# Enhancing the Human Robot Interface: The White Stick with Obstacle Avoidance and Depth Sensing

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**ABSTRACT-** Without the use of the proper tools to guide the visually impaired, visual impairment can lead to a series of unexpected and frustrating challenges. Being able to move around and complete simple chores, as well as move around in the crowded streets of today's fast-moving life can be an arduous task for the visually impaired. With the aid of an efficiently designed navigational tool and some training to master the technology, the visually impaired can go about their accustomed routine with a marked degree of confidence. This paper aims at developing an assisted recognition system for the white cane with three operational modes to aid the mobility of the visually impaired. The proposed work is designed to enhance the use of the white stick making it act like an extended eye and alarm system through the use of a synchronized array of ultrasonic sensors to detect the activities of the user's vicinity sending the data to the microcontroller (Arduino Uno R3), the microcontroller depending on the feedback received from the sensors gives a haptic feedback to the user through the use of a buzzer. A secondary feedback system allows pre-recorded voice commands to be played via a smartphone app. The significance of the proposed work is hinged on the fact that it not only helps the user to navigate through his surrounding, avoiding impact with obstacles but also goes further to detect possible depressions or potholes on the path of the user and send feedback depending on the depth of the depression encountered. The proposed system is geared towards making an efficient light-weight yet affordable assisted system for the visually impaired.

**Indexed Terms-** White Stick, Depth Sensing, Obstacle Avoidance, Visually Impaired, Assisted Recognition System, Edge Detection, Voice Command, Pothole Detection



## 1. INTRODUCTION

There is no denying the challenges visually impaired persons face in performing everyday activities. Completing simple household chores could take enormous planning and execution time. Visual impairment could cause several limitations to the visually impaired, forcing them to acquire new skills to achieve common and familiar everyday activities. The inevitable isolation from freely interacting with one's immediate environment can over the course of time, cause a lot of psychological and emotional stress and frustration [1]. In the modern metropolitan cities and households, the obstacles that the visually impaired are faced with are numerous, ranging from staircases, sidewalks, turns, walls, people, doors, furniture, narrow path, rough surfaces, steeps and depressions on their path [2].

The white cane was introduced in order to assist the visually impaired have better and wider participation in their daily routine, allowing them a chance to interact with their environment with a certain degree of freedom and exactitude. The white cane was introduced to help the visually impaired scan their environment for obstacles and objects.

Although extraneous to this research, the color of the stick makes it possible for onlookers and passersby to identify the user as visually impaired and act accordingly. The cane is lightweight and cost-efficient, making it affordable to everyone. As efficient as the cane is, it still has some shortcomings, thus the need for the enhancements researched by this paper.

## 2. SYSTEM REVIEW

Previous researchers have attempted to develop several variants of systems to aid the visually impaired to navigate through static objects and obstacles in their path. Whereas these previous research focused mainly on systems that only attempt to detect objects that could come in direct collision with the visually impaired and produce an audio feedback if an object is in close proximity in an attempt to steer the user to safety [3], [10], [11], none has really focused on the aspect of detecting complex potholes and other major depressions that can occur along the path of the visually impaired. This research introduces a system capable of analyzing the edges leading to the depression and the subsequent depth of the depression and is able to provide reliable feedback to warn its user of the dangers ahead and help keep the visually impaired safer.

In the aspects of aiding the visually impaired navigate through undulating terrains, whereas previous researches had depended heavily on assisting the visually impaired down flight of stairs by employing a triaxial accelerometer with limited results [12], this research utilized a simple array of ultrasonic sensors to achieve a broad range of demonstrable success in detecting not only flight of stairs but also sudden depressions, potholes or precipice on the part of the visually impaired.

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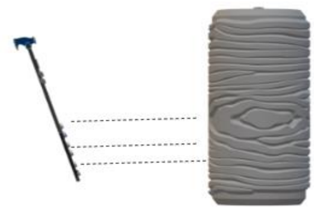
During the course of this paper, a possible enhancement to the commonplace white cane was considered not only to detect objects in the environment but also focused on detecting the height, width, and depth of depressions (holes) present in the user's environment. The data collected will serve to notify the user if it is a safe depth or not. To help avoid the user coming into direct contact with obstacles around them as well as falling into holes along the walking path. The white cane will be equipped with seven ultrasonic sensors which will obtain the dimensional data from the user's environment, such as height, width, and depth of the encountered obstacle. The ultrasonic sensors will obtain information from the surrounding and send an output signal to the microcontroller which triggers the notification system [7], [8], [9]. To make the system more efficient the sensors are mounted at carefully calculated points on the cane. For the edge and object detection, an ultrasonic sensor array will be mounted at the base of the cane; to evaluate the height of an encountered objects, three sensors will be position vertically on the cane at right angle to the edge sensors; to obtain an approximated width of an obstacle, three sensors will be placed horizontally on the cane, parallel to the base. Ultrasonic sensors are able to continually send out sound waves to the surrounding, wait for echoes to return and send received echoes to the microprocessor [7], [8], [9]. When the signal from the ultrasonic sensor is sent to the Arduino processor, the signal is analyzed and feedback is sent to the notification system.

