integrates three ultrasonic sensors for multi-directional obstacle detection, a water level sensor for puddle detection, a DFPlayer Mini with speaker for audio feedback, a vibration motor for tactile feedback, and a GPS module connected to a Telegram Bot for location monitoring. The prototype was designed and evaluated through functional testing of each subsystem and overall system performance. The results show that the smart cane successfully detects obstacles, provides audio and vibration warnings, and transmits user location information remotely. The developed system demonstrates the potential of IoT-based assistive technology to support safer and more independent mobility for visually impaired users.
Keywords: Assistive Technology; ESP32; Internet of Things; Smart Cane

Article History:
Received: July 27, 2026 ; Revised: August 3, 2026 ; Accepted: August 6, 2026

INTRODUCTION

Visual impairment significantly affects an individual's ability to perform independent mobility due to limitations in obtaining visual information, recognizing obstacles, and understanding surrounding environmental conditions. Visually impaired users often experience difficulties when navigating unfamiliar areas because conventional white canes generally provide information only through direct physical contact with objects (Kathiria et al., 2024; Mulyana & Pertiwi, 2026; Rahmawati & Sunandar, 2018). This limitation may increase the risk of collisions, falls, and difficulties in identifying environmental hazards such as obstacles and water puddles (Pataropura et al., 2023). Therefore, the development of assistive devices capable of providing early environmental information and improving mobility safety is an important research area.

The development of embedded systems and Internet of Things (IoT) technology has encouraged various innovations in assistive devices for visually impaired users (Kathiria et al., 2024; Zhang et al., 2024). Several studies have attempted to improve conventional canes by integrating sensors, microcontrollers, and communication technologies. Mei et al. (2021) developed a smart cane using ultrasonic sensors and a water level sensor to detect obstacles and puddles, with warning outputs through audio and vibration mechanisms. However, the system was limited by the absence of location monitoring and IoT-based communication features. Panacara et al. (2021) proposed a smart cane equipped with GPS and Telegram communication to transmit user location information remotely. Nevertheless, the system mainly focused on emergency location sharing and did not emphasize multi-directional obstacle detection.

Further developments have integrated more advanced components, including ESP32-based processing systems, GPS modules, and wireless communication (Elmannai & Elleithy, 2017; Farooq et al., 2022; Khera & Whig, 2021; Zhang et al., 2024). Pataropura et al. (2023) developed a smart cane integrating ultrasonic sensors, water level sensors, GPS, and audio output to assist visually impaired users. However, the system did not implement tactile feedback and focused primarily on basic assistance functions. Puspitasari et al. (2024) introduced an IoT-based smart cane using ESP32, ultrasonic sensors, GPS, speakers, and Telegram for remote monitoring. Although the system demonstrated the potential of IoT implementation, the notification mechanism still relied on general alerts and did not provide detailed information regarding obstacle direction. Similarly, Zakhir and Maulana (2025) developed an ESP32-based smart cane incorporating ultrasonic and water-level sensing with vibration and audio warnings; however, the system did not provide GPS-based remote monitoring or multi-directional obstacle information.

Based on previous studies, various technologies such as ultrasonic sensors, GPS modules, IoT communication, and audio-based feedback have been implemented individually in smart cane development. However, existing research still shows limitations in integrating multi-directional obstacle detection, water hazard identification, informative audio feedback, tactile feedback, and real-time location monitoring within a single compact system. Therefore, a comprehensive assistive device that combines environmental sensing, user feedback, and remote monitoring remains necessary to improve the safety and independence of visually impaired users.

This study aims to develop an ESP32-based IoT smart cane for multi-directional obstacle detection and real-time monitoring. The proposed system integrates three ultrasonic sensors positioned on the left, front, and right sides for obstacle detection, a water level sensor for puddle identification, a DFPlayer Mini module with a speaker for directional audio feedback, a vibration motor for tactile alerts, and a GPS module connected to a Telegram Bot for remote location monitoring. The contribution of this research lies in the integration of multiple sensing, feedback, and communication mechanisms into a single IoT-based assistive device, followed by functional testing to evaluate the performance of each subsystem and the overall system.

