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Wearable Obstacle Detection for Visual Impairment People with GPS Location

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Abstract

In 2021, the International Agency for the Prevention of Blindness released the Vision Atlas, which showed that 43 million people worldwide are blind and 295 million people have moderate-to-severe visual impairment. For many people, mobility is a significant barrier that affects their everyday activities and social relationships. The traditional white cane is useful for navigating, but it can't identify obstacles higher than waist level. In order to overcome this constraint, this research developed a wearable, compact obstacle detection device that uses an ESP32 microcontroller and ultrasonic sensors to provide sound alerts using a buzzer. To further ensure user safety, a GPS device built within the cap delivers location updates via Telegram. The process comprised initially simulating using the Arduino IDE and Wokwi software after assembling and then testing the hardware. The design was influenced by feedback from visually impaired students at Sekolah Menengah Kebangsaan Tun Ismail in Parit Raja. The device's capacity to identify obstacle within range of 2 cm to 300 cm and provide location updates was tested for reliability, precision, and functionality. The ultrasonic sensor produced separate sound alarms for varying distances, and the results demonstrated that it could precisely identify obstacles within the designated ranges. Ensuring real-time tracking, the GPS module was dependable in sending location updates and answering requests from Telegram. For visually impaired people, the designed wearable obstacle detection cap is a useful addition to a white cane, increasing their mobility and freedom. By addressing the shortcomings of the available aids, this creative solution offers a useful and trustworthy secondary tool for obstacle detection and location.

1. Introduction

The International Agency for the Prevention of Blindness's Vision Atlas, which compiles the most recent information on eye health, was officially launched in 2021. According to the findings, there are 295 million people worldwide with moderate-to-severe vision impairment and 43 million people who are blind (Mahmoud et al., 2015). Individuals with visual impairments face significant challenges in navigating their surroundings independently, often relying on assistance from others. The primary issue to be addressed is the development of self-contained solutions for the visually impaired, particularly those that aid in detecting and avoiding obstacles encountered from above while moving. Currently, the most widely used solution for visually impaired individuals is the white cane. Although traditionally considered the best friend of visually impaired individuals, the white cane is not always as effective as intended, highlighting the need for innovative solutions to enhance its effectiveness in facilitating mobility and independence for the visually impaired (Elsonbaty, 2021).

Other innovative solutions include smart wearable obstacle detection glasses for people with low vision. These glasses record and analyze the surroundings, projecting information onto a screen near the user's eyes to enhance spatial awareness (Mahmoud et al., 2015). However, the design is bulky due to the full-screen assembly, which may cause discomfort if worn for extended periods. The smart blind stick project enhances the traditional white cane by providing audio alerts and enabling phone calls for assistance, though it may still have limitations in complex environments (Elsonbaty, 2021). IoT-based smart shoes connect with smart glasses to cover a wider area by detecting obstacles. However, technological difficulties with these devices may cause confusion for the user, as they may detect obstacles at a large scale, leading to false detections (Chava et al., 2021). The combination of object recognition, obstacle detection, and text-to-speech features offered by Netra smart gloves may assist with navigation. However, accuracy issues may arise due to frequent hand movements, making it difficult to detect objects (Srivastava & Singh, 2018). Finally, when combined with other aids like canes or GPS, a sonar-based obstacle-avoidance belt can improve travel aids using ultrasonic technology. However, it requires specific conditions to be effective, such as being tucked into the shirt (Raghuvanshi et al., 2014).

The project aimed to overcome these challenges by creating a compact, wearable device capable of real-time obstacle detection using an ultrasonic sensor with a detection range of 2 to 300 cm. The ESP32 microcontroller was employed to process sensor data and generate sound alerts through a buzzer. Additionally, a GPS module was incorporated to enhance the device’s functionality. This GPS module, managed by a separate ESP32 microcontroller, was connected to the user’s hotspot or Wi-Fi. Upon pressing the alarm button, a parent’s Telegram account received alerts notifying them of any unexpected events. To add an additional level of security and comfort, parents could use a Telegram bot to request the cap user’s current location at any time.

