



Obstacle and Fall Detection to Guide the Visually Impaired People with Real Time Monitoring

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Abstract

To assist the visually impaired people to travel independently without external aid and monitoring real-time location information of these individuals, a wearable electronic device is presented in this paper. The system is able to detect the obstacles in front of the user, humps on the ground, moving objects. In addition, the system detects the sudden fall and informs the user's guardian. The system is comprised of ultrasonic sensors, a PIR motion sensor, an accelerometer, a smartphone application, a microcontroller, and a data transmission device. The microcontroller transmits the data to the user's smartphone via Bluetooth module. The smartphone application generates audible instructions to navigate the user properly. The application also updates the current location of the user to keep track and notifies the guardians when the user falls down or in distress. The developed system obtained an accuracy of about 98.34% when the obstacle is 50 cm away from the user. The system is proved to be very effective and efficient for users to navigate using precise speech instructions. Overall, the developed system will make the visually impaired people and their guardian's feel much safer and confident.

Keywords Visually impaired people · Obstacle detection · Ultrasonic sensor · Accelerometer · Smartphone · Fall detection · Hump detection

Introduction

According to the World Health Organization (WHO), approximately 1.3 billion people are living in this world with various kinds of visual defects. Among them, about 217 million people suffer from moderate to severe problems, and about 36 million people are completely blind. Most of the

people having a visual impairment are aged above 50 years [1]. Visually impairment or blindness is considered as a curse. Visually impaired people feel uncomfortable at the time of moving or traveling independently [2]. They also struggle to perform daily activities and need the assistance of friends or family while walking. Most of the time they face the restriction of movement because they most often get lost while traveling alone. Visual impairment or blindness cannot be fully cured. But with the help of modern science, their sufferings can be reduced.

Most of the cases visually impaired people prefer to use a white cane or guide dog for performing their daily moving activities. The white cane [3] is the most basic assistive tool which can provide tactile information to the user but this information is confined by its size. A guide dog [4] can detect obstacles as well as dangerous situations in a short-range. In most cases a guide dog cannot notify the user precisely for example if there is a hump on the road then the guide dog cannot realize it to the user. Recently, various works have been done in developing electronic travel aid based on sensors and actuators [5–8], computer vision [9, 10], deep learning [11, 12], and machine learning [13] for providing a flexible interaction [14, 15] with environment.

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The devices provide various information about the surroundings which are easily understandable for the user. The devices are based on sensors or cameras. The sensors detect obstacles through sensing surroundings and notify the user. On the other hand, the camera-based object detection is performed by analyzing the captured pictures using computer vision-based techniques.

From the motivation of the previous researches, we have developed an electronic assistant system for visually impaired people to guide them safely. The system is developed with a combination of hardware and software which is capable of detecting both static and moving obstacles; detects path humps. We achieved 98.34% accuracy for obstacle detection when the obstacle was within 50 cm distance and 96.36% on average. In addition, the developed system is capable of detecting a sudden fall and sending this information to an authorized guardian. The user also can send a message if he/she faces any kind of danger. The guardian can monitor the user's real-time location as well as find a way to reach the user. All the information is provided to the user via text to the speech signal. Overall, the system is cost-efficient and user-friendly.

The remainder of the paper is arranged as follows. Some recent developments related to this field are described in Section "[Overview of the State of the Art](#)". Section "[Major Hardware Components](#)" describes the major hardware instruments that are used. In Section "[The Proposed Methodology to Develop the Guidance System](#)" the methodology of the proposed wearable electronic device is illustrated. The implementation of the prototype is described in Section "[Implementation of the Prototype](#)". Section "[Results Analysis](#)" outlines the experimental results of the developed system. Section "[User's Experience](#)" describes a brief discussion about user experience. Section "[Conclusion](#)" concludes the paper.

Overview of the State of the Art

To assist the visually impaired people in navigation, many assistants are developed. To make well-organized and cost-efficient tools for them many researchers have been working for a long time. Some of the related works in this field are described briefly as follows.

Shaha et al. [16] proposed a system where they used a low latency communication algorithm to notify the user about the obstacle in different distances using different types of vibration and buzzing. The system is also comprised of a GPS module and an application module for real-time location monitoring. Shahira et al. [17] developed an assistance system that senses the obstacle, identifies it and notifies the user with audio. For sensing and measuring the distance of the obstacle, an ultrasonic sensor was used.

The identification of the obstacle was done using YOLOv2 algorithm on an image acquired by a webcam of a laptop. Therefore, their proposed system was not entirely portable.

