A SENSOR NETWORK DRIVEN OBSTACLE LOCALIZATION SYSTEM WITH 3-D PERCEPTION BASED FEEDBACK FOR VISUALLY IMPAIRED PERSONS

A thesis submitted to the
University of Petroleum and Energy Studies

For the Award of
Doctor of Philosophy
in
Computer Science and Engineering

By

Bhupendra Singh

May 2021

SUPERVISOR

Dr. Monit Kapoor

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Department of Virtualization
School of Computer Science
University of Petroleum & Energy Studies
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Professor
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DECLARATION

I declare that the thesis entitled "A Sensor Network driven Obstacle Localization System with 3-D Perception based Feedback for Visually Impaired Persons" has been prepared by me under the guidance of Dr, Monit Kapoor, Professor of School of Computer Science, University of Petroleum and Energy Studies. No part of this thesis has formed the basis for the award of any degree or fellowship previously.

Bhupendra Singh

School of Computer Science

University of Petroleum and Energy Studies,

Dehradun, Uttarakhand 248007

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CERTIFICATE

I certify that Bhupendra Singh has prepared his thesis entitled "A Sensor Network driven Obstacle Localization System with 3-D Perception based Feedback for Visually Impaired Persons". I have read this abstract and in my opinion, it is fully adequate, in scope and quality, as abstract for the degree of Doctor of Philosophy.

Monit Kapoor

Internal Supervisor

Dr. Monit Kapoor

School of Computer Science
University of Petroleum and Energy Studies,
Dehradun, Uttarakhand 248007

Abstract

The reduced ability of ability of eyes to see clearly even with the use of glasses is known as the state of Visual Impairment. Among the many challenges faced, outdoor travel is one of them requiring to travel through surfaces, which has potholes and bumps. In addition, the white cane most commonly used by the Visually Impaired persons for obstacle detection in their traveling route has its limitation with the inability to detect obstacles above waist height. Due to this limitation head injury is very commonly faced by the Visually Impaired persons. In our work, these problems are addressed and warning or feedback is provided to the user through vibro tactile mean, so that precautionary actions can be taken. The depth of the pothole and height of the bump is also conveyed to the user through different vibration pattern of various intensity. With available Electronic Travel Aids, the VI persons are still more inclined to rely on their white cane then carrying additional equipment for obstacle avoidance. In our work, all the components can be attached to the white cane, requiring no additional device to carry. Upon experimentation with different obstacle types, our system obtained 24.88% higher score in comparison to normal walking cane. A comparison with the state of the art available systems is also provided. Moreover, the accuracy of the assistive cane can be heavily degraded if the cane is not properly held by the user. To restrict the user to hold the cane in only required orientation an Alignment Sensing Switch is also proposed which is missing in the current available literature.

We further, present a model inspired by the real world settings for detecting low lying obstacles, considering few assumptions and constraints. The simulations are also proposed based on the model to generate obstacle data any number of time. Furthermore, to validate our model and simulations, field experiments are conducted, and the results obtained are compared with the simulation result. The obstacles are classified into four types on the basis of their height, first the case for no obstacle, the second for the small obstacle, third the medium obstacles and the last the large obstacles. The three different speeds is also considered in the work, slow, normal and fast. The evaluation parameter in terms of standard deviation, accuracy, false positive, errors encountered suggest that the proposed model and simulations effectively encapsulates the real-world parameters and thus can be explored and utilized further by the research community. To benchmark the results, three different obstacle classification methods are also presented along with the obtained results by

various methods. The three methods are cluster, histogram and quadratic curve based.

Finally, we have developed eyeglasses, which consist of two ultrasonic sensors and two buzzers for obstacle detection and localization. The location of the obstacle in 3D space is conveyed to the user with varying frequency patterns through the buzzers. The 3D location of the obstacle is conveyed in terms of laterality, elevation and depth information. Upon testing the system for the effectiveness in detecting the obstacle in 3D space, it is found as 70.5% laterality detection rate, 70.5% elevation detection rate and 80.8% depth detection rate. On comparing our results with similar works reported in the literature as a state of the art, our system performs better. The power and cost analysis of the developed system in comparison to the computer vision based system is also provided which advocates in favor of the US sensor based system.

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Dehradun

May, 2021 (Bhupendra Singh)

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List of Abbreviations

3D	3 Dimensional
AH	Amphere Hour
ASS	Alignment Sensor Switch
AVR	Alf and Vegard's RISC processor
BLE	Bluetooth Low Energy
BVI	Blind and Visually Impaired
CPMM	Chaotic pulse position modulation
CSV	Comma Separated Value
DOF	Degrees of Freedom
EM	Electro Magnetic
ETA	Electronic Travel Aid
GPS	Global Positioning System
HCI	Human Computer Interaction
HMI	Human Machine Interaction
IC	Integrated Circuit
ICT	Information and Communication Technology
IDE	Integrated Development Environment
IMU	Inertia Measurement Unit
iOS	I Operating System
IoT	Internet of Thing
LiPo	Lithium Polymer battery
N	Number
Ob	Obstacle
Oblg	Obstacle large
Obmd	Obstacle medium
ObNO	No Obstacle
Obsm	Obstacle small
PE	Pose Estimation
PWM	Pulse Width Modulation
QuD	Queue of Distances
RGB	Red Green Blue
RGB D	Red Green Blue Depth
SD	Standard Deviation
TOF	Time of Flight
US	Ultrasonic Sensor
USB	Universal Serial Bus
USD	US Dollar

USODataGen	Ultrasonic Sensor Obstacle Data Generator
USSL	Ultrasonic Sensor Left
USSR	Ultrasonic Sensor Right
VI	Visually Impaired
WHO	World Health Organization
WWII	World War 2nd

Title of the Thesis

A Sensor Network driven Obstacle Localization System with 3-D Perception based Feedback for Visually Impaired Persons

Chapter 1: Introduction

Our eyes play an important role in conveying information about our surroundings and thus forms an essential part of our body. However, in some cases there can be reduced activity of the eyes where one is not able to clearly interpret the environment around. One such case is described by the term Visual Impairment (VI). In this case, the ability of the eyes are decreased up-to that level that even the usage of eyeglasses are not of help. There is one more term, which is visual acuity, which is defined as the clarity of the vision. There are psychophysical tests to measure the visual acuity of a person. For a normal vision person, visual acuity is measured as 6/6. While in case of visual impairment, it can worsen up-to 20/40 or even 20/60. The extreme case of visual impairment is termed as blindness where there is complete loss of vision. When a person losses vision, it becomes extremely difficult to get information about the environment in front of the person. Daily tasks like navigation to a different place and locating nearby objects also becomes very difficult. This leads visually impairment persons prone to injury when navigating to an unknown environment.

There are a number of causes for visual impairment. Out of all 43% cases are attributed to uncorrected refractive errors whereas un-operated cataract accounts for 33% of the cases [1]. The refractive errors consists of myopia or shortsightedness, the case when light focusses in front of the retina and not exactly on it. Hyperopia or astigmatism is the case when light focusses behind of the retina and not on it. The case cataract is the clouding of the eye lenses which leads to the blockage or deviations of the passage of the light which is necessary for normal vision.

As per fact sheet which has been provided by WHO [1], August 2014

- It is approximated that 285 million people are visually impaired worldwide.
- Out of the total of visually impaired, there are 39 million persons who are completely blind and rest 246 million have a very low vision.
- The age group of 82% of blind people are 50 and above.
- Unfortunately, there are 80% cases of visual impairment, which are preventable or curable.
- The income settings of around 90% visually impaired persons around the world is low.

The last point is important to note which clearly grabs our attention that most of the visually impaired persons belongs to low income category. It also worthwhile to note that most of the visual impairment cases are curable or avoidable. Screening and early treatment can play an important role in this regard. Nevertheless, the lack of awareness and even a simple education acts as barrier for covering these services. Thankfully it is also mentioned in the WHO factsheet that in the last 20 years, the reporting of new cases are reducing. This may be attributed to the government measures and programs nationwide and also to the availability of the eye care institutes, campaigns organized by the schools for educating and raising awareness among children about the importance of visual function.

1.1. Current Aids for Visual Impairment Persons

There are a number of aids available for the VI persons for travelling from one place to another in the form of various training, devices, and mobile applications and to get awareness about the current location of the person. These various aids are discussed next.

1.1.1 Orientation and Mobility Training

A new discipline now known as Orientation and mobility training came into existence during the World War II. Richard E. Hoover, Russel Williams and C. Warren Bledsoe created specialized trainings for blind army personnel so that they can collaborate effectively together which lead to the development of orientation and mobility training. Today there are a number of training institutes around the world, which provides these training for VI persons. These training provides them instructions for

- Commutation through their environment or even unknown environment in an effectively safe manner.
- The development of their sensory perception to maximize all of their senses for better perceiving of their environment.
- Usage of white cane for safely walking.
- Learning to cross streets and perceiving the traffic.
- Usage of public transport system.

Fig 1.1. White Cane training IC: leaderdog.org

1.1.2 White Cane

A White cane is a thin, long, lightweight stick very commonly used by VI persons. The VI persons uses white cane to get information about their environment in order to travel through it. With the help of white cane, VI persons can accomplish a number of daily tasks like going through stairs, finding dropped objects, doorways, using escalators and one of the most importantly avoiding obstacles if there is any in their path.

How white cane is used?

The user starts with holding the cane with the handle to a height up to their waist such that the index finger points along the cane shaft which points towards the tip of the cane, which is situated at the other end of the cane and regularly touches ground. Once the user starts walking, the cane has to be swept from left to right in the form of an arc, which is of the size of the width of the user itself. In this manner, if there is any obstacle on the path, the tip of the cane is expected to encounter it first. Thus, this way they gets useful time to avoid the obstacle and take appropriate alternate path.

1.1.3 Travel Dog

To travel safely in a route having obstacles or crowded, the travel dog comes handy for the VI persons. These dogs undergoes special training for these purpose only. However, it should be noted that these dogs do not assume by themselves the route to choose or when it is the right time to cross the road.

Instead, the VI persons commands them and the travel dogs only helps in avoiding obstacles in the path.

Few important points needs to be considered before buying dog guides for the VI persons

- High Cost: These travel dogs do not come cheap and have high maintenance cost to cover daily food, grooming and exercise.
- Constant Practice: These travel dogs need to perform mobility tasks almost daily otherwise there are chances of them losing mobility skills.

Figure 1.2: Use of travel dog

IC: vissionware.org

1.1.4 Global Positing System for the Visually Impaired Persons

A number of commercial as well as free software applications and standalone devices are available in order to help VI persons for the purpose of travel. Some of them are described below.

Android Operating System based devices:

- Corsair GPS: This is an application, which helps in locating useful places around the user and getting there. The vibration of the mobile phone is used to instruct the user for the directions to follow.
- Cydalion: It is a navigation application for the users having special platform called Tango (Augmented Reality computing platform) which has to be available on the devices. It is able to detect objects along with their heights and to provide feedback to the user custom-based sounds are used.

iOS Operating System based devices:

- Ariadne GPS: It was released in June 2011 and was one of the first applications to be designed for VI persons. It offers several features:-
- Information about the location whenever requested by the user.
- Saving the locations as desired by the person and alerts them whenever they are approached.
- User can slide over the map on the device and the application informs the user about the location.

Blindsquare Application:

A number of features for VI persons are provided by this application which includes:-

- Announcement of interesting public points.
- Sending geographic location coordinates of destinations to others.
- User interface in the form of audio menu.
- Simulation of any distant place, in order to help user know about them without first actually visiting them.

Standalone Devices:

- Trekker: This is a portable device launched in March 2003 and weighing around 600g. It offers a number of features like maps and menus, which can interface with users audibly. It also has a search functionality, which can find public point of interests like restaurants, ATMs, hotels etc.

- BrailleNote GPS: The device was launched in the year 2002 and uses satellite information for the purpose of triangulation to help user find location on the map. The location is provided to the user through spoken information using speech synthesizer.

1.2. Electronic Travel Aids

Electronic travel aids (ETA) are the electronic devices, which uses sensors to perceive and gather information about the user's environment, processes the sensed information to extract useful information and conveys the information to the user through another sensory means. These three parts are described in details below.

1.2.1. Sensing System: In the first step the information about the environment is sensed through, different means, which can be-

a. Computer Vision: A camera is used which takes image of the environment of the user. The image is further processed to extract the different obstacles present. To get the depth information of the obstacles a technique called stereo vision is used which requires simultaneous working of two cameras. The two cameras are situated at different places. The two images thus obtained are compared for similarities and differences. This information is then used to create a 3-dimensional environment in front of the user.

b. Ultrasonic Sensors (US): Ultrasonic sensors employs ultrasonic waves which have frequency more than 20Kz not audible to human ears. Human ears can hear frequency in the range of 2 to 20Kz. These sensors finds application in the areas of ultrasonic flaw detection in robotics, industries, vehicle navigation and communication. In robotics, these sensors are used extensively for ranging purposes. In order to roam freely in their environment by the autonomous robot, collision avoidance is a basic concern. The US sensors offers a number of other promising applications. For example in order to detect potholes and bumps on the road surfaces which are very common especially in developing countries, the US sensors can be employed by pointing towards the road surface and reading the distance continuously. If a bump is encountered the successive readings will show decrease in reading while in the case of pothole the successive readings will show increase in readings. However, this simple looking approach turns out to be difficult when there are multiple reflections with the obstacle surfaces, which can cause interference in distance measurements. A very commonly used US sensor by the hobbyist is HC SR 04. The sensor works for measuring distances up to 4meter.

Working Principle: In very common settings, the US sensor hosts two transducers. One transducer emits US pulses in front of it while the other transducer keeps on checking whether any emitted pulse is received back after hitting the obstacles in front of the emitting transducer. The total time taken by the US pulse after being detected by the receiving transducer is known as time of flight (TOF).

c. Laser: Laser stands for Light Amplification by Stimulated Emission of radiation and works on the principle of optical amplification of narrow guided light. In order to find out the distance by the laser, the sender towards the target emits a narrow beam of light and after reflection, the same sender senses the beam. As the distance of the light is known to be 300m/s, the distance of the target is easily calculated with the help of simple distance, time formula. The advantage of the laser over the US sensor is its range and speed with which it can measure the distance of the target. Because of this the laser sensors are used extensively to measure the speed of a moving target. However, the laser devices are costly and high power consuming in comparison to US sensor.

1.2.2 Processing System

The data from the sensors and the input/output peripherals need to be processed through software modules in the form of programming. Currently there are a number of microcontrollers system available for this purpose. Below is the details of two very popularly used one.

Arduino: The Arduino microcontroller board was launched in the year 2005 as a general purpose system. Since then it has gain world wide popularity and till date there are billions of these devices which have been sold. The sharp rise in its popularity can be attributed to its simplicity to program and interfacing external sensors and the low cost of the device at the same time. The logic level for the board is 5V and its working frequency is 8 to 16Mhz.

The Arduino boards are based on ATmega168 or Atmega328 processing chip by Atmel which is based on advance Harvard architecture with 8-bit RISC processor core. There are also a number of different Arduino boards of different size available which have different number of I/O pins and also different memory capabilities.

A typical Arduino board has 6 analog pins, 14 Input/ Output pins out of which 6 can provide Pulse Width Modulated Signal (PWM) which means that the voltage of the PWM pin can be changed in between 0-5V with the help of software programs.

To work with the board, it has to be connected with the computer through a USB cable and programming in a similar C language can be done on a desktop based IDE. The IDE also provides a number of supported libraries to work with different types of sensors. Once the program is written on the desktop based IDE, it can be transferred to the Arduino board through the USB cable.

Raspberry PI: Raspberry Pi is another very popular microcontroller board developed by Raspberry PI foundation and released in the year 2013. The aim of the foundation is to promote computer education in developing country where people cannot afford the cost of a computer. The board is a full-fledged mini computer with a size of just 85.60 mm × 56.5 mm, and the weight of the system is also around 31g. Still the board has decent processing capability and hosts a number of GPIO pins (General Purpose Input Output) which can be used for interfacing external sensors or I/O devices. There are two models available named as Model A and Model B. First model is cheaper but has limited features, on the other hand the second one provides a number of functionalities.

The popular language Python is used for programming in Raspberry. The small credit card size board also hosts a HDMI port for display purpose.

1.2.3 Feedback System

Once the information about the environment have been sensed by the sensors and processed for extracting meaningful information by the processor, the processed information needs to be provided to the user. This can be achieved by any of the below means.

- Auditory: Headphone-based devices are attached to the ears. Moreover, to guide the user through the environment, a number of recorded audio message are played.
- Vibrato tactile: In this case, a number of vibration motors are attached to the body of the user. In order to provide different feedback the intensity of these motors are modified. The body part where these vibration motors can be attached includes head, chest or hands.
- Electro tactile: In this mode, a number of array of electrodes are attached to the skin of the user and a low voltage, controlled current is applied to the user in a desired pattern. The idea of this setup is to mimic the working of the eye and how the eyes have provided feedback to the user if normally working.

1.3 Research Gaps

Based on inferences drawn in previous section the following research gaps have been identified:-

I. Computer Vision based techniques are not very much reliable as a small change in operating conditions can result a different input image for the system.

II. The complexity involved in the camera-based system is also very high, which may not result to work in real time.

III. Few works have demonstrated the use of smartphone as providing vibration feedback to the user, however not all the VI persons carry smartphone and if so, then dedicating a smartphone for the system may not be appropriate.

IV. Few systems require VI persons to wear them on the chest or on the arms, which may not be comfortable for the VI persons.

V. Few systems have proposed voice command based feedback for obstacle location information. However, processing voice commands by the user would slow down the process of obstacle identification and avoidance, thus limiting the system to work in real time.

1.4 Motivation

The following facts about ETAs for VI persons provide us motivation for research.

- Most of the ETAs are not wearable for the VI for practical purposes.
- The high cost of the ETAs also makes them unaffordable for the VI persons.
- The feedback mechanism through the ETAs are not close to the natural way of sensing of Humans.
- Most of the present systems are not tested for feedback mechanism, as it requires experimental set up very close to real world involving VI persons.
- Most of the present systems are not designed to provide 3 dimensional feedbacks.

1.5 Problem Statement

ETAs proposed in the literature suffers from similar drawbacks like cost, weight, size and the unavailability of reliable dataset for the study of obstacle data which can form the base for continued research.

1.6 Objective:

The aim is to develop a sensor network driven obstacle avoidance system, which shall provide frequency modulated acoustic feedback for the perception of the 3 D environment in front of the visually impaired user.

Sub-objectives incidental to the main objective**:**

- Functional
  - The system should work in real time.
  - The system should detect static obstacles in defined field of view with good accuracy.
- Ergonomic
  - The system should be wearable with comfort by the end user.
  - The system should not result as impediment to user's normal way of work.

Chapter Scheme

The rest of the thesis is organized as; the chapter 2 discusses the work reported in the literature, which consists of survey papers, works based on camera devices, or ultrasonic sensors, mobile phone and others. Next, chapter 3 describes our work in which a framework is presented which can be used to generate obstacle data using ultrasonic sensors. Next, in chapter 4 our work is described which presents an assistive cane which can detect potholes and bumps on the road surface. The chapter also describes our novel alignment sensor switch, which can restrict the orientation of the cane to desired range only. Next in chapter, 5 an eyeglass based obstacle avoidance device is described which uses two ultrasonic sensors and two buzzers for the detection of obstacles in front of the user and provides vibration pattern based audio feedback to the user to perceive the location of the obstacle. Finally, chapter 6 concludes the thesis.

Chapter 2: Literature Survey

In this chapter the related work which has been reported in the literature are discussed. The related work includes survey papers, works based on camera, ultrasonic sensors, lasers and other devices. There are other works also where electromagnetic waves have also been investigated for the purpose of obstacle detection. Few of these work has also been used for comparative study.

Ramiro Velazquez [3] has presented various work on assistive technological devices. Though there are a number of different travel aids available for VI persons which includes travel dogs, GPS devices, mobile applications, here the work on Electronic Travel Aids (ETAs) are discussed. The work in [4] discusses other available travel aids in detail. The ETAs are the electronic devices which acquire the information about the user's environment with the help of different types of sensors and convey the information which have been sensed after processing to the user with the help of another sensory means. There are a number of work which have been reported in the literature on ETA devices in order to assist VI persons, which are discussed in this section.

Dimitrios and Nikolas [5] in their work surveyed 17 wearable obstacle avoidance devices and ranked them on the basis of their performance on 14 proposed different parameters. In the work by Md Milon et. al. [6] surveyed different work on computer vision, mobile phone based, embedded system in order to assist VI persons. Kanak Manjari et. al [7] also provides a survey of different assistive technologies available for VI persons. Similarly Alexy Bhowmick and Shyamanta M. Hazarika [8] in their work presents state of the art work as well as future trends. In the work by Wafa Elmannai and Khaled Elleithy [9], current work, challenges present and future directions are proposed. In another work by William Grussenmeyer and Eelke Folmer [10], accessible touchscreen technology for VI persons are presented.

In the work by Mun-Cheon Kang et al. [11], the obstacle is detected using monocular vision camera and the resulting image is divided into a grid of equidistant pixels. The grid thus formed changes its shape when the camera is moved towards or away from the obstacle. This way identifying whether the obstacle is approaching or receding away. In the work by Aravinda S. Rao et al. [12], a method is proposed for analyzing received laser pattern after being emitted. The surface having pothole or unevenness is detected after employing Hough transform and using computer vision algorithms. In the work by Noorjahan and Punitha [13], the technique of segmentation which is commonly used in computer vision is used, thereby recognizing the objects presents and helping VI persons to identify public transport vehicles, busses and recognizing the information present on them. Thus helping in travelling from one place to another. In the work by Ong et al. [14], infrared sensors for obstacle detection are used. There are also a number of work where the capability of smartphone is tested for obstacle detection and also to provide audible or vibro-tactile feedback to the user. In one such work by Pablo Vera et al [15], smartphone's camera and the laser beams are used together to find the distance of the obstacle from the user. The vibration sensor of the smartphone is used to provide different types of feedback to the user.

Few researchers have also proposed different types of wearable devices like Navbelt [16], waist-belt [17] and a bracelet [18] for assisting VI persons in finding low height obstacles. Kai et al. [19] proposes an eyeglass based stereo vision system as an assistive device for visually impaired persons. Their system helps in avoiding obstacles and also streams video in real time to mobile phone using 3G networks.

Laser Cane [20], Teletact [21] and Minitact [22] are some other examples of assistive devices which are based on laser principle. There are some drawbacks associated with the laser that they are unable to detect transparent glass since the emitted beam is not reflected on it. Laser systems are also costly but they can detect obstacle upto a very long distance. Another assistive device K sonar canes [23], is able to identify floor as well as head height obstacles. To convey the feedback to the user different frequency pattern of the sound is used. CyARM [24] is a handled system for obstacle recognition. The concept of' human-machine interface' is utilized to design an especially accessible device for visually impaired persons. The authors developed an electric aid which can be used for guiding orientation as well as locomotion. Ching et. al. [25] in their work presented an obstacle avoidance system and also for path planning using Kinect depth sensor for mobile robots. Their research combined the Kinect depth sensor along with the omni-directional RBG camera in order to construct the vision system of FIRA named RoboSot. They used the above two complementary devices in order to enable robots which can position themselves and also to detect their distance from obstacles.

To detect the stairs, Sonda Amar et al. [26], designed an assistive white cane using US sensors. The authors considered system requirements as well as the technology cost, and used, for the conception of their tool, ultrasonic sensors and one monocular RGB camera to enable the user of being aware of the presence and nature of potential obstacles which may be encountered. A phase beamforming principle is devised by Marcin et al. [27] to detect the obstacles precisely. US sensors are used a lot by many other researchers for obstacle avoidance because of their low cost and easy to use feature. In the work by

Cheng- Lung Lee et al. [28], an obstacle avoidance system is presented which employs US sensors. They also tested their system on a designed route which consisted of various obstacles like plants, trees, bike, cycle and others. In the work by Gu-Young Jeon and Kee-Ho Yu [29], multiple US sensors are employed which are seven in total. Each sensor faces different directions and are fixed on a mini robotic system which itself is attached to the cane bottom. US sensors along with camera is used in the work by Bogdan Mocanu et al. [30], where static and dynamic obstacles are detected and the user is alerted with the help of acoustic feedbacks.

To detect knee above obstacles smart cane is developed by M Balakrishnan et al. [31] using US sensors. In their work, the authors reported the design and implementation of a specially detachable different units which acts together to augment the functionality of the prevalent white cane, in order to allow knee-above obstacle detection. In the work by Arnesh Sen et al. [32], three US sensors are used and attached to the user's chest, toe and knee. Their work aims to design a special artificial navigating system which have the functionality of adjustable sensitivity with the help of ultrasonic sensor and a module of GPS in order to assist blind persons so that they can walk fearlessly as well as independently in both indoor and outdoor environment. Their system is able to detect any type of obstacles in front of the user and potholes using the reflection property of ultrasound waves. The system can be attached to the clothes, body area, shoe as well as to the walking cane which makes its utilization somewhat more versatile as well as reliable. In the work by Shripad et al. [33], total six US sensors are used on the walking cane of the VI persons for assessing the obstacle height. The main feature of their cane is that it is able to constructs the logical map of the obstacles in the surrounding environment which can help to deduce the priority information. It also provides a simplified representation of the surrounding environment without unnecessarily causing any information overload to the user. To convey different priority information to the user through intuitive vibration, audio or voice feedback are used.

In another work by Kailas et al. [34], a NavGuide shoe is developed which consists of US sensor for obstacle detection and vibration motor for conveying feedback to the user about the nearby obstacles. They also conducted a survey consisting of total of 177 VI persons, among them 95.5% acknowledged that the white cane provides inadequate information while scanning the surroundings. In addition 90.3% participants wanted to have a portable and lightweight ETA and around 24% requested for a low cost system (less than $20USD). This survey can play a useful role as part of the user requirement while designing and developing any ETAs for VI persons. In contrast to US pulses Lorenzo Scalise et al. [35], used Electromagnetic (EM) wave for the detection of obstacles and compared the results with US sensor based approach. It is found that the US sensor performed well in measuring distances but for measuring every types of obstacles like plastic pole, wooden door after a certain angle, the EM based approach performed better. In the work by De Jesus Oliveira et al. [36], the objective is set as to provide feedback to the user in a virtual environment every time the user is reoriented. In the work, a number of vibration motors are placed on the head of the test subjects. The information about the elevation of the obstacle is provided though modulating vibration frequency using seven different levels.

Senugin Shin et al. [37] works are on increasing the effective measurable range by the US sensors through a method based on chaotic pulse position (CPPM). Their work introduces a computationally intensive algorithm which can help measuring obstacle distance at high frequency rates using a chaotic pulse-position (CPPM) signals and also a single-bit signal processing, hosting everything in a single ultrasound sensor system. In order to prevent crosstalk phenomenon from other ultrasonic sensor systems, a chaotic system has been used, and the ultrasonic pulses are transmitted after hitting the obstacle as a pulse sequence generated by CPPM. Borensten and Koren [38], [39] also provides a method for increasing the accuracy of the US sensor with the idea of taking consecutive readings and incorporating alternate delays using a technique called error elimination rapid US firing.

When multiple US sensors are used together, there comes the challenge of crosstalk. It is the phenomenon of interference when the emitted echo pulse from one sensor is received by another sensor thereby resulting in false distance measurement. To address these issues a number of techniques have been proposed in the literature. Some of them are provided by Luigi et al. [40] and Meng et al. [41].