METHOD

This study used a prototype-based engineering design method to develop and evaluate an ESP32-based Internet of Things (IoT) smart cane for visually impaired users. The research stages included system requirement analysis, hardware design, software design, component integration, prototype implementation, and functional testing. The system was designed to detect obstacles from multiple directions, identify water puddles, provide audio and tactile warnings, and transmit user location information through Telegram**.**

The proposed smart cane consists of several main components: an ESP32 microcontroller, three ultrasonic sensors, a water level sensor, a DFPlayer Mini module, a speaker, a vibration motor, a GPS Neo-6M module, an I2C LCD, and a rechargeable battery system. The ESP32 was used as the central processing unit because it supports sensor data processing and wireless communication through Wi-Fi. The ultrasonic sensors were positioned on the left, front, and right sides of the cane to detect obstacles based on object distance. The water level sensor was placed near the lower part of the cane to identify puddles or wet surfaces. The DFPlayer Mini and speaker were used to deliver audio warning messages, while the vibration motor provided tactile feedback when an obstacle or puddle was detected.

The hardware architecture of the proposed system is shown in Figure 1. The ultrasonic sensors send distance data to the ESP32, while the water level sensor provides analog readings to indicate the presence of water. The GPS Neo-6M module receives latitude and longitude data and sends them to the ESP32 through serial communication. The ESP32 then processes the sensor readings and determines the appropriate output response. When an obstacle is detected within the predefined threshold of 50 cm, the system activates a directional audio warning and vibration feedback. When the water sensor reading exceeds the threshold of 1300 ADC, the system triggers a puddle warning. The LCD is used as a diagnostic display during testing and maintenance, not as the primary output for visually impaired users.

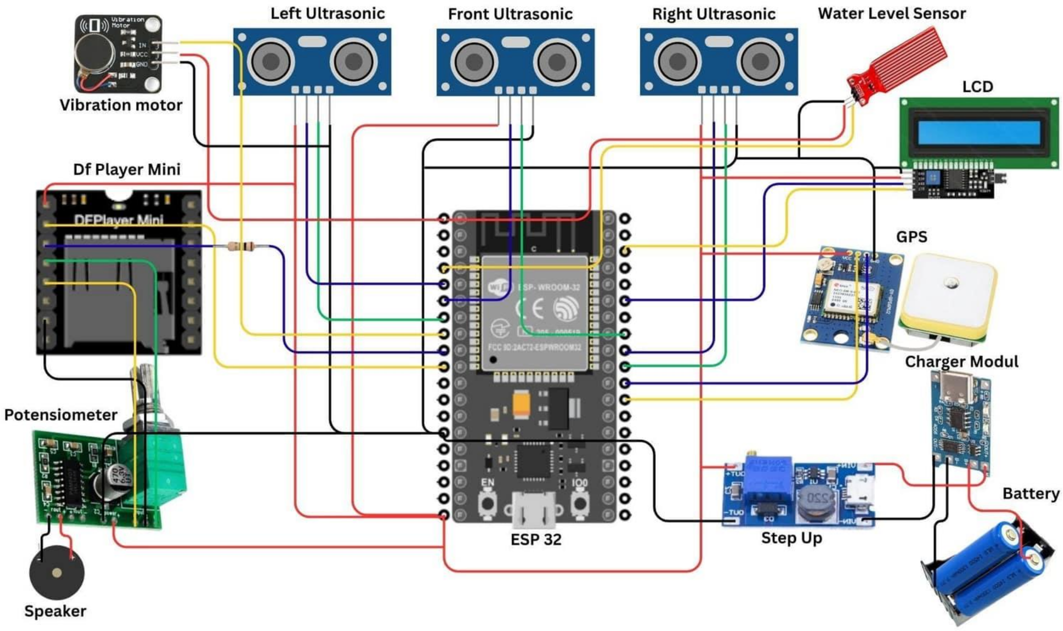

Figure 1. Hardware Architecture of the ESP32-Based IoT Smart Cane

The software was developed to control the interaction between sensors, actuators, and the communication module. The system starts by initializing the ultrasonic sensors, water level sensor, GPS module, LCD, DFPlayer Mini, vibration motor, and Wi-Fi connection. After initialization, the system provides an audio notification indicating that the device is ready to use. The ESP32 then reads sensor data continuously. If an obstacle is detected on the left, front, or right side, the system plays an audio message corresponding to the obstacle direction and activates the vibration motor. If water is detected, the system plays a puddle warning message. In parallel, GPS coordinates are processed and transmitted to a Telegram Bot when location monitoring is requested or activated.