Agrawal et al. [18] proposed a smart stick for the blind and visually impaired people. Some electrical components like sonar sensor, buzzer, GPS module, GSM module, RF module are embedded with the stick. It can sense the obstacles situated in front of the user and give notification through the buzzer. SIM808 module is used as GPS and GSM to track the location of the user. It provides a real-time user location to the microcontroller of the system. A panic button is added with the prototype by which the user can request for help to his/her relatives. Bhatlawande et al. [3] designed Electronic Mobility Cane (EMC) for visually impaired people. The EMC contains six sonar sensors. Using these sensors, a sub-map of front-way and side-way is obtained. The situation of the front-way and side-way obstacles is measured through the EMC. The developed EMC is capable of responding in obstacle detection about a 400 cm range around the user. But, a matter of concern that EMC must be kept 90° angled with the surface. A liquid detection sensor and a metal detection sensor are used to sense the floor if it is wet or metallic. The cane must be kept 90 degrees angled with the surface and cannot detect overhanging obstacles.

O'Brien et al. [19] proposed a cost-efficient system integrated with a walking stick that provides an alarm when it detects obstacles. A customized printed circuit board (PCB) with a microcontroller organized all the sensors and motor. The weight of the proposed system was about 110 g including battery. After calculating the distance the system notified about the obstacles. If the computed distance is between 20 and 60 cm, then a notification signal is generated and if the distance within 60 to 100 cm, then another notification signal is provided. If there are no obstacles within 20 to 100 cm, the system does not provide any response.

Sahoo et al. [20] proposed a system based on a walking stick including a Raspberry Pi controlled hardware and an android application module. The user is notified via vibration or alarm when the system detects obstacles or water. The application is used for sending GPS location of the user to parents. The emergency application helps the user to connect with friends or parents in case of emergency by various smartphone gestures. Chen et al. [21] also proposed an assistance system that is based on a walking stick and a pair of glasses. The system detects an obstacle in front and fall of the user by sensors notifies using vibration. The mobile application stores GPS module info and automatically messages the user's family in case of fall or collision.

Meshram et al. [22] introduced a system to help visually impaired people by autonomous navigation called NavCane. Auditory and tactile communications are used for transferring sensed data to the user. NavCane detects obstacles at different heights, colors of cloths, ascending and descending

staircase. It also senses water on the surface. It can find out the way in the outdoor and indoor environment. Caretakers are informed about the user's situation when they press a switch. The system was tested over 80 visually impaired people and the outcome of the test supported its effectiveness over the white cane.

Major Hardware Components

There are various types of hardware components that are used to develop any kind of guidance system for visually impaired people. The major components which are used for developing this assistive device are outlined as follows.

ESP32

ESP32 [23–25] is referred to as a system or platform which is embedded on a chip integrated some features like hybrid Wi-Fi, dual-mode Bluetooth, etc. Additionally, it consists of touch-sensitive pins, temperature sensor, Hall Effect sensor, amplifiers, and some power management modules. This microprocessor is low cost, less noisy and low power consuming. It is reliable and can survive in an industrial environment. It is used in mobile devices as well as IoT purposes. ESP32 is a small single-chip microcontroller that can be used with different operating systems such as Windows, Mac, Linux as well as microcontroller kits. It has an instruction set that is efficient in performing various micro-operations. It is also capable of running Arduino codes through 'Arduino' software. The ESP32 with all components is shown in Fig. 1a.

Ultrasonic Sensor

Ultrasonic sensors [26, 27] are widely used for developing various kinds of assistive devices to provide different services. It can calculate the distance of obstacles situated in a fixed range. The range is usually 3 cm to 3 m which covers up to 15 degrees. It comprises of only 4 pins. The pins are

VCC, GND, trigger and echo which are shown in Fig. 1b. VCC pin is used to provide power to the sensor. The input voltage of VCC pin is at most +5 V. The GND pin is connected with the ground. When the trigger pin is high the sensor sends out an ultrasonic pulse. When the pulse signal is reflected by an obstacle, the reflected signal is received by the sensor and the echo pin is activated. The distance is measured from the time interval between activation of trigger pin and echo pin. In this time, the sound wave travels forth and back to the sensor. The distance between the sensor and obstacle is measured using (1).

$$\text{Distance} = (\text{speed of sound} \times \text{travel time})/2 \quad (1)$$

Accelerometer

Accelerometer [28, 29] is basically an acceleration detecting device. The acceleration can be generated by changing both speed and direction. An accelerometer is mainly interfaced with microcontrollers like Arduino, Esp32, etc. It is a small, thin, less noisy and low power-consuming device with signal conditioned voltage outputs. It has 6 pins consisting of VCC pin, a GND pin, X pin, Y pin, Z pin and ST pin. The power range of the accelerometer is about 3 V to 5 V. The size of the accelerometer around $4 \times 4 \times 1.45$ mm. The X, Y and Z pins are used to provide input to the microcontroller by sensing from surroundings. The accelerometer is shown in Fig. 1c.