2. Material

The project relied on an ultrasonic sensor and an ESP32 microcontroller, which were programmed using the Arduino IDE and simulated using Wokwi. The ultrasonic sensor, chosen for its affordability and ability to measure distances within a few centimeters, detected obstacles in front of the user. The ESP32 read and processed this data, alerting the user to the distance between them and the obstacle through sound. Additionally, a separate ESP32 microcontroller was used with the GPS module due to its high-power consumption, which could have interfered with other components. This setup included an alarm button connected to the user’s hotspot or Wi-Fi. When pressed, it sent a notification to a parent’s Telegram account, informing them of any unforeseen circumstances. Parents could also use a Telegram bot to request the cap user’s current location at any time. A list of hardware and software can be seen in Table 1.

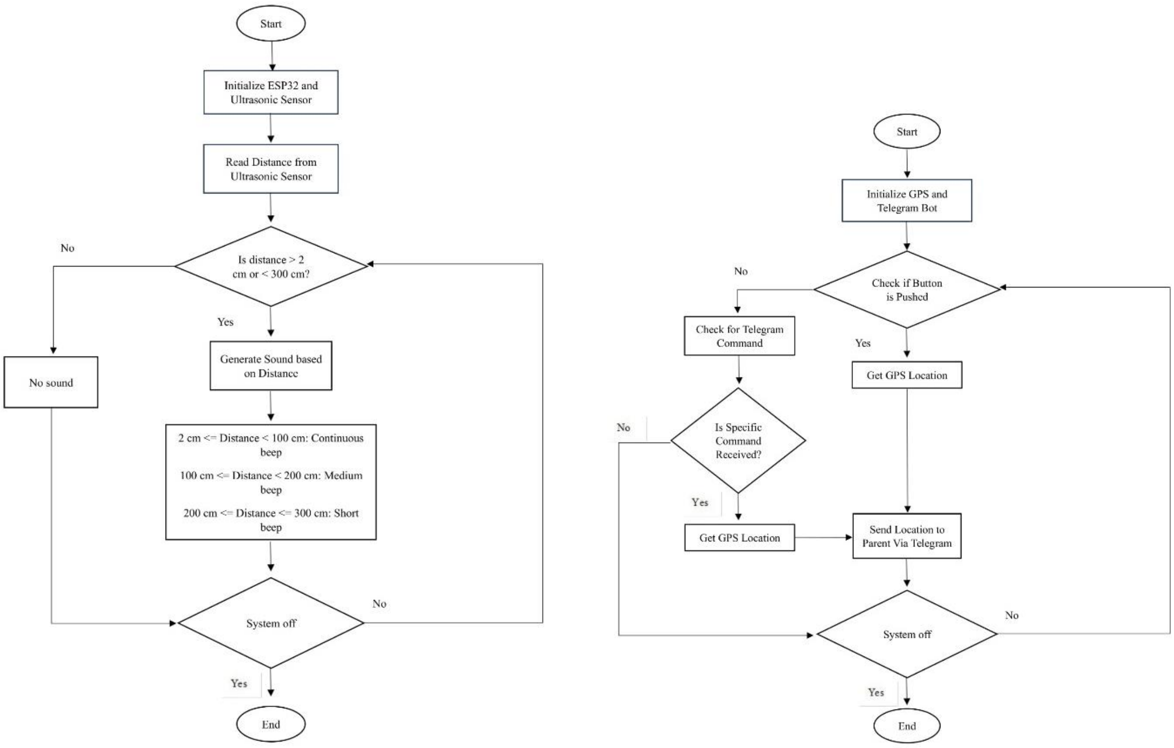
Table 1 *List of hardware and software*

Hardware	Software
ESP32 Microcontroller	Wokwi simulation
Ultrasonic Sensor	Arduino IDE
GPS module	Telegram
Buzzer	
3.7V Lithium Battery	

3. Methodology

A flowchart of the ultrasonic sensor system and GPS system is shown in Fig. 1(a) for the ultrasonic sensor system and Fig. 1(b) for the GPS system. Using an ESP32 microcontroller, the ultrasonic sensor system measured distances between 2 and 300 cm. Depending on the distance, it generated three distinct sound patterns: a continuous beep (2-100 cm), a medium beep (100-200 cm), and a short beep (200-300 cm). If no obstacle was found, no sound was produced. When a button on the cap was pressed, the integrated GPS sent location updates to a parent's Telegram account. Parents could use Telegram commands to request location updates, ensuring they were always aware of their child's whereabouts.