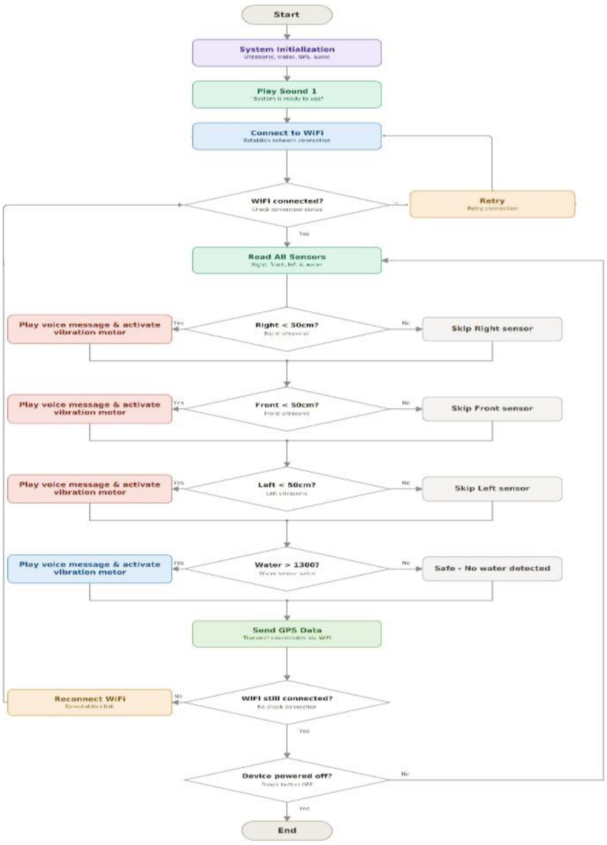

Figure 2. System Flowchart of the Smart Cane

Functional testing was conducted using a black-box testing approach to evaluate whether each subsystem produced the expected output based on given input conditions. The tested subsystems included the ultrasonic sensors, water level sensor, DFPlayer Mini and speaker, vibration motor, GPS module, Telegram Bot, LCD, and the integrated system. The parameters observed during testing included distance measurement accuracy, water detection status, warning output suitability, GPS coordinate availability, Telegram transmission success, and overall system response.

Table 1. System Testing Design

Tested Component	**Testing Procedure**	**Observed Parameters**
Ultrasonic sensors	Objects were placed at several measured distances in front of the left, front, and right sensors.	Measured distance, error percentage, accuracy percentage, and obstacle direction detection.
Water level sensor	The sensor was tested under dry and wet conditions.	ADC value, water detection status, and warning suitability.
DFPlayer Mini and speaker	Each obstacle and puddle condition was triggered.	Audio message suitability and response status.
Vibration motor	Obstacle and puddle detection conditions were activated.	Motor activation status and response suitability.
GPS Neo-6M	GPS readings were observed in several outdoor locations.	Latitude, longitude, coordinate availability, and GPS status.
Telegram Bot	Location data were sent through Wi-Fi connection.	Message delivery status and location data display.

LCD	Sensor, GPS, and connection status were observed during system operation.	Displayed information suitability.
Integrated system	The prototype was tested under obstacle, puddle, GPS, and Telegram monitoring scenarios.	Overall system response and subsystem integration.

The accuracy of ultrasonic sensor readings was calculated by comparing the measured distance with the actual distance. The error percentage and accuracy percentage were calculated using Eq. (1) and Eq. (2).

$$Error\ (\%) = \frac{Actual\ Distance - Measured\ Distance}{Actual\ Distance}\ x100 \quad (1)$$

$$Accuracy\ (\%) = 100 - Error\ (\%) \quad (2)$$

The testing results were analyzed descriptively by comparing the expected output and actual output of each subsystem. The system was considered successful when the sensor readings, warning outputs, GPS data acquisition, Telegram transmission, and integrated system response matched the expected operation.

RESULTS AND DISCUSSION

1. Prototype Implementation

The ESP32-based Internet of Things (IoT) smart cane prototype was successfully implemented by integrating obstacle detection, water detection, audio warning, vibration feedback, Global Positioning System (GPS) tracking, Telegram communication, and LCD-based diagnostic monitoring. The ESP32 microcontroller served as the main controller for processing sensor input and activating the corresponding output devices.