PIR Sensor

PIR sensor [30] is a sensor that can sense the movement of any obstacles in a certain range. It is a small, wide-ranged, inexpensive and low power consuming sensor. The detection range of the PIR sensor is about 5–12 m. It has three pins at the side or bottom of the sensor. The pins are ground, power and signal. The signal pin used to provide output. PIR sensor senses the movement by measuring the change in the levels of infrared emitted from the obstacle. The PIR sensor is shown in Fig. 1d.

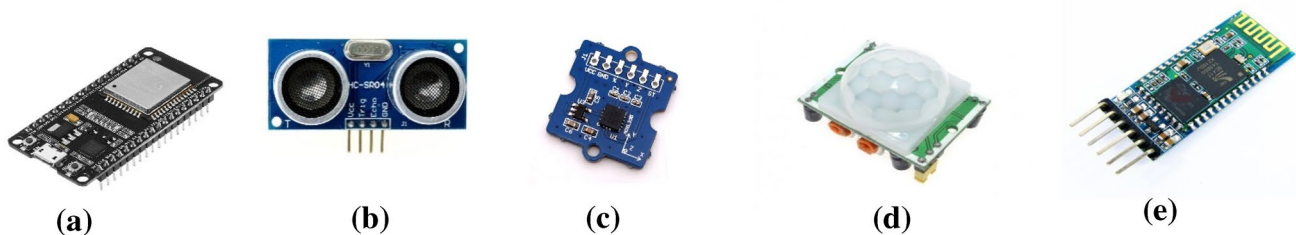


Fig. 1 Major hardware components that are used to develop the system. **a** ESP32 **b** ultrasonic sensor **c** Grove—3-axis analog accelerometer **d** HC-SR501 PIR sensor module **e** bluetooth module

Bluetooth Module Breakout (HC-05)

Bluetooth module HC-05 is designed for transparent wireless serial connection setup. Most of the prototypes [31] used Bluetooth for communication between the users and the processor. Any serial data stream from 9600 to 115200 bps can be passed from an Arduino to a target device. The Tx pin of the Bluetooth module is connected with Arduino's Rx pin and its Rx pin is connected with Arduino Tx pin. VCC and GND pin is connected with 3 to 5v and ground voltage, respectively. The Bluetooth module is shown in Fig. 1e.

The Proposed Methodology to Develop the Guidance System

In the proposed method, an ultrasonic sensor is used for obstacle detection in front of the users. Another ultrasonic sensor is used to detect humps on the ground or on the road. A PIR motion sensor is used for detecting the moving objects in front of the user. A 3-axis analog accelerometer is used for monitoring if the user has fallen. All the sensor data will be sent to the user's smartphone using a Bluetooth module. The user will be notified if there is an obstacle or a hump or a moving object in front of him/her by speech instructions from his/her smartphone. If the user falls down, the guardian will be instantly notified by the smartphone module. The user also can send an emergency signal if needed. The block diagram of our proposed system is depicted in Fig. 2. The proposed system contains of two modules named as a sensor module and a smartphone module. Each of the modules is described in the following steps.

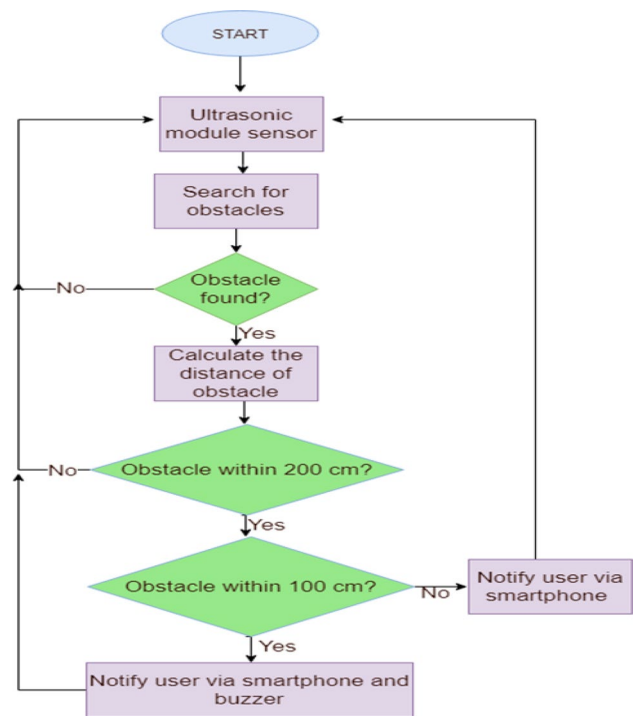


Fig. 3 The working flow of the ultrasonic sensor module for our proposed system

Sensor Module

Two sonar sensors are integrated into the proposed system. One of them is aligned horizontally to detect obstacles situated in front. The working flow of the obstacle detecting ultrasonic sensor module for our proposed system is illustrated in Fig. 3. If the obstacle is detected within 200 cm