For the simulation design, as shown in Fig. 2, the Wokwi platform was utilized, providing a convenient environment compatible with the C++ programming language and encompassing all essential components for this project. Wokwi allowed users to visualize and test their code in a virtual environment before deploying it onto the physical hardware. The choice of Wokwi was influenced by its compatibility with C++, ensuring consistency across both simulation and implementation phases, streamlining the development process, and reducing potential discrepancies between the simulation and the actual performance of the ESP32 component. By leveraging Arduino IDE for programming and Wokwi for simulation, the development workflow was optimized, fostering a comprehensive understanding of the C++ code's impact on the ESP32's behavior in both virtual and real-world scenarios. The buzzer's sound changed based on the distance range, confirming that the simulation operated as expected, with buzzer sounds varying every 100 cm up to a maximum distance of 300 cm.



(a) **(b)**

Fig. 1 *(a) Flowchart of the Ultrasonic Sensor; (b) Flowchart of GPS system*

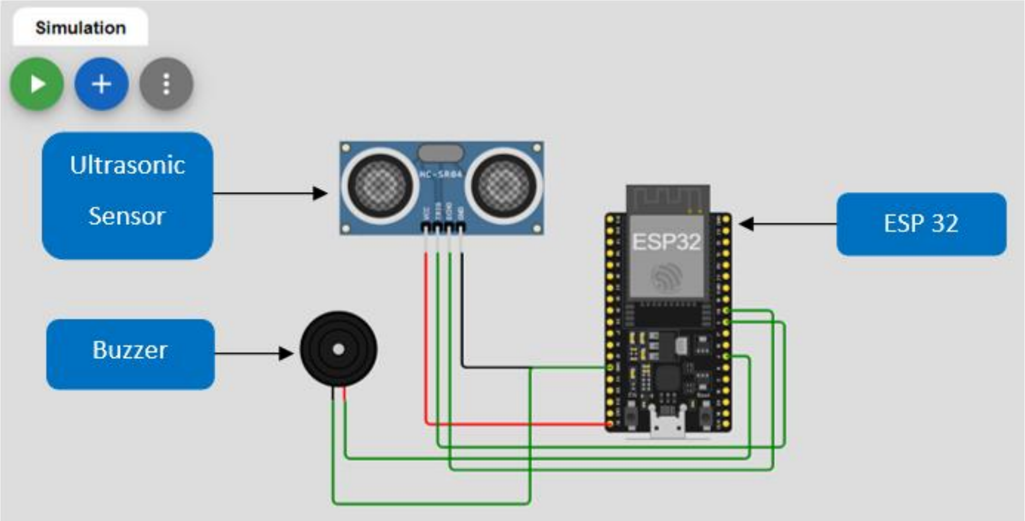


Fig. 2 *Simulation of the Project*

In Fig. 3 and Fig. 4, the ESP32 microcontroller was the central component, and two microcontrollers were used for each system: the ultrasonic sensor system and the GPS module system. One of them was programmed using Arduino IDE software to read data from the ultrasonic sensor, as it could measure distances between the user and obstacles within a few centimeters (Babiuch et al., 2019; Carullo & Parvis, 2001), and to issue sound alerts upon detecting obstacles (Wohiduzzaman et al., 2023). The other was programmed using Arduino IDE software to track the user's location using the GPS module and to send notifications to Telegram, connected to the user's hotspot or Wi-Fi. An alarm button triggered notifications to the parent's Telegram account about any unforeseen scenarios, and parents could query the cap user's location through the Telegram bot at any time.