Guilia Cappagli et al. [44] in their work tries to assess the social competence in VI persons and also proposed an interventional program for VI childrens. Their work assesses social competence in normally sighted and VI people and proposes an interventional strategy in the children suffering from visually impaired. They also designed a task that assesses the capability to initiate and sustain an interaction with the experimenter person while performing hand movements in freely way using a sound based feedback on the experimenter's wrist. Dianne T.V. Pawluk et al. [45] addresses the issues related to the design of haptic technology for VI persons. Their work considers issues relevant for the design as well as the use of haptic technology for the case of assistive devices for the individuals who are blind or VI in some of the major areas which are of importance: Tactile graphics, Braille reading, orientation and mobility. They show that there is an available wealth of behavioral research which are highly applicable to the area of assistive technology design. In few of the cases, conclusions from behavioral experiments have been directly applied to design with positive results. Sile O Modhrain et al. [46], in their work discusses the important issues of designing media for VI persons. Their work considers the influence of human factors which can act effectively in terms of presentation and also as the strengths and weaknesses of vibrotactile, tactile, haptic, and other multimodal methods for the purpose of rendering maps, graphs, and models.

Jizhong Xiao et al. [47] provides a framework for navigation services, which are context aware. Their work integrated advanced intelligence for the purpose of navigation, which requires knowledge of the semantic properties of the obstacles which are around the user's environment. Huaping Liu et al. [48], designed a perception which is based on image to tactile. The developed algorithm module and the developed hardware are integrated into a single portable device, which helps in providing VI people with effective surrounding obstacle perception capability. Additionaly, a visual-tactile cross-modal data set is also constructed which can be used to train the proposed deep-learning architecture. The experimental results conducted show that the proposed system can help VI people sense the ground surface and also brings a better traveling experience for them. Wan-Jung Chang et al. [49] provides MedGlasses which is a wearable smart glasses for the detection of drug pill using deep learning approaches.

A. Aladrén et al. [50], provides navigation assistance to the VI users using red, green, blue and depth sensor. In this work, a new system for the purpose of Navigation assistance for visually impaired (NAVI) is presented which is based on visual and range information. Instead of using multiple sensors, the work choose a single device, a consumer RGB-D camera, and takes advantage of both visual information and range. Xiaodong Yang et al. [51], works on assisting the VI persons for recognition of the cloth pattern. The authors developed a camera-based system in the form of prototype that can recognizes clothing patterns in four different types of categories (plaid, striped, patternless, and irregular) and also helps in identifying 11 different clothing colors. B. Andò et al. [52] provides an assistive device which provides the information about the presence of obstacle through haptic means. 25 blindfolded normally sighted persons participated in the experiment in order to assess the performance of the system in detecting different obstacles and correctly conveying their location by the designed haptic interface. In the results with respect to detecting different obstacles and their locations, the average values of the sensitivity achieved in the case of left, center, and right locational obstacles are 0.735, 0.803, and 0.830, while for the same obstacles the specificity values are 0.924, 0.835, and 0.827, respectively.

Ping-Jung Duh et al. [53] provides a vision based navigation system V-Eye. The experiments conducted establish that the system proposed by the authors can reliably provide precise position and orientation information (with a median error of approximately 0.27m and 0.95°) of the obstacle; and also detect unpredictable obstacles; and can also support navigating both within and between outdoor and indoor environments. Carolyn Ton et al. [54] works with LIDAR system and provides spatial sensing assistive device. This work proposes and also evaluates a proof-of-concept prototype system with light detection and ranging (LIDAR) assist spatial sensing (LASS), the system intends to overcome different restrictions by obtaining the spatial information in front of the user's surroundings through a method involving LIDAR sensor and translating the obtained spatial information into the stereo sound of different pitches.

He Zhang and Cang Ye [55] provides an indoor based way finding system on the basis of geometric features added graph SLAM. This work presents a 6-degree of freedom (DOF) based pose estimation (PE) method along with an indoor wayfinding system which is based on the method for the VI. The described PE method involves two-graph simultaneous localization method and mapping (SLAM) processes in order to reduce the accumulative pose error of the device. Wan-Jung Chang [56] provides aerial obstacle and fall avoidance intelligent system. This work proposes an intelligent assistive system which is based on wearable smart glasses along with an intelligent walking stick for VI people in order to achieve the goals of the aerial obstacle avoidance system as well as fall detection system. The proposed assistive system consists of wearable smart glasses, a mobile device app, an intelligent walking stick, and finally an information management platform based on cloud. A survey on different works for constructing an indoor navigation system is presented by Roya Norouzi Kandalan and Kamesh Namuduri [57]. In the article, a compact but comprehensive collection of various available methods in order to build each component is summarized. The methods discussed in the article may have not been implemented for the purpose of a navigation assistive technology for VI directly but they have been found to have great potential for the purpose of integration as an individual building block for this task.

Guojun Yang and Jafar Saniie [58] works on human machine interface for guidance and navigation using sight to sound method. In the work, the authors present a sight-to-sound human-machine interface called as (STS-HMI), and a novel machine vision guidance system which can enables VI people for the purpose of navigation with instantaneous and intuitive responses. Emli-Mari Nel et al. [59] proposes a Ticker system for an adaptive text entry method based on single switch. Ticker is defined as a probabilistic stereophonic single-switch text entry algorithm for VI users who are having motor disabilities and rely on single-switch scanning devices to communicate. For such scanning systems they are sensitive to a variety of different noise sources, which are inevitably found in practical use of single-switch systems. Robert K. Katzschmann et al. [60] for the safe local navigation provides time of flight based haptic feedback device. This work presents ALVU (Array of Lidars and Vibrotactile Units), a hands free, contactless, intuitive, and discreet wearable system that allows VI users for the purpose of detection of low-and high-hanging obstacles, and physical boundaries in their working environment. The provided solution allows much safe local navigation in both open and confined spaces by enabling the VI user to distinguish between free space from obstacles.

Md. Milon Islam et al. [61] provides an automated walking guide to enhance the mobility of VI persons. Their work has shown the implementation detail of a spectacle designed prototype system in order to assist the VI people for the purpose of safe and efficient walking in their working surrounding's environment. The developed walking guide uses three different pieces of ultrasonic sensors in order to identify the various obstacle in three different directions: front, left and right. A. Fernández et al. [62] uses computer vision based technique for the face recognition and spoofing detection. In their work, a device which can allow facial recognition as well as detection of spoofing adapted for the purpose of disabled people is proposed, implemented as well as validated. The provided architecture is carefully selected as well as subsequently implemented following an innovative algorithm for facial normalization for the purpose of increasing both the recognition rate of facial identification as well as spoofing detection. Kok-Meng Lee et al. [63] uses a sensor based on magnetic tensor for way finding applications. The work provides a method which utilizes geomagnetic field effects which is commonly found in nature for the help of the VI persons for the purpose of safe navigation; for both outdoor and indoor applications. Emanuele Cardillo et al. [64] based their work for autonomous walking upon electromagnetic sensor. The implemented idea consists of applying a microwave based radar system on the commonly used white cane making aware the VI user about the location of an obstacle in a much safer and wider. They also compared their system with the already existing ETAs devices, and found that their system exhibits much better noise tolerance, performance, and reduced dimensions.

Xiaobai Chen et al. [65] works is based on deep neural network based fast processing method for object detection. The work presented a fast and low-power object detection processor which is always on and which allows VI people for the purpose of understanding their surroundings. Edwige E. Pissaloux et al. [66] proposes a framework in order to better understand the locomotion of human cognition. This work provides a novel framework which can better understand human cognitive locomotion as well as its interaction with the new designed tactile technologies in order to assist the mobility and the acquisition of surroundings spatial knowledge in the absence of sight. Yang Tao et al. [67] proposes a framework for the validation of indoor navigation of VI persons. In this provided work, the authors introduce the first validation framework for the blind and VI persons in an indoor navigation system, which is proposed to be a significant step in order to develop a cost effective indoor route-finding system for BVI users. Aboubakr Aqle et al. [68] proposes an interactive search engine for VI persons. The proposed work evaluates, designs, and improves a provided search engine interaction for the (VI) users in order to efficiently perform web search activities. The proposed conceptual modeling technique is based on a proposed Formal Concept Analysis (FCA) which is used for the purpose of data analysis.

Sulaiman Khan et al. [69] works on analyzing the navigation assistants. The provided systematic review work is performed with the definition of a set of relevant keywords, for the purpose of formulating four different research questions, and defining different selection criteria for the articles, as well as synthesizing the empirical evidence. Zhuorui Yang and Aura Ganz [70] provides an indoor spatial awareness sensing framework. In the provided work, Bluetooth low energy (BLE)-based sensing framework is proposed which provides real time surround spatial awareness for the (BVI) users for the purpose of navigating independently through large public venues. Bogdan Mocanu et al. [71] provides a mobile face recognition system. In their proposed work, the DEEP-SEE FACE framework is introduced, an assistive system is designed in order to improve interaction, cognition, as well as communication of (VI) people in different social encounters. The provided approach jointly exploits image processing methods (ATLAS tracking, region proposal networks, and global, and as well as low-level image descriptors) as well as deep CNN for the purpose of detection, tracking, as well as recognizing, in real-time, different persons which are existent in the video streams. Rabia Jafri et al. [72] work on visual and infrared sensors data for obstacle detection. The proposed system is developed for the Google Project Tango Tablet SDK equipped with a more powerful graphics unit and various sensors in order to allow it for tracking its motion as well as orientation in the 3-D location in real-time.

Daniele Croce et al. [73] proposes an indoor as well as an outdoor navigation system. In their work, a system is proposed that allows VI people for the purpose of autonomously navigation in an unknown outdoor and indoor environment. The proposed system, is explicitly designed for the purpose of low vision people, and can also be generalized for other users as well in an easy way. The work assumed that special function landmarks are posed for the purpose of helping the users in the localization of existing paths. Jean Connier et al. [74] provides a perception assistance through smart objects. In this work, the SO2SEES, a system designed for the purpose of interface between its user and neighboring SOs is proposed. The SO2SEES allows VI persons to query their surrounding SOs in a more intuitive way, and rely on knowledge bases which are distributed on (IoT) cloud platforms and also in the SO2SEES's own back-end system. Bin Jiang et al. [75] develops a vision assistance system which is wearable on the basis of binocular sensors. The purpose of the work is to improve the quality of life of the VI people, thus a wearable system is provided in this work. Generally, the performance of visual working sensors is most of the time affected by a variety of different complex factors in real world, resulting in a large number of different noise and distortion problems. Charalampos Saitis and Kyriaki Kalimeri [76] works on multimodal classification of stressful scenarios using EEG and biomedical signals. The work provides a multimodal framework which is based on a random forest classifier, and which can also predict the actual real environment among well defined generic classes of various urban settings, inferring on noninvasive, practical, ambulatory monitoring of the brain and the peripheral bio signals. The provided model performance reached 93 for the outdoor settings and 87 percent for the indoor environments settings (expressed in weighted AUROC).

Adriano Mancini et al. [77] presents mechatronic system to help VI persons during walking and running. The provided system is a set of image processing methods in order to extract lines/lanes which are meant to follow. The embedded system works on the basis of a small camera and a board which is responsible for mainly processing the acquired images and communicating them with the developed haptic system. Juan Manuel Sáez et al. [78] works for the detection of aerial obstacles with 3D mobile devices. In this work, the authors present a new approach for the purpose of aerial obstacle detection (for eg, branches or awnings) with the help of a 3-D smartphone which is in the context of the (VI) people and their assistance. The target obstacles are very challenging since they are not able to be detected by the walking cane or the helpful guide dog. Wan-Jung Chang et al. [79] works for the safety crossing of zebra signs using artificial intelligent edge computing. The work provides a wearable assistive device which is based on artificial intelligence edge computing method in order to help VI consumers safely make use of marked crosswalks, or in other word zebra crossings. The provided wearable assistive device contains a pair of smart eyeglasses, an intelligent walking stick and a waist-mounted intelligent system. In the work Federica Barontini et al. [80] integrates wearable haptics and obstacle avoidance for the purpose of indoor navigation. In the work, the authors provides a new indoor navigation device which is based on wearable touch based technologies. All the developmental phases of the proposed system is driven by continuous feedback from the VI persons. The developed travel aid device contains a RGB-D camera, a central processing unit which can compute sensed visual information for the purpose of obstacle avoidance, and a wearable system, which can help in providing normal and tangential force cues for the purpose of guidance of VI people in an unknown indoor environment settings.

Vidula V. Meshram et al. [81] developed astute assistive device for object and mobility recognition. In order to provide autonomous navigation methods as well as orientation to the VI people, this work provides a novel ETA called the NavCane. The proposed device helps the VI people in finding obstacle-free routes in both outdoor and indoor settings. The NavCane device also helps in the recognition of different objects in an indoor environment. Salma Kammoun Jarraya et al. [82] works with deep multi-layer perception method for obstacle classification. The provided system handles high levels of external noise as well as bad resolution in image frames as captured by a mobile phone camera. Additionally, the proposed work offers maximum flexibility to the VI users and use the very least expensive available equipment. The authors report the efficiency of the proposed system to be experimentally 90.2% accurate as measured on a variety of experiments studies on different complex scenes. Jinqiang Bai et al. [83] developed smart glasses for guiding VI persons for indoor navigation. In comparison to a number of different existing methods, a new multi-sensor fusion based obstacle avoiding method is provided, which uses both the depth camera sensor as well as ultrasonic sensor in order to solve the problems of finding small obstacles, as well as transparent obstacles, for eg the French door. Luciana oliveira Berretta et al. [84] works for assisting the mobility employing natural interaction. The provided system is developed using the methods of Virtual Reality as well as Natural Interaction in order to assist the development of cognitive spatial location map and subsequently the mobility of the VI people. The proposed system allows the modeling of 2 dimensional or 3 dimensional virtual environments. Cang Ye and Xiangfei Qian [85] developed a robotic navigation aid with 3 D object recognition. This work provides a 3-Dimensional object recognition technique as well as its implementation on a defined robotic navigation aid in order to allow real-time working detection of indoor structural obstacles for the purpose of the navigation of the VI and blind person. The technique segments a point cloud into a number of numerous planar patches and then tries to extracts their inter-plane relationships (IPRs).

Wafa M. Elmannai and Khaled M. Elleithy [86] provides a reliable data fusion method in order to guide VI persons. With the use of the fuzzy logic, the authors is able to provide precise information in order to help the VI user for the purpose of avoiding in front obstacles. The provided system is also deployed and tested in real-time real life scenarios. It obtained an accuracy of 98% for detecting the obstacles and 100% accuracy in order to avoid the detected obstacles. Laurindo Britto Neto et al. [87] provides a wearable face recognition system based on Kinect device. For the purpose of validation a newly prepared dataset openly available for download is used, which consists of 600 videos of 30 people, and contains variation of background, illumination, and movement patterns. On conducting experiments with existing datasets which are available in the literature results are presented. Yang Tao and Aura Ganz [88] provides an indoor navigation validation and optimization framework. On the contrary, the provided framework by the authors provides a significant improvement with the help of refinement of the user feedback resolution with the help of continuously collecting the following given information in a spatial-temporal context obtained during the trials: user interface, user comments, and navigation instructions. Sung-Ho Chae et al. [89] uses segmentation technique for detecting collision. In the provided method, the given input frame is segmented over and over into super pixels with the help of super pixel lattices technique. The segmentation result obtained by applying a graph based method of region merging technique to the super pixels. In the final stage, the collision is found to be detected with the help of geometric relationship which exists between the size variation of the provided image segments in comparison to the distance variation from the camera to that particular segment in a real world environment. Samantha Horvath et al. [90] presents a sensing of virtual environment using fingertip haptics. Experiments conducted with the help of an initial developed prototype in order to trace a continuous straight edge found quantified the user's ability in order to discriminate the angle of the edge, in order to a potentially useful feature for the purpose of higher levels analysis of the visual scene.

Shota Nakashima et al. [91] works for identifying the road surface based upon the reflection intensity of the US pulses. In this work, the variation in the reflection intensity as measured through the investigations at multiple types of spatial locations. These found variation in the given reflection intensity is introduced in the work as a parameter which can be used to improve the road surface identification accuracy. Adam J. Spiers and Aaron M. Dollar [92] uses shape changing haptic interface for the smooth navigation of pedestrians. The developed system is intended for the purpose of providing an alternative method to screen or audio based interfaces for the VI persons, hearing impaired, deafblind, and even the sighted pedestrians. The motivation and design behind the haptic system is presented in the work, which is followed by the results of a navigation experiment which is aimed in order to determine the role of each device DOF, which is in terms of facilitating guidance. Anuradha Ranasinghe [93] et al. uses hard reins based on haptic devices for navigation purpose. By modeling the follower's dynamics with the help of a time varying virtual damped inertial system, the authors found that it is the given coefficient of virtual damping which is found to be most sensitive to the trust level of the follower. Bing Li et al. [94] uses vision based methods for indoor navigation. A multi-modal human-machine interface (HMI) in this work, is designed along with speech-audio interaction and also the robust haptic interaction with the help of an electronic SmartCane. Finally, the authors also field experiments by blindfolding and also incorporating blind subjects which demonstrated that the provided device provides an effective tool in order to help blind and VI individuals with the sense of indoor navigation and wayfinding. Minghui Sun et al. [95] uses user’s mobile services for obstacle detection and navigation. If there found to be any potential risk which is being exposed to injury, then the provided device delivers a warning message and also helps in indicating a safe path for the user.

Yang Tao and Aura Ganz [96] provides a framework for the evaluation of indoor navigation systems. The proposed simulation engine by the authors, uses the popular Unity game engine, which helps in tracking the virtual user interaction and also in motion in a virtual environment which represents the real physical environment for the user to navigate. Zhongen Li et al. [97] works on a wearable device for obstacle detection in indoor environments. The system proposed by the authors, can provide various information about the distance, category, and direction of the found objects with the help of fusing the depth image and also neural network obtained results. The work also provides 3D acoustic feedback mechanism in order to improve the situational awareness for VI people, and help them travel safely. Yeongmi Kim et al. [98] works on identifying the different vibration patterns for obstacle distance purpose. Three tactile rendering methods are proposed with temporal variation only by the authors, spatio temporal variation and spatial or temporal or intensity variation is also investigated in the work for providing two vibration feedback configurations. Laxmi Raja and R Santhosh [99] conducted experimental study for the navigation of VI persons on the basis of shoe based assistive device. The device is developed for the VI persons in which an individual can be assisted in order to travel around freely in the given surrounding environments. It also helps the person to avoid different types of obstacles when alone travelling. As the navigation device in the work, is fitted on the individual's wearable shoes, it aids the person to move freely. Tiziana Campisi et al. [100] evaluated the walkability and mobility requirement of VI persons in urban spaces. Multiple-choice questions are used in the work, in applying Likert scale for the purpose to assess physical characteristics (for e.g. sidewalk width, slope surface) which are related to infrastructural elements present in the analyzed path and also worked on their influence in the movement of difficulty, and interferences (e.g. help from other people, need to stop) and feelings (e.g. tiredness, anxiety) in the experimented along it.

Durgesh Nandini and K.R.Seeja [101] works on algorithm for planning path. The novelty of the provided path planning technique is the minimization of the number of turns as well as distance, since VI people prefers to travel through straight paths which don't consists of any turns. ManuelaChessa et al. [102] provides a framework on the basis of integrated artificial vision. In this proposed work, the authors refer specifically to a particular set of video analysis algorithmic modules, which consists of semantic annotations of the scene as well as the interpretation of the 3D environment. Dragan Peraković et al. [103] provides a model for the guidance in traffic conditions. The use of survey and interviews in this work, with a target group of particular users are used in order to evaluate all the different relevant parameters for the purpose of guidance and navigation which results from the analyses and through performing training of mobility and orientation during the duration of six months. Pedram Gharani and Hassan A.Karimi [104] proposes a context aware method for navigation for obstacle detection. The authors validated their proposed method with the help of experiments which compared it against two available comparable methods. The experiments conducted in the work, in different indoor environments and the results are compared and analyzed on the basis of precision, recall, accuracy, and f-measure. Jun Park and Subeh Chowdhury [105] investigates the different barriers faced by users with disabilities while travelling through public transport. Participants volunteered in the study are from cities in New Zealand. A semi-structured interview with a sample of people having disabilities is conducted. The attitude of Bus driver's and unawareness of differently abled users' needs is found to be common concern in both of these groups.

P. Katemake et al. [106] work on the influence of LED based lighting solutions for the autonomous travel of low vision person. Using a total of 134 participants in the study which comprises of low vision, elderly, and normal vision subjects are required to wear a low-vision simulation eye-glasses, the impact is analyzed of these lighting solutions of low vision subjects on the mobility with blurry vision in the tunnel vision, central scotoma and cataract is presented in the work, which makes them a potential good alternative to normally used conventional mobility aids. Chul Hyun Park et al. [107] proposes a framework for evaluation of travel trainings on the basis of integrative theory. The aim of this research is to build an integrative theory driven framework of evaluation of the various programs based on prior studies for the travel training and the available literature on the program evaluation and various learning and training theories. Lorena Lobo et al. [108] works for obstacle avoidance and route selection with a short range haptic device. The authors analyzed route selection in the work and performed a vibro tactile SSD which can detect various environmental surfaces within a short spatial range, which thus limits the availability of various information about the remote parts of the given environment which needs to be navigated. Jose Rivera-Rubio et al. [109] proposes an assistive device for indoor navigation based on haptic interface. The work assess the accuracy of various vision-based localization methods by drawing comparisons with the estimates of various locations derived from both given a recent SLAM-based method and also from indoor surveying equipment. António Pereira et al. [110] proposes guiding blind people based on body area network. In this work, the authors provides the use of an ultrasonic body area network for the purpose of obstacle detection and a warning system as a complementary solution for effectively aiding blind users when they are moving from one place to another.

Emanuele Cardillo and Alina Caddemi [111] reviews on electromagnetic technologies for developing electronic travel aids. The task is considered as a research area because of the rapid growth in the total number of people with VI problem. For decades, there are a number of different technologies are employed for solving the important challenge of improvising the mobility of VI people, but appropriate solution are still not developed. Limin Zeng et al. [112] works with camera based mobile ETAs in order to support cognitive mapping of unknown spaces. In this work, the author conducted a case study involving seven VI participants, in order to investigate how they use a depth camera based ETA in order to explore unknown location spaces, and how it can reconstruct cognitive mappings of available surrounding objects. Simone Spagnol et al. [113] proposes the future of spatial audio technologies in ETAs. The authors believe there is ample space for the application of the technologies presented in this work, with the final aim of progressively providing the bridge or the gap between accessibility and also accuracy of the spatial audio in the ETAs. Bujacz, M. and Strumiłło, P. [114] reviews the auditory display solutions for ETAs. The review work covers both commercially devices and various stages of these research, as per the input used, and the level of signal processing method used and also sonification. Alex Kreilinger et al. [115] studies auditory information loss in comparison to the information gain. This study provides objective, as well as quantifiable measures for the impact of reduced hearing which affects the navigation performance in a very low vision subject. Significant effects in the work of 'Auditory Information Loss' is found for all various measures; for example, it is found that the passage time increased by 17.4%.

Weijian Hu et al. [116] presents a comparative study for real time scene sonification. The findings highlight that the features as well as the differences of 3 scene detection methods and the corresponding sonification algorithms. Santiago Real and Alvaro Araujo [117] presents the challenges available for navigation system. The analysis done in the work found that limited interest among researchers are in combining different haptic interfaces and various computer vision capabilities in smartphone camera based ETAs for the blind and VI, and also few attempts have been made to employ new state of the art computer vision based methods which are based on deep neural networks, and there is no evaluations of existing off the shelf provided navigation solutions. Andrius Budrionis et al. [118] systematically reviews smartphone based image processing systems as ETAs. The provided device consists of a consumer grade Red, Green, Blue and Depth based camera and also an Inertial Measurement Unit (IMU), which are provided on a single pair of eyeglasses, and a smartphone. The proposed device leverages the ground height continuity among consequent image frames to break the ground accurately and also rapidly, and finally search for the moving direction as per to the ground. Jinqiang Bai et al. [119] presents work for environment perception and navigation. RuxandraTapu et al. [120] surveys the available wearable travel aids for VI persons. This work presents a survey of various wearable and assistive devices and also provides a critical various presentation for each system, which emphasizes the related strengths and limitations. This work is designed so as to inform the research community about the various capabilities of available existing systems, and also the progress in assistive technologies as well as provide an essential glimpse in the possible short or medium term axes of the available research that can improve various existing devices.

Piotr Skulimowski et al. [121] presents their navigation aid on the basis of interactive sonification of U depth images. The proposed system is comprised of the depth sensor which is connected to a mobile device and also consists of a dedicated mobile application for segmenting the captured depth images and converting the parts into sounds in real time environment. One of the important feature of the system is that one can interactively select the available 3D scene region for the purpose of sonification with the help of a simple touch gestures applied on the mobile device screen. Mateusz Owczarek et al. [122] presents stereo vision based on 3D scene reconstruction. The proposed ETA is based on the notion of sensory substitution, which is way in which visual information is changed into either sound or touch based stimuli. Simona Caraiman et al. [123] works on stereo vision based sensor substitution for the VI. The proposed stereo based technique is designed in order to work with the wearable acquisition system but it still provide a real time working, and a reliable description of the captured scene in the context of noisy available depth input from the stereo camera correspondence and of the complex six degrees of freedom motion of the head weared camera system. Md Mahfuz Ashraf et al. [124] provides systematic literature review of advance technology for VI persons. This systematic literature review by the author in this work provides the findings on the available existing state of the art ICT projects and also describes various outstanding issues which are there in ICT support of VI persons. Rajesh Kannan Megalingam et al. [125] provides autonomous path guiding robot. The authors have designed affordable low cost system with the navigation system which works for the purpose of guiding the VI people both in outdoor and indoor environment.

Jan B. F. van Erp et al. [126] provides a vibration belt and tests tactile working memory capacity of users. The work recommend using two types of items as the maximum touch based working memory load as long as the users are trained and or the user can adopt their applied strategy without the unacceptable costs, for e.g. reducing their walking speed. Aylwin Chai Bing Chun et al. [127] develops a tool for detecting ground plane hazards. This work discusses the developed system which is able to detect various ground plane obstacles like ramps, staircases potholes, and drainage. A real time detection experiment is conducted and the results found that the system performs up to the expectation in real time environment. T Kiuru et al. [128] presents an assistive device for the orientation and mobility purpose on the basis of mustimeter wave radar technology. The investigation included in this work involves a training session and opening and closing interviews, which are including a standard QUEST 2.0 form in order to evaluate user satisfaction with the presented assistive technology devices. It is found that 92% of the participants, observed that the device improves their capability in order to perceive their working environment, and 80% are observed in increasing their confidence in independent mobility. C Lee et. al. [129], proposed a simple obstacle detection system, on the basis of an automobile parking sensor, and assessed the mobility aid for the VI persons.

The source code of our work is available repository in [130]. Rahman et. al. [131], in order to help the VI people to travel on their own without needing any external help and monitoring real time working location information of various obstacles, a worn ETA is presented in this work. Mekhalfi et. al. [132] in their work, describe an innovative developed system, which can offers the various capabilities in order to (i) move autonomously and also to (ii) recognize various multiple objects in the public indoor settings. Wade et. al. [133] in their study explored the feasibility of a developed automated characterization of their functional mobility with the help of an Instrumented Cane System (ICS) to be used by the older adult sample of cane users. Jubril et. al. [134], in their work presents an obstacle detection device which is flexible, compact and wearable. When the usability test is performed the results proved that the users is able to navigate around various obstacles with the help of minimal training.