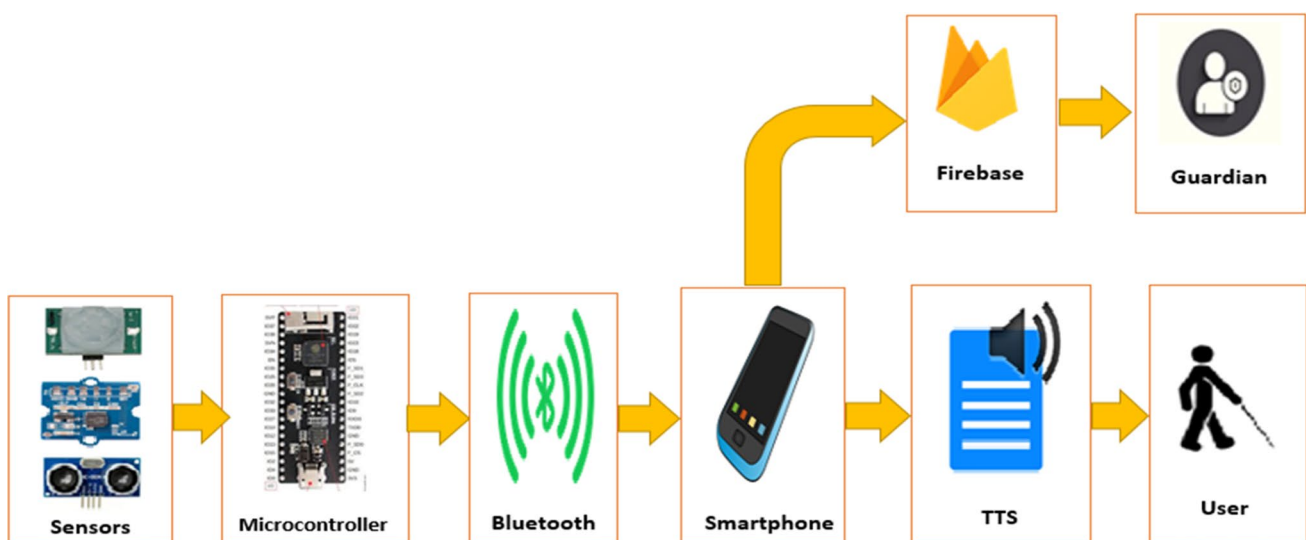


Fig. 2 Block diagram of the proposed system



Fig. 4 Hump detection process in the proposed system

front, the sonar sensor sends the signal to the microcontroller. If the obstacle is within 100 cm then a buzzer produces a unique sound. The micro-controller sends the message to a smartphone through a Bluetooth module, and the user gets a notification. The other ultrasonic sensor is aligned in an angle and aimed towards the ground. It calculates an initial threshold value from the distance of plain ground. When a hump is on the ground, its distance value changes to a much smaller value than the threshold value. Thus, a hump on the ground is detected and sends the message to the microcontroller to generate a notification for the user. The process of hump detection is illustrated in Fig. 4. There is an integrated touch sensor in ESP32 that is used by the user when he/she is in need of help. When the user touches, the device sends a signal to the user's smartphone. From the user's smartphone, an emergency message is sent to the user's guardians. A PIR motion sensor is used for detecting moving objects. It also generates a notification for the user. A 3-axis analog accelerometer is embedded with the system

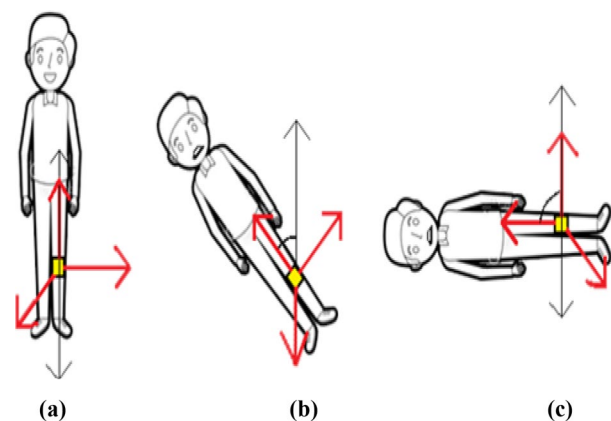


Fig. 5 Fall detection procedure: a 0° b 30° c 90° between y-axis of accelerometer and vertical axis

to detect if the user has fallen down. The sensor is attached to the device in such a way that its y-axis is always vertical when the user is standing. The accelerometer gives a different output (mV) for different axis position. The output value decreases with the increase of angle between the y-axis and vertical axis. If the user falls down, the y-axis value (mV) of the sensor decreases significantly. Thus, it detects the fall and sends the message to the microcontroller for generating an instant notification for the guardian. Figure 5 shows the different axis positions for detecting a fall. The communication between the system and the smartphone is done by a Bluetooth module (HC-05). The sensors send the signal to the microcontroller and it sends the data to the smartphone after processing through Bluetooth communication.