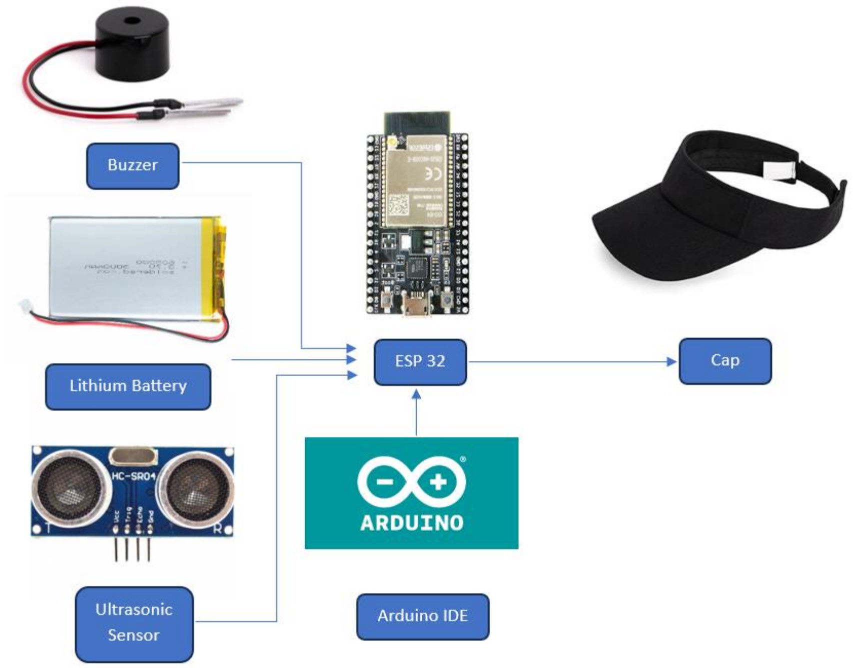


Fig. 3 *Ultrasonic Sensor design schematic*

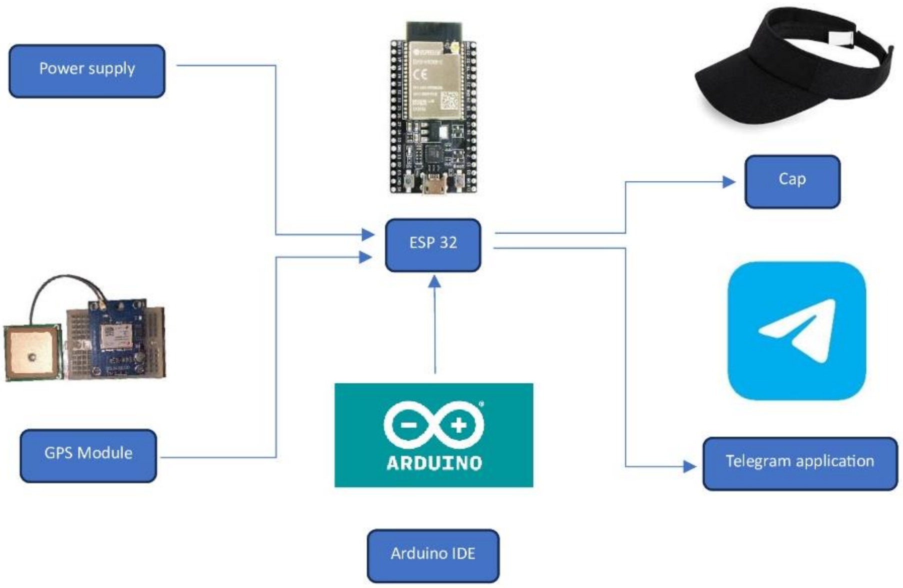


Fig. 4 *GPS Module design schematic*

4. Result and Discussion

All the systems were then assembled to develop the wearable obstacle detection device. The ultrasonic sensor was mounted on the top front of the cap, with the lithium battery positioned to its left. On the right side of the ultrasonic sensor were two ESP32 modules, all connected using jumper wires. The GPS module, with its antenna perched on top of the ESP32 modules, was situated below them. The two ESP32 modules, the lithium battery, and the ultrasonic sensor were protected by a 3D-printed cover. Additionally, the cap's adjustable design allowed it to fit the wearer's head comfortably, much like any other cap. When fully powered on, the cap detected obstacles within the predetermined range as expected. The delicate and eco-friendly sound distinction ensured that it did not contribute to environmental harm. The cap was powered by a 3.7 V lithium battery that could be manually unplugged and recharged with the appropriate cord. The actual prototype can be seen in Fig. 5.