The prototype consisted of three ultrasonic sensors positioned on the left, front, and right sides of the cane, a water level sensor placed near the lower part of the cane, a DFPlayer Mini module, a speaker, a vibration motor, a GPS Neo-6M module, an I2C LCD, and a rechargeable battery system. The ultrasonic sensors were used to detect obstacles from different directions, while the water level sensor was used to detect puddles or wet surfaces. The DFPlayer Mini and speaker provided audio warnings, and the vibration motor provided tactile feedback. The GPS module and Telegram Bot supported remote location monitoring.

Figure 3. Prototype of the ESP32-Based IoT Smart Cane

The LCD was used during testing to display sensor readings, GPS status, and connection information. Although the LCD is not the primary interface for visually impaired users, it is useful for system diagnosis, testing, and maintenance by developers or caregivers.

2. Ultrasonic Sensor Testing

Ultrasonic sensor testing was conducted to evaluate the ability of the system to detect obstacles within the operational warning range. In this study, the obstacle-warning threshold was configured at 50 cm. The measurement results are presented in Table 2.

Table 2. Ultrasonic Sensor Measurement Results

No.	Actual Distance (cm)	Measured Distance (cm)	Error (%)	Accuracy (%)	Status
1	20	20	0.0	100.0	Successful
2	30	30	0.0	100.0	Successful
3	40	39	2.5	97.5	Successful
4	50	49	2.0	98.0	Successful
5	60	60	0.0	100.0	Successful

Based on Table 2, the ultrasonic sensor produced stable readings within the tested short-distance range. At 20 cm and 30 cm, the measured values were equal to the actual distances. At 40 cm and 50 cm, the sensor produced a small deviation of 1 cm. The most important result was obtained at 50 cm because this distance corresponds to the warning threshold used in the system. At this distance, the sensor measured 49 cm, resulting in an error of 2.0% and an accuracy of 98.0%.

These results indicate that the ultrasonic sensor was suitable for the intended function of the smart cane, which is to detect nearby obstacles and provide early warnings to the user. Although readings at distances greater than 60 cm may become more variable, this limitation does not significantly affect the main function of the system because the warning threshold was configured at 50 cm.

3. Water Level Sensor Testing

The water level sensor was tested under dry and wet conditions to evaluate its ability to detect puddles near the lower part of the smart cane. The system used a threshold value of 1300 ADC. A sensor reading above this threshold was interpreted as the presence of water and triggered audio and vibration warnings. Representative results are presented in Table 3.

Table 3. Representative Water Level Sensor Testing Results

No.	Condition	ADC Value	System Response	Status
1	Dry	0	No warning activated	Successful
2	Wet	1350	Audio and vibration warnings activated	Successful
3	Wet	1515	Audio and vibration warnings activated	Successful

Table 3 shows a clear difference between dry and wet conditions. In the dry condition, the sensor produced an ADC value of 0, and no warning was activated. In wet conditions, the representative ADC readings were 1350 and 1515, both exceeding the predefined threshold of 1300 ADC. As a result, the system activated the audio and vibration warnings.

Additional wet-condition observations produced ADC values ranging from 1242 to 1602. Most readings exceeded the configured threshold, indicating that the water level sensor could generally distinguish between dry and wet conditions. However, the presence of one wet reading below the threshold indicates that the sensor response may be affected by the amount of water and the contact area between the water and sensor surface.

4. Audio and Vibration Feedback Testing

The audio and vibration feedback systems were tested to determine whether the prototype could provide appropriate warnings based on detected environmental conditions. The DFPlayer

Mini module was used to play recorded voice messages through the speaker, while the vibration motor was used to provide tactile feedback.

Table 4. Audio and Vibration Feedback Testing Results

No.	Testing Scenario	Expected Output	Actual Output	Status
1	Obstacle detected on the left side	Left obstacle audio warning and vibration activated	Audio and vibration activated	Successful
2	Obstacle detected in front	Front obstacle audio warning and vibration activated	Audio and vibration activated	Successful
3	Obstacle detected on the right side	Right obstacle audio warning and vibration activated	Audio and vibration activated	Successful
4	Water detected	Puddle warning audio and vibration activated	Audio and vibration activated	Successful
5	No obstacle or puddle detected	No warning activated	No warning activated	Successful

Based on Table 4, the audio and vibration feedback systems worked according to the expected output. Directional audio warnings allowed the system to provide more specific information than a simple buzzer because the warning could indicate whether the obstacle was detected on the left, front, or right side. The vibration motor also provided an additional tactile warning, which is useful when the surrounding environment is noisy or when audio warnings are less noticeable.