Chapter 3: A framework for the generation of obstacle data [137]

In this chapter, a model inspired by the real world settings for detecting low-lying obstacles, considering few assumptions and constraints is presented. The simulations are also proposed based on the model to generate obstacle data any number of time. Furthermore, to validate the model and simulations, field experiments are conducted, and the results obtained are compared with the simulation result. The evaluation parameter in terms of standard deviation, accuracy, false positive, errors encountered suggest that the model and simulations effectively encapsulates the real-world parameters and thus can be explored and utilized further by the research community.

3.1 Research problem and main contribution

In most of the proposed works as we discussed in chapter 2, focus has been either on image processing based approach or US sensor approach, while for analyzing the results of the proposed system are done one the basis of some experimental setup and in most of the cases, not on any benchmark dataset. As per our knowledge, the latter is not available in the form of reliable dataset for the problem of obstacle detection for VI persons. For e.g., if we take some examples from the literature, the assessment of the developed system, which is proposed in the work by [29] is done in the environment by placing obstacles of different types at different locations. The obstacle mainly consists of crossbar, blocking rod, boxes, hanging objects. On considering another work by [129], the evaluation of the system is done with a route, which formed the experimentation and validation. The route designed consists of different obstacles like a pedestrian overpass, side door, plant terrace, tall tree and others as shown in Fig. 3.1.

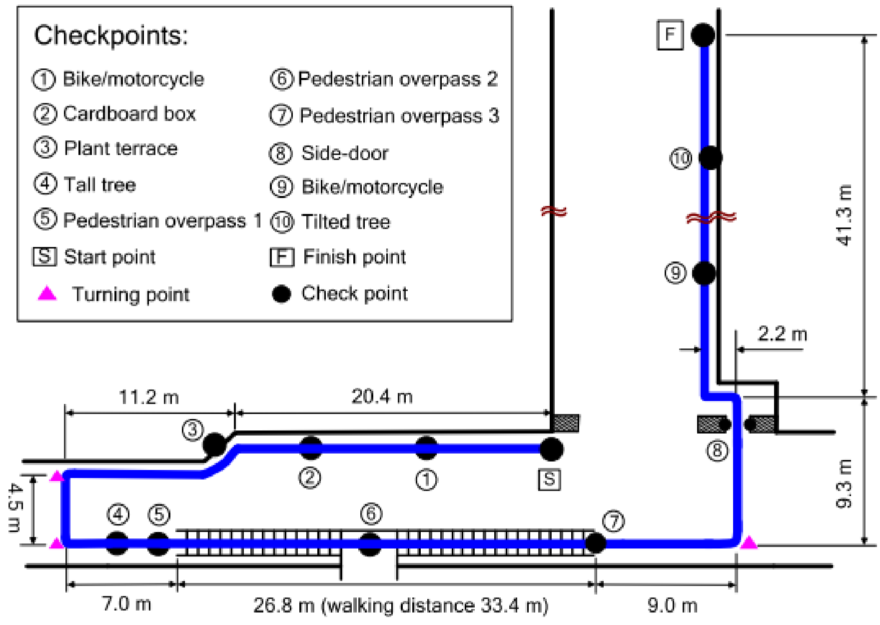


Fig 3.1 Experimental route [129]

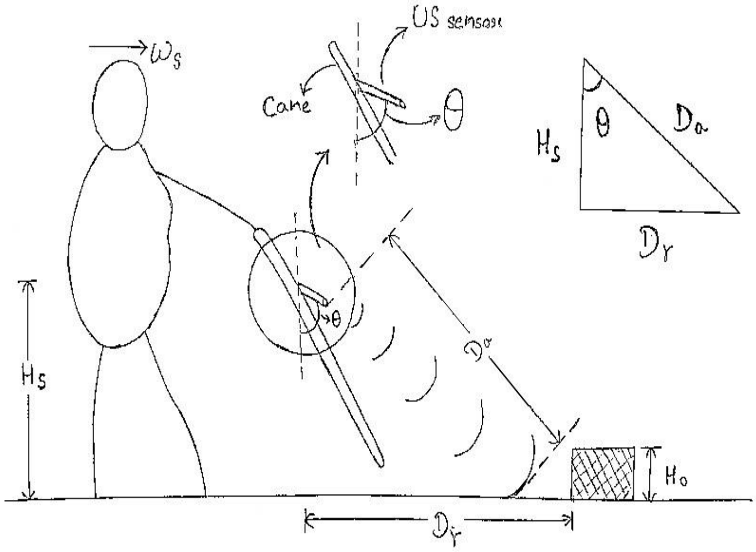
On reviewing these various works, it can be observed that there is a problem of repeating the experimental scenario. In order to overcome these challenges which we found in the literature, we present a solution which consists of a model inspired by real world settings and in order to generate the obstacle data on the basis of the model simulations are also. The major contributions of our work are:

1. A model is presented which is inspired by real-world parameters and contains some constraints and the designing of simulations is also presented based on the proposed model which can be used to generate obstacles data. We provide acronym to this as USODataGen (US sensor Obstacle Data Generator).
2. The designed simulation which are based on the model is validated with the data obtained after conducting on field experiments. Four parameters are chosen for the validation purpose which are similarity in total errors encountered, accuracy rate, standard deviation, and false positive.
3. The validated model and simulation can be explored to generate obstacle data any number of times and can be used further in future by the research community for comparing their results.
4. We have released all the data which are simulation data, on field experimental data and the source code for generating the simulations on the online repository which is publicly accessible.

5. We have also presented three obstacle data classification methods for the simulation data in order to set baseline or benchmark which shall guide fellow researchers in this field for further research continuation.

3.2 System model

Here a model is presented which the real world scenarios inspire. As illustrated by the Fig. 3.2, the model depicts the VI person holding the assistive cane, which is having the US sensors attached in front of it. The obstacle is also shown lying on the ground. The height of the obstacle, the angle at which the assistive cane is oriented along with other parameters are highlighted in the figure. All these parameters are generalized here. Some of them will be considered as constant in the coming sections.



Here,
Θ = angle of the orientation of the cane;
Ho = Height of the obstacle;
H_s = height of the sensor from the ground;
D_r = distance of the obstacle

Fig. 3.2 System Model

3.2.1 Working Scenario

The formulas (2) and (3) can bed deduced by the simple trigonometric formulas, with the help of Fig. 3.2

$$D_r = H_s * \tan\Theta \quad (2)$$

$$D_a = H_s / \cos\Theta \quad (3)$$

Here,

- Ɵ, denote to the angle at which the assistive cane carrying the US sensor is oriented;
- Ho, in the Fig 3.2, is the height of the obstacle which is lying in front of the user;
- H_s, the height of the assistive cane holding US sensor above the ground surface;
- D_r, the distance, between the obstacle and the user holding the cane;
- D_a, the distance between the US sensor as measured from the obstacle's surface which is in front of it;

3.2.2 Constraints and Assumptions

To build a system, which should be predictive in nature, the following assumptions, which are part of the model, are considered.

- W_s, the speed at which the VI person walks as 62cm/sec, the number to the speed is obtained after conducting on field experiments in the lab a number of times;
- H_s is constrained to be 82 cm;
- D_r the desired range is constrained to be 82 cm;

In order to achieve the desirable range D_r, Ɵ is found in conjunction with the equation 2, as Ɵ = 35 degree.

Similarly,D_a which is the actual distance of the cane having US sensor in front of the ground at angle Ɵ = 35, is computed in conjunction with equation 2 to be 80cm.

The low-lying obstacles in front of the user are assumed and constrained to be of three types and are mentioned below as:-

- Oblg, name given for the obstacle of height approx. 40 cm;
- Obmd, name given for the obstacle of height approx. 20 cm;
- Obsm, name given for the obstacle of height approx. 10 cm;
- ObNO, name given for the obstacle of height less than 10cm, or if there is no obstacle at all;

3.2.3 Ultrasonic Sensors

As work rely heavily on the US sensors, in this section we discuss about their working. The US sensors consists of single transducer or dual transducer. In both the case, US pulse which is slightly above 20KHz is emitted from one of the transducer while the second transducer keeps on listening for the arrival of the emitted US pulse after reflection from the obstacle. The total time the US pulse takes after emission from the emitter upto the time of its receiving at the other transducer is measured and is commonly known as the time of flight (ToF). The distance of the obstacle in front of the US sensor is thus computed as

$$\text{Distance} = (\text{ToF}/2) * \text{speed\_of\_US\_pulse} \qquad (4)$$

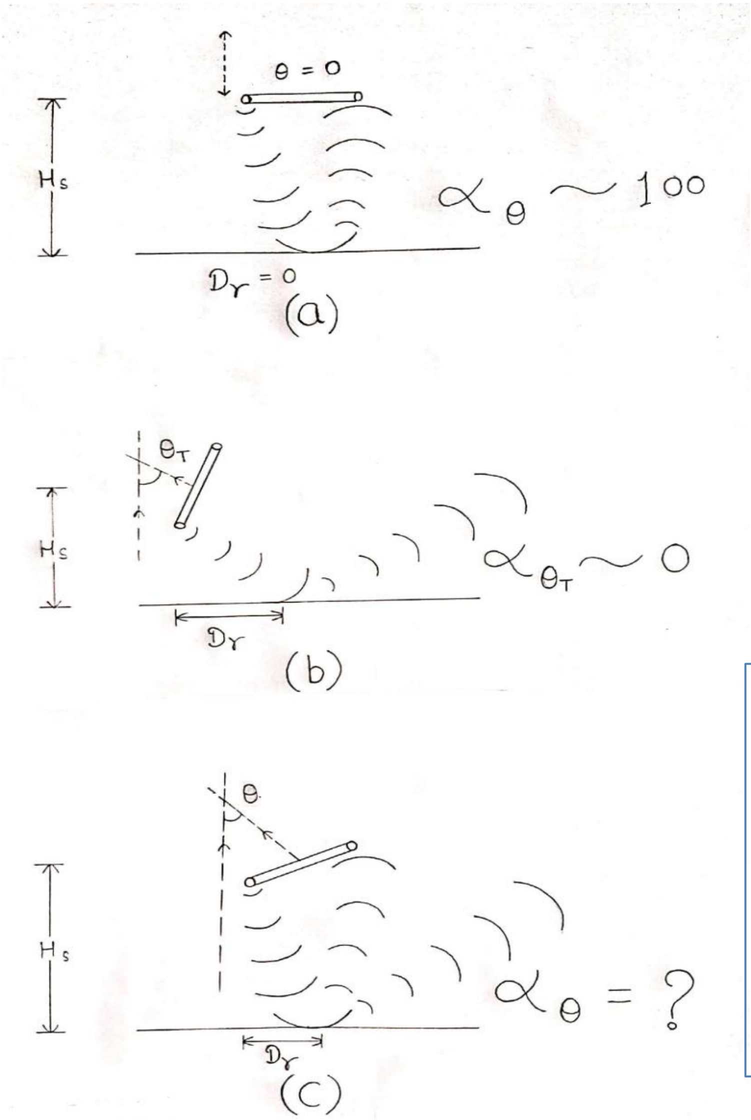
The speed of the US pulse is the same as the speed of sound which is (334m/s).

The distance is thus computed as

$$\text{Distance} = (\text{ToF}/2) * 334 \qquad (5)$$

In our work, we have used ultrasonic-sensor which can detect distance in the range of 2cm upto 4000cm working with the frequency of slightly over 2KHz.

3.2.4 Ultrasonic sensor characterization



Here,
ϴ = angle of the orientation of the cane;
ϴT = cutoff angle, after which the US sensor has almost zero accuracy;
Alpha(ϴ) = Accuracy of US sensor for angle ϴ;
H_s = height of the US sensor from the ground;

Fig. 3.3. US sensor accuracy deviation

The low-cost and popularly used US sensor comes with a drawback of measuring the distances unreliably when the angle of orientation between the US sensor and the obstacle is at angle ϴ, as shown in Fig. 3.3. In fact, the accuracy of the US sensor is inversely proportional to the orientation angle.

Table 3.1: Alpha(Θ) calculation

Sampling Rate (SR)	Mode	Average	Max (D_{mx})	Min (D_{mi})	SD	α(Θ)
195	80	80.45	94	45	2.5	97.4%

The reason for this phenomenon can be understood with the help of Fig. 5.3. In the Fig. 5.3 a) if the US sensor is oriented perpendicular against the obstacle, i.e., the case for Θ = 0 degree, approx. all the transmitted US pulses are returned back and received by the receiving transducer. In this case most of the US pulses are received back without interfering with the environment. In this case the accuracy of the US sensor corresponds to approx. 100%. On the other case, as seen in Fig. 3.3 c) if the US sensor is oriented at some angle against the obstacle which is more than 45 degree, it will result in the transmitted US pulse diverging away from the receiving transducer and none reaching it. In this case, the resulting accuracy of the US sensor is approx. to be around 0 degree. In our case at which the model is approximated to be working, the US sensor is oriented against the obstacle at an angle as shown in Fig. 3.3 b), such that very few of the transmitted US pulses are reflected away from the US sensor or received back after some interference with the environment. In this case, the accuracy of the US sensor is approx. to be less than 100%.

For the given US sensor which is operating at angle Θ degree, the corresponding parameters can be characterized as,

- Alpha, at an angle Θ the accuracy of the US sensor;
- SD, at an angle Θ, the standard deviation in the readings of the US sensor;
- D_{mx}, is the maximum distance as measured by the US sensor, in contrast to the actual distance, D_a;
- D_{mi}, is the minimum distance as measured by the US sensor, in contrast to the actual distance, D_a;

To find out these parameters, on field experiments are conducted in which the angle Θ is set to 35 degree, H_s is fixed to 82cm and D_a is already known to be 80cm. Next, the US sensor readings are measured continuously, for a total of 10,000 runs. The results are shown in Table 3.1, which are computed at the sampling rate(SR) of 195 Hz. These results will be used later on to design the simulations which are discussed next.

3.3 Designing Simulations

As the VI person walks while carrying the cane having US sensor as shown in Fig 3.2, there are three scenarios possible. In this section, these three scenarios are simulated, with the help of constraints and variables along with few assumptions.

The common parameters for the three simulations are:-

- Alpha the accuracy of the US sensor, as 97.4%;
- N: for a single simulation run, the total number of distance readings;
- Q_N: the queue capturing the N distance readings in sequence;
- E_t: total number of errors available for the set sensor characteristics and with the given N number of points which are required to be generated. The formula for getting E_t is given below

$$E_t = N * (1 - alpha / 100) \qquad (6)$$

- E_c: the number of errors which have occurred for the current US sensor reading;
- E_r: the number of remaining errors, out of initially given E_t errors after the measurement by the US sensor have started;

3.3.1 No obstacle scenario

This scenario is the case, which is supposed to be followed when there are not a single obstacle in front of the VI person walking with the cane. In this case, the US sensor is supposed to read the values constantly since there is no obstacle on the ground. However, as it was discussed in section 3.2.4, the US sensor gives noisy reading if the angle of incidence of the US sensor is not 0 degree. Thus, the actual distance from the US sensor in this scenario is not the same even without the presence of obstacle. To generate N points, Algorithm 1, which is detailed below is used together with Table 3.1.

Algorithm 1 No Obstacle Scenario

Result: Q_n, Distance data points

Step 1: Initiate a loop upto N
Step 2: for each iteration, generate a random number D_i, within range of $[D_{mi}\ D_{mx}]$
Step 3: Add D_i to Q_n
Step 4: E_c is computed as abs($D_a - D_i$) and
$E_r = E_t - E_c$
Step 5: Break the loop if $E_r = 0$, and assign D_a to the rest of the elements of Q_n

3.3.2 Ideal Obstacle scenario

In this scenario, the accuracy of the US sensor is assumed to be working perfectly i.e., around 100%, or the US sensor is assumed to be working with absolutely no error in its working. The distance readings from the US sensor would thus follow same value in consecutive readings. Once the US sensor encounters the obstacle in front of it, the distance readings by the US sensor starts decreasing in its value first for some time, then there are constant US sensor reading value which is the same as the height of the US sensor subtracted by the height of the obstacle which is encountered by the US sensor and finally once the US sensor walk over the obstacle is finished, the distance readings by the US sensor are again constant.

The total number of points for the case at which the US sensor walks through the obstacle, can be computed as

$$N_t = \text{SR} * \text{Ho}/W_s \qquad (7)$$

The first distance D_0, as measured by the US sensor, is assumed to be same as D_a. The last distance D_{-1}, as measured by the US sensor ends the walk over the obstacle can be calculated as

$$D_{-1} = D_a - \text{Ho} \qquad (8)$$

The sampling interval distance, that is, the discrete distances as measured by the US sensor in between D_0 and D_{-1}, can be calculated as

$$\text{Delta} = (D_0 - D_{-1}) / N_t \qquad (9)$$

Upon simplification of equation 9 using equation 6, we get

$$\text{Delta} = \text{Ho} / N_t \qquad (10)$$

The N distance points for the ideal scenario are calculated with the help of Algorithm 2 below:-

Algorithm 2 Ideal Obstacle Scenario

Result: Q_n, Distance data points

Step 1: Save D_a as first value to Q_n
Step 2: Initiate a loop upto N - 1
Step 3: Compute, $D_i = D_i - \Delta$
Step 4: Save D_i to Q_n
Step 5: Repeat till loop ends

3.3.4 Noisy Obstacle Scenario

Since the accuracy (alpha) of the US sensor in actual environment is below 100%, the obstacle data which are obtained is thus expected to deviate from the ideal obstacle scenario which we discussed in the last section, and in accordance to the characteristics of the US sensor captured in Table 3.1. The input data queue Q_{idn}, in this scenario, is obtained with the help of Algorithm 2.

Algorithm 3 Noisy Obstacle Scenario

Result: Q_n, Distance data points

Step 1: Initiate a loop upto N
Step 2: Fetch corresponding value D_{idn}, from Q_{idn}
Step 3: Generate a random number D_i, around D_{idn}, within range of $[D_{mi}\ D_{mx}]$
Step 4: Save D_i to Q_n
Step 5: Computer errors as
Ec = abs($D_{idn} - D_i$)
Er = $E_t - E_c$
Step 6: Repeat till loop ends

Fig. 3.4 shows the actual data, which are generated with the help of simulations, USODataGen, for the case the user, is moving at the speed of 62.31cm/s and the obstacle is of height 40cm. In the X-axis the time is denoted as the user walks while the Y-axis denoted the distance measured by the US sensor.

3.4 Model Implementation

To test the actual efficacy of the proposed model and proposed simulation, on field experiments are conducted as per the constraints considered in the proposed model to analyze how well the on field experiments are in line with the proposed model.

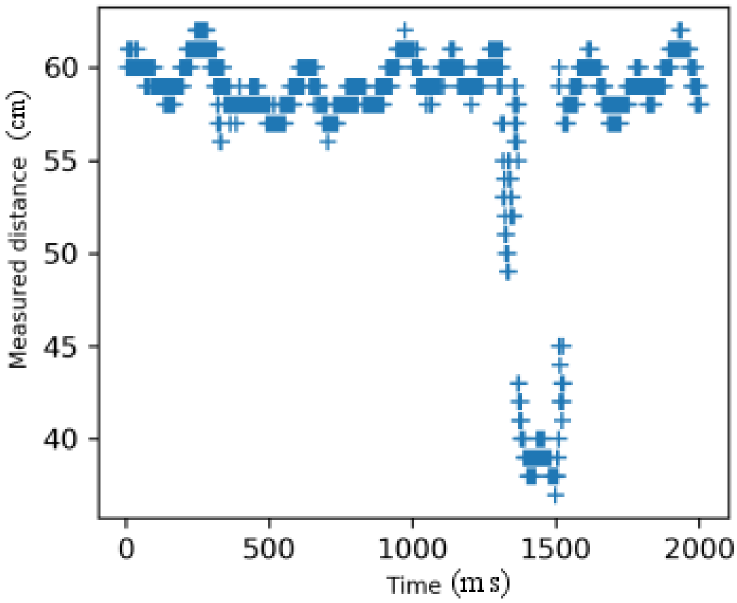


Fig 3.4. Sensor walk over obstacle of height 20cm

3.4.1 System Prototype

A walking cane similar to the white cane as used by the VI persons is equipped with an US sensor is attached at the front of the cane. An Arduino microcontroller is also attached to the walking cane for processing the data collected from the US sensor and transmitted to the laptop connected via a USB cable. Once an on field experiment run is complete on the field, the distance data is transmitted to the connected laptop, the transmitted data is then copy and pasted to a CSV file on the laptop.

3.4.2 Environmental Set Up

Table 3.2: Walking speed in cm/sec

Slow	Normal	Fast
62.3	95.7	122

The obstacles in the form of cardboard boxes of various height 10cm, 20cm and 40cm are used for the on field experiments. 3 test subjects in the ages 19 to 20 years are tasked to carry the cane and walk with it in the designated route having a cardboard box. As the subject starts walking over the obstacle, the distance readings are noted down. To, better compare, experimental on field results versus the simulation results, the different subjects are asked to tasked to walk in three different speed modes which are fast, medium and slow, details in Table 3.2, 10 times for each case. In each and every single run, a total of 2000 distance readings are recorded at the rate of 235 Hz. One such distance reading for an experiment on field run is shown in Fig. 3.5. The X-axis denotes the time in ms while the Y-axis denoted the distance measured by the US sensor in cm. As it can be deduced from the figure, up to the distance readings 980, the US sensor recorded the distances about 62 cm having the deviation in between 60 to 65 cm. As the obstacle is found and passed over, the consecutive distance readings shows the drop in recorded distances up to the point of around 45 cm which is assumed to the case when the US sensor's pulses reach to the top of the obstacle and after distance readings 1300,

3.4.3 Obstacle type Identification Algorithm

To identify the obstacles type or the height of the obstacle, based on the data pattern obtained, an algorithm is devised on the basis of simple clustering algorithm, which finds out the type of the obstacle. The pattern of the distance data helps in deducing the algorithm which finds the height of the obstacle. The detail of the Algorithm 4 is described below:-

Algorithm 4 Obstacle Identification by cluster method

Result: Obstacle type, Ob_{sm}, Ob_{md}, Ob_{lg}, Ob_{NO}

Step 1: Define four clusters corresponding to each obstacle type as $Cluster_{NO}$, $Cluster_{sm}$, $Cluster_{md}$, $Cluster_{lg}$

Step 2: Read obstacle data from i'th Experiment

Step 3: Assign individual data points to the cluster having closest distance

Step 4: Repeat Step No 3 for all the obstacle data points

Step 5: Finally, the cluster having the most number of data points assigned is the identified obstacle type

3.5 Comparative Study

In this section, an attempt is made to validate the proposed model and proposed simulation earlier with the on field experimental distance data, with the help of various data analysis tools and methods.

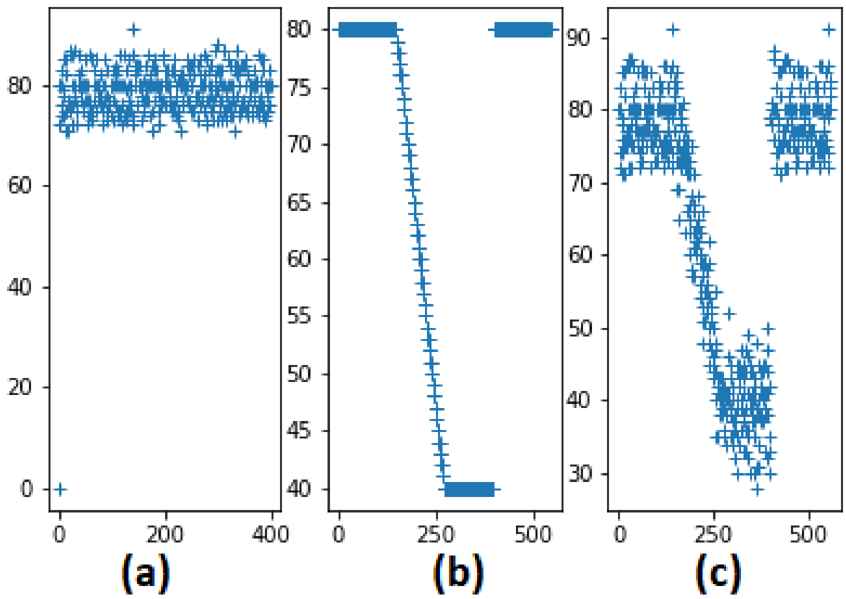


Fig 3.5. Simulated data for a) No Obstacle Scenario b) Ideal Obstacle Scenario c) Noisy Obstacle Scenario

3.5.1 Data analysis with Standard Deviation

Table 3.3: Standard Deviation: Simulation Vs Experimental on Field

	No Obstacle			Small Obstacle			Medium Obstacle			Large Obstacle		
	slow	normal	fast	slow	normal	fast	slow	normal	fast	slow	normal	fast
Simulation	1.87	2.62	3.05	2.62	5.03	5.17	5.91	8.69	9.48	13.13	14.4	16.69
Experimental	2.88	3.31	3.34	7.61	9.59	12.32	11.84	12.99	10.65	13.81	14.25	18.85

The distance data is analyzed in terms of standard deviation (SD) for the simulation data results vs experimental on field data results are compared. All the scenarios for the 4 obstacle types with user moving with three different speed as shown in Table 3.3 are considered. As the mode of the walking speed of the user increases starting from slow to fast, theoretically the error in distance measurement by the US sensor is also expected to increase in response, similarly the SD is also expected to increase. The same can be seen in the simulation data results for all the obstacles types excepts ObNO, which shows the reverse trend in Table 3.3 which may an anomalous behavior. In the case of experimental on field data results, there appears inconsistent response; however, at overall level, it also shows the same pattern of increase in the SD as the speed of the user increases.

3.5.2 Accuracy comparison

The accuracy comparison for the simulated data versus the experimental on field data is shown in Fig 3.6. It can be observed that though ObNO, Obmd and Oblg types of obstacles are detected with some decent accuracy of 91.11% and 93.92% and 95.81% respectively during simulations run but for the case of detecting small obstacle with good accuracy appears to be tough task with 88.51% accuracy during simulation run. The reason for this case can be deduced from Fig. 3.9, which shows that for the case of larger obstacle Oblg the total number of obstacle data points (W1) obtained is much larger than medium-sized obstacle Obmd (W2) and again too larger than small-sized obstacles Obsm (W3). In fact it can be seen that W1 > W2 > W3. Both simulation data and experimental on field data results show the same similar trends.

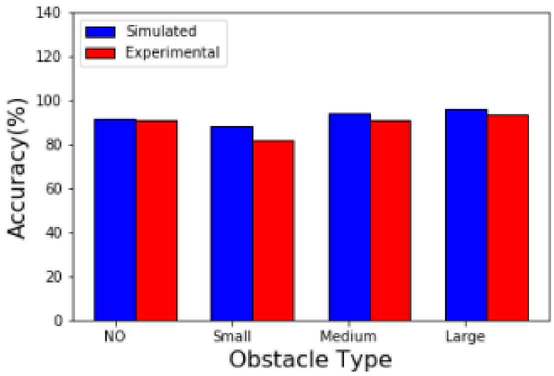


Fig 3.6. Accuracy comparison

3.5.3 False positive comparison

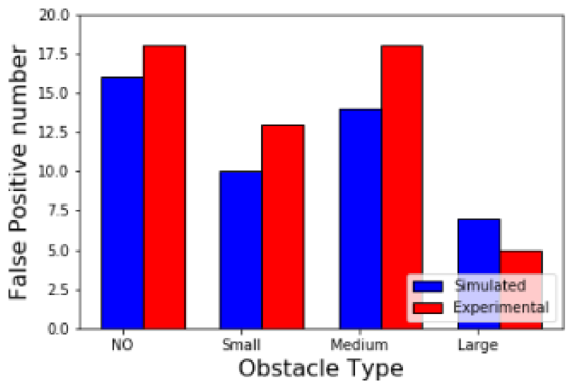


Fig 3.7. False positive rate comparison

The obstacle type ObNO occurs a high numbers of false-positive which is 15 during simulation run, while the obstacle type Oblg shows the least number of false positive 0.4 during simulation run, while comparing with other obstacles types, as shown in Fig 3.7, both simulation run and experimental on field data results show the same similar trends.