At the core of the enhancement to the white stick introduced by this research is a simple but effective and efficient notification system that receives feedback signals from the Arduino board and notify the user accordingly. There are two types of notification systems available to the user; the basic and the enhanced notification system. The basic notification system is a simple tactile vibrational intensity-based system that utilizes a series of buzzers to alert the visually impaired to the presence of danger [10], [11]. The enhanced notification uses a Bluetooth module on the Arduino board to send preset signal feedbacks to an app on the user's smartphone [5]. The app plays back prerecorded voice notification signifying the detected condition. Whereas users are at liberty to choose between any of the notification system, a master switch on the stick allows both notification systems to be active simultaneously.

Figure1. CAD design of cane.

Text



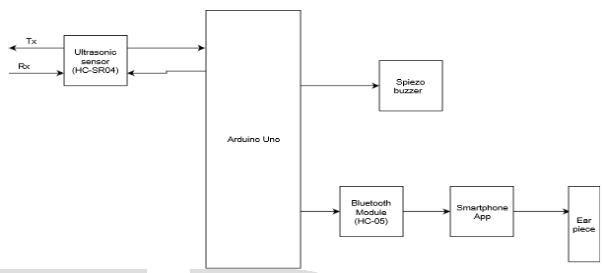



Figure2. Block Diagram of the proposed system.

The proposed system was developed to avoid accidents such as falling into a hole and collisions for the visually impaired both at home and on the road.

## 3 MAJOR-COMPONENTS REQUIRED

**Arduino Uno R3 microcontroller**:

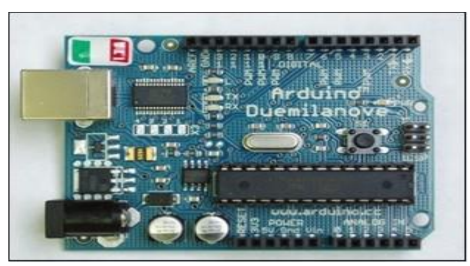


Figure 3. An Arduino microcontroller

The diagram in figure 3 above is a microcontroller board based on the ATmega328P. It consists of 14 digital input/output pins: 6 PWM outputs, 6 analogue inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header, and a reset button. It contains the required components for the experimentation of this research. An on-board LED connects to digital pin 13. There is also a rest button.

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### 3.2 Ultrasonic Sensor:

Figure 4. Ultrasonic sensor.

The HC-SR04 ultrasonic sensor is used in this research. This economical sensor provides 2cm to 400cm of non-contact measurement functionality with a ranging accuracy that can get up to 3mm. Each HC-SR04 module includes an ultrasonic transmitter, a receiver and a control circuit. There are four pins on the HC-SR04: VCC (Power), Trig (Trigger), Echo (Receive), and GND (Ground). It generates high-frequency sound and calculates the time interval between the sending of the signal and the receiving of echo from the signal. The Ultrasonic transmitter transmits an ultrasonic wave, this wave travels in the air and when it encounters interference from an object it gets reflected back toward the sensor this reflected wave is observed by the Ultrasonic receiver module and the time between generation and reception of echo is evaluated.

Therefore, the ultrasonic sensor can be used to measure distance.

This sensor is a very popular sensor used in many applications where measuring distance or sensing objects are required. The module has two eye-like projections in the front which form the Ultrasonic transmitter and Receiver system. The sound usually travels at approximately 340meters per second in air this can be expressed as 29.412μs per centimetre. To measure the distance, the sound has travelled the formula below is used:

**Distance = (Speed × Time)/2**

The signal travels back and forth and thus the reason for diving by 2.

### 3.3 Buzzer:

Figure 5. Piezo buzzer.

A piezo buzzer is basically a tiny speaker that you can connect directly to an Arduino.

Piezoelectricity is an effect where certain crystals will change shape when you apply electricity to them. By applying an electric signal at the right frequency, the crystal can make sound.