5. GPS Neo-6M Testing

The GPS Neo-6M module was tested at three outdoor locations within the UNHAN RI area to evaluate its ability to obtain latitude and longitude coordinates. The test focused on coordinate acquisition because the GPS subsystem was designed to support real-time location monitoring through Telegram. The testing results are presented in Table 5.

Table 5. GPS Neo-6M Testing Results

No.	Testing Location	Latitude	Longitude	Testing Result	Status
1	Rectorate Field, UNHAN RI	-6.525.617	106.879.812	Coordinates successfully obtained	Successful
2	Football Field, UNHAN RI	-6.521.807	106.876.888	Coordinates successfully obtained	Successful
3	Retention Pond, UNHAN RI	-6.520.367	106.878.117	Coordinates successfully obtained	Successful

Based on Table 5, the GPS Neo-6M module successfully obtained coordinate data at all tested outdoor locations. The recorded coordinates consisted of latitude and longitude values, which were then processed by the ESP32 and prepared for transmission through the Telegram Bot. These results indicate that the GPS subsystem was functional for supporting the location monitoring feature of the smart cane.

The results should be interpreted as coordinate acquisition testing rather than GPS accuracy testing because the obtained coordinates were not compared with reference coordinates from a calibrated positioning device. Therefore, further testing is required to measure positional accuracy, coordinate error, and acquisition time under different environmental conditions.

6. Telegram Bot Testing

Telegram Bot testing was conducted to verify whether the ESP32 could transmit GPS coordinate data through an internet connection. In this test, GPS data obtained from the Neo-6M module were sent to the Telegram Bot using Wi-Fi communication. The result of the Telegram transmission test is shown in Figure 4.

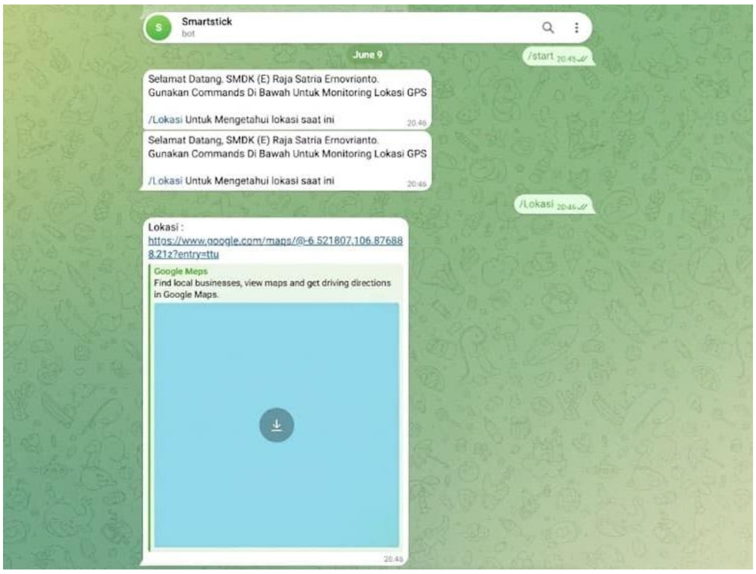

Figure 4. Telegram Bot Display of GPS Coordinate Transmission

Figure 4 shows that the Telegram Bot successfully received the GPS coordinate message transmitted by the ESP32. The received message contained latitude and longitude information that could be used by family members or caregivers to monitor the user's location remotely. This result indicates that the Telegram communication subsystem functioned according to the expected operation.

The use of Telegram provides a practical monitoring method because it does not require the development of a separate mobile application. However, this feature depends on Wi-Fi availability and internet connection quality. If the internet connection is unstable or unavailable, the transmission of GPS data may be delayed or unsuccessful.