3.5.4 Errors encountered comparison

In Fig. 3.8, the comparison between the simulation run and the experimental on field run can be seen in terms of total errors encountered while the user walks with different walking. For each different speed, the number of runs are 60. It can be seen in the figure that as the speed of the user increases the number of errors encountered is also increased, the reason can be attributed to the increase in SD, as can be noted in Table 3.3. Both simulation data and experimental on field data results show the same similar trends. However, the number of errors for the case of experimental on field run are higher than simulation run and the reason can be attributed to the fact that the real experiments on field are in practice more prone to errors, which are not expected in comparison to the simulations run.

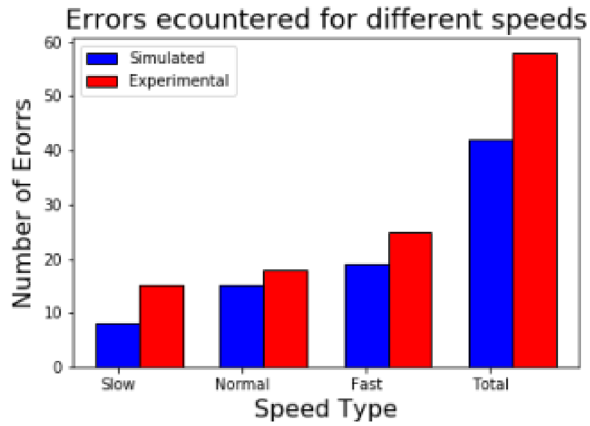


Fig 3.8. Errors for different speeds

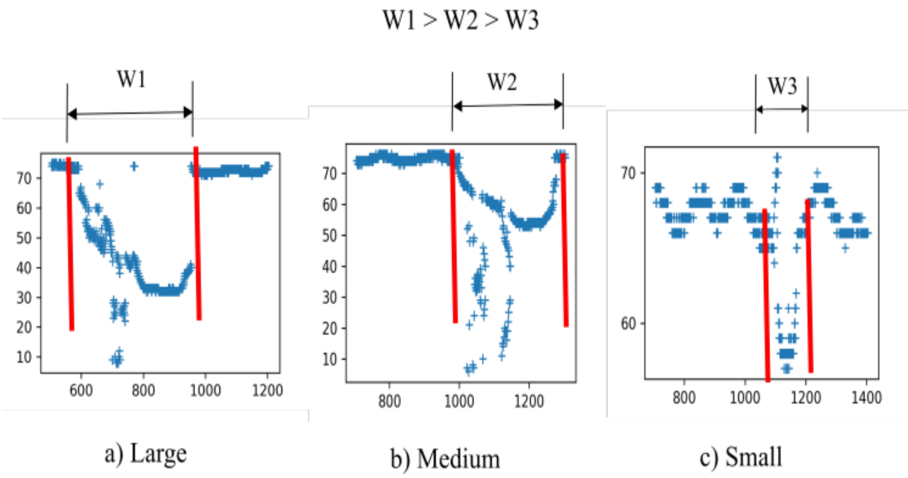


Fig 3.9. Sensor walk over obstacles of different height

3.6 Setting up Benchmark for obstacle classification

In order to set up a benchmark of the obstacle data generated by the simulation discussed above, which can be reproduced any number of times and the results can be compared. In this section, further two more methods are presented and discussed in this section in addition to the cluster method which is described above by the algorithm 4.

3.6.1 Quadratic method

In this method, a curve fitting technique is discussed to fit a quadratic curve for the generated simulation data with the help of different obstacle type. Mathematically, curve fitting is the process of fitting a best curve to a given data points. Once the equation with the curve fitting method of the quadratic curve is known, the height of the curve using simple mathematics is used as an indication of the type of the obstacle. An example of the method of quadratic curve which is fitted to the simulated data of obstacle type which is large Oblg, is shown in Fig. 3.10.

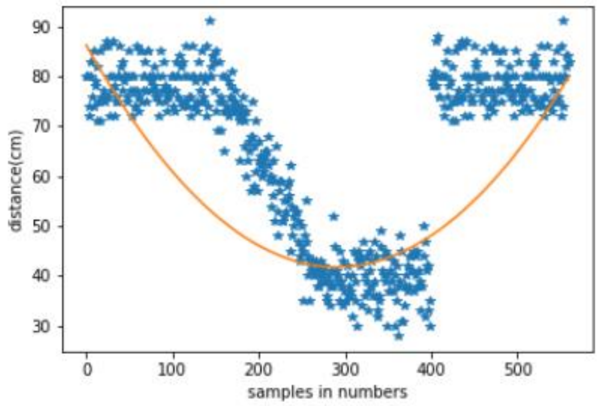


Fig 3.10. Quadratic curve method

3.6.2 Histogram method

A histogram is a graphical representation of numerical data in the form of various size bins of a defined range. In this obstacle type detection method, the histogram for the simulations obstacle data is find out. A histogram with bins size of five is constructed for the simulation data. All the different bins are next processed to check presence of the number of data points. The bin having the highest number of data points is considered as the possible candidate for obstacle type. In addition, the height of that particular bin is considered as the possible height of the obstacle found.

Table 3.4: Obstacle Detection Results by Various Methods

	No Obstacle			Small Obstacle			Medium Obstacle			Large Obstacle		
	Precision	Recall	Fscore	Precision	Recall	Fscore	Precision	Recall	Fscore	Precision	Recall	Fscore
Cluster Method	82.6	84.4	83.5	87.9	81.1	84.4	85.4	91.1	88.2	92.1	91.1	91.6
Quadratic Method	73.4	76.7	75.0	78.1	71.1	74.4	85.1	88.9	86.9	91.1	91.1	91.1
Histogram method	71.4	72.2	71.8	74.4	67.8	70.9	88.3	93.3	90.7	92.5	96.7	94.6

The results obtained with the different obstacle type detection method i.e., cluster method, quadratic method and the histogram method in terms of various parameters i.e., precision, recall and Fscore can be seen in Table 3.4. In all three methods discussed, the recall rate for small obstacles appears to be the most challenging while the same for large obstacles is best among all different obstacle types. It can also be observed that the Histogram method has the lowest recall rate for small obstacles type but at the same time has the highest recall rate for large obstacles type. It can also be observed that the precision rate of ObNO type is the lowest among all different obstacle types while on the same time large obstacles have the highest precision rate. It can also be observed that the cluster method has the top precision for all the different obstacle types but not for the case of large obstacles. The Histogram method can be observed to have the highest precision rate for large obstacles type among all the different obstacle detection methods. Fig. 3.11 shows the accuracy rate for the three different types of obstacle detection methods. In overall the cluster method performs much better among all other methods for different obstacle types but not for large obstacles. It can be observed that the Histogram method has the highest accuracy among the three for the large obstacles types.

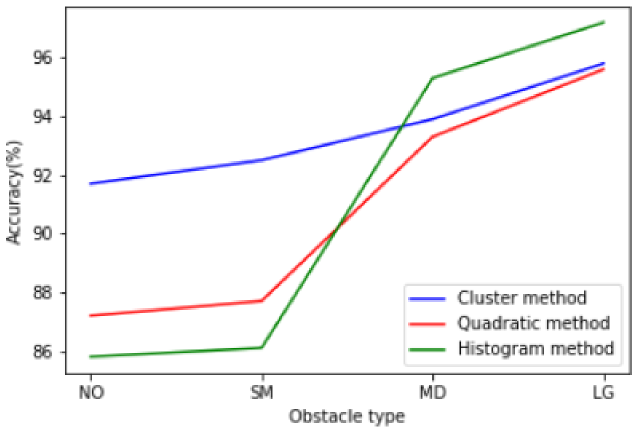


Fig 3.11. Accuracy results for different methods

3.7 Summary

The problem of unavailability of any reliable benchmark dataset for the study of obstacle data using ultrasonic sensors for VI persons is considered in this chapter. A model inspired by the real world settings is proposed and the various constraints are discussed. To generate obstacle data using the model a number of simulation algorithms are presented. Field study consisting of the same settings as discussed in the proposed model is conducted to validate the effectiveness of the proposed model and simulations. On different parameters the obstacle data obtained by the simulations is found to be consistent with the field study data. Finally, three methods for analyzing the simulation data to find out the type of the obstacle are also presented.

In this study, the current setting of handling the cane by the user considers to firmly holding the cane, but in the real world settings, the cane undergoes a number of continuous change in its orientation of the cane. In future, this constraint needs to be taken up to achieve better realistic results. To solve this problem a solution approach can be to use the accelerometer, which can find out the current orientation of the cane.

One more limitation are the way test subjects are involved in this study. In the current settings, every test subject were having normal eyesight and to conduct the field experiments are blindfolded. If more realistic results are required than, the actual VI persons or blind persons are required to be involved for the study.

In the next chapter, the detail about the assistive cane which have been developed as part of our objective is discussed. The assistive cane is able to detect obstacles in the form of potholes and bumps. There are few assistive cane available in the literature but the restriction of alignment is unique in our work.

Chapter 4: An Assistive cane for the detection of potholes and bumps [136]

There are a number of challenges faced by the VI persons, outdoor travel is among one of them which requires them to travel through uneven surfaces, containing a number of potholes and bumps. In this chapter, this particular problem is addressed and to provide feedback or warning to the user vibro-tactile feedback is used as a precautionary action which needs to be taken from the user. The information about the depth of the pothole and also to provide information about the height of the bump is conveyed through vibration pattern of varying intensity pattern to the user. With the available ETAs, it is observed that the VI persons are more inclined on their white cane for reliability in comparison to carrying additional devices for obstacle avoidance. In the system we are hereby providing, all the different components can be attached on the white cane, thus requiring no other device to be carried by the VI persons.

In this chapter, the focus is on detecting potholes and bumps with the help of an algorithm discussed in detail in section 4.3, in order to restrict the VI user to keep the orientation of the proposed cane in the required orientation only, we propose a novel Alignment Sensor Switch in section 4.2.7 which also helps in the reduction of the false alarm rate and restraining the orientation of the cane in the desired range only. Further, to compare the performance of our system to the white cane we propose a score based matrix which is discussed in section 4.5. The results obtained with the help of our assistive cane system is also compared with the available or best suited state of the art results as obtained by [28], [29] and [30]. At the end, the improvement in the performance of our assistive cane system on continuous training is also described in section and finally the power consumption and also the system cost analysis is described in section and respectively.

4.1 Research problem and main contribution

On reviewing various related works presented by different researchers in chapter 2, it was found that to find out bump and potholes on the road surface are considered up-to very limited extent. It is also found that almost none of the research work as per the best of our knowledge have considered the way the cane is oriented by the user while walking with it. We found that the orientation could play very important role since if the proposed cane is not oriented to the same fashion as used by the real VI persons, the accuracy of the sensors employed for environment sensing may decline undesirably.

The major contribution of the work presented in this chapter are

- Focused on detecting potholes and bumps with our method.
- A novel Alignment Sensor Switch is proposed to restrict the user to orient the proposed cane in the desired orientation.
- A score based matrix is proposed to assess the performance of our system.
- Description of improvement in the performance of usage of our system on continuous training.
- Analysis of the power consumption and system cost.

4.2 System Architecture

The various components of the implemented system are explained in detail in this section.

4.2.1 Walking Cane

In this work, a low-cost normal walking cane of height three feet has been used with all the required components installed on it. The walking cane in real world can be replaced by a white cane and all the components can be attached over it.

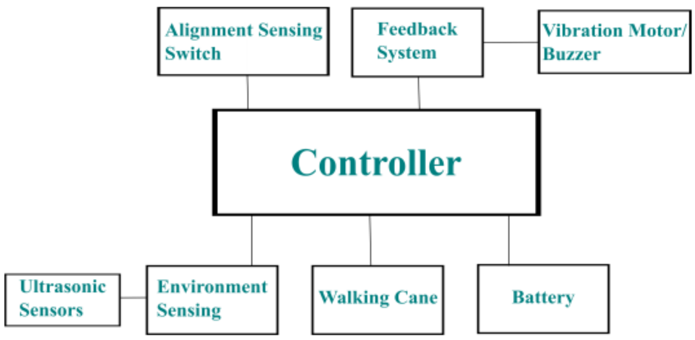


Fig 4.1. System Architecture

4.2.2 Ultrasonic Sensors

Ultrasonic sensors or US sensors usually consist of two transducers for its functioning, through the first transducer ultrasonic pulse or US pulse (usually slightly above 20Kz) is emitted which after reflection from the surface of the obstacle in front of the obstacle, is received by the second transducer. (The frequency which is audible for the human ear is 2 to 20Kz, thus the US pulse is not affected by the mixing of human voice or any similar human-audible sound waves). The total time taken by the US pulse till the time it is received back by the second transducer is called as the time of flight (ToF) Fig. 4.2.

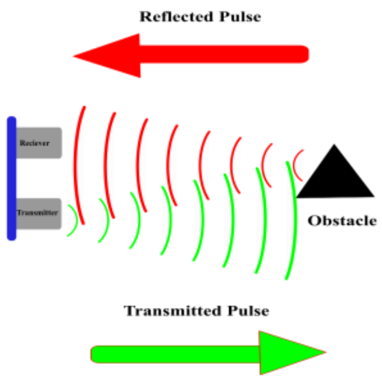


Fig 4.2. Ultrasonic Sensor working

These US sensors have applications areas in ultrasonic flaw detection in various industries, communication, robotics and vehicle navigation. In robotics, these US sensors are used extensively for distance ranging measurements. For the case of an autonomous robot, to freely roam the robot around, avoiding collision with the surrounding environment is very basic concerns. However, there is some limitations with US sensors for the purpose of distance ranging, as the measured distance in most of the time gets noisy if the distance of the obstacles from the US sensor is increased because of multiple reflections with the surrounding of the emitted US pulse, which is shown in Fig. 4.3. Because of their very low cost and their easy to use feature in comparison to the camera or laser-based systems, in this work US sensors have been utilized for environment sensing.

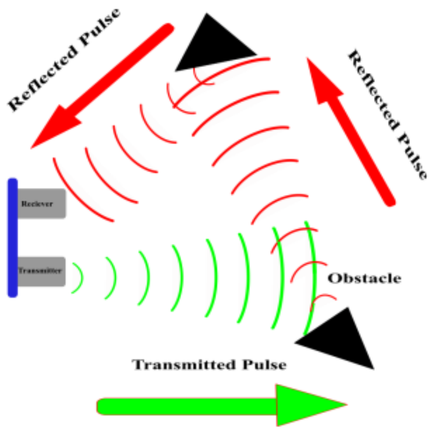


Fig 4.3. Noisy Ultrasonic Sensor reading

4.2.3 Controller

The microcontroller used in this system is from Atmel family which is Atmega328P. It is a 1 Byte RISC instruction set based AVR micro-controller which has 32 kB ISP flash memory which have the capabilities of read-while-write operations. It also hosts 1 KB of EEPROM memory to store programs which has to be run through it, 2 kB SRAM memory and 23 Input/Output pins which can be used for Pulse Width Modulation for general purpose programming. It also host 32 registers for general purpose, 3 flexible timers/counters, both internal and external interrupts. The micro-controller can be powered with 5-12 volts supply. To program it a host machine in the form of computer is required with a C like. Once the program is ready it can be transferred after successful compilation from the Host computer to the microcontroller chip, with the help of a USB cable.

4.2.4 Buzzer

It is a device, which is used to produces sound with the given input voltage. Thus on the variation of input voltage by modulation different sound can be produced. In our assistive cane, the buzzer is used to provide the feedback to the user and also about the ON/Idle condition of the assistive cane.

4.2.5 Vibration Sensor

This tiny coin-shaped sensor produces output vibration with various intensity in response to provided voltage through the microcontroller. To provide feedback about the found obstacle, or pothole or bump, various types of tactile vibration pattern are given to the user.

4.2.6 Power Supply

To provide source of the power for the microcontroller and other different sensors, Lithium Polymer rechargeable battery is used. Lithium polymer battery are advantageous in comparison to Lithium-ion battery which are small shape, size and very lightweight.

4.2.7 Alignment Sensing Switch

To maintain the proper orientation of the assistive cane, A novel Alignment Sensing Switch hereby ASS is implemented. The ASS is attached to the white cane. The ASS has a disk which contains a needle in the middle of it and a metallic pointer which can be rotated freely over the circumference of the disk (similar to the clock dial but) with the force of its gravity. Few regions on the circumference of the ASS disk are coated with copper as can be seen in Fig. 4.4.a. A wire is touched to the copper coated surface of the disk, while another second wire is touched to the center of the needle Fig. 4.4.b. The idea behind the engineering is that once the current is passed to one end of the wire, the current will reach to the other end of the wire only for the case, if the metallic pointer of the needle comes in contact with the metal-coated surface this way closing the ASS and forcing it to ON state, otherwise forcing it to OFF state.

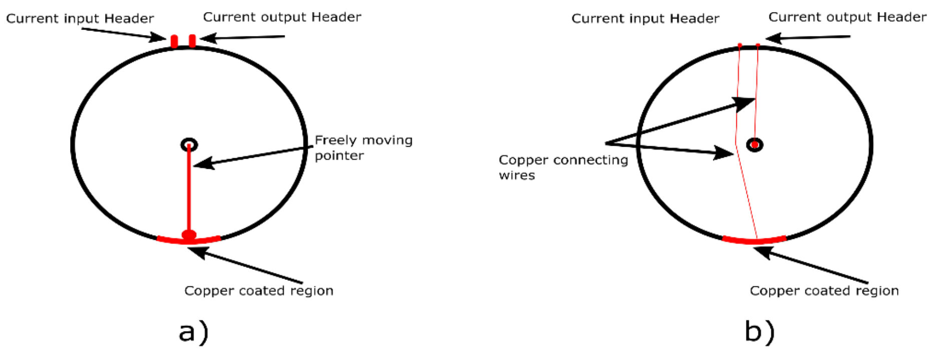


Fig 4.4. Alignment Sensor Switch a) Front b) Back

4.3 Pothole and Bump Detection

This section details the method for detecting the various obstacles on the walking surface which is then followed by the various feedback patterns, provided by the assistive cane to the user and at the end of the section an algorithm is presented, which drives various components of the system and carries out necessary decisions.

4.3.1 Environment Sensing

A US sensor (US1) is fixed to the front side of cane, which gathers information about the possible obstacles which are in the front side of the user. Another US sensor (US2) is fixed to the backside of the assistive cane, both the US sensors points downwards towards the walking road surface, US2 has the purpose of reducing the rate of false alarms. The US1 keeps on measuring distance and looks for obstacles in the form of pothole and bumps. When the pothole is faced by the US1, the continuous distance readings of the US1 shows an increment in its measurements. Similarly, for the case of the bump type obstacles, the continuous distance readings shows a decrease in its measurements. The same is shown in Fig. 4.5. in which the assistive cane keeps reading distances at the time t and checks for the amount of distance readings at time $t+\Delta T$. If there is enough difference in distance readings, it may be an indication of obstacles in the form of pothole or bump.

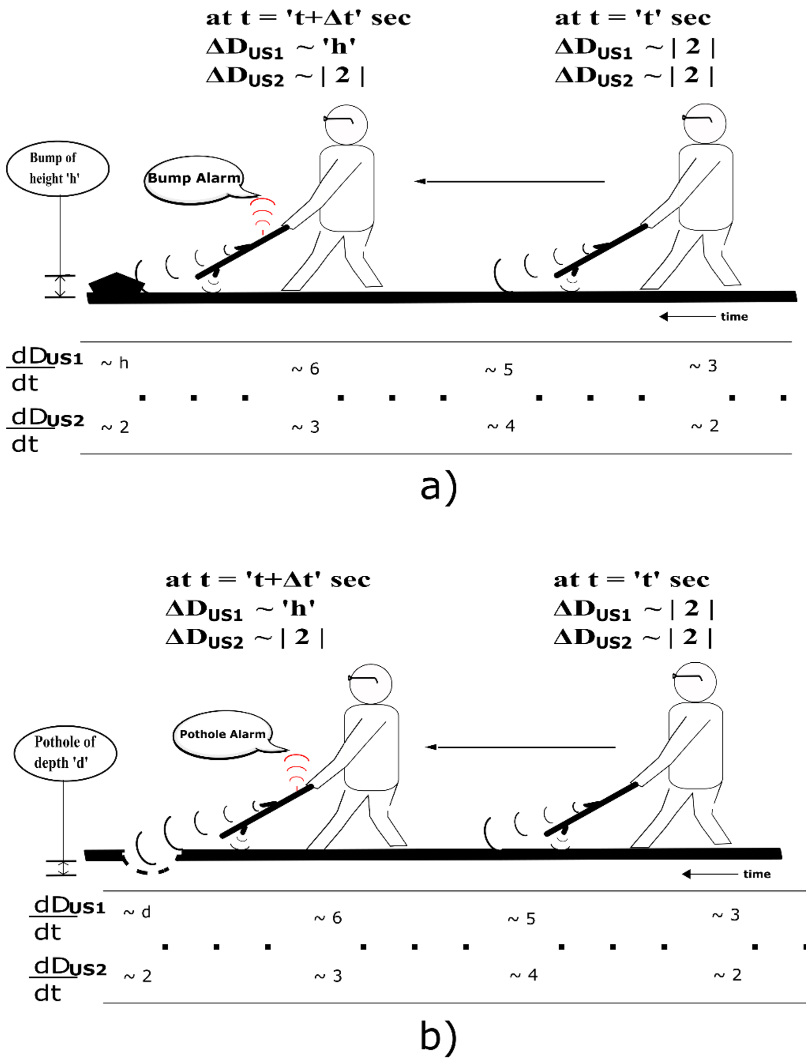


Fig 4.5. System in action a) Bump detection b)Pothole detection

There can be a possibility of the case when the user may have lifted the assistive cane upwards or moved it downwards, which may result in false obstacle alarm of pothole and bump respectively. In order to avoid these false alarms, the utility of US2 comes into picture. If the user moves the assistive cane, then both US1 and US2 sensors shows the same trend where there is increase in the distance readings by both the sensors, if the user moves the cane upwards. On the similar case, both US1 and US2 sensors shows a decrease in the distance readings when the assistive cane is pushed downwards. The algorithm to check for these conditions is discussed in the next section with Step 6 and Step 8. This way helping in avoiding false alarms rate. Since the distance readings of the US sensor often gives an unusual reading occasionally. A method for US sensor distance readings correction is also implemented in subsection 4.3.3 which works on buckets of capacity of 10 data items having consecutive distance readings to carry out decisions.

Certain limitation is set upon the minimum distance height of bump to be of 10cm and maximum of height as 30cm. Similarly, the limitation is also set for the depth of the pothole to be in between 10cm up-to 20 cm.

4.3.2 Orientation Challenge

There is a problem with the current discussed design and methodology, which is the orientation of the assistive cane. In fact the challenge of orientation is discussed in very limited extent in the literature. There is the possibility of the user to hold and orient the assistive cane at different angles as shown in Fig. 4.6, this way decreasing or increasing the subsequent distances as measured by the two sensors, US1 and US2. To force the restriction on the orientation of the assistive cane, the usage of the ASS come into picture. The ASS is in ON state only for the case when the pointer of the ASS and the copper metal layer of the ASS come in contact with each other, which is the case when the assistive cane is picked and moved at required orientation as, demonstrated with Fig. 4.6.b. Thus, this way maintaining the required orientation of the assistive cane.

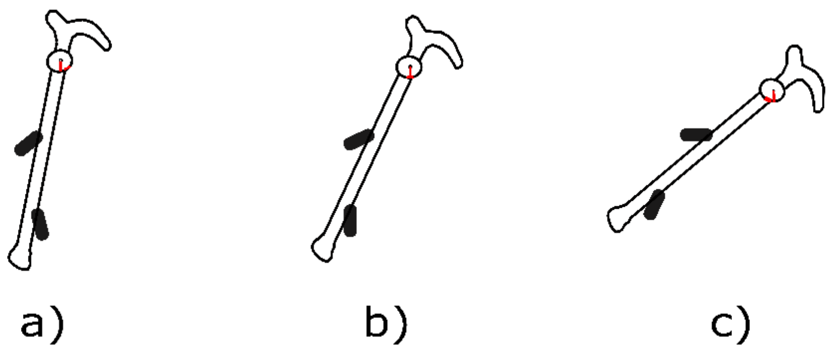


Fig 4.6. a) System OFF b) System ON c) System OFF

The ASS also provides additional functionality as an On/Idle switch to the entire assistive system. If the user requires the assistive cane, the user has to hold it in the required orientation, and the ASS finishes the internal circuit and turns on the entire assistive system in working state and to inform the user the buzzer produces the corresponding ON state tone. In another scenario, when the user stops or does not have require the assistive cane, and the assistive cane is in resting state, it will be in different orientation opening up the ASS internal circuit, turning itself off and switching the entire system to the idle state. In this way, with the ASS the user do not have to turn the system ON or OFF manually, easing out the usage of the system with comfort.

4.3.3 Ultrasonic Sensor Correction

The US sensor does not always provide accurate distance readings, as the US pulse emitted by the US sensor may be received back by the receiving transducer after undergoing multiple reflections through various objects in its working environment. To overcome this problem, a method is devised which discards the distance readings above 4m value as the distance readings in our system set up are not expected to go beyond 4m distance reading. In addition, using the average of 4 distances readings around median distances which are among ten successive sensor distance readings. The Algorithm1 below describes the detail steps:

Before the start of the algorithm, few notations are introduced. QuD, is the queue of capacity 10 data items, to store distances which are read from the US sensor. Once ten distance readings are stored in the queue continuously with successive distance readings, the standard deviation (SD) of the stored distance readings are computed. If the SD is greater than the cutoff value of five, it is expected to indicate noisy distance readings and all the distance readings in the queue QuD are discarded and not processed further. The process of storing the distance readings to the queue QuD is started again.

Algorithm 1 US sensor readings correction

Result: True US reading, D_{true}

Step 1: Get readings from the US sensor
Step 2: Check if reading greater than 4m
Step 3: if yes, discard it and go to step 1
Step 4: If no, Store the readings to the QuD
Step 5: Check if the size of QuD is 10
Step 6: If no, go to step 1
Step 7: If yes, get the standard deviation (SD) of the readings in QuD
Step 8: Check if SD >5, empty the QuD and go to step 1
Step 9: If no, arrange the readings of the queue in ascending order
Step 10: get the average of the readings at 3rd, 4th, 5th and 6th index
Step 11: return the average as true reading from the sensor

4.3.4 Uneven surface detection algorithm

In this section the uneven surface detection technique shown as flowchart Fig. 4.7 is discussed, which can detect pothole and bumps types obstacles. Some other obstacles which are speed breaker, four wheeler, and wall are categorized under bumps types obstacles.