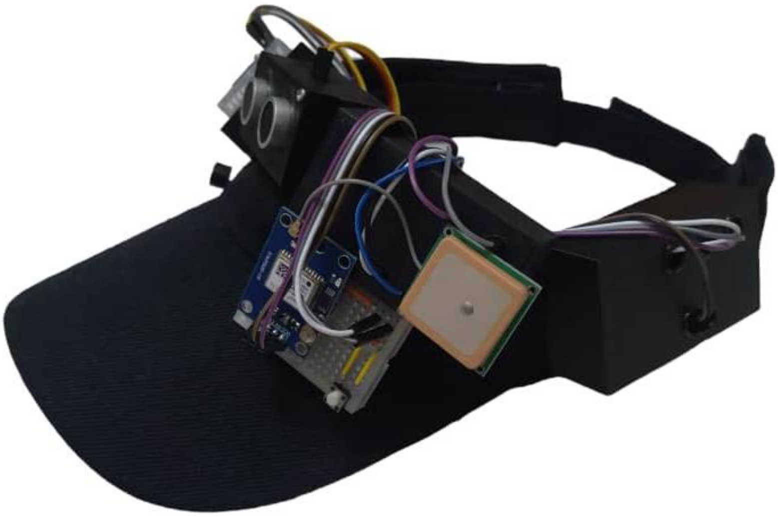
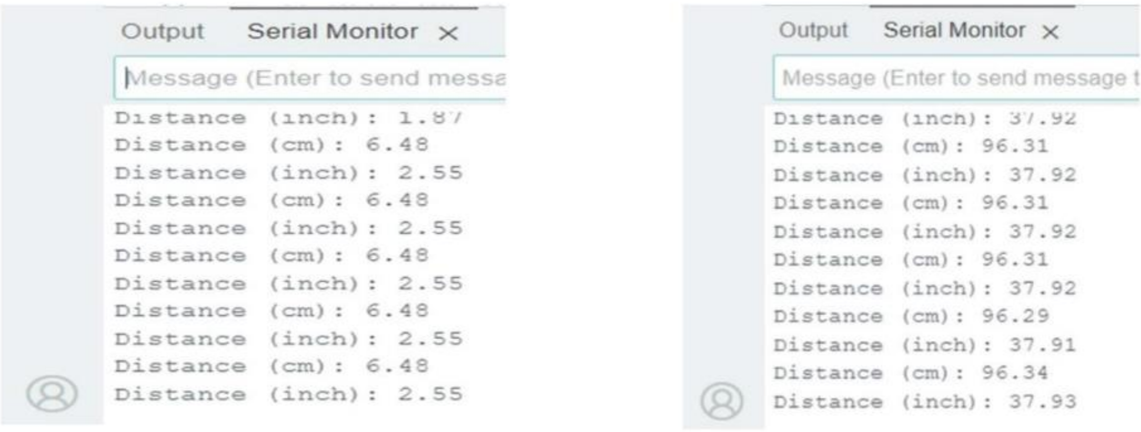


Fig. 5 *Wearable Obstacle Detection*

Fig. 6 and Fig. 7 demonstrated the ultrasonic sensor's readings for variable distances. Fig. 6(a) showed the reading distance from the ultrasonic sensor at 0 cm, and Fig. 6(b) showed the reading distance at 100 cm. Meanwhile, Fig. 7(a) displayed the reading distance at 200 cm, and Fig. 7(b) at 300 cm. The ultrasonic sensor continually transmitted sound waves, and the duration variable measured the travel time of these waves. Although the sensor was expected to detect a minimum distance of 2 cm, it recorded a minimum of 6 cm due to the sensor's dead zone, a common disadvantage of ultrasonic sensors. This issue could be addressed by calibrating the sensor or, if close-range detection was crucial, considering the use of an alternative sensor with a smaller minimum range or higher accuracy for close distances in future studies. The buzzer indicated three different sounds: a continuous sound for obstacles within 2 to 100 cm, a long beep for 100 to 200 cm, and a short beep for 200 to 300 cm, alerting the user accordingly. The hardware prototype results closely matched manual measurements. The performance of the ultrasonic sensor was calibrated to compare the distance range with the actual measurements, as depicted in Fig. 8. Finally, Fig. 9 showed that the maximum range the ultrasonic sensor could sense was 1194 cm, which is quite far for a non-line of sight (NLOS) measurement.