Smartphone Module

An android application is developed to receive the signal from the prototype. For notifying the user, it uses TTS (Text to Speech) technology for providing real-time direction to the user. The user can customize the TTS settings for different languages, voices and volume levels. The app will locate the user's current location using Global Positioning System (GPS) and save it into the firebase database in real-time. So, the guardians can monitor user's whereabouts using this app. The guardian section of the application provides guardians with the user's current location. The guardian can see the user on Google map and also find a path to the user on the map. An emergency signal or a fall of the user will be instantly notified to the guardians. The message is sent using a cellular network.

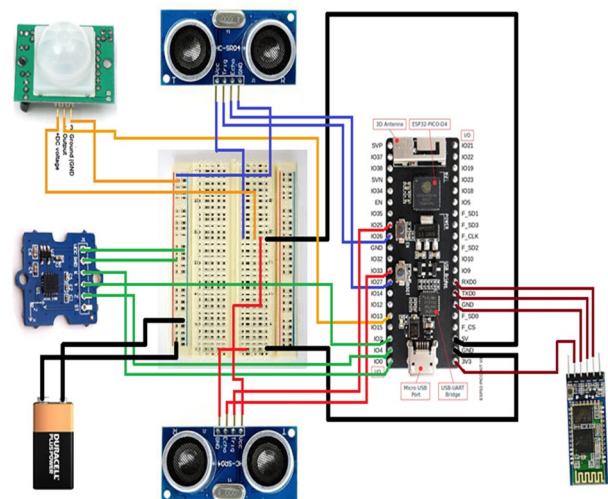


Fig. 6 Circuit diagram of the prototype

Table 1 The mapping between ESP32 and other components

ESP pin	Connected device
25	Trigger pin of angled sonar sensor
33	Echo pin of angled sonar sensor
26	Trigger pin of front sonar sensor
27	Echo pin of front sonar sensor
13	Pir output pin
Rx	Tx pin of Bluetooth
Tx	Rx pin of Bluetooth
VIN	Common +5 V for all Device
A0	Accelerometer X axis
A3	Accelerometer Y axis
A4	Accelerometer Z axis
GND	Common ground(-) for all device

Implementation of the Prototype

We have integrated our proposed system in a compact, light-weight wearable device that is to be attached to the user’s shin (the front of the leg below the knee). In the prototype, all the sensors, microcontroller, and the communication device are integrated into the device. The overall circuit diagram is given in Fig. 6. The connection of each component is mapped with the microcontroller which is shown in Table 1. From Table 1, it can be shown that the Trigger and

Echo pin of the front sensor is connected with 26 and 27 pins of the microcontroller. The Tx and Rx pin of Bluetooth is connected with Rx and Tx pin.

We have developed an android application using the android studio. The application will act as a bridge between the user and the prototype. The interfaces of the developed application are shown in Fig. 7. The guardian section of the application access firebase real-time database for showing user’s location information. The non-users i.e. guardians have to authenticate via username and password. After successful login, they can see real-time location information of the user. The guardian can also find the user on the Google map and find a route to the user. The user section has a very large button so the user can easily access it. The user does not need any authentication, the application will automatically connect with the embedded system. After establishing a connection with the embedded system, the application will provide the user with proper instructions.

Result Analysis

The system was tested in a real environment. We have collected data for both ultrasonic sensors by positioning obstacles and humps in different positions. We have measured data for a 50 cm, 100 cm, 150 cm, 200 cm and 300 cm distance of the obstacle.