The flowchart first starts checking for correct orientation with the help of ASS in Step 1. Then to correctly approximate US sensor distance value of the actual distance of the walking surface from US1 sensor denoted as Da, continuous measurements of total of 1000 distance readings are obtained and the statistical mode value is chosen for the approximation of Da. In Step 6 and Step 8, distance readings from US1 sensor and US2 sensors are checked for the possible presence of false alarm. After the described checks twenty continuous distance readings from US1 sensor are processed with the help of functions f1(n), f2(n) and f3(n) and the obtained results are stored in the form of sum1, sum2, sum3 respectively. If the assistive cane has encountered a pothole type obstacle at least twelve out of twenty readings should follow pothole condition (f1(n)). On the other hand, if the assistive cane encounters a bump type obstacle which is of height in between 10 to 30 cm, there is the possibility that at least twelve out of the twenty distance readings would satisfy the condition of the f2(n). Finally, if there are obstacles types like four-wheeler, wall, at least twelve out of twenty distance readings would follow the condition of f3(n).

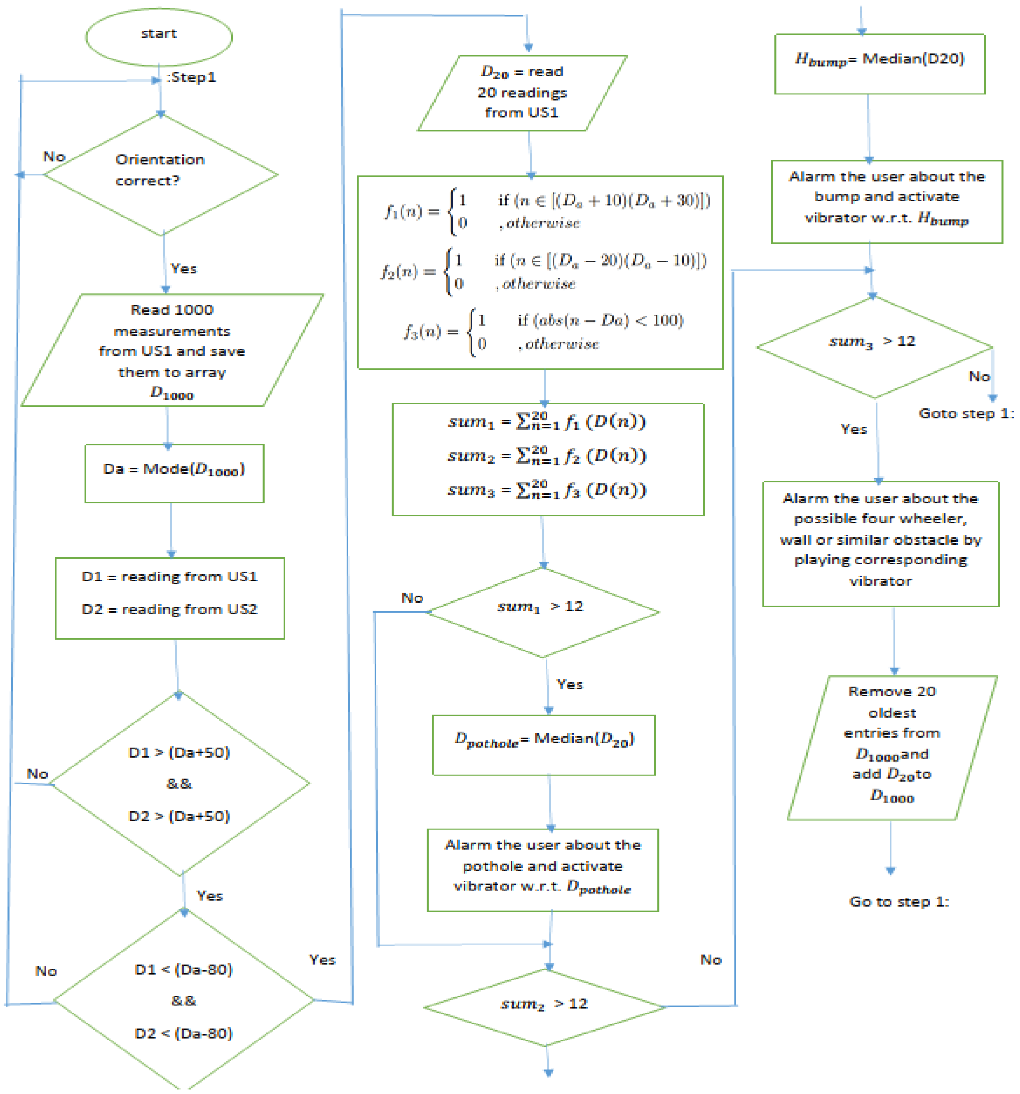


Fig 4.7. Flowchart for Uneven surface detection

4.3.5 Feedback System:

As the user picks the assistive cane for walking in the desired orientation, the buzzer first sends a sound signal, to inform the user that the system is ready for use and the entire system comes to be in working state. For the moment user orients the assistive cane to vertically downwards direction or moves it to a horizontal direction, in that case orientation is out of range of the ASS (as shown by Fig. 4.6), the buzzer starts generating alarming sound such that the assistive system goes to the idle state. In this way the user does not have to think about switching the system to ON state or OFF state. Different feedback to the user about possible obstacles of type pothole or bump is provided with the help of various vibration sensors. The different vibration sensors (vibrator) provides vibrations of various intensity levels which further depends upon the type of information which needs to be conveyed to the user.

Further, if there is a pothole type obstacle which is detected by the assistive system, the vibrator or the vibration sensor starts producing low-frequency type vibrations patterns with their intensity which depends upon the depth of the pothole type of obstacle as shown in Fig. 4.8. Low intensity types pattern for low depth pothole and high-intensity vibrations patterns for deep depth pothole type obstacle detection.

If there is a bump type obstacle which is detected by the assistive system, the vibrator starts producing comparatively high-frequency sound patterns with low in intensity for the obstacles of type low height bump and high-intensity vibrations pattern for high bump type obstacles detection as shown in Fig. 4.9.

For the other case of larger obstacles like four wheeler or wall, the vibrator generates very high frequency types intensity feedback pattern as shown in Fig. 4.10. The intensity of vibration pattern is directly related to the distance from the user of the large obstacle.

The frequency pattern of the vibrator is here defined with the help of the number of times the vibrations are generated in a given time.

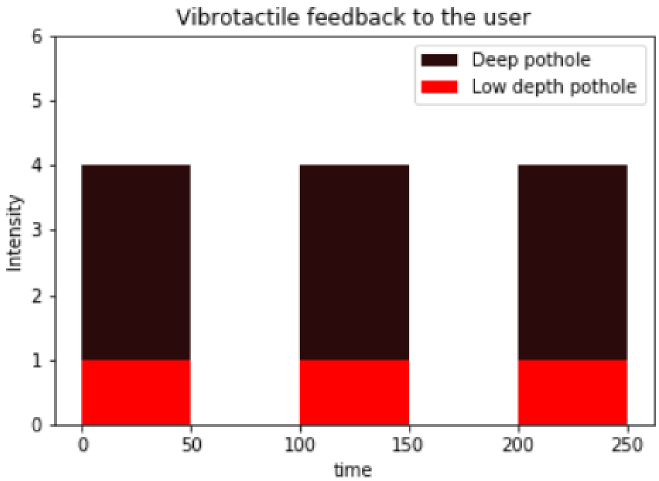


Fig 4.8. Feedback for pothole warning

To give ergonomic and more appropriate sensible feedback to the VI user, a total of 4 vibration sensors or vibrators are used. All of them are attached on to the handle of the Assistive cane. The 4 vibrators are placed in vertical direction or order which helps to define the information of the amount of depth of the pothole type obstacle or the height of the bump type obstacle. For example, if there is low height bump type obstacle which is detected, then the vibrator situated in low height is activated. In the similar case, if the depth of the pothole type obstacle is not much, the vibrator or vibration sensor placed high in vertical direction or order is activated with already defined feedback pattern. The particular defined range of the activation of various vibrators can be seen in Table 4.1.

Table 4.1: Vibration Sensor Activation

SNo.	Vibration Sensor	Pothole Depth (in cm)	Bump Height (in cm)
1	VS-01	<10	30 - 80
2	VS-02	10 - 20	20 - 30
3	VS-03	20 - 30	10 - 20
4	VS-04	30 - 80	<10

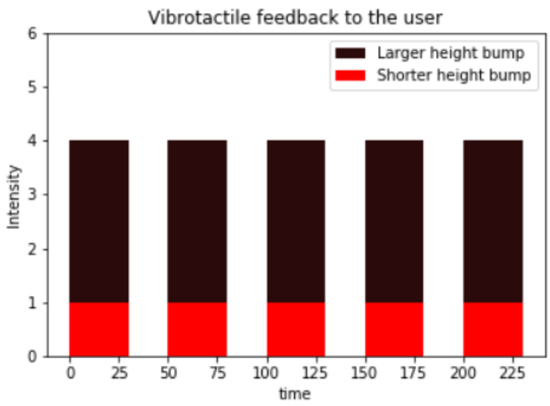


Fig 4.9. Feedback for Bump warning

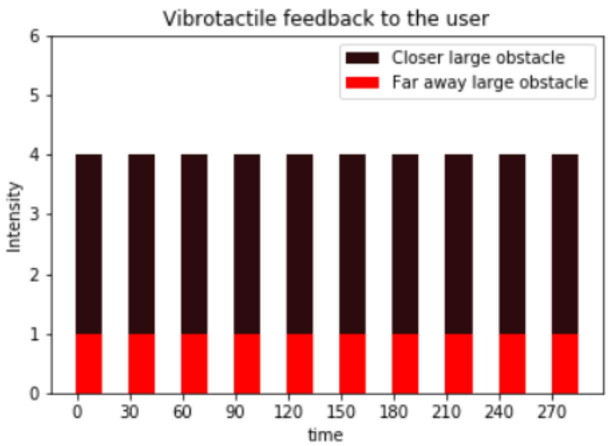


Fig 4.10. Feedback for large obstacle warning

4.4 Experimental Setup

In order to test the effectiveness of the assistive cane, the corresponding work in the literature have been studied, With reference to the images added in the Annexure I. In the work by [25] the proposed methodology is tested on the designed routes shown with Annexure I, II and III. In the work by [31] the work is tested after designing the path having different height obstacles as shown in Annexure IV. In the work by [30] the designed assistive cane is tested with the path consisting of obstacles in the form of card boxes and can be seen in Annexure V. Similarly, the work by [29] have been tested with the help of path having obstacles consisting of boxes, chair and others and can be seen in Annexure VI. An experimental route is set up in the university campus of total length 200-meter which have various obstacles types. The various obstacles are

2 mounted stones in the form of a cardboard box of dimensions 10cm*10cm*10cm and 10cm*10cm*20cm, 2 potholes type obstacle of varying diameter first one of diameter 10 cm and depth 10 cm and while the other one with diameter 20 cm and depth 40 cm. One speed breaker, which is normally used for braking down the speed of the speeding vehicles, of dimension 20 cm in height and 300cm in length, 2 four-wheeler, both are hatchback type and also of the same model, first one facing its front and other one facing its back is also used, finally two wall-like structures, first one of height 80 cm and the other one of height more than 200 cm is also used. The experimental route with the set up of the obstacles and their placements are diagrammatically shown with the help of Fig. 4.11.

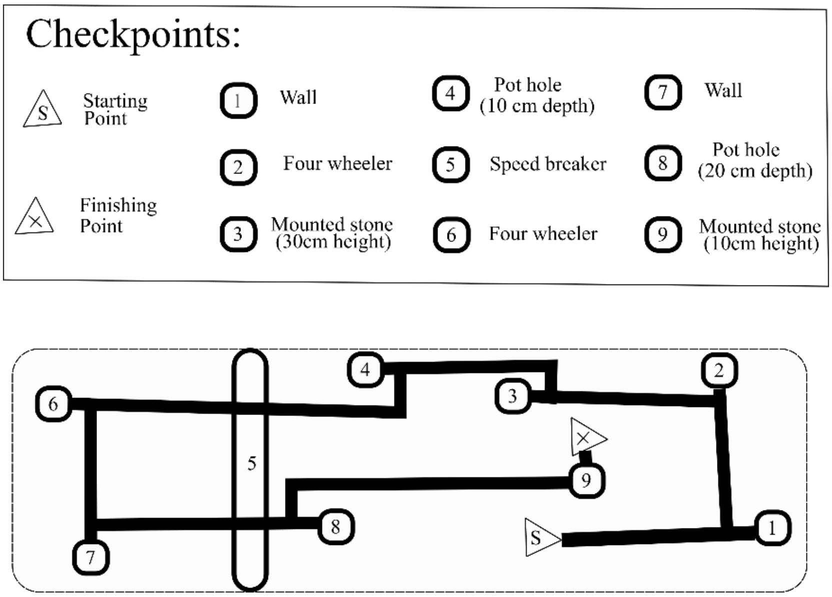


Fig 4.11. Experimental Route

With the available resources in the university campus, 40 undergraduate students are recruited to be used as test subjects for the experimental study are of age between 19-20, all the test subjects are males. To mimic the test subjects as VI persons, all of them are blindfolded by covering their eyes with a thick cloth. The experimental route is travelled by the test subjects in total of five trips to check for assistive cane's usage improvement with the time required to travel the same route by the assistive system one by one. Further, the entire experimental route is also covered with 3 conditions. In the first, without using any type of assistive aid by a normal person without even blindfolding their eyes. In the second case, by blindfolding both eyes of the test subjects and using our assistive system in OFF state as an assistive aid and in the third case, with blindfolding both eyes of the test subject and travelling the experimental path with the help of the assistive system. To avoid memorizing the experimental path by the test subjects, they are asked to move forward and rotating them several times while travelling the experimental route. The test subjects are also asked to move left, right, or in straight direction whenever required, in order to stick them to the designed experimental route only. Before the start of the experiments, training of about one hour is also undertaken, in order to acquaint the test subjects with the assistive cane and traversing in the experimental route, blindfolded.

4.5 Assessment Score for obstacle detection

A total of 5 various types of obstacle are involved in our study. The types of obstacles ranged from speed breakers to mounted stones of various height to stationary vehicles or four-wheeler. As these obstacles types are different in importance, for example, it can be observed that a speed breaker is comparatively less hazardous to the mounted stones. In the similar way, potholes types obstacles of different depths have danger levels dependent on their depth.

There are few other stationary obstacles like walls and four-wheeler which can very easily be detected by the simple usage of the commonly used white cane itself, which then makes the usage of additional assistive system unnecessary or redundant. To evaluate various different obstacle types with our assistive system and in order to draw inferences; it requires to devise a score-based approach. In this particular approach, the different obstacles which are comparatively more dangerous are assigned higher weight in comparison to various obstacles with lesser danger level. A sum of hundred is distributed between the various obstacle types which are used in this study. The fine details of these different obstacles and their appropriately assigned score can be seen in Table 4.2. In the experimentation stage, if the assistive system is able to detect the obstacle, the corresponding score is assigned to the assistive system otherwise zero is assigned when the assistive system fails to detect the encountered obstacle.

Table 4.2 Obstacle Assessment Score

SNo	Obstacle Type	Obstacle Feature	Obstacle Score
1	Mounted Stones	Height (cm)	
		10	10
		30	20
2	PotHoles	Diameter (cm)	
		10	10
		20	30
3	Speed Breaker	Dimension 20cm height, 60cm wide	10
4	Four wheeler	Same attributes	
		Front facing	5
		Back facing	5
5	Wall	Same attribute	
		Wall 1	5
		Wall 2	5

4.6 Results and Discussion

The assistive system is tested inside the campus of the University having most of the obstacles situated at an uneven distance interval. All the test subject involved in the study are supported by another person walking just behind them in order to avoid any kind of injury if collides with the various obstacles. If the test subject collides with anyone of the various obstacle he is then asked to take back a few steps and as per the designated route turns left or right side. Two different scenarios are considered for the case of the experiment. In the first scenario, the blindfolded test subjects walks with the assistive cane in the OFF state and moves the assistive cane from left to right in the manner of an arc, the same way popular white cane is used. In the second scenario, the assistive cane is held firm by the test subject at an appropriate angle (which is the same used by the VI persons) without even moving it while walking with it. In this way, a total of 40 trials (one for each test subject) considering both scenario i.e., walking with normal cane and walking with our assistive system are available.

Table 4.3: Obstacle Detection Test

SNO	Obstacle Type	Obstacle Feature	Obstacle Detected (Averaged out of 10)	
			Proposed Cane	Normal cane
1	Mounted Stones	Height (cm)		
		10	6.25	4.25
		30	7.5	7.75
2	Pot Holes	Diameter (cm)		
		10	6.5	1
		20	8.5	3.25
3	Speed breaker	Dimension 20 cm height 300 cm wide	5	4.25
4	4 wheeler	(Same attributes)		
		Front facing	9.25	9.5
		Back Facing	9.5	7.5
5	Wall	(Same attributes)		
		Wall 1	10	10
		wall 2	10	9

The results obtained of the test subject's collision with obstacles can be seen in Table 4.3 (the different obstacles detected by the total 40 trials are averaged and presented here as 10 in order to obtain final score out of 1000). The table shows the total number of times the various obstacles are detected by our assistive system when compared to the normal cane. On comparing the obtained results in terms of obstacle assessment score, our assistive system achieved 24.88% higher score Table 4.4, when compared to the normal cane or popular white cane. Different obstacles types like speed breaker and vehicles or four-wheeler can be seen to be detected by both the assistive system and the normal cane but for the case of potholes type obstacles, which are found much better by our assistive cane.

Table 4.4: Achieved Score

SNO	Obstacle Type	Obstacle Feature	Achieved Score	
			Proposed Cane	Normal Cane
1	Mounted Stones	Height (cm)		
		10	62.5	42.5
		30	150	155
2	Pot Holes	Diameter (cm)		
		10	65	10
		20	255	97.5
3	Speed breaker	Dimension 20 cm height 300 cm wide	50	42.5
4	4 wheeler	(Same attributes)		
		Front Facing	46.25	47.5
		Back Facing	47.5	37.5
5	Wall	(Same attributes)		
		Wall 1	50	50
		wall 2	50	45
		Final Score(1000)	**776.25**	**527.5**

In comparison of our work with the similar work which are obtained by Shripad et al. [29], it can be found that they have attached the various sensors on to the walking cane itself thus requiring the user to carry no additional equipment. In their work the accuracy is reported for bump type obstacles to be 80% for blind persons and compared it to white cane which obtained accuracy of only 55%. If the accuracy of our assistive system is compared for detecting bump(or mounted stones and speed breaker) which is 65% in our case which is lesser. But then in their work there is no method devised for detecting potholes types obstacles. Thus making our assistive system slightly more functional. In addition, their proposed system has to be lifted and moved straight upright at 90◦ angle with the ground floor to get better consistent results, or else, the detection of the obstacles may be missed. But in real world this practice of walking with this constraint seems to be very difficult as the person cannot know whether the orientation is correct considering the usage time to be very high. In our assistive system, the results which are presented with the assistive cane oriented in the same way as held by the VI persons within the same range. And in our work there a unique mechanism is also devised on keeping the orientation in check with the help of presented novel ASS, which sends audio alarms to the user if required, in order to keep the held cane in the desired orientation only. This functionality helps significantly in achieving results consistently. In addition, in our work there is no usage of any complex audio feedback to confuse the user in order to comprehend, this thus makes the expected comparative travel time by our assistive system to be less.

On comparing the presented work to the work and results achieved by Kailash Patel et al. [30] in their work the same strategy multiple US sensors is used. In particular 3 of the US sensors faces front while 3 of the US sensors faces back and 1 of the US sensor to the left and 1 of the US sensor to the right, to get the entire obstacle presence detection. Nevertheless, there is a drawback in their work, as all these US sensors needs to be installed in a specially designed shoe which may pose the challenge of acceptance from the VI persons as at best they need to carry no additional equipment.

On comparing with the similar work by Arnesh Sen et al. [28], in their work the idea of attaching the US sensors on to the body of the VI user makes their system less ergonomic and again not much welcomed by the VI user in practical real conditions. In comparison to their work, we have attached the US sensors to the cane itself which is already used the VI persons for their travel needs.

4.6.1 False rate reduction

In the trial runs of the experimental set up it was observed that the VI person moves the cane in the upwards or downwards direction at a count of 2 to 3 times in every single usage of the cane of around 20 mins. In our work the two US sensors approach helps in detecting these scenarios and ignores them as being a false alarm. In a similar manner, the VI person orients the cane almost in horizontal direction at a count of 5 to 6 times in every single usage run of the cane of around 20 mins. In our work, the presented ASS most of the time accurately detects these scenarios and correspondingly alarms the test subject for the possible incorrect orientation of the cane which needs to be maintained for proper working of the system. Thus on average it is found that for every 20 mins of usage of our assistive cane the ASS system removes 7 to 9 false alarms. These two novel features which are not found in the reviewed literature help in reducing a considerable amount of false alarm rates.

4.6.2 System training performance

The proposed assistive system is also tested with an experiment of 5 number of trips to know whether there is any improvement in its usage. A normal user when tested is found to walk through different obstacles avoiding them in the experimental in around 20 sec, on further trials it was found of not much improvements in consequent trial runs. The same trend is also found with the normal cane usage. The travel time was found to hardly decrease significantly over the five trips. In contrast, for the case of our assistive cane, it is found that initially the user took longer to travel within the experimental route but with consequent usage, once the user became acquainted with the functionality, audio feedback and usage of the assistive cane, a significant reduction in travel time is observed with 55 sec in the 1st trial run to the 40 sec in the 5th trial run which is 15 sec lower. In the 5th trial run of normal cane by 5 sec which is again significant in itself. The same information is shown in Fig. 4.12.

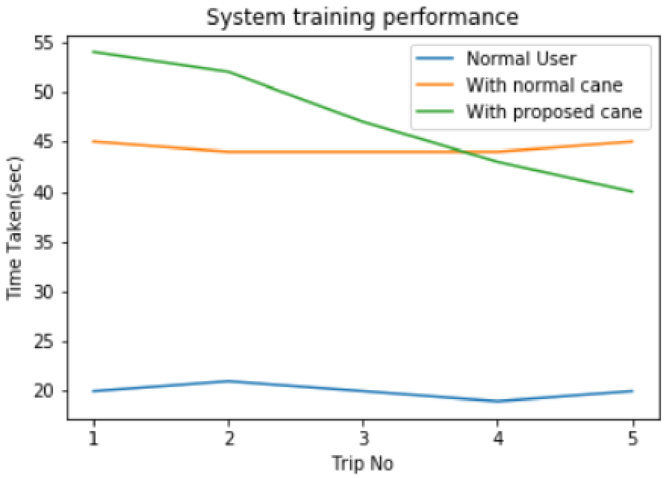


Fig 4.12. System training performance

4.6.3 Power consumption analysis:

The current consumption requirement by each individual components of our assistive system are shown in Table 4.5. The presented assistive system work in 3 power states which are power OFF, idle state and power ON i.e., working state.

Table 4.5: System Power Consumption

SNo.	Component	Quantity	Current required (mA)	Total (mA)
1	Microcontroller (Arduino Nano)	01	16	16
2	US Sensor (HC-SR 04)	02	7	14
3	Buzzer	01	8	8
4	Vibration Sensor	01*	5	5

*Only one operating out of 4 at any given moment.

Below computations are performed on the basis of using a battery of 1 Ampere Hour.

1. Power OFF/ON: In the assistive system, a push button is given to the user to turn it to OFF or ON state as per the need. In the state of OFF, the assistive system requires zero current.
2. Working state: Here all the components of the assistive system are in active state and draws the required current all the time, leaving Buzzer and vibration sensor which requires the current only when audio or vibration feedback to the user is required. It is estimated that on an average of a 20 min complete trip, the sound buzzer is activated approximately 10 times for a total of 10 sec, while the vibration sensor

is activated at least 30 times for 50 sec approximately. Thus the two i.e., buzzer and vibration sensor draws on an average 0.67mA and 6.25 mA current per second respectively. In all the total current usage in working state is 31mA approximately.

The battery of 1AH is found to sustain 32 hours of working state journey approximately for the usage by the VI person for commutation.

3. Idle state: The ASS component of the assistive cane is connected to the analog pin of the Arduino micro-controller. At the moment the user orients the assistive cane out of the required range, the assistive system is programmed to move the micro-controller to the idle state, further switching off current to all the different attached components except ASS component and in this idle state, the assistive cane requires only 16 mA current. At the moment the ASS component moves to the required orientation, the ASS with the help of analog pin, signals the micro-controller to change it back to working state. In this way, the idle state can run the assistive system for 62.5 hour long journey.

4.6.4 System Cost analysis

Most of the system components are available online for purchase and the cost of each of the component are shown in Table 4.6.

Table 4.6: System Cost Analysis

SNo.	Component	Quantity	Unit Cost (in $ USD)	Total cost (in $ USD)
1	Microcontroller	01	8	8
2	US Sensor	02	5	10
3	Buzzer	01	.6	.6
4	Vibration Sensor	05	.8	4
5	walking cane	01	15	15
6	Battery	01	10	10
			Total cost	47.6

The cost analysis shown here is for the development of a prototype. For the case, the assistive system is manufactured industrially in large scale, the cost shown here can reduce drastically to at least 1/5th. The industrial cost can come in acceptance to the budget of the VI persons belonging to the low income category. And as we read from the WHO survey[1] there are around 90% of the VI persons belonging to the low income. This cost is very hard to be achieve if a camera based approach have been used for obstacle detection purpose. Though there is a downside that the camera-based approach is more capable of even classifying the different obstacle categories.

In a nutshell, our presented assistive system poses additional functionalities not present in the reviewed literature but for the acceptance by the VI persons, the accuracy of the assistive system needs further improvisation with even more sophisticated methods.

4.7 Summary

In this chapter, the common problems faced by Visually Impaired persons are presented in addition to the currently available ETAs. Our presented assistive cane of detecting obstacles (potholes and bumps) is explained with all the necessary details. Our presented work relied on the usage of US sensors and provided an Alignment Sensor Switch (ASS) in order to restrict the orientation of the assistive cane when in use by the user. The noisy distance readings by the US sensor are also corrected with the help of described algorithm, for the possibility of multiple reflection causing the noisy distance readings. Information about the presence of the potential obstacle is provided with the help of vibro tactile patterns feedback mechanism to the user. The main emphasis of the presented work is on the basis of unfaltering user's known acquaintance of the white cane. The shown effectiveness of the presented assistive system is tested on the experimental outdoor environment which contains the obstacles different sizes potholes and bumps. The obtained results after conducting experiments proves the effectiveness of our presented method. The obtained results are also assessed based on the hazard dependent obstacle score as well as also compared with the comparatively related works available in the reviewed literature. The effectiveness in reducing false-positive rate with the help of ASS is also discussed with apt details. The power requirement by the proposed assistive cane and the cost analysis is also discussed. The cost analysis is important considering the fact that the majority of VI population still lives in low-income settings. Any future attempts for the development of any assistive system should focus on simplicity of the employed methods to get welcome and acceptance from the VI persons.

In this chapter, some limitations in our presented work is also discussed which needs to be addressed by the researchers in their future endeavor. The assistive system presented in this chapter, is tested with the test subjects with normal vision and blind folding their eyes with clothes. In order to get more realistic practical results and audio and vibration feedback, the presented assistive system should be tested in future on real VI persons.

In the next chapter, details about the eyeglasses developed in this work is discussed. The eyeglasses consists of US sensors for obstacle detection around the head level. The location of the obstacle is provided to the user though different audio feedback patterns.