From the Arduino board, tone based sound can be produced. The processor needs to be notified on the out pin to which the buzzer is connected, what frequency (in Hertz, Hz) is required, and the duration (in milliseconds) the tone should persist. How to select the right frequency? The range of hearing is usually better in young people ranging from 20 Hz and 20,000 Hz than in old people who find it difficult to hear up to 20,000 Hz [13]. This varies from person to person. However, it is worthy of note that the buzzer may not be able to reproduce all the range of frequencies stated above. This is more likely for the very high and low notes.

### 3.4 Bluetooth module(hc-05):

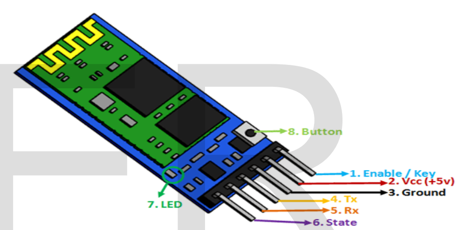


Figure 6. HC-05 Bluetooth module.

HC-05 Bluetooth Module is a design-friendly Bluetooth SPP (Serial Port Protocol) module, designed for efficient wireless serial connection setup. It transmits via serial communication which makes an easy way to interface with controller or PC. HC-05 Bluetooth module provides switching mode between master and slave mode implying that it is able to utilize either receiving nor transmitting data. This module will connect to the user's smartphone wirelessly to relay audio information to the user through any wireless audio device of choice. A mobile application containing a set of pre-recorded voice commands will be installed on the user's smartphone.

Specification:

- Model: HC-05
- Input Voltage: DC 5V
- Communication Method: Serial Communication
- Master and slave mode can be switched

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## 4 EXPERIMENTAL SETUP

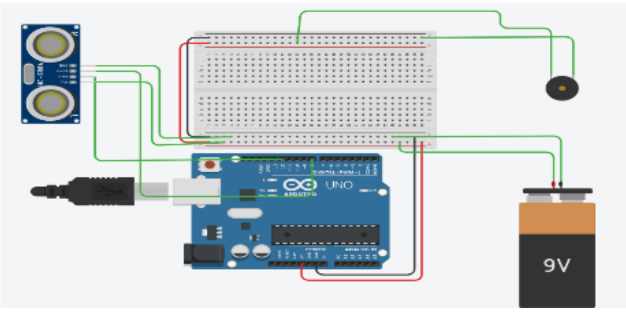



Figure 7. Circuit diagram of the proposed system.

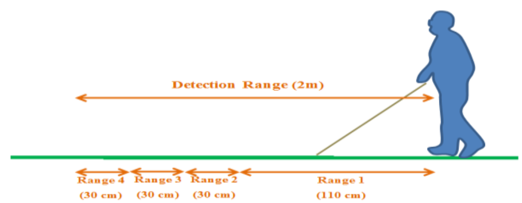
The buzzer and the sensors are connected to the Arduino board. The Arduino board is able to perceive the environment by receiving input from the sensors. It works to guide the user by controlling the buzzer. The sensors generally detect objects around and send either a HIGH or LOW signal to the microcontroller which processes this signal. The microcontroller is programmed to give appropriate feedback through the buzzer to the user depending on the signal it receives from the sensors. The cane generally works by detecting objects and obstacles around through the use of the Ultrasonic sensor. The functionality of the cane is broken down into 3 parts: Firstly, detecting objects and obstacles, secondly, measuring the height and width of the obstacles, and lastly, detecting edges of depressions on the path of the user. The Ultrasonic sensors provide a 2cm-400cm non-contact measurement function, with a ranging accuracy of 3mm good for detecting close-range objects.

The ultrasonic sensors extend the range of obstacle awareness of the cane to about three times the distance of the traditional cane (i.e. 3m). The range of vibration patterns by the buzzer is assigned to different distances helping the user get a clearer indication as to the closeness of the objects and most importantly the differences in depths of depressions.

As soon as the visually impaired starts moving with the white stick, the ultrasonic sensors are activated, sending the output from the sensors to the Arduino microcontroller. The base sensor registers the presence of an obstacle as well as detecting edges. The presence and closeness of an obstacle will be noted by the return of an echo signal, the base sensor also upon activation obtains a reference value that serves as the ground level. The reference level will be the ground level and the information is transferred to the microcontroller and will be used by the system to continually compare different levels obtained by the base sensor. As soon as a change in level is observed, a signal is sent to the notification system to alert the user. This functionality helps evaluate the depth of depressions and potholes. To obtain the height and width of the obstacle encountered, a system of sensors can be utilized to obtain the data and have it analyzed by a microprocessor [4], [6]. This research utilized sensor modules mounted horizontally and vertically, housing an array of 3 ultrasonic sensors each to obtain the distance and height data. The difference in the time of response obtained by the sensors was used to compute the possible width and height of the objects.