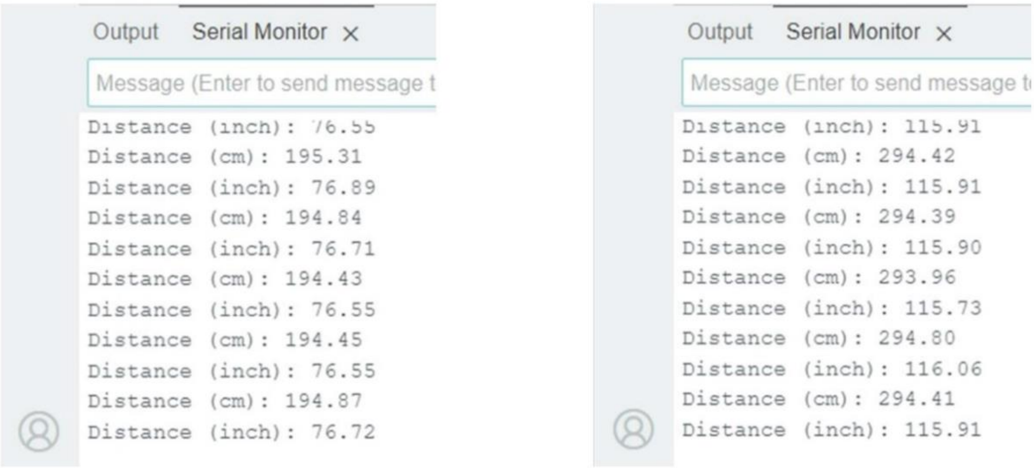


```
Distance (inch): 1.87
Distance (cm): 6.48
Distance (inch): 2.55
Distance (cm): 6.48
Distance (inch): 2.55
Distance (cm): 6.48
Distance (inch): 2.55
Distance (cm): 6.48
Distance (inch): 2.55
Distance (cm): 6.48
Distance (inch): 2.55
```

```
Distance (inch): 37.92
Distance (cm): 96.31
Distance (inch): 37.92
Distance (cm): 96.31
Distance (inch): 37.92
Distance (cm): 96.31
Distance (inch): 37.92
Distance (cm): 96.29
Distance (inch): 37.91
Distance (cm): 96.34
Distance (inch): 37.93
```

(a) **(b)**

Fig. 6 *(a) Reading distance from Ultrasonic sensor for 0 cm; (b)Reading distance from Ultrasonic sensor for 100 cm*



```
Distance (inch): 76.55
Distance (cm): 195.31
Distance (inch): 76.89
Distance (cm): 194.84
Distance (inch): 76.71
Distance (cm): 194.43
Distance (inch): 76.55
Distance (cm): 194.45
Distance (inch): 76.55
Distance (cm): 194.87
Distance (inch): 76.72
```

```
Distance (inch): 115.91
Distance (cm): 294.42
Distance (inch): 115.91
Distance (cm): 294.39
Distance (inch): 115.90
Distance (cm): 293.96
Distance (inch): 115.73
Distance (cm): 294.80
Distance (inch): 116.06
Distance (cm): 294.41
Distance (inch): 115.91
```

(a) **(b)**

Fig. 7 *(a) Reading distance from Ultrasonic sensor for 200cm; (b) Reading distance from Ultrasonic sensor for 300cm*