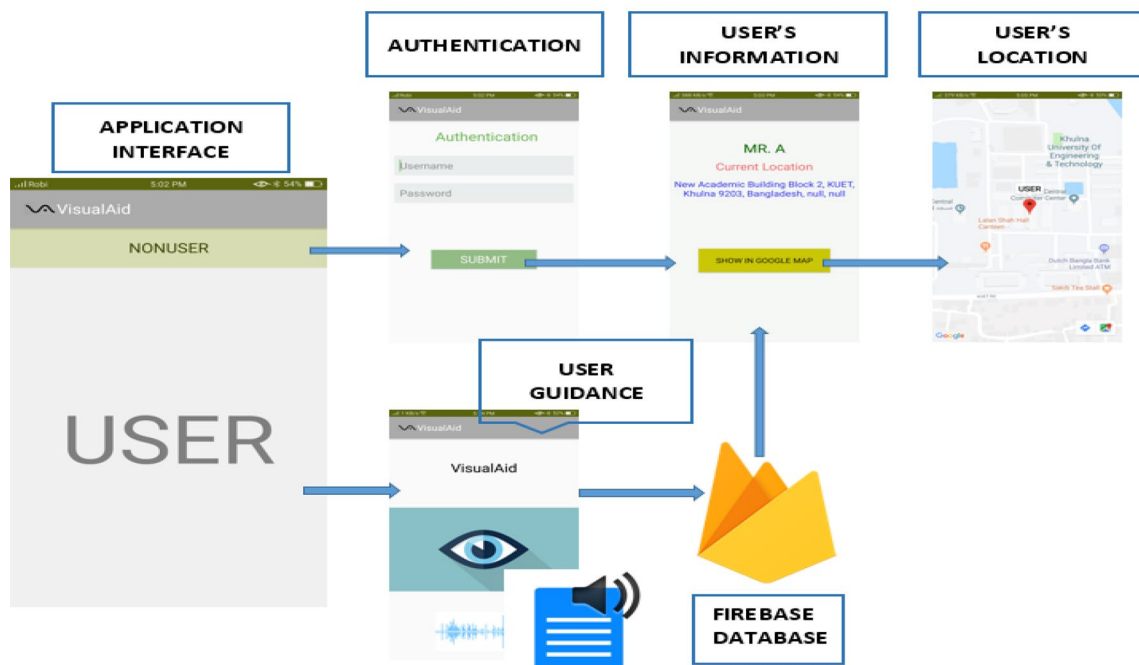


Fig. 7 Android application interface

Table 2 Real-time data collected from the ultrasonic sensor

Actual distance (cm)	Measured distance (cm)						Average distance	Average error	Accuracy (%)	Error (%)
	1	2	3	4	5	6				
50	49	50	51	48	50	51	49.83	0.833	98.34	1.66
100	97	102	98	97	104	101	99.83	2.5	97.50	2.5
150	146	144	143	147	140	152	145.33	5.33	96.45	3.55
200	214	194	212	188	209	204	203.5	9.5	95.25	4.75
300	290	285	278	321	330	295	299.83	17.167	94.28	5.72

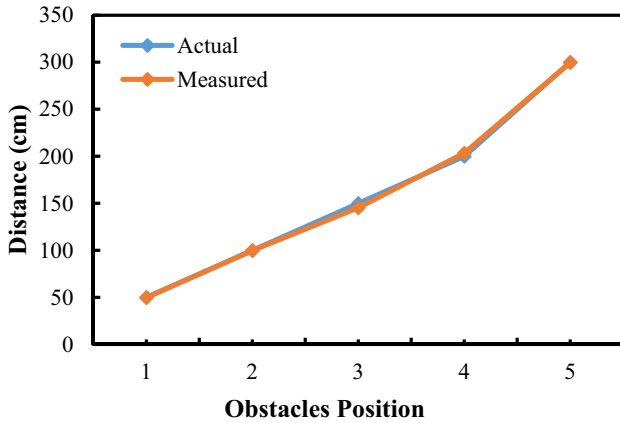


Fig. 8 The comparison between actual and measured distance for the ultrasonic sensor

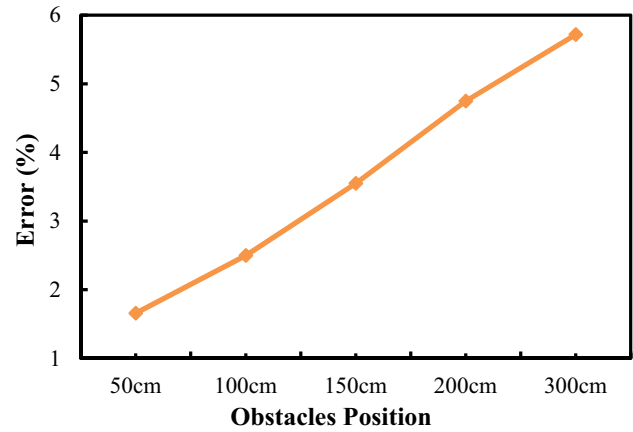


Fig. 10 The error rate of the ultrasonic sensor achieved by the proposed prototype