## 5 RESULT

In order to illustrate the efficiency of the proposed system




several tests were carried out, these tests are basically broken down into:

- First, the cane was tested to detect objects at preset distances

Figure 8. Object detection.

- Secondly, the cane was tested to detect edges and depressions at different depths.

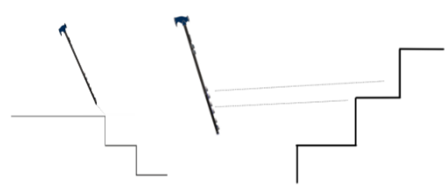


Figure 9. Depth detection.

- Thirdly the width of the obstacle will be calculated for routing purposes.

Figure 10. Width detection

- Also, the height of the obstacle detected is also calculated.

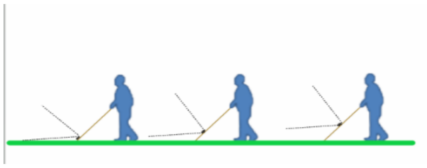


Figure 11. Height detection

The data recorded is shown below:

Case 1. Feedback at preset distances:

| Distance(cm) | Vibration /voice feedback |
|---|---|
| 10 | Ceaseless /critical danger |
| 20 | |
| 30 | |
| 40 | Swift/ serious danger |
| 50 | |
| 60 | |
| 70 | |
| 80 | Rapid/ likely danger |
| 90 | |
| 100 | |
| 110 | |
| 120 | Slow /caution |
| 130 | |
| 140 | |
| 150 | |

Table 1. Behavior of the stick in detecting obstacles at different distances:

Case 2. Feedback at preset depths:

Firstly the system will be tested at different depth levels:

| Depth(In) | Depth(m) | Feedback |
|---|---|---|
| 0-11 | 0<0.2794 | Slow soft tone and vibration Safe approach with caution |
| > 11 | >0.2794 | Rapid vibration with a high pitch tone. Not safe |

Table 2. Behavior of the stick in detecting depressions of different depths.

Case 3. Table showing the response time of the cane with the width of an obstacle:

Response time of sensors with respect to a wide object at different distances:

| Distance(m) | Width(cm) | Sensor1 (µs) | Sensor2 (µs) | Sensor3 (µs) |
|---|---|---|---|---|
| 10 | 65 | 20.9 | 21.1 | 21 |
| 20 | 70 | 20.5 | 20.5 | 20.5 |
| 30 | 73 | 20.3 | 20 | 20.1 |
| 40 | 76 | 19.49 | 19.5 | 19.5 |
| 50 | 81 | 19 | 19 | 19 |
| 60 | 84 | 18 | 18 | 18 |
| 70 | 87 | 16 | 16 | 16 |
| 80 | 89 | 14 | 14 | 14 |
| 90 | 94 | 12 | 12 | 12 |
| 100 | 98 | 10.49 | 10.49 | 10.5 |

Response time with respect to a narrow width:

| Distance(cm) | Width(cm) | Sensor1 (µs) | Sensor2 (µs) | Sensor3 (µs) |
|---|---|---|---|---|
| 10 | 10 | - | 9.7 | - |
| 20 | 15 | - | 9.4 | - |
| 30 | 20 | - | 9.1 | - |
| 40 | 25 | - | 9 | - |
| 50 | 30 | - | 8.8 | - |
| 60 | 35 | - | 8.5 | - |
| 70 | 40 | - | 8.2 | - |
| 80 | 45 | - | 7.9 | - |
| 90 | 50 | - | 7.5 | - |
| 100 | 50 | - | 7 | - |

Table 3. Width of an obstacle

Case 4. Height of obstacle

Response time of sensors for a vertical non-leaning wall:

| Height(c/m) | Sensor 1 (µs) | Sensor2 (µs) | Sensor3 (µs) |
|---|---|---|---|
| 120 | 21 | 20.5 | 20 |
| 110 | 19 | 18.9 | 18.75 |
| 100 | 18 | 17.89 | 17.89 |
| 90 | 17.5 | 17.25 | 17.25 |
| 80 | 17 | 16.89 | 16.9 |
| 70 | 15 | 15.77 | 15.9 |
| 60 | 15.5 | 15.3 | 15.45 |

Response time from sensors for a descending forward-leaning wall:

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| Height(cm) | Sensor 1(μs) | Sensor 2(μs) | Sensor 3(μs) |
|---|---|---|---|
| 150 | - | - | 20.12 |
| 140 | - | - | 18.66 |
| 130 | - | 17.5 | 18.45 |
| 120 | 16.89 | 17.5 | 17.59 |
| 110 | 16.89 | 17 | 17.5 |
| 100 | 15 | 15.8 | - |
| 90 | 15.5 | 15.68 | - |

Response time from sensors for an ascending forward-leaning wall:

| Height(cm) | Sensor 1(μs) | Sensor 2 (μs) | Sensor 3(μs) |
|---|---|---|---|
| 150 | 20.00 | 20.05 | 20.10 |
| 140 | 18.45 | 18.50 | 18.60 |
| 130 | 17.40 | 17.50 | 18.00 |
| 120 | 16.50 | 17.50 | 17.59 |
| 110 | 16.89 | 17.00 | 17.50 |
| 100 | 15.10 | 15.45 | 15.55 |
| 90 | 15.55 | 15.67 | 15.70 |

Table of the height range of operation for the sensors:

| Height Range(In) | Sensor 1(μs) | Sensor 2(μs) | Sensor 3(μs) |
|---|---|---|---|
| Above 10 | - | - | 20.5 |
| 4.5-9.5 | - | 19.7 | - |
| 0-5 | 19 | - | - |

Table 4. Height of obstacles.

## 6 ANALYSIS OF RESULT

After the system was implemented and the test of the stick was carried out under the set conditions:

Case 1: Detecting obstacles at preset distances:

From table 1, we see that the intensity of the vibration obtained from the buzzer is directly influenced by the distance of the object from the sensor. Obstacle within the range 10cm≥distance≤30cm caused the buzzer to produce steady vibration and audible tone indicating the presence of constant, critical danger. The danger signal will allow the user to consider an alternative path of progress or adjust to a safe navigation parameter.

As the test distance increased between the stick and the obstacle (40cm≥distance≤70cm), the buzzer's intensity diminishes slightly to serious danger, gradually terminating at soft caution alert at (120cm≥distance≤140cm)

Case 2: detecting edges and depressions of ranging depths:

Results of testing the stick on depressions of varying depth are tabulated on table 2. It can be seen from Table 2 that the buzzer's feedback reflected the depth of encountered depression. The strength of the vibration acts as a guide to the user. If it is a pothole considered to be too deep for the visually challenged it gives a stronger faster vibration; if it is a safe depression but a pothole nonetheless it still gives a vibration but a lighter slower one just to allow the user to become aware of the imminent danger.

Case 3. Detecting the width of an obstacle:

The system implements an array of 3 sensors to detect the approximate width of an encountered object. From table 3, it can be observed that when an obstacle is large the 3 sensors give a response time that is similar within the margins of error. However, when the object is narrow or small only one sensor returns a signal to the Arduino. Also from the table, it can be gathered that as a user approaches an object the width or size of that obstacle appears to increase as all the sensors begin to report similar values. Taking note of the width can help in developing a guidance system for the user.

Case 4. Detecting the height of an obstacle:

For a vertical non-leaning wall all 3 sensors return signal to the microcontroller within the same time range. The results are similar for both static and dynamic obstacles. Tables 4.

Two types of forward-leaning walls were tested on this experiment: descending and ascending forward-leaning walls. In both cases, staircases were involved in the test and data gathering. For a descending forward-leaning wall, it was observed that not all three sensors picked up a signal as the two topmost sensors did not register bounced back echoes. Thus, this research could not reliably determine the height of a forward-leaning descending walls using the array of sensors. However, for ascending forward-leaning walls, all three sensors registered echoes with varied time ranges with the topmost sensor returning the longest time and the base sensor returning the least time. This variation in time was the bases in the calculation to determine that the wall was an ascending forward-leaning wall.

## 7 CONCLUSION

The different functionality of the cane might be confusing to a new user, taking into consideration that the feedback system might take some time to get used to. The equipment has been designed to allow the user to optionally turn on the different functionalities of the stick. The user can activate only basic obstacle sensing without the need for the more complex operations of height, width, and depth sensing. The other sensing capabilities can also be switched on independently of

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each other, giving the user a wide range of flexibility required to gradually learn and get used to the gamut of functionality offered by the equipment. When the enhanced stick has been fully mastered by the user, a master switch allows the user to activate the full range of functions all at once.

Whereas this research was able to develop a system that enables the white stick to determine the width of encountered objects, it was unable to use the width information to reliably modify the user's path. Future improvement of this research would focus on reliably evaluating the width of encountered objects and the height of forward-leaning descending heights and used the data to reliably modify the user's path by suggesting safer paths to the user.

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