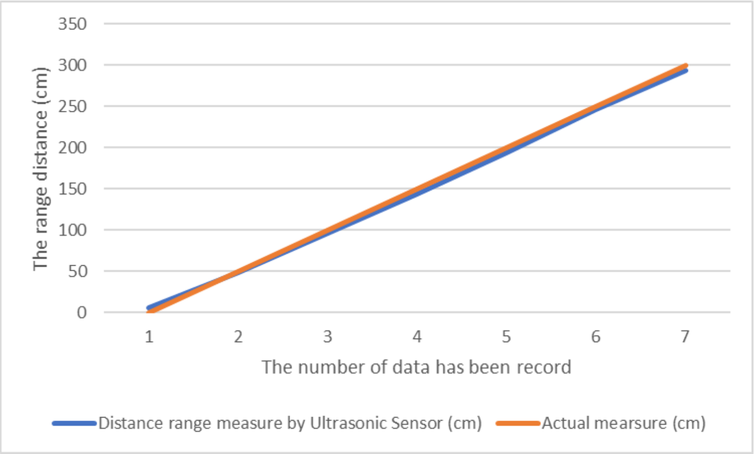
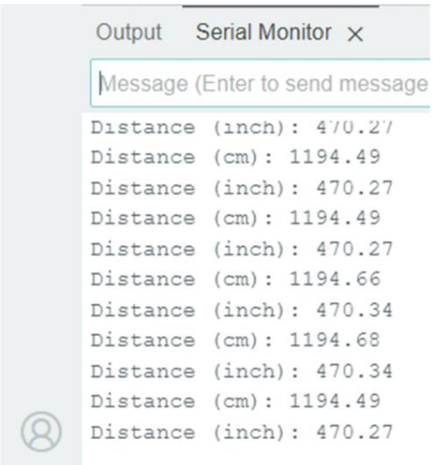


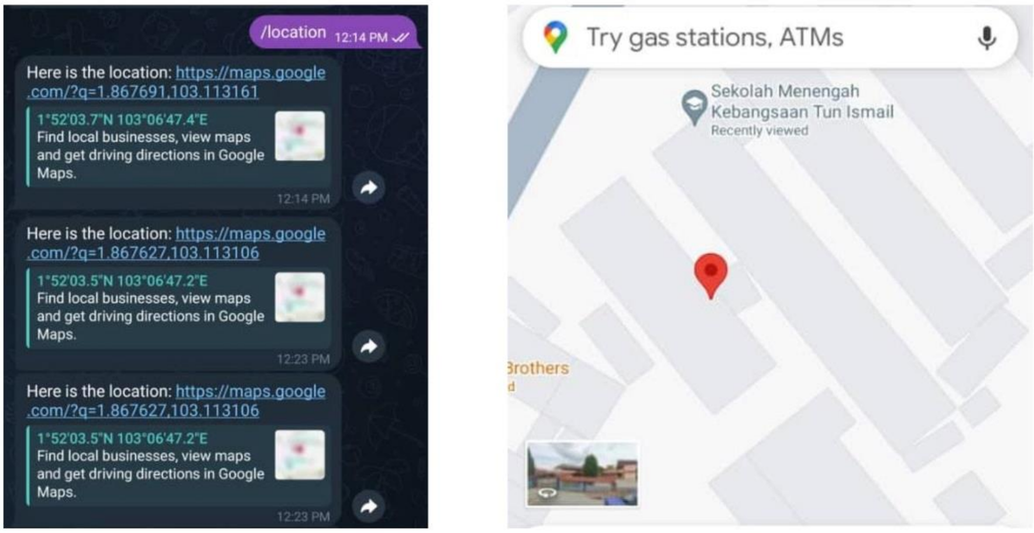
Fig. 8 *Graph of the range distance (cm) against the number of data has been record*



```
Distance (inch): 470.27
Distance (cm): 1194.49
Distance (inch): 470.27
Distance (cm): 1194.49
Distance (inch): 470.27
Distance (cm): 1194.66
Distance (inch): 470.34
Distance (cm): 1194.68
Distance (inch): 470.34
Distance (cm): 1194.49
Distance (inch): 470.27
```

Fig. 9 *Maximum range of the Ultrasonic sensor for obstacle detection*

Fig. 10(a) depicted the result of the message in the Telegram app after the alert button was triggered, and Fig. 10(b) displayed the GPS results, illustrating how accurately and consistently the module tracked and reported the user's location. The reported coordinates closely matched the actual locations, with only slight differences, when the GPS device was positioned at different specified points. This consistency, demonstrated at test locations, suggested that the GPS module was capable of producing accurate location data. Furthermore, when the push button was triggered, the system successfully delivered location notifications to the parent's Telegram account. The instruction to obtain the current location from the Telegram bot also worked as intended, providing precise coordinates in a timely manner. These findings verified that the GPS module was well-suited for the project and ensured that parents could receive real-time, accurate position tracking information.