Chapter 5: An Eyeglass based head level obstacle detection system

The white cane most commonly used by VI for obstacle detection in their route has its limitation with the inability to detect obstacles above waist height. Due to this limitation head injury is very commonly faced by the Visually Impaired persons. In this chapter, we discuss the developed eyeglasses which consist of two US sensors and two buzzers for obstacle detection and localization. The location of the obstacle in 3D space is conveyed to the user with varying frequency patterns through the buzzers. The 3D location of the obstacle is conveyed in terms of laterality, elevation and depth information.

5.1 Research problem and main contribution

Although there are a lot of works which uses computer vision based approach which are discussed in details in chapter 2.5. These approaches have supremacy in detecting the range of obstacles types but suffers from few drawbacks as well. First, the accuracy of the camera based approach are dependent on the lightning conditions which can limit their availability. Second, the cost of the camera based system is much higher in comparison to the US sensors which makes them unsuitable for the common VI persons. As we know from the WHO statistics above that they come from low income group. This motivated us to work with US sensors in our developed prototype.

In this work, a prototype is developed, wearable on the head as eyeglasses, to avoid head level obstacles. The system consists of one pair of US sensors and one pair of the buzzer for each respective US sensor. The US sensors calculate the distance of the obstacle which are in front of the head of the user. Based on the distance of the obstacle, the buzzer produces the sound with an intensity directly proportional to the distance of the obstacle. The location of the obstacle in 3D space i.e., lateral which is the horizontal distance of the obstacle in front of the head of the user as shown in Fig. 5.5, elevation which is the height of the obstacle in front of the user calculated from the head of the user as shown in Fig. 5.7 and depth which is the radial distance of the obstacle from the user head, is then conveyed to the user with the help of frequency-modulated audio feedback.

The major contribution of our work which is discussed in this chapter can be summarized as:-

- Our work highlights and proposes the solution for the need to prevent head level injury, which is most commonly encountered by the Visually Impaired persons.
- The 3D location of the obstacle detected in front of the user is

communicated to the user with the help of different audio feedback.

- All the components of the system are placed together on the eyeglasses which makes the system wearable.
- All the components which are used in the system are of low cost in comparison to the vision based system.
- The developed prototype is a proof of concept which can be electronically miniaturized to obtain a working product to be used by the VI persons.

5.2 System Architecture

The system architecture with its different components are shown in Fig. 5.3.2. In this section, different components of the proposed system shown in Fig. 5.3.1 are explained in detail along with the methodology for obstacle localization in 3D space. There are few components, which are similar to the one discussed in previous chapter. Here, there is no ASS and walking cane but eyeglasses are added to support the various component onto it.

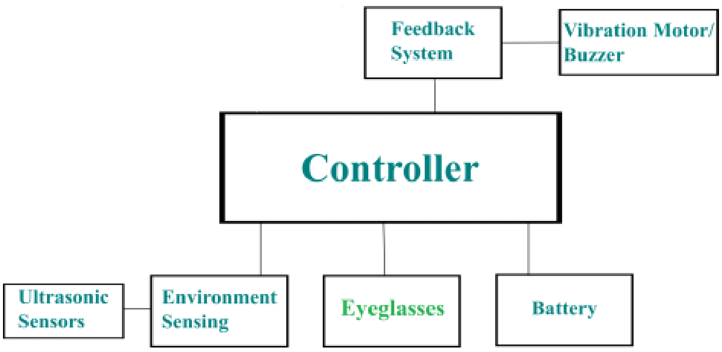


Fig 5.1. Proposed system architecture

The developed prototype consisted of a regular standard eyeglasses upon which the electronic components are attached. The US sensors are attached to the left and right glasses for detecting obstacles in front of the head of the user. Similarly, the buzzer is attached to the left and right handle of the eyeglasses for providing acoustic feedback to the user. The brief details of the electrical components are discussed next.

5.2.1 Ultrasonic Sensor

The sensors used in this work is ultrasonic sensors which consist of two transducers, one for transmitting ultrasonic pulse (slightly above 20KHz) in front of it, and the other for receiving the transmitted pulse. The total time taken by the pulse until it is received back by the other transducer is known as the time of flight (ToF).

5.2.2 Microcontroller

The micro-controller used in this work is the popular Atmel Atmega328P. It is an 8-bit RISC-based AVR micro-controller having 32 kB ISP flash memory with read-while-write capabilities. It also has 1 KB EEPROM to store programs to run, 2 KB SRAM and 23 I/O pins which can be used for general purpose programming. It also has 32 registers for general purpose working, 3 flexible timers/counters, internal and external interrupts. The micro-controller works in a range of 5-12 volts. Programming can be done on the Host machine in C like language. To transfer program after compilation from the Host computer to the Atmega328P chip, a USB cable is used.

5.2.3 Buzzer

It is a device, which produces sound on providing input voltage. Thus varying sound can be produced by modulating the input voltage. In our system, the buzzer is used to realize different types of distance information to the user.

5.2.4 Battery

The battery used in this work is lithium ion which provides sufficient voltage for the system to work for sufficient long duration of time.

5.3 Obstacle localization in 3D space

A 3D space can be defined w.r.t different types of the coordinate system, for example, the Cartesian coordinate system where any point is defined in terms of the triplet (x, y, z). There is another coordinate system as well, called a spherical coordinate system, in which the position of a point is specified by three numbers: the radial distance of that point from a fixed origin, its polar angle measured from a fixed zenith direction, and the azimuthal angle. In our case, we define the location of the obstacle in front of the user with the help of Cartesian coordinate system, where the 'x' coordinate is defined in terms of laterality, 'y' coordinate is defined in terms of height or elevation and the 'z' coordinate is defined in terms of distance or depth from the user. To identify these three attributes following strategies are employed which are discussed next.

5.3.1 Laterality identification using Dual ultrasonic sensors strategy

Two US sensors, USSL for the US sensor attached at the left handle of the eyeglass and USSR for the US sensor attached to the right handle of the eyeglass, are attached to the eyeglasses as shown in Fig. 5.3.1. Any obstacle in front of the head of the user towards the left side will be closer to USSL than USSR. And same will appear in the readings of the two. Similarly, any obstacle situated right side in front of the user's head will result in the distance reading of USSL more than USSR. Further, the magnitude of the difference of the distance reading of USSL and USSR, itself identifies how extreme the obstacle is located. Thus the location of the two US sensor on the eyeglasses results in the difference of the distance readings of the two in such a way that the location of the obstacle (whether situated towards left or right) can be known.

5.3.2 Depth identification with frequency-modulated audio feedback

The frequency modulated audio feedback system for the user consists of two buzzers placed near to the left and right ear. The intensity of the respective buzzer is directly proportional to the distance which is least out of USSL or USSR. The distance is further divided into three levels of danger notification as per their proximity from the user, with the object most closer is treated as most dangerous, while the obstacle very far to the user is least dangerous. And the obstacle in between the two is treated as dangerous. These levels are shown with Table 5.1. The frequency feedback for each respective level is conveyed to the user with different intensity levels of the audio feedback. As shown in Fig. 5.3, the leftmost bar of intensity 5 is provided to the user for most dangerous severity of obstacles labelled as D2, while the middle bar of intensity 3 is provided to the user for dangerous severity of obstacles labelled as D1 and the rightmost bar of intensity 1 is provided to the user for least dangerous obstacles labelled as D0.

Table 5.1: Danger Levels

SNo.	Distance Range in cm	Dangerous severity	Intensity Level (1-5)
1	[0 50]	Most Dangerous, D_2	5
2	[51 200]	Dangerous, D_1	3
3	[201 300]	Least Dangerous, D_0	1

Table 5.2: Intensity Levels

SNo.	Intensity Level	Audio Frequency in Hz
1	1	100
2	3	400
3	5	1000

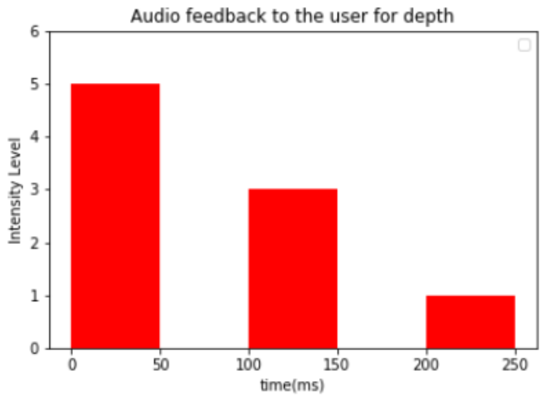


Fig 5.2. Depth feedback to the user

5.3.3 Elevation estimation with head movements

The lateral identification of the obstacle requires two US sensor. However, to include elevation information, more than two US sensors would be necessary. To incorporate further US sensors, it not only requires complex signal processing as well as the phenomenon of crosstalk which itself requires additional processing. To avoid these subtleties, we propose head movements by the user upwards and downwards while walking to scan for obstacle laterally as well as vertically. This addition of effort for elevation estimation can be justified noting the fact that the VI person already exercises such activity with their white cane. To detect obstacles on the ground the VI person moves their white cane continuously from left to right in the fashion of arc. Thus, some efforts from the user help to estimate the elevation of the obstacle in front of the head of the user.

5.4 Experimental Set up

For the experiment purpose, 20 test subjects are recruited from the University's students. The details of the experimental set up and procedure is communicated to the test subjects. The written consent is also undertaken by the test subjects before the actual experiments. Each test subject is of the age 19-20 with a normal vision of 6/6. The test subjects are blindfolded to carry out the experiments. Tests are performed for laterality, elevation and depth detection. Each test subject performed each of the tests twice. Thus the total of forty tests are performed for each scenario. Obstacle in the form of a circular disk of cardboard of radius 15 cm is placed in front of the user as shown in Fig. 5.4. All the tests are performed with the test subject sitting in stationary conditions.

Before undergoing the actual experiment a 10 minutes demo test is conducted for each test subject to get them accustom to the actual experimental scenario.

The details of the experimental scenario for each of the lateral, vertical and depth are discussed below. With each scenario tested one by one.

Fig 5.3. System Testing

5.4.1 Laterality Detection

To test the effectiveness of our system, an experiment is setup which consist of placing obstacle in the form of cardboard disk in front of the user's head laterally among five positions labeled as L0, L1, L2, L3, L4 placed equidistant to each other as shown in Fig. 5.5 in random order. The distance between the center of each adjacent lateral label being 15cm. The distance between the disk and the user being 200cm in all the lateral positions.

To provide feedback to the user about the lateral position of the obstacle two types of feedback are required. One which is closer to L0, i.e., L1 and L2 and the other feedback type for the obstacle location at L3 and L4. For the obstacle location at L0, as the distance from USSL and USSR is same which means the obstacle is equally distant to the left ear and the right ear, therefore, no feedback is provided for laterality, but the depth information is provided with the different feedback. The Fig. 5.6 displays the feedback which is provided for different laterality location, above sub figure in Fig. 5.6 displays the feedback which is provided for the obstacle location at L1 and L2 while the sub figure below in Fig. 5.6 displays the feedback provided for the obstacle location at L3 and L4.

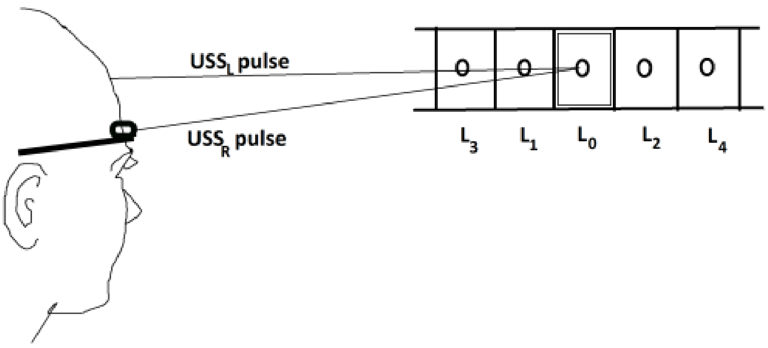


Fig 5.4. Laterality Identification Test

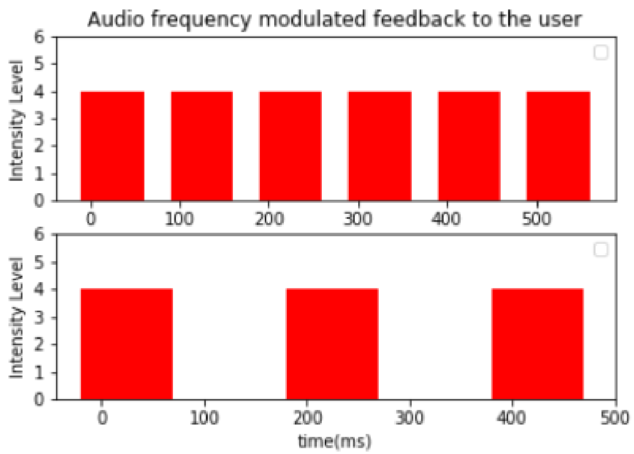


Fig 5.5. Lateral feedback to the user

5.4.2 Elevation Detection

For the elevation detection testing the setting consists of placing the obstacle in the form of cardboard disk vertically at different locations labelled as V0, V1, V2, V3, V4 as shown in Fig. 5.7 in random order. The distance between the center of each adjacent vertical label being 15cm. The obstacles are placed in one of the position one by one and the blindfolded subject is asked to identify the location of the obstacle with moving the head in a vertical fashion and listening to the audio feedback by the system. The distance between the disk and the user being 200cm in all the lateral positions.

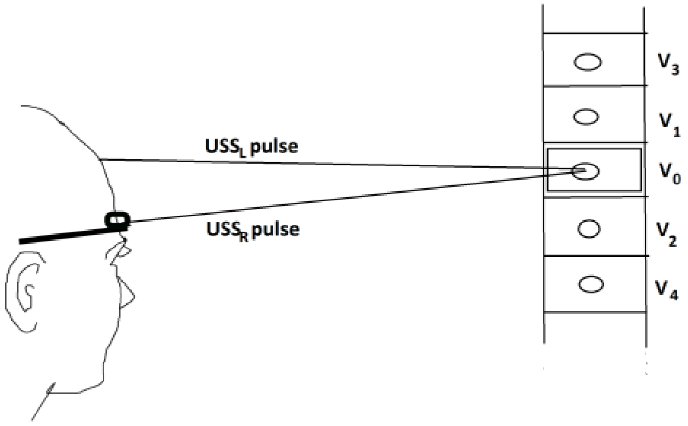


Fig 5.6. Elevation Identification Test

5.4.3 Depth Estimation Test

For the depth test, the disk is placed at different depth levels, D0, D1 and D2 from the user in random order. The test is performed with the disk placed at one of the depth levels as per the Table 5.3.1 and the user is asked to identify the correct depth level of the disk on listening to the feedback in terms of depth feedback as shown in Fig. 5.3.3 by the system.

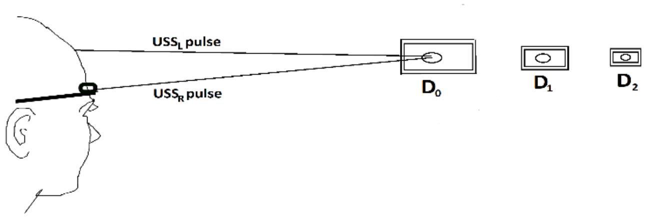


Fig 5.7. Depth Identification Test

The entire working of the system is shown with the help of flowchart below. The flowchart works with measuring the distance of the obstacle with the help of Left and right US sensors. It then checks whether the obstacle is located towards the left or right of the user. It then activates the corresponding buzzer with the designated frequency pattern. The depth of the obstacle is also provided to the user through different frequency pattern.

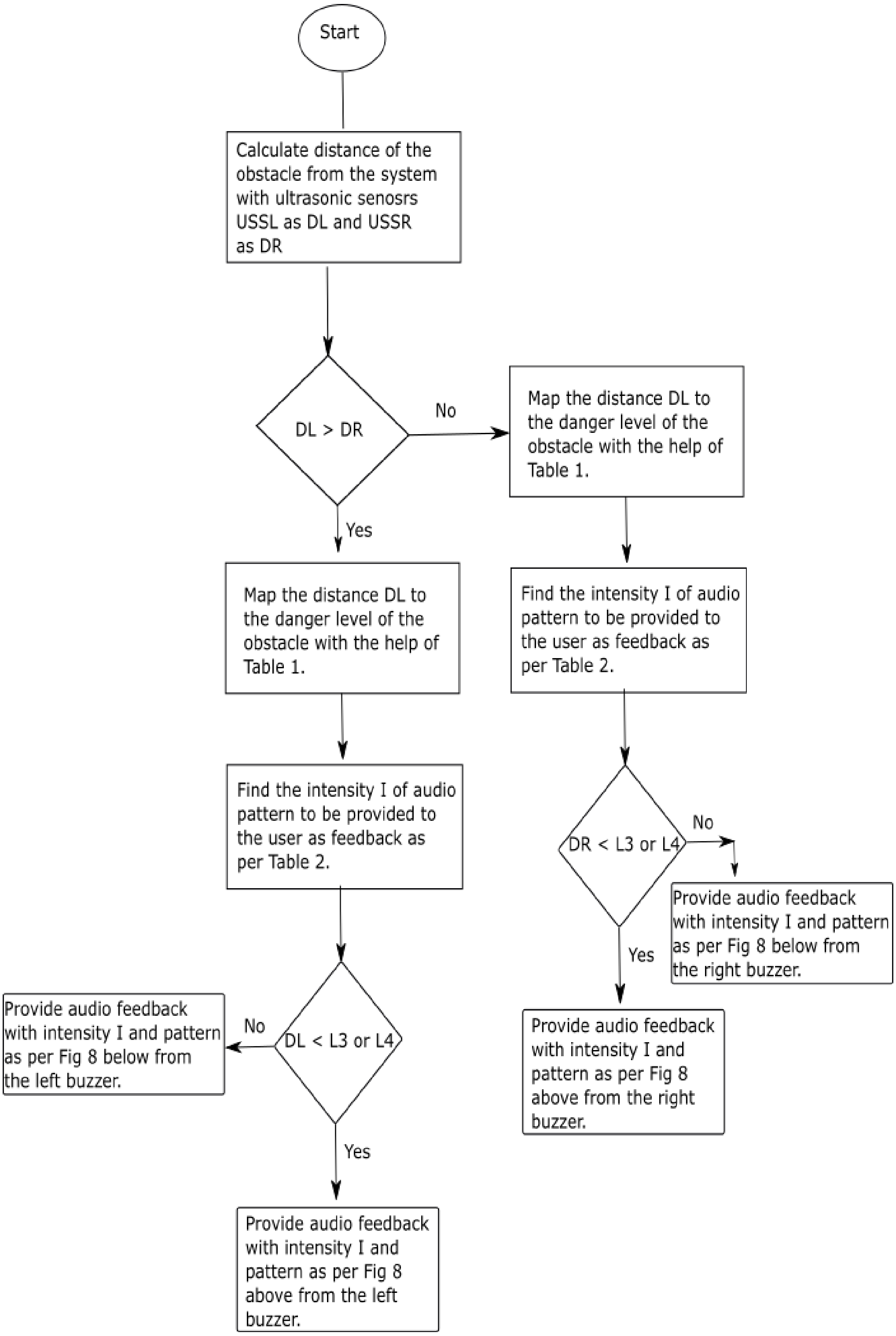


Fig: 5.8 Flowchart for the working of the system

5.5 Results and Discussion

The results of the laterality detection test are shown with the help of the confusion matrix as shown in Fig. 5.8. It can be seen that each of the Lateral labels are detected almost equally with L0 detected most of the time while L2 detected least of the time. L4 label also has the least false positive rate among all.

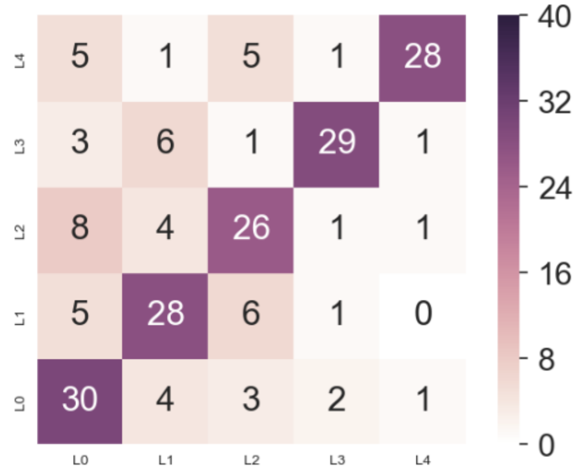


Fig 5.9. Confusion Matrix for laterality test

The results obtained after conducting the experiment 40 number of times is shown with the help of the confusion matrix as shown in Fig. 5.9. It can be noted that elevation position V0 is identified by the user successfully 32 times out of 40 whereas V4 is identified least number of time.

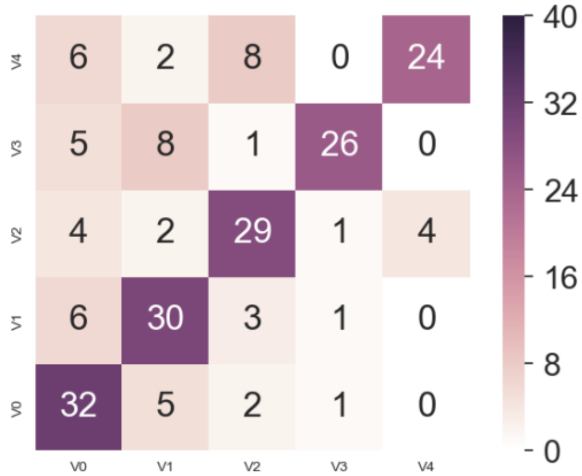


Fig 5.10. Confusion matrix for elevation test

The results are shown in the form of the confusion matrix as shown in Fig. 5.10. On comparison with the other two tests i.e., laterality test and elevation test, the results for the depth test is quite more efficient. The depth label D2 is detected with 85% accuracy.

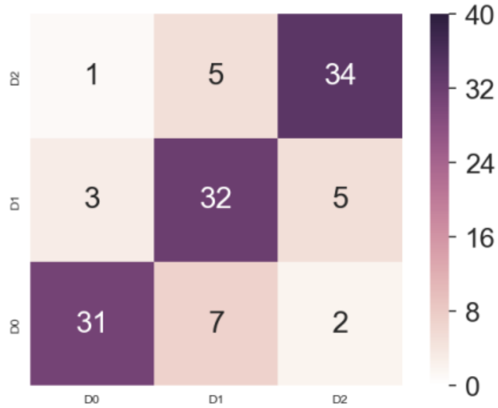


Fig 5.11. Confusion matrix for depth test

In this section the results obtained earlier for laterality, elevation and depth detection are combined in Table 5.3 to get a better picture. Thus, the overall detection rate for laterality and elevation is the same as 70.5% and for depth is 80.8%.

The false-positive rate for laterality and elevation is again very close to each other as 7.38% and 7.37% respectively and for depth, it is 9.58%. Looking more closely, it appears that for laterality and elevation, detecting the obstacle located at the center position is comparatively easy than at other locations. The results for depth detection is quite satisfying as the danger level D2 is detected very precisely as 85% of the time.

On comparing the results with the state of the art available in the literature, [38] reported 86.2% detection results for laterality which is 15.7% higher than our results but for the case of elevation they achieved 68% detection rate which is 2.5% less than the results obtained by us which is significant. Similarly, for depth estimation test they reported 70% detection rate which is again much lesser to 80.8% rate achieved by us.

There are other works in the literature which don't have the same experimental setup as ours but are related to our work in terms of using the US sensor for obstacle detection. Thus in comparison with few of them, the accuracy may not be used. In the work by [43] identifies obstacle distance from the user with

69.4% accuracy. In the work by [131], the system consists of ultrasonic sensor attached towards the knee of the user. The system is able to detect towards knee obstacles with 98.3% accuracy but the system is unable to detect towards head level obstacles. In another work by [61], the system consists of multiple US sensors and a camera for obstacle detection. It achieves accuracy of 97.05% with 140$ cost. Our system in comparison cost 32.2$ and the accuracy doesn't deviates with different lightning conditions. In the work by [132] and [133] the US sensors for detection of obstacles are placed in a walking cane, thus making it difficult to detect head level obstacles and even if the cane is oriented upwards, it would be difficult for the user to do this exercise continuously. In another similar work [134], the US sensor are attached to the shoe for obstacle detection. Thus making it impossible to detect head level obstacles in anyway.

Table 5.3: Combined Detection Results

Detection Test		Achieved detection rate (%)		False positive rate (%)	
			Average		Average
Laterality	L0	75	70.5	13.12	7.38
	L1	70		9.4	
	L2	65		9.4	
	L3	72.5		3.12	
	L4	70		1.86	
Elevation	V0	80	70.5	13.12	7.37
	V1	75		10.62	
	V2	72.5		8.75	
	V3	65		1.88	
	V4	60		2.5	
Depth	D0	77.5	80.8	5	9.58
	D1	80		15	
	D2	85		8.75	

5.5.2 Power Analysis

The power analysis of our proposed system and a typical vision based system is shown in Table 5.4. It can be seen that the power requirement by our proposed system is around 25 times less than that of the vision based system. With such a lesser battery consumption our proposed system is expected to run for much longer amount of time and requires less frequent power recharge.

Table 5.4: System Power Consumption

Our Proposed System				
	Component	Current requirement (mA)	Quantity	Total power consumption (mA)
	Microcontroller (Arduino Nano)	16	1	16
	Ultrasonic Sensors (HC SR 04)	7	2	14
	Feedback System (Buzzer)	5	2	10
Total power requirement				**40**

Vision Based System				
	Microcontroller (Raspberry Pi 4)	600	1	600
	Camera System (Raspberry Pi 4)	420	1	420
	Feedback System (Buzzer)	5	2	10
Total power requirement				**1030**

5.5.2 Cost Analysis

The cost analysis for our proposed system and a typical vision based system is shown in Table 5.5. The cost of a single prototype comes out to be around 30USD which is when mass manufactured shall come down significantly making it affordable to the real user. This cost is hard to achieve if a camera based approach for obstacle detection has been employed which is almost four times than our proposed system. Though the downside is the camera-based system is more capable of classifying different obstacle types.

Table 5.5. System Cost Analysis

Our Proposed System				
	Component	Unit Cost (USD)	Quantity	Total Cost (USD)
	Microcontroller (Arduino Nano)	8	1	8
	Ultrasonic Sensors (HC SR 04)	5	2	10
	Feedback System (Buzzer)	0.6	2	1.2
Total cost requirement				**19.2**

Vision Based System				
	Microcontroller (Raspberry Pi 4)	90	1	90
	Camera System (Raspberry Pi 4)	24	1	24
	Feedback System (Buzzer)	5	2	10
Total cost requirement				**124**

5.6 Summary

The chapter addresses the problem of head injury faced by the VI persons while navigating through their environment. The solution is provided in the form of an eyeglass based device which consisted of two US sensors for obstacle detection and two buzzers for conveying the location of the obstacle to the user. The intensity of sound at the left and right buzzer is modulated according to the location and distance of the obstacle with respect to the device. The device is tested for laterality, elevation and depth detection. The results are presented in the form of tables and confusion matrix. On comparing our work with the state of the art available results, it can be seen that our technique performs better than them.

Currently, the elevation assessment about the obstacle needs the user to move the head vertically, which can be a challenge for the VI persons to learn in the initial usage of the system. In future works it is aimed to design and develop a system to find elevation where the head movement is reduced or removed altogether.

With the obtained accuracy our system demonstrates the proof of concept of the methodology proposed. Certain components like battery can be replaced with lithium polymer type in order to miniaturize the size of the overall system and a finished product can be obtained.