7. Overall System Testing

The overall system was tested using a black-box testing approach to evaluate whether the integrated prototype produced the expected output under several operational scenarios. The tested scenarios included obstacle detection, water detection, audio and vibration feedback, GPS activation, Telegram location transmission, and full system operation.

Table 6. Overall System Testing Results Using Black-Box Testing

No.	Testing Scenario	Expected Output	Actual Output	Status
1	Object detected at a distance of less than 50 cm	Audio and vibration warnings activated	Audio and vibration warnings activated	Successful
2	No object detected	No warning activated	No warning activated	Successful
3	Water detected by the water level sensor	Puddle warning activated	Audio and vibration warnings activated	Successful
4	GPS activated in outdoor location	Latitude and longitude obtained	Coordinates displayed for UNHAN RI test locations	Successful
5	Location transmission through Telegram Bot	GPS coordinates sent to Telegram	Coordinates received in Telegram chat	Successful
6	Entire system activated	All components operate normally	All main functions operated	Successful

Table 6 shows that the integrated system operated according to the expected output in all tested scenarios. When an object was detected at a distance of less than 50 cm, the system activated the warning output. When water was detected, the system activated the puddle warning.

The GPS module successfully obtained coordinate data, and the Telegram Bot successfully received the transmitted location information.

These results indicate that the integration of obstacle detection, water detection, warning output, GPS tracking, and Telegram communication was successfully implemented. The local safety functions, including obstacle detection, puddle detection, audio warning, and vibration feedback, remained the primary functions of the device. Meanwhile, the GPS and Telegram features supported remote monitoring by family members or caregivers.

8. Discussion

The testing results show that the proposed ESP32-based IoT smart cane can perform the main functions required for short-range mobility assistance. The ultrasonic sensor demonstrated stable performance within the operational warning range of up to 50 cm. At the 50 cm threshold, the measured distance was 49 cm, with an error of 2.0% and an accuracy of 98.0%. This result supports the suitability of the ultrasonic sensor for detecting nearby obstacles before direct physical contact occurs.

The water level sensor also functioned according to the expected operation. In dry conditions, the sensor produced an ADC value of 0 and did not activate any warning. In wet conditions, representative readings exceeded the 1300 ADC threshold and activated the audio and vibration warnings. This feature is important because puddles and wet surfaces may create mobility risks for visually impaired users. Nevertheless, the variation in wet-condition readings indicates that further calibration is needed to improve detection consistency.

The integration of audio and vibration feedback provides a stronger warning mechanism than a single-output system. Audio feedback allows the system to deliver specific warning messages, while vibration feedback provides an additional tactile signal. This combination is useful because environmental noise may reduce the effectiveness of audio warnings.

The GPS and Telegram testing results show that the system can support remote location monitoring. The GPS Neo-6M module successfully obtained latitude and longitude coordinates at the Rectorate Field, Football Field, and Retention Pond within the UNHAN RI area. The Telegram Bot also successfully displayed the transmitted GPS coordinates in the chat interface. However, GPS and Telegram functions depend on external conditions, including satellite signal availability, Wi-Fi connectivity, and internet stability.

Overall, the proposed system successfully integrates multi-directional obstacle detection, puddle detection, audio feedback, vibration feedback, and Telegram-based location monitoring into a single smart cane prototype. The main limitation of this study is that testing was still conducted at the prototype and functional testing stages. Future testing should involve more varied environmental conditions, longer battery endurance evaluation, GPS accuracy measurement using reference coordinates, and direct usability testing with visually impaired users.

CONCLUSION

This study developed an ESP32-based Internet of Things (IoT) smart cane for visually impaired users by integrating multi-directional obstacle detection, water detection, audio feedback, vibration feedback, GPS tracking, and Telegram-based location monitoring. The prototype was able to detect nearby obstacles using ultrasonic sensors, identify wet conditions using a water level sensor, and provide warning outputs through voice messages and vibration. The ultrasonic sensor showed stable performance within the operational warning range, particularly at the 50 cm threshold, while the water level sensor was able to distinguish dry and wet conditions based on ADC readings.

The GPS Neo-6M module successfully obtained latitude and longitude coordinates at outdoor test locations within the UNHAN RI area, and the Telegram Bot successfully displayed the transmitted location data through the chat interface. These results indicate that the proposed system can support both local mobility assistance and remote monitoring functions. The integration of directional audio warnings and tactile feedback provides a more informative warning mechanism than a single buzzer-based output.