/location 12:14 PM

Here is the location: https://maps.google.com/?q=1.867691,103.113161
1°52'03.7"N 103°06'47.4"E
Find local businesses, view maps and get driving directions in Google Maps.
12:14 PM

Here is the location: https://maps.google.com/?q=1.867627,103.113106
1°52'03.5"N 103°06'47.2"E
Find local businesses, view maps and get driving directions in Google Maps.
12:23 PM

Here is the location: https://maps.google.com/?q=1.867627,103.113106
1°52'03.5"N 103°06'47.2"E
Find local businesses, view maps and get driving directions in Google Maps.
12:23 PM

(a) **(b)**

Fig. 10 *(a) GPS location notification in Telegram for the test (b) GPS location shown for the test*

A visually impaired student, standing 168 cm tall with the prototype cap tilted 15 degrees downwards, participated in the angle test. With a 15-degree vertical beam angle, the ultrasonic sensor generated a wave that traveled 627 cm to the ground, as determined by Equation 1:

$$\begin{aligned} \text{Tan } 15^0 &= 168 \text{ cm}/ X \\ X &= 168 / 0.268 \\ X &= 627 \text{ cm} \end{aligned} \tag{1}$$

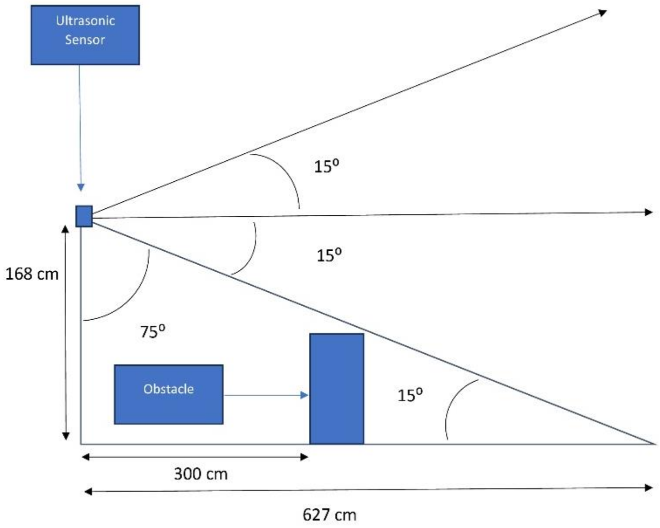


Fig. 11 *Angle of the Ultrasonic sensor emitted wave*

Due to the downward angle, as shown in Fig. 11, the obstacle, which was 300 cm away, fell into the blind spot area of the sensor. As a result, the ultrasonic wave missed the obstacle, highlighting a limitation of the project. Consequently, the obstruction remained undetected because the sensor's beam did not intersect with it.

5. Conclusion

In conclusion, the objectives of the project were successfully achieved, resulting in a modern and effective solution to support visually impaired individuals. The wearable obstacle detection system, utilizing an ESP32 microcontroller and ultrasonic sensors, proved reliable in detecting obstacles and providing timely alerts. The system was able to detect obstacles within its specified range and alert users through distinct sound patterns, significantly enhancing their ability to navigate their environment.

However, the system had limitations, such as a blind spot for certain distances due to the downward angle of the sensor. This limitation meant that obstacles within a specific range could remain undetected. Despite this, the system effectively complemented the traditional white cane, offering an additional layer of support and enhancing mobility for visually impaired users.

Validation tests confirmed the system's functionality and accuracy. The results showed that the wearable device could reliably detect obstacles and communicate this information to users in real time. This functionality demonstrated the system's potential as a valuable tool for improving the independence and safety of visually impaired individuals. The successful implementation of the project underscored its effectiveness in addressing the challenges faced by visually impaired individuals, making it a promising addition to the existing range of mobility aids. Overall, the project not only achieved its goals but also contributed valuable insights into wearable obstacle detection technology, paving the way for future enhancements and applications in assistive technology.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Muhammad Irfan Yazid*, Maisara Othman*;* ***data collection:*** *Muhammad Irfan Yazid;* ***analysis and interpretation of results:*** *Muhammad Irfan Yazid;* ***draft manuscript preparation:*** *Muhammad Irfan Yazid, Maisara Othman. All authors reviewed the results and approved the final version of the manuscript.*

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