In the next and final chapter, all the work which is discussed so far have been concluded. The section also discusses limitations of the present work and the future scope available.

6 Conclusion and Future Scope

The work in this thesis report try to solve few problems faced by the Visually Impaired persons. The most important being travelling through their environment daily. The different types of aids currently available for them are discussed in the form of Orientation and Mobility training, Travel Dogs and various mobile applications, which helps VI persons to travel from one place to another. The electronic travel aids commonly known as ETAs uses various kinds of sensors to scan the environment for different kinds of obstacles. The ETAs also employs various tactile or vibration or audio means to convey the information about the obstacle sensed to the user. The state of the art methodology employed by various researchers for the detection of obstacles are discussed in detail. Few of the researchers have employed computer vision based methods, which is found to be out of reach to VI persons as most of them belongs to low income settings. Thus in this work the primary method for obstacle detection is Ultrasonic sensor based for the detection of obstacles on the ground surface like potholes and bumps by developing Assistive cane, on the head level by developing eyeglasses and the problem of unavailability of reliable dataset for obstacle detection with US sensor is also discussed. Thus the work is divided into three parts, first being addressing the problem of unavailability of reliable dataset, second the problem of finding obstacles on the road surface and finally detecting head level obstacles.

The current approach employed by most of the researchers in evaluating their assistive device is by placing different types of obstacles on the experimental route, traversing through it and then counting the number of times the obstacles are detected by their proposed assistive device. To extend the work of earlier researchers it would be a challenge to repeat this scenario. To address this we provided a framework for generating obstacle data by the ultrasonic sensors while travelling with the obstacles in the path. A model is presented which encapsulates the real world settings taking into account some assumptions and constraints. To generate the data on the basis of the model, simulations are also presented which can output the obstacle data with implementation in any programming language. In order to validate the model and the simulated data, a field study is also conducted which consisted of the same experimental settings as proposed in the model. On the basis of various measures as standard deviation, false positive rate, accuracy, our model came out to be consistent with the actual field experiments. For the purpose of benchmarking three different obstacle type classification method namely histogram, quadratic curve and cluster based are also developed. The accuracy of these methods are found to be 86%, 87.5% and 92% for detecting NO types obstacles respectively. For detecting large obstacles, the histogram method outperforms all the other methods.

The problems faced by Visually Impaired persons are many. The most important of them are travelling through unknown terrain having obstacles of different sizes. The white cane currently used by them is unable to detect potholes and bumps as well as obstacles, which are above of waist height. This problem is addressed with the developed assistive cane which can detect potholes and bumps on the road surface. The algorithm for the detection of road surface obstacles involves dual ultrasonic sensor based strategy. The algorithm employing the dual US sensor based strategy is also provided. The feedback system for alarming the user about the obstacles in the form of vibration sensor matrix is also considered in the work. The various designed vibration patters are used to alarm the user about the different types of obstacles. An alignment sensor switch is also developed which helps in detecting the orientation of the assistive cane and thus helps avoid false alarms. The ASS is found to reduce the false rate by 3 times in average run of 20 minutes of usage. The problem of finding the orientation of the assistive cane is completely missing in most of the similar work in the literature. An obstacle assessment score on the basis of the severity of danger by the obstacle, is presented to compare the effectiveness of the proposed cane with the traditionally used white cane. The obstacle assessment score assigns more weightage for the risky obstacles for e.g. potholes and walks in comparison to the less risky obstacles for e.g. speed breaker. An experimental route which consists of various types of obstacles like four wheeler, stairs, potholes are also presented in the work. Our assistive cane achieved 24.88% higher score on this measure. On comparing with the work reported in the literature our developed assistive cane is much more ergonomic as it does not carry additional heavy equipment as is used by other researchers. On conducting the system's training performance, the developed assistive cane is found to be taking 5 seconds lesser in comparison to white cane from the 5th journey onwards. The system cost analysis found the developed system to be costing 47.6 dollar on average for the prototype cost.

To avoid head level injury to the Visually Impaired persons, an ultrasonic sensor driven obstacle detection and localization system in the form of eyeglass is presented. The system hosts two ultrasonic sensors at the left and right side. The combination of the two US sensors helps in locating the obstacle. The algorithm for the same is presented with the help of detailed flowchart. 3-D localization information about the obstacle to the user, is conveyed in the form of different ultrasonic sensor frequencies. The corresponding information is provided in the form of suitable tables which maps various obstacle type to the different audible frequencies, To test the performance of the developed system, various tests for laterality, elevation and depth is constructed. The test consists of placing the obstacles at various places and then asking the user about the location of the obstacle after hearing to various audible feedbacks. The system upon experimentation found to detect obstacles laterally with 70.5% accuracy while the obstacles presented vertically are also detected with 70.5% and the depth of the obstacles are detected with 80.8% accuracy. The power and cost analysis of the developed system in comparison to the vison based system is also performed which found that the developed system costs 32.2 USD in comparison to 137 USD based on vision based and 40mA in comparison to 1030mA based on vision based system. The power and cost analysis clearly highlights the better performance of US sensor based system in comparison to vision based system.

The current setting of holding the cane by the test subjects in the proposed model which works for developing simulations for generating obstacle data, is considered to firmly holding the cane, while in real world the cane is subjected to continuous change in orientation of the cane. This constraint needs to be taken up in future work. The example solution approach can consists of accelerometer which keeps track of the orientation of the cane. The accelerometer are excellent sensors for finding the relative change in the orientation of the sensor. However, there is a problem of finding the absolute orientation of the sensor which is again missed by the accelerometers. Thus a more appropriate sensing scheme should take into account the problem of finding the absolute orientation and not only relative orientation.

The developed assistive cane is tested with the subjects having normal vision and blind folding their eyes. To get more realistic results and feedback, the system in future should be tested on actual visually impaired persons. The VI persons will not only result in more appropriate results but also useful feedback from them. This will also include the ergonomic aspects from the desired system. The battery charging and consumption issue may be one of them. Another may be the mode of feedback by the system. The audible based feedback may not be desired as it may confuse the VI users and also attract unnecessary attention by the passerby. On the other hand, the touch and vibration feedback may address these drawbacks but they may introduces additional complexity to be handled by the VI users. Moreover, it should be noted that the reason for the success of acceptability of white cane is its ease of usage and requiring very less usage training.

Currently, the elevation assessment about the obstacle in the eyeglasses developed needs the user to move the head vertically, which can be a challenge for the VI persons to learn in the initial usage of the system. In future work, it is aimed to design and develop a system to find elevation where the head movement is reduced or removed altogether. The solution approach may involve employing additional US sensors which can together provides both laterality and elevation information to the user. However, it should also be taken into consideration that the more there are US sensors working together, the more is the problem of crosstalk to be taken care of. This additional problem may be addressed with the help of specially designed algorithms which assigns unique signature to different US sensor such that the sensor processes only the reflected US pulse which have been sent by itself only. There is one more additional issue of simplicity of usage by the end users. If more sensors are employed, the more types of feedback pattern will also be required to be designed.

All the different types of limitations existing in current systems and the provided solution approaches once addressed is the most probable solution system for the VI users. And while developing such solutions the cost and power consumption should also be taken care of. And finally the last but not the least, the end user acceptance test is the most critical to get the acceptance by the VI person to bring the research on the developed assistive system prototype to the actual industrial grade ETAs to serve for the Visually Impaired peoples community.

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Patent

1. Singh, Bhupendra., and Monit Kapoor. (2018). Walking Aid for Uneven Surface detection and Obstacle avoidance for Visually Impaired Person. Application number 201811038118A

Journals

1. Singh, Bhupendra, and Monit Kapoor. "A Framework for the Generation of Obstacle Data for the Study of Obstacle Detection by Ultrasonic Sensors." IEEE Sensors Journal 21.7 (2021): 9475-9483.
2. Singh, Bhupendra, and Monit Kapoor. "Assistive cane for visually impaired persons for uneven surface detection with orientation restraint sensing." Sensor Review 40.6 (2020).687-698
3. Singh, Bhupendra, and Monit Kapoor ”An Ultra sonic sensors driven obstacle detection system with 3D obstacle localization.”
   Under Revision in Journal of Circuits, Systems and Computers. Dated 22 May 2021

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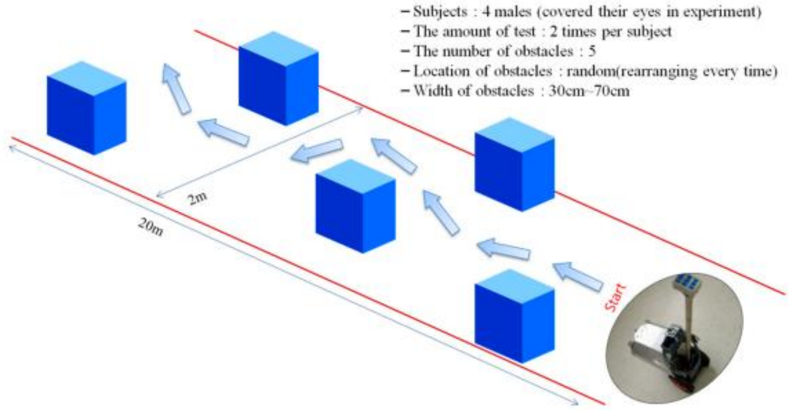
1. Singh, Bhupendra, and Monit Kapoor. "A survey of current aids for visually impaired persons." 2018 3rd International Conference on Internet of things: Smart Innovation and Usages (iot-siu). IEEE, 2018.

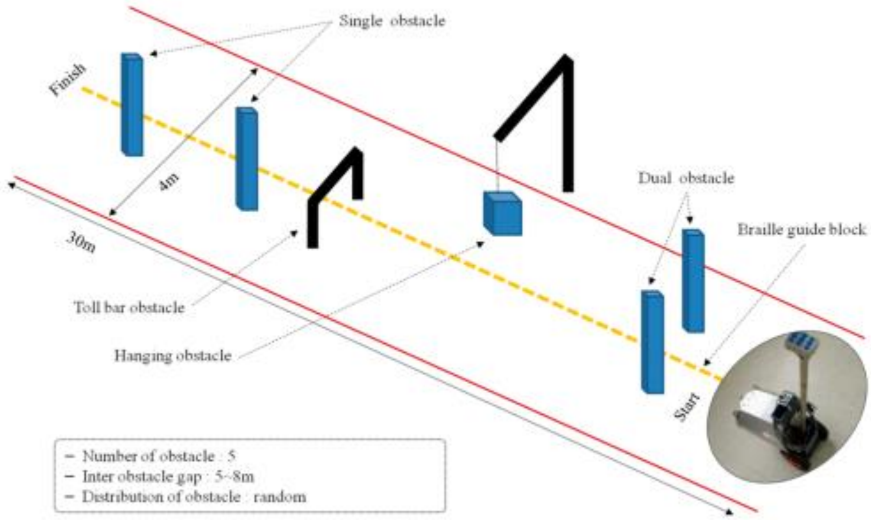
Annexure I

Experimental Path as designed by [25]



Environmental Set up for the first walking test [25]

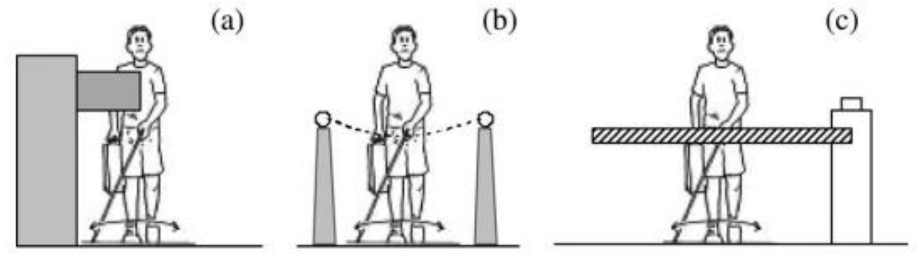
Annexure II



Environmental Setup for the third walking test [25]

Annexure III

Experimental Setup by [31]

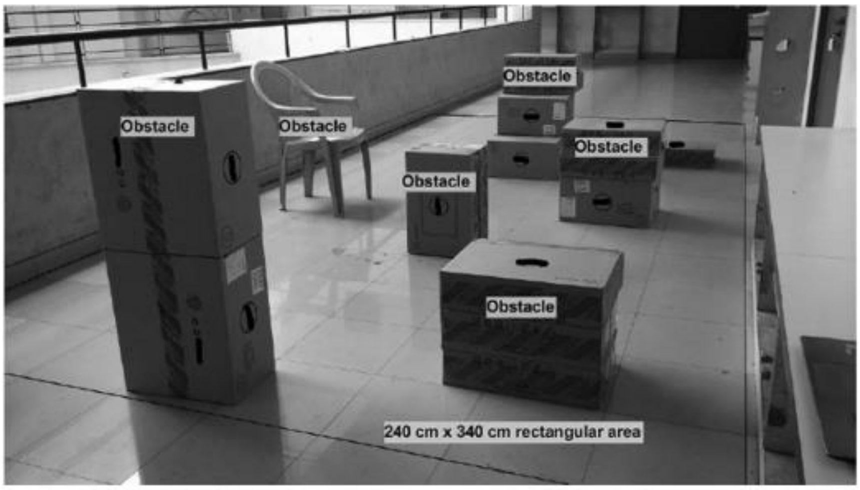


Examples of obstacles for VI mobility not detectable by the cane

a) An open drawer b) A horizontal chain and c) a car parking barrier [31]

Annexure IV

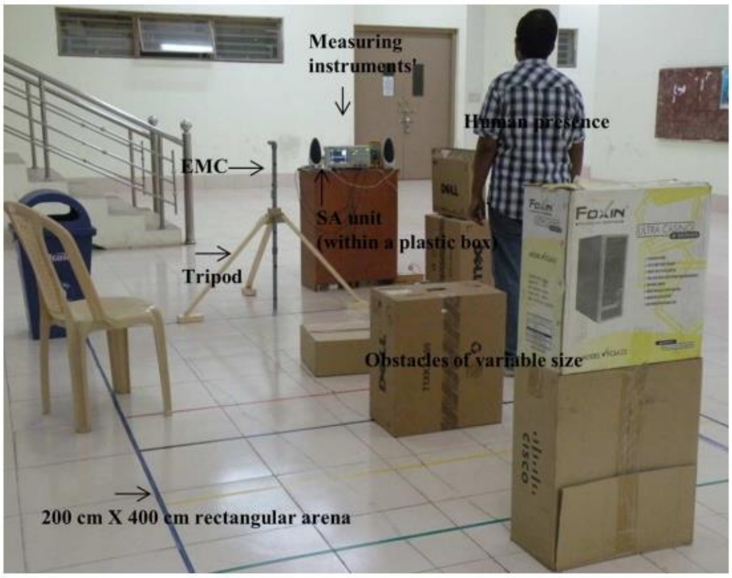
Experimental path setup by [30]



Experimental setup for indoor environment with obstacle at random places [30]

Annexure V

Experimental path setup by [29]



Experimental assessment of the electronic mobility cane. [29]

Annexure VI

Publication 1 [4]

A Survey of Current Aids for Visually Impaired Persons

Bhupendra Singh
School of Computer Science and Engineering
University of Petroleum and Energy Studies, Dehradun, India
bhupendra.singh@ddn.upes.ac.in

Monit Kapoor
School of Computer Science and Engineering
University of Petroleum and Energy Studies, Dehradun, India
monit.kapoor@ddn.upes.ac.in

Abstract— The lost ability of our eyes to perceive visual information leads to the state of Visual Impairment. Among many challenges of day to day activity faced, is navigation through the environment safely. To assist Visual Impaired persons a number of aids ranging from specialized trainings, GPS devices, Electronic Travel Aids, are currently available. In this work, these aids are surveyed and discussed. In particular, recent advancements in the development of Electronic Travel Aids(ETA) are discussed in detail. The role of ergonomic factors for the success of ETA devices is also stressed and discussed. With the advancement in sensor technology these ETA devices hold much potential. With this work, an insight into these developments will be gained to motivate future course of work to overcome existing drawbacks and include new cutting edge sensor technology for the betterment of the tools available for Visual Impaired persons.

Index Terms—Electronic Travel Aids, GPS for VI, Microcontroller, Sensors, Visual Impairment, White Cane

I. INTRODUCTION

Our eyes are one of the most essential parts of our bodyand play an important role in describing and perceiving theworld around us. In simple definition, Visual Impairment canbe defined as the decreased ability of eyes to see upto thatlevel which cannot be fixed with the application of glasses. Interms of visual acuity which is known as clarity of vision, andmeasured with the help of psychophysical test, a normal personhas visual acuity of 6/6. But in case of visual impairment, itcan be worse up to 20/40 or 20/60. The term blindness refersto the case where there is completely loss of vision throughthe eyes.With the loss of vision, a person is unable to scan environmentand perform his daily activities like navigating and locatingnear objects. A visual impaired person is more prone to injurywhen navigating in an unknown environment.

The major cause of visual impairment is attributed to uncorrected refractive errors in 43% cases and un-operatedcataract in 33% cases [1]. Refractive errors include myopiaor shortsightedness, when light focuses in front of the retinainstead of on it and hyperopia or astigmatism, when lightfocusses behind the retina instead on it. Cataract is clouding ofthe eyes lenses which blocks or changes the passage of lightnecessary for vision.

As per fact sheet provided by WHO [1], August 2014

- 285 million people are approximated to be visually impaired worldwide. With 39 million are blind and 246million having low vision.
- About 90% visually impaired of the world lives in lowincome settings.
- 82% of blind people are aged 50 and above.
- 80% cases of visual impairment are preventable or curable.

As the last point suggests, in more than half of the cases visualimpairment can be avoidable. Screening and early treatmentplays vital role in this regard. However lack of awarenessand education, sits as a barrier for covering these services.

Thankfully, WHO factsheet also suggests that over the last 20years, there has been reduction in the reporting of new caseswhich can be attributed to government established nationalprograms, increase in eye care institutions availability, schoolbased campaigns to educate and aware children about visualfunction importance.

The rest of the paper is organized as:- Current Aids for Visual Impaired persons are discussed next, then the working of ETAsystem is described, next review of research on ETA devicesis discussed and finally conclusion is presented.

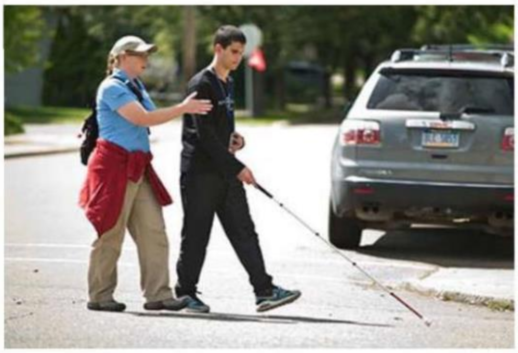


Fig. 1. White Cane training IC: leaderdog.org

2.2 Current Aids for Visually Impaired persons

A. Orientation and Mobility Training

The World War II can be attributed to the development ofa new discipline known as Orientation and Mobility Training.Richard E. Hoover, Russel Williams and C. Warren Bledsoein order to treat the blind army personnel, collaborated significantly to the development of this profession [2]. Thesetraining institutes are distributed around the globe and provide
VI person instructions for

- Commuting through their environment in safe and effective manner.
- Sensory development and maximizing all of the sensesfor better understanding of the place where one is.
- Use of white cane for safe and efficient walking.
- Learning to cross streets and examining traffic.
- Using public transport system

B. White Cane
A White cane is a long, light weight rod like device used byVI persons to give them information about their environmentin which they are travelling through. The white cane helpsthem to accomplish their daily tasks such as going throughstairs, escalators, finding doorways, finding dropped objects,and more importantly avoiding obstacles in their path.
How white cane is used? [3]
To start, the user holds the cane from the handle upto the levelof their waist in such a way that his/ her index finger pointsalong the cane shaft pointing towards the cane tip, which isat the other end of the cane and touches the ground. Whenthe user starts walking, the cane is swept from left to right toform an arc of the size of the width of the person. This wayif there is any obstacle or hole on the path, the tip of the caneencounters it first. This helps them get quick time to avoid theobstacle and take appropriate action.

C. Travel Dog
The guide dog is another mobility aid which helps VIpersons to travel safely around obstacles and crowded places.These dogs are specially trained for these purposes. However,it should not be assumed that these dogs guides the personwhere to go, or when it is safe to cross road. As the dogsonly guides though obstacles and need commands from theperson.
There are few things which come while considering buyingdog guides for the VI persons

- High Cost: These dogs don't come cheap and also havehigh maintenance cost for their food, grooming and dailyexercise.
- Constant Practice: These dogs must perform mobilitytasks everyday otherwise they will lose their mobilityskills.

D. Global Positioning System for the Visually Impaired Persons
There are a number of commercial software applicationsand standalone devices in order to assist VI persons for travelpurposes. For example

1) Android based:

a) Corsair GPS: This application helps in findingplaces around and getting there. It uses the vibration of the smartphone for the directions to follow.
b) Cydalion: It is a navigation aid for users havingTango (Augmented Reality computing platform)enabled devices. It can detect objects and theirheights and provides custom sound for feedback.

2) iOS based:

a) Ariadne GPS: It was released in June 2011 andwas one of the first applications to be designed forVI persons. It offers several features:-
   1. Information about the location whenever requested by the user.
   2. Saving the locations as desired by the person and alerts them whenever they are approached.
   3. User can slide over the map on the deviceand the application informs the user about thelocation.
b) Blindsquare: This application offers a wider rangeoffeatures for the VI users. Examples include:-
   1. Announcement of public point of interest.
   2. Sending coordinates of destinations to others.
   3. Audio menu as user interface.
   4. Simulation of places, helping user know aboutthe distant places before actually travellingthem.

3) Standalone Devices:

a) Trekker: The portable device having weight 600gwas launched on March 2003 and offers featureslike talking maps and talking menus. It also provides search functions for public point of interestfor example restaurant, ATMs, hotels etc.
b) BrailleNote GPS: The device was launched in2002 and uses satellite to triangulate and find userlocation on map. It provides the location to the userin the form of spoken information through speechsynthesizer

2.3 Electronic Travel Aids (ETAs) for Visually Impaired Persons
These are the electronic devices which perceive the information about the person's environment with the help of sensorsand convey the sensed information to the person throughanother sensory means. They usually consist of three parts.

A. Sensing System
First, information is gathered about the environment throughdifferent kinds of sensors, there details are described below.
a. Computer Vision: To enable depth information, the technique of stereo vision is used. In this, image of the samescene is captured from two cameras situated at differentplaces. The two images captured simultaneously, are matchedfor similarities and differences and with the help of thisinformation, a 3-dimensional scene is created.
b. Ultrasonic Sensors (US): Ultrasonic sensors work on the ultrasonic waves having frequency more than 20kz. The audiblefrequency for human ear is 2 to 20Kz. These sensors haveapplication areas in ultrasonic flaw detection in industries,communication, vehicle navigation and robotics. In

robotics,they are used very extensively for ranging measurements.

For an autonomous robot to freely roam around, collisionavoidance with the environment is one of the basic concerns.

Working Principle: The ultrasonic sensor has two transducersone for transmitting ultrasonic pulse. If there is any solidobject in front, the transmitted US pulse are reflected back.The incoming waves are detected by the other transducer ofthe sensor module. The time taken by the pulse to come backis known as time of flight (TOF). The distance of the objectcan then be calculated as

$$\text{Distance} = TOF * \text{velocity of sound in air} \quad (1)$$

c. Laser: The term laser is acronym for Light Amplification byStimulated Emission of radiation and works on the principleof optical amplification of narrow guided light. To determinethe distance from the laser device, a narrow beam of light isemitted towards the target and the reflected beam is sensed bythe system. The time taken by the travelled beam is measured,and thus with the help of equation 1, distance is calculated.The advantage of laser over ultrasonic sensor is the long rangeof distance it can measure.

B. Processing System

The sensors and the input/output devices need to be derived through software controls in the form of programming.Currently, there are a number of embedded systems availablein the market, below is the details of two very popular one.

C. Feedback System

a. Auditory: These are headphone based devices attached tothe ears. In order to guide the user about the environment, arecorded audio message is played.

b. Vibrato tactile: In this case, a number of mechanical motorsare attached to the body of the user and the intensity of thesemotors is adjusted, corresponding to the type of informationto be conveyed to the user. The body part includes head, chestor hands.

c. Electro tactile: In this case, an array of electrodes is attached to the skin and a small, controlled current is appliedthrough them to the user in a suitable pattern. The idea is tomimic the input that would normally be perceived by the userthrough their functioning eyes.

IV. REVIEW OF RESEARCH ON ETA DEVICES

There is good deal work reported in the literature for theETA devices to assist VI persons. These works can be categorized into three categories: computer vision based devices,ultrasound based devices, and hybrid devices employing bothcomputer vision and ultrasonic waves. In addition, other workswith the help of smartphone are also discussed in this section.Dimitrios and Nikolaos [4], surveyed 17 wearable obstacleavoidance devices for VI persons. The systems are categorizedinto ETAs, position locator devices (PLDs) and electronicorientation aids (EOAs). Then qualitatively and quantitativelycomparison of these devices on the basis of 14 features and performance parameters is done. Finally, each device is scoredon the basis of these 14 features and ranked accordingly. Thefeatures of the study are listed in Table I.In the work of Mun-Cheon Kang et al. [5], monocular visioncamera is used to detect the obstacles and presented the screeninto grids of pixels at equi distance. Their idea is that, as thecamera is closer to the object the magnitudes of the motion ofthe object pixels will also increase. Similarly, when the objectmoves away from the camera or out of view of the camera, themagnitude of the motion of the object pixels also decreases.A new structure called deformable grid is also devised whichchanges its shape as per the motion of the object. The systemalso detects object which are at the risk of collision by usingextent of deformation of the deformable grid. Theperformanceof the system is tested on the parameters of true positive,true false positive rate and processing time. To compare thework with others, comparisons are drawn with four methodsnamely Optical flow based method, homographic transformbased method, Delaunay triangulation based methods and DT2methods. In another work by Aravinda S. Rao et al. [6],a method is proposed which exploits emitted laser patternand analyzing the returned pattern with the help of Houghtransform and computer vision algorithm to detect unevensurfaces and potholes. The accuracy is reported to be morethan 90%. Few authors have also exploited the camera andprocessing capability of smartphone to devise methods toaid VI persons. One such work is by Pablo Vera et al [7],in which a laser together with smart phone camera is usedto develop a virtual white cane which can calculate thedistance of the obstacles in front of the system. The ideais to capture the reflected laser beam from the smartphonecamera and note the time it took, and then calculating thedistance using the technique of active triangulation. To alertthe user, a personalized vibration, of the magnitude relative todistance is generated through smartphone. In another work byChalittaKhampachua et al. [8], a system is designed to connectsmartphone of the user and can be wearable on the wrist. Thedetection of the obstacle is performed using ultrasonic sensorsand accelerometer of the smartphone. Whenever the obstacle isfound, the user is alerted through both audio and haptic tactilefeedback from the smartphone. When a person is tested withthe combination of the system and the white cane, it took themless time than using only the white cane. Ultrasonic sensorhas been found effective in the detection of obstacles. Usingmulti sonar system, Sylvain Cardin et al. [9], developed thesystem for obstacle detection and to send feedback to the user,vibrotactile mechanism is used. The result is 50% reduction ofthe time to travel through a path having obstacles after only couple of minutes of training with the system. Multiple USstrategyis also exploited by Gu-Young Jeong and Kee-Ho Yu[10], where seven US sensors facing at different directions are attached to a mini robotic systems which can itself is attachable to the bottom of a cane. User is alerted through vibrotactile feedback mechanism. The system is tested on blind people in a realistic looking experimental set up consisting of box type object post or blocking rod, hanging object and crossing bars. A paper based on ergonomics is presented by Cheng- Lung Lee et al. [11] with the help of US sensor for object detection. A number of practical disadvantages of available systems are provided on the basis of ease of use, which is a primary requirement when it comes to real world use of the ETA devices. A description of the experimental set up (Fig 2) consisting of 30m long path with obstacles in the form of bicycle, chairs, overhanging cardboard boxes, shoe cabinets, shelves for the testing facility is also presented. To test the system finish time and collision frequency is used. After conduction of a number of tests, results are assessedwith one-ay ANOVA techniques.To improve the efficiency of the systemBogdan Mocanu etal. [12], have employed both US sensors and Computer Visionapproach. The idea is to exploit computer vision techniquesto identify both static and highly dynamic objects accuratelyexisting in a scene and alert the user about possible dangerthough acoustic feedback. In another work by Qing Lin andYoungjoon Han [13], a 2 D laser scanner is used along witha camera to produce three dimensional information aboutthe environment. Theidea is to detect low objects in nearfield with the laser and high object in the far field withthe help of computer vision. In another work by LorenzoScalise et al. [14], the effectiveness of EM wave isassessedand compared with the traditional US based sensors.