Overall, the developed smart cane demonstrates the potential of IoT-based assistive technology to improve mobility safety and monitoring support for visually impaired users. However, this study was still limited to prototype-level functional testing. Further research should include direct usability testing with visually impaired users, GPS accuracy measurement using reference coordinates, battery endurance evaluation, and testing under more varied environmental conditions.

ACKNOWLEDGEMENTS

The authors declare that an artificial intelligence tool, ChatGPT by OpenAI, was used to assist in the process of language refinement, English translation, and grammar checking. The tool was not used to collect data, conduct experiments, generate research results, or determine the scientific conclusions of this study. All technical content, experimental data, analysis, and final interpretations were reviewed and approved by the authors.

REFERENCES

Elmannai, W., & Elleithy, K. (2017). Sensor-based assistive devices for visually impaired people: Current status, challenges, and future directions. *Sensors*, *17*(3), 565. https://doi.org/10.3390/s17030565

Farooq, M. S., Shafi, I., Khan, H., De La Torre Díez, I., Breñosa, J., Martínez Espinosa, J. C., & Ashraf, I. (2022). IoT-enabled intelligent stick for visually impaired people for obstacle recognition. *Sensors*, *22*(22), 8914. https://doi.org/10.3390/s22228914

Kathiria, P., Mankad, S. H., Patel, J., Kapadia, M., & Lakdawala, N. (2024). Assistive systems for visually impaired people: A survey on current requirements and advancements. *Neurocomputing*, *606*, 128284. https://doi.org/10.1016/j.neucom.2024.128284

Khera, Y., & Whig, P. (2021). IoT-based novel smart blind guidance system. *Journal of Computer Science and Engineering*, *2*(2), 80–88. https://doi.org/10.36596/jcse.v2i2.172

Mei, J., Surapati, A., & Santosa, H. (2021). Perancangan tongkat untuk tunanetra menggunakan sensor ultrasonik dan sensor water level. *Majalah Teknik Simes*, *15*(1), 46–54. https://doi.org/10.32663/simes.v15i1.1749

Mulyana, A., & Pertiwi, D. E. (2026). Penggunaan tongkat konvensional dan tongkat sensor dalam meningkatkan kemandirian anak tunanetra pada siswa SDLB. *JIIP - Jurnal Ilmiah Ilmu Pendidikan*, *9*(2), 2068–2075. https://doi.org/10.54371/jiip.v9i2.10689

Panacara, P., Siregar, M., & Taryo, T. (2021). Rancang bangun piranti penuntun tongkat pintar untuk penyandang tunanetra berbasis mikrokontroler Arduino. *HUMANIS (Humanities, Management and Science Proceedings)*, *1*(2), 774–785.

Pataropura, A., Adhinugraha W, D., Fernand, M., & Kurnia, Y. (2023). Perancangan tongkat pintar sebagai alat bantu jalan untuk meningkatkan kualitas hidup peyandang tunanetra. *Rubinstein*, *1*(2), 91–102. https://doi.org/10.31253/rubin.v1i2.2133

Puspitasari, R., Diamah, A., & Maruddani, B. (2024). Rancang bangun tongkat pintar berbasis Internet of Things (IoT) bagi penyandang tunanetra. *Jurnal Pendidikan Vokasional Teknik Elektronika*, *7*(2), 57–63. https://doi.org/10.21009/jvote.v7i2.54684

Rahmawati, R. Y., & Sunandar, A. (2018). Peningkatan keterampilan orientasi dan mobilitas melalui penggunaan tongkat bagi penyandang tunanetra. *Jurnal Ortopedagogia*, *4*(2), 100–103. https://doi.org/10.17977/um031v4i12018p100

Zakhir, Z., & Maulana, H. (2025). Smart blind stick design using HC-SR04 sensor and ESP 32 based water level sensor to improve the mobility of blind persons. *Tsabit Journal of Computer Science*, *1*(2), 60–67. https://doi.org/10.56211/tsabit32

Zhang, X., Huang, X., Ding, Y., Long, L., Li, W., & Xu, X. (2024). Advancements in smart wearable mobility aids for visual impairments: A bibliometric narrative review. *Sensors*, *24*(24), 7986. https://doi.org/10.3390/s24247986