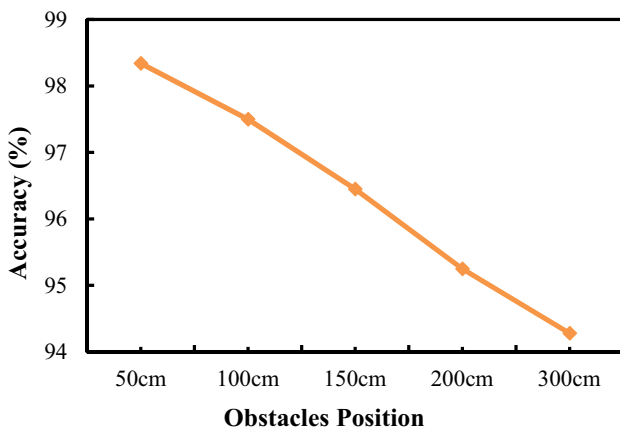


Fig. 9 The accuracy rate of the ultrasonic sensor achieved by the proposed prototype

Table 3 Estimation of the threshold value

Distances (cm)	Threshold value (cm)
120,115,100,125,118,113,112,104,109,124	114
114,97,122,103,110,120,109,117,103,115	111

the measured distance and actual distance. This illustration implies that the difference of the measured distance from the actual distance. It is presented that the deformity is not severe and the measured distance is acceptable. The accuracy and error rate along with the distance for the ultrasonic sensors are shown in Figs. 9 and 10, respectively. From Table 2, it can be demonstrated that the highest accuracy of 98.34% achieved by the system at the actual distance position of 50 cm. The efficiency is decreased with the increase of distance. The highest error found at the exact distance position of 300 cm which is about 5.22%.

The threshold value for hump detection is set equal to the average of ten distance obtained from the ground facing the ultrasonic sensor. The average is calculated

For each interval, we have taken data three times and calculated the average value of these data. We also estimated the accuracy rate, the error of measured data. The collected data from each sensor with accuracy and error rate is represented in Table 2. Figure 8 shows a relationship between

Table 4 Result of hump detection from the measured distance

Status	Measured distance(cm)	Output	Result
Hump present	$65 < (111 - 10 = 101)$	Hump detected	Accurate
Hump present	$90 < (111 - 10 = 101)$	Hump detected	Accurate
Hump not present	$110 > (111 - 10 = 101)$	Hump not detected	Accurate
Hump not present	$(111 - 10 = 101) < 118 < (111 + 10 = 121)$	Hump not detected	Accurate

Table 5 Real-time data collected from 3-axis analog accelerometer

Angle with Y-axis	Measured Y-value (mV)			Average
	1	2	3	
0°	1884	2118	2087	2029.67
30°	1750	1854	1863	1822.33
60°	1740	1753	1747	1744.67
90°	1590	1584	1641	1605

Table 6 Comparison with the proposed system and other related system based on accuracy

Developed system	Year	Accuracy (%)
Sadi et al. [32]	2014	96.00
Zhou et al. [33]	2016	85.42
Sharma et al. [34]	2017	87.70
Shaha et al. [16]	2018	90.12
Khanom et al. [35]	2019	95.22
Shahira et al. [17]	2019	97.00
Proposed system	–	96.36

Text message
Tuesday, February 12

From VisualAid: Mr. A is in danger!

10:03 AM 2

From VisualAid: Mr. A has fallen!

10:05 AM 2

Fig. 11 Received message in guardian’s smartphone

using (2). Table 3 shows the calculated threshold value. If the measured value is between (threshold – 10 cm) and (threshold + 10 cm) then we conclude that there is no hump else there is a hump on the surface. Table 4 shows the results of hump detection when the threshold is 111 cm.

$$\text{Average value} = (\text{sum of 10 values})/10 \tag{2}$$

The 3-axis analog accelerometer data was also measured at the angle of 0, 30, 60 and 90 degrees. For each value of the angle, data was taken 3 times and the average was calculated. The collected data from 3-axis analog accelerometer sensor is represented in Table 5. When the user falls down, the angle between the y-axis and vertical axis changes from 0° to 90°, as a result, the output of accelerometer along with y-axis changes from 2029.67 (mV) to 1605 (mV). This goes for all directions whatever the user could have fallen e.g. sideways, front or backward. When the angle is greater than 60°, then fall is detected. The message sending from the user to the guardian was found almost 100% accurate. The

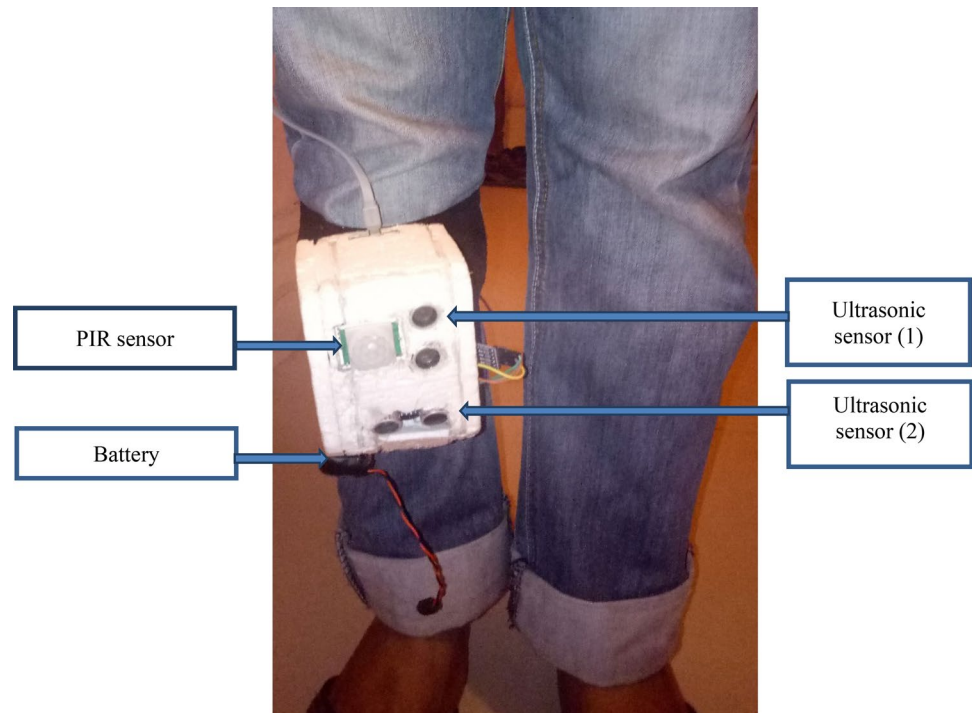
accuracy completely depends on the cellular network. The received message in the guardian’s smartphone is shown in Fig. 11. The application guided the user accurately when the user is at a moderate speed. The instructions were clear and easily understandable.

The microcontroller takes 3 s time for each instruction to avoid overlapping of speech instructions generated by TTS. The buzzer produces an alarm when the obstacle is within 100 cm (0.1 m) range from the user. The distance is measured by the ultrasonic sensor using ultrasound wave. The velocity of ultrasound wave is about 343 m/s in air. Thus response time for ultrasonic sensor is $(2 * 0.1/343) = 0.000583$ s. Hence the maximum response time for the buzzer module can be up to $(3 + 0.000583) = 3.000543$ s.

TTS module notifies the user when the obstacle is within 300 cm. The response time of ultrasonic sensor for the distance 300 cm is $(2 * 0.3/343) = 0.0017$ s. The information about the obstacle is sent to the smartphone using hc-05 Bluetooth module which has average 2 Mbps speed. The distance information is sent as a 4 Byte (4*8 bit) float data which takes $(4 * 8/2^{20}) = 0.000032$ s. Speech navigation instructions are produced by Google TTS API, which can produce 20 s of speech in 1 s time. The average time duration of a navigation instruction is 3 s. Hence, average response time for TTS is only 0.15 s. The maximum response time for the speech instruction can be up to $3 + 0.15 + 0.000032 + 0.0017 = 3.151732$ s.

In Table 6, we compared our proposed system with some previously developed system in terms of obstacle detection accuracy. The system proposed in [17] obtained 97% accuracy for obstacle detection. The system

Fig. 12 Developed prototype with the user



developed in [16, 32–34] and [35] obtained 96.00%, 85.42%, 87.70%, 90.12%, 95.22% accuracy, respectively. From our proposed methodology, we achieved an accuracy of 96.36% for obstacle detection.

User's Experience

We have tested the prototype in a real environment with the target people. For hearing the instructions we used a headphone.

When an obstacle is raised in front, the user heard “Obstacles in front of 97 cm”. Similarly, the user heard clear instructions for hump and moving objects. The touch sensor for sending message worked well. We tested the prototype by a fall it responded accurately, but there was a little delay. The guardian part of the application was also tested and the location monitoring was almost accurate with respect to the actual location with very low distortion. Figure 12 shows the prototype with the user.

Conclusion

The developed system was able to detect both obstacles and humps in front of the user effectively. It also detects any moving object in the front. The system detects an obstacle 98.34% accurately at a distance of 50-cm front. The firebase database based real-time monitoring system

works instantaneously and the positioning is accurate as per the user's smartphone GPS. The main purpose of this proposed system is to develop a user-friendly and cost-efficient guidance system. The user gets real-time notifications about the surroundings via a mobile application and the guardians get notified instantly if the user is in distress or fell down. Thus, it assures the user's safety. Hopefully, the system will help visually impaired people in navigation and make their life much safer and easier.

Compliance with Ethical Standards

Conflict of Interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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