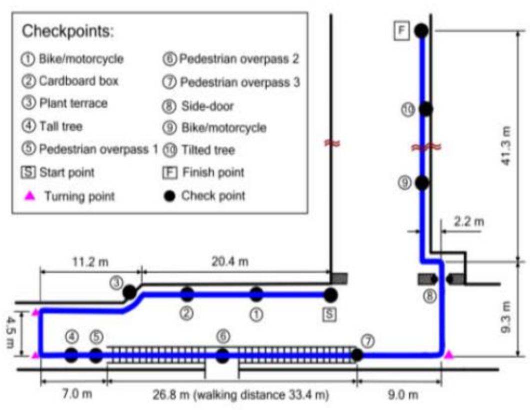


Fig. 2. Experimental Route [11]

Theresults are drawn based on precision, accuracy in detectingobstacle distance and the ability todetect specific obstaclessuch as plastic pole, open door. Results show that though theaccuracy of measuring distance with US sensor is superiorbut when it comes to detectingevery type of obstacles likeplastic pole, wooden door, after a certain angle, sensors basedon EM wave is superior. Moreover EM wave is also be usedunder garments reducing the stigma related to ETA use. Oneinteresting work not targeted for VI users is of importanceby De Jesus Oliveira et al. [15]. The objective of the work isto provide feedback to a user for reorientation in a virtual environment. A number of vibratory motors are placed at different places over the head as it is the most sensitive portion of the human body. To provide elevation information the frequency is used as modulating it upto 7 different levels using quadratic growth function. To test the system, experiments areconducted for five different elevation angles (45, 22.5, 0, -22.5,-45) and frequency is varied from 0 to 175Hz. The benefit oflow price, simple hardware interface together with small sizeof the US sensor comes with a drawback of cross talk, whenit comes to using more than one US sensor. Cross talk is aninterference issue when one US sensor unit detects the echopulse of another and computes the corresponding false TOF.The work of Luigi et al. [16] and Meng et al. [17] can bereferred for this purpose. They have purposed different pulseposition modulation technique for cross-talk minimization.

V. CONCLUSION

In this paper, the problem of Visual Impairment is introduced and brief related statistics are provided. In order toassist visual impaired persons, a number of currently availableaids are also provided which included specialized trainings,GPS devices, including mobile and handheld. ETAs, which usemodern electronics and sensors to guide and assist VI personsare also discussed in detail. The state of the art researchinsight in this regard is provided which included informationprocessing from camera, ultrasonic sensor, infrared and otherdevices. It is also highlighted the importance of ergonomicfactors from the perspective of visual impaired persons, toachieve maximum acceptance from them.

TABLE I
STRUCTURAL AND OPERATIONAL FEATURES OF ETAS [4]

S.No.	Features	Descriptions
F1	Real Time	The system operates fast enough so that the information exchange with the user is useful e.g. if an obstacle detection system needs 10 seconds to detect an obstacle that is 6 feet in front of the walking-user, then the device is not real time.
F2	Wearable	The device is worn on the user's body or as a piece of his clothing. Wearable devices are useful for applications that require computational support while the user's hands, voice, eyes, ears or attention are actively engaged with the physical environment. The interaction between the user and the device is constant. Another feature is the ability to multi-task: it is not necessary to stop what you are doing to use the device: it is augmented into all other actions.
F3	Portable	The device is light and small with an ergonomic shape so that the user can carry it without effort, for long distances and time.
F4	Reliable	The system functions correctly in routine but also in different hostile or/and unexpected circumstances.
F5	Low-cost	The device is (or it will be, when it comes to the massive production stage) affordable for most users.
F6	Friendly	The device is easy to learn, easy to use and encourages the user to regard the system as a positive help in getting the job done.
F7	Functionalities	The number and the importance of the system's functionalities.
F8	Simple	The complexity of both hardware and software is small. The hardware parts are few and simple to use (from the user's part) and simple to build (from the designer's part).
F9	Robust	The device is well constructed so it can resist in difficult environment conditions or in hard use. Its functionality varies minimally despite of disturbing factor influences. It can still function in the presence of partial failures.
F10	Wireless Connectivity	The device is connected wireless to a computer (server/database) in order to continuously exchange information. Additionally, part of the processing needed for its operation can be done on the remote computer.
F11	Performance	Overall performance.
F12	Originality	The idea and the methodology are original promoting scientific and technological knowledge.
F13	Availability	The system is implemented. A device that is ready to use and real-time experiments can be performed e.g. a system that is only in the software stage is not available.
F14	Future	Future improvements or enhancements.

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Annexure VII

Publication 2 [136]

Assistive cane for visually impaired persons for uneven surface detection with orientation restraint sensing

Bhupendra Singh and Monit Kapoor
School of Computer Science, University of Petroleum and Energy Studies, Dehradun, India

Abstract

Purpose – The reduced ability of eyes to see clearly even with the use of glasses is known as the state of visual impairment. Among the many challenges faced, outdoor travel is one of them requiring to travel through surfaces, which has potholes and bumps.

Design/methodology/approach – The depth of the pothole and height of the bump is also conveyed to the user through different vibration pattern of various intensity. With available electronic travel aids, the visually impaired persons are still more inclined to rely on their white cane than carrying additional equipment for obstacle avoidance. In the system, all the components can be attached to the white cane, requiring no additional device to carry.

Findings – Upon experimentation with different obstacle types, the system obtained a 24.88% higher score in comparison to normal walking cane. A comparison with the state of the art available systems is also provided.

Originality/value – Moreover, the accuracy of the assistive cane can be heavily degraded if the cane is not properly held by the user. To restrict the user to hold the cane in only required orientation an alignment sensing switch is also proposed, which is missing in the current available literature.

Keywords Body sensors, Acoustic

Paper type Research paper

1. Introduction

Our eyes play an important role in perceiving the environment around us. Visual Impairment (VI) in simple words can be defined as the inability of eyes to see up to a level, which cannot be fixed even with the application of glasses. Another term visual acuity is known as clarity of vision and is measurable with the help of a psycho-physical test; for a normal person, the visual acuity is 6/6. However, in the case of VI, it worsens up to 20/40 or 20/60. The term blindness refers to complete loss of vision through the eyes. With the diminished vision, a person is unable to scan the environment and perform his daily activities such as navigating and locating near objects. One of the most commonly used aid/tool by VI persons for navigation is a white cane.

The white cane is a long, slim, lightweight rod to get information about the environment through which the person is traveling. The white cane enables VI persons to perform their daily tasks such as ascending or descending through stairs, escalators, finding dropped objects, finding doorways and more importantly avoiding any obstacles present in their path.

1.1 Usage of white cane

First, the user has to hold the cane from the handle up-to-the height of their waist in such a way that the index finger points along the cane shaft pointing toward the cane tip, which is at the other end of the cane touching the ground. Upon walking, the cane is swept from left to right forming an arc of the size of the person's width. In this way, if there is an obstacle on the path, the tip of the cane has to encounter it first. Thus, helping to get a quick time to avoid the obstacle and take appropriate action. In our proposed system, we have experimented our method using a walking cane, but the same sensors and components can be attached to any white cane also, empowered the white cane with its usage very natural to its existing way. Though white cane plays a vital role for the commutation of VI persons, however, it suffers from a number of limitations such as its reach to detect obstacles, which are within its proximity or reach, which gives the user less time when any obstacle is encountered. This limits the moving speed of the user with the white cane. As the surface of the walkway may include potholes and bumps, traveling through them even with the white cane is prone to injury especially when navigating in an unknown environment.

The VI problem is mostly related to aging and as per UN report (UN, 2019), the pace of aging of the world population is accelerating. Hence, we need solutions for the needs of VI persons. Before presenting our work, we also want to highlight a few statistical figures about VI and blind persons.

As per the fact sheet provided by WHO (Who.int, 2019), August 2014, 285 million people are approximated to be VI

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worldwide. With 39 million are blind and 246 million having low vision. Again, about 90% visually impaired of the world lives in low-income settings. With 82% of blind people are aged 50 and above. Out of the total, 80% of cases of VI are preventable or curable.

The leading cause of VI is uncorrected refractive errors, cataract or age-related macular degeneration. An estimate (Velázquez, 2010) shows that the number of blind people may be double by 2020. The statistics also suggest the majority of the VI persons cannot afford high-cost travel aids.

On reviewing the related works by different researchers (more details in Section 2), we found that detecting bump and especially potholes are either not considered at all or up-to some limited extent and have focused on detecting obstacles, which are in front of the user ignoring the fact that walking on uneven surfaces, which consists of bumps and potholes may be extremely dangerous as they are hard to detect with a white cane. This may lead to serious injuries to the VI person. The presence of potholes and bumps on the surface is very common in developing countries. Thus, ignoring this issue do not appears to be rational. It can also be found that none of the research work considered the orientation of the proposed cane while the user walks with it. The orientation plays an important role as if the proposed cane is not oriented in a similar fashion as the real VI users the accuracy of the used sensors may decline undesirably, more on this is elaborated in Section 4.2. In our work, we have focused on detecting potholes and bumps with an algorithm discussed in detail in Section 4.4, to restrict the user to orient the proposed cane in the desired orientation, a novel alignment sensor switch is proposed by us in Section 3.7, which helps in reducing the false rate and restraining the orientation in the required range. Further, the performance of our system in comparison to the white cane is explored with the help of a score-based matrix discussed in Section 6. The results obtained with our proposed system is also compared with the state of the art results obtained by Sen *et al.* (2018), Bhatlawande *et al.* (2014) and Patil *et al.* (2018).

2. Related work

Though there are different types of aids available for VI persons such as travel dogs, GPS devices, we will focus here on electronic travel aids (ETAs). Our earlier work (Singh and Kapoor, 2018) discusses other travel aids in detail. The ETAs acquire the information around the user's environment through the help of sensors and convey the sensed information after processing to the user through another sensory means. A good deal of work is reported in the literature on ETA devices to assist VI persons, which will be discussed in this section now. Dimitrios Dakopoulos and Nikolas Bourbakis (2010), to rank available ETAs on the basis of their performance, surveyed 17 wearable obstacle avoidance devices. Based on 14 proposed features, performance parametrization is done and the devices are ranked accordingly. Similar review work is provided by Md Milon Islam *et al.* (2019) reviewing computer vision, embedded system and mobile phone-based frameworks for assisting visually impaired persons. The work by MunCheon Kang *et al.* (2015), uses a monocular vision camera for obstacle detection and the image formed is divided into grids of pixels of equidistance. This deformable grid changes shape on moving the camera closer or away. Thus, identifying if the obstacle is approaching or receding. Aravinda Rao *et al.* (2016) propose a method, which analyzes the received laser pattern of the emitted laser beam with the help of Hough transform and uses a computer vision algorithm for the detection of uneven surfaces and potholes. In another work by Noorjahan and Punitha (2019), uses computer vision techniques of segmentation and object recognition to help VI persons identify Public transport bus vehicle board recognition to help them travel. In the work by Ong *et al.* (2013), the effectiveness of Infrared sensors for obstacle detection is demonstrated. Few authors have also tested the capability of smartphones for obstacle detection or providing feedback to the user. One such work by Pablo Vera *et al.* (2014), uses a laser together with a smartphone camera, to calculate the distance of the obstacle in front of it. To alert the user, the smartphone provides different vibration patterns dependent upon the distance of the obstacle. Some have proposed wearable devices such as navbelt (Shoval *et al.*, 1998), waist-belt (Bhatlawande *et al.*, 2012) and electronic bracelet (Bhatlawande *et al.*, 2013) to assist VI persons for detecting low lying obstacles. An eyeglasses based on stereo vision system is proposed by Kai Lin *et al.* (2014) as an assistive device for visually impaired laser cane (Bolgiano and Meeks, 1967), Teletact (Farcy *et al.*, 2006) and Minitact (Villanueva and Farcy, 2011) are few examples of laser-based assistive devices. However, the laser has the drawback of not detecting transparent glass as its beam does not reflect on it. K sonar canes (Hersh and Johnson, 2010) can identify the floor and head level obstacles and conveys feedback to the user through modulating frequency pattern of sound. An example of a handheld obstacle recognition system is CyARM (Ito *et al.*, 2005).

Ultrasonic sensors are exploited a lot for obstacle avoidance purposes because of the low cost and ease of use. The work by Gu-Young Jeong and Kee-Ho Yu (2016), uses multiple ultrasonic sensors strategy. Seven ultrasonic sensors facing at different directions are fixed to a mini robot system, which itself has to be attached to the bottom of a cane. To improve the efficiency of the system, Bogdan Mocanu *et al.* (2016), uses ultrasonic sensors together with computer vision to identify both static and dynamic obstacles and alerts the user through acoustic feedback. Smart cane developed by M Balakrishnan *et al.* (2007) uses an ultrasonic sensor for the detection of knee above obstacles.

Three other works are of particular interest because they will be referred later to draw comparative analysis with our work are reviewed now. In the work by Arnesh Sen *et al.* (2018), three ultrasonic sensors are attached to the chest, knee and toe of the user to assess the obstacle in front of the user. In another work by Shripad Bhatlawande *et al.* (2014), six ultra-sonic sensors are attached to the walking cane to assess the obstacle heights. Similar work is carried out by Kailash Patil *et al.* (2018) developing a NavGuide shoe consisting of ultrasonic sensors and vibration motors to help assist VI persons about the nearby obstacles. The authors have also conducted a useful survey with 177 VI persons, in which 95.48% participants acknowledged the inadequate information is provided by the white cane in scanning information about the surroundings. In all, 90.3% participants preferred a portable and lightweight electronic aid and about 24% participants requested for a cost-effective

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system (less than US$20). This survey played a useful role as a user requirement in designing and developing our system.

In a significant work by Lorenzo Scalise *et al.* (2012), the effectiveness of EM wave for obstacle detection is assessed and compared with the traditionally used ultra-sonic pulse-based sensor approach. Their results suggest the accuracy of the ultrasonic sensor is superior in terms of measuring distance but the detection of every type of obstacle such as a wooden door, plastic pole after a certain angle is superior using EM wave. An interesting work, not originally targeted for VI users is of de Jesus Oliveira *et al.* (2017). The objective of the work is to provide feedback to the user for reorientation, in a virtual environment. A number of vibratory motors are placed over the head of a test subject and elevation information is provided by modulating vibration frequency up to seven different levels. To increase the effective measurable range of the Ultrasonic sensors, a method based on chaotic pulse-position is presented by Senugin Shin *et al.* (2018). Borenstein and Koren (1992) and Borenstei and Koren (1995) method also work for increased accuracy of ultrasonic sensors using the idea of comprising consecutive readings and comparing with alternating delays a technique called error eliminating rapid ultrasonic firing.

When it comes to using multiple US sensors together, the challenge of crosstalk comes into play. Cross talk is the interference phenomenon when the echo pulse of one sensor is received by another sensor resulting in false distance reading. However, to address the issue many different techniques have been proposed, for example, by Luigi Fortuna *et al.* (2003) and Meng *et al.* (2009).

3. Proposed system architecture

In this section, different components of the proposed system (Figure 2) are explained in detail.

3.1 Walking cane

In our work, we have used a low-cost walking cane of height 3 feet and installed all the required components on it, as shown in the real image of the system (Figure 1). The walking cane can be replaced by a white cane with all the components fixed to it, in a similar manner as our walking cane.

3.2 Ultrasonic sensors

Ultrasonic sensors usually consist of two transducers, through one transducer ultrasonic pulse (usually slightly above 20Kz) is sent, which after reflection from the obstacle in front of it, is received by the other transducer [Figure 3] (The audible frequency for the human ear is 2 to 20Kz, thus the ultrasonic pulse is not affected by the human voice or similarly human-audible sound waves). The total time taken by the pulse until it is received back by the other transducer is known as the time of flight (Figure 3). The distance is calculated as:

$$\text{Distance} = (T\,oF/2) * \text{speed\_of\_US\_pulse} \tag{1}$$

The speed of the pulse is assumed to be the same as the speed of sound (334 m/s).

Thus, the distance is then calculated as:

$$\text{Distance} = (T\,oF/2) * 334 \tag{2}$$

These sensors have applications in ultrasonic flaw detection in industries, communication, vehicle navigation and robotics. In robotics, they are used extensively for ranging measurements.

Figure 1 System actual image

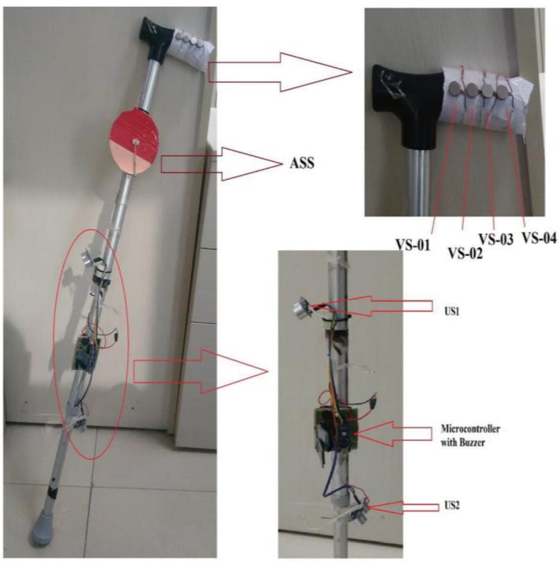


Figure 2 System architecture

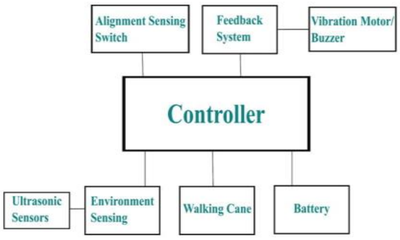
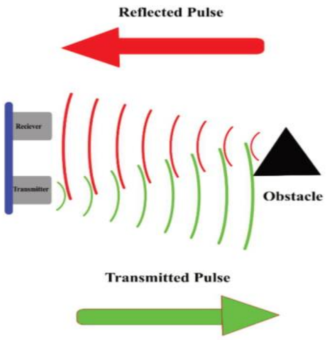


Figure 3 Ultrasonic sensor working



For an autonomous robot, to freely roam around, collision avoidance with the environment is one of the basic concerns. However, these US sensors are limited for the purpose of ranging, as the measured distance gets noisy with increasing the distance of the obstacles because of multiple reflections of the emitted US pulse with the surrounding environment as shown in Figure 4.

Because of their ultra-low-cost and easy to use feature over the camera or laser-based systems, we have used them for environment sensing purpose.

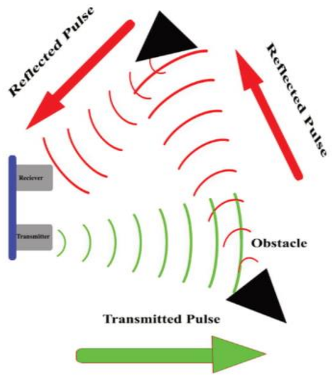
3.3 Controller

The microcontroller used for our system is Atmel At-mega328P. It is an 8-bit RISC-based AVR micro-controller having 32 kB ISP flash memory with read-while-write capabilities. It also has 1 KB EEPROM to store programs to run, 2 kB SRAM and 23 I/O pins, which can be used for general-purpose programming. It also has 32 registers for general purpose working, 3 flexible timers/counters, internal and external interrupts. The micro-controller works in a range of 5–12 volts. Programming can be done on the host machine in C like language. To transfer program after compilation from the host computer to the Atmega328P chip, a USB cable is used.

3.4 Buzzer

It is a device, which produces sound on providing input voltage. Thus, varying sound can be produced by modulating the input voltage. In our system, the buzzer is used to inform the user about the ON/Idle state of the system.

Figure 4 Noisy ultrasonic sensor reading



3.5 Vibration sensor

This tiny coin-shaped device produces vibration with intensity varying in response to varying voltage through the controller. To provide feedback about the detected obstacle, pothole or bump, different types of tactile vibration patterns are provided to the user. More on vibration pattern is covered in Section 4.6.

3.6 Power supply

To feed the power need of the controller and other sensors, a rechargeable Lithium Polymer battery is used. These are advantageous to Lithium-ion batteries in terms of small shape and lightweight.

3.7 Alignment sensing switch

A novel alignment sensing switch (ASS) is proposed, which helps to maintain the appropriate orientation for the cane. The ASS is attached to the white cane as shown in Figure 8. The switch has a disk with a needle in the middle of the disk and pointer, which can freely rotate over the circumference of the disk shape (same as clock dial but) under the force of gravity. Few regions of the circumference of the disk are coated with copper (Figure 5a). One wire is attached to the copper surface, while another wire is attached to the center end of the needle (Figure 5b). If the current is passed through one end of the wire, it will reach to the other wire's end only when the pointer of the needle is in contact with the metal-coated surface thus, closing the ASS and bringing it to ON state, otherwise bringing it to OFF state. The usage of the ASS will be covered in Section 4.2.

Additionally, to prevent any unnecessary false readings from the moving US sensors, as the VI persons walk with the cane. A Sensor holder 6, which attaches US sensor with the walking cane is designed and three-dimensional printed, so that the US sensors are firmly attached with the walking cane (Figure 6).

4. Pothole and bump detection

In this section, the method for detecting the desired obstacles is explained followed by the feedback patterns, provided by the system to the user and finally presenting core algorithm, driving

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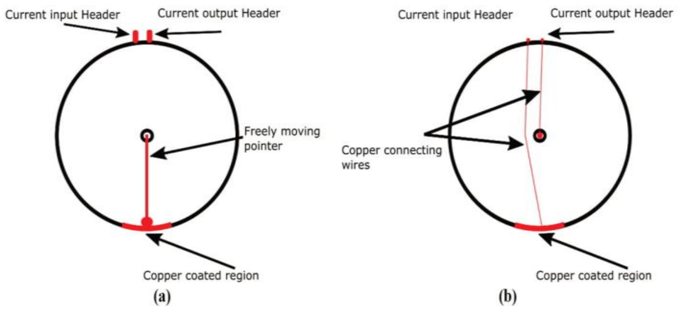
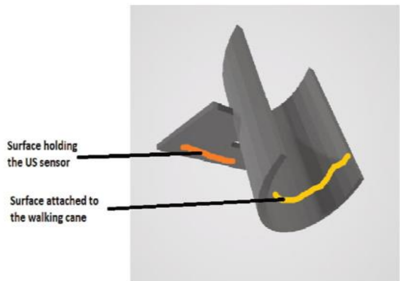
Figure 5 Alignment sensing switch



Notes: (a) Front; (b) Back

Figure 6 Sensor holder



different components and carrying out necessary decisions, system power requirements and cost analysis is also presented. The real working system is shown in Figure 1.

4.1 Environment sensing

A US sensor (US1) is attached to the front of the cane, which gathers obstacle information in front side of the user. While another US sensor (US2) is attached to the backside of the cane, both pointing downwards toward the surface Figure 1, US2 with the purpose of reducing false alarms as shown in Figure 1. The US1 keeps on reading distance and checks for pothole and bumps. When the pothole is encountered the successive readings of the US1 show an increase in measurements. Similarly, in the case of the bump, the successive readings show a decrease in measurements. The same is depicted in Figure 7 where the system starts reading distances at the time t and at time $t+$ T, it checks whether there is enough difference in successive distance readings $\frac{dD_{US1}}{dt}$. If so, it may be an indication of a pothole or bump.

There is also a possibility of the scenario where the user may lift the cane upwards or downwards resulting in false alarm of pothole and bump, respectively. To avoid this false alarm, US2 comes to aid. Both US1 and US2 shows the same trend of increase in the distance if the user moves the cane upwards. Similarly, both US1 and US2 shows a decrease in the distance if the cane is moved downwards. The algorithm, which follows in the next section captures these checks with Steps 6 and 8 and helps in avoiding false alarms. As the readings of the US sensor often gives an anomalous reading once in a while. Thus, the method for US sensor readings correction is also proposed in Subsection 4.3, which works on buckets of size 10 of consecutive readings to carry out decisions.

A limitation is set upon the minimum height of bump to be 10 cm and maximum as 30 cm. Similarly, the limitation on the depth of pothole is set to 10 cm up-to 20 cm.

4.2 Orientation challenge

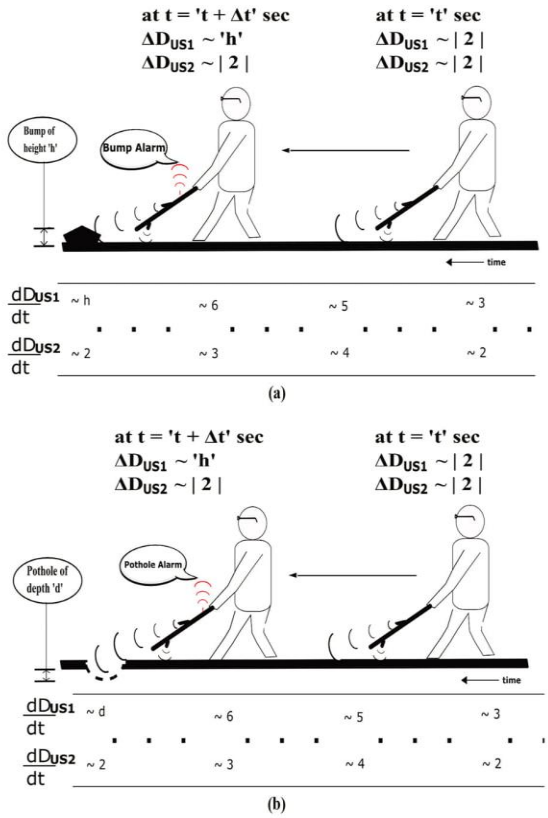
There is an issue with the discussed design and method, the orientation of the cane. It is very much possible for the user to hold and point the cane at a different orientation (Figure 8), thus correspondingly increasing or decreasing the subsequent distances measured by the US1 and US2. To enforce the restriction on the orientation of the cane, the usage of ASS comes into play. The ASS is enabled only when the pointer and the metal layer of the alignment sensor switch come in contact, which is the case when the cane is held at the required orientation as shown in Figure 8b. Thus, maintaining the required orientation of the white cane.

The ASS also acts as an On/Idle switch to the whole system. If the user needs the cane, as soon as the user holds it in the required orientation, the ASS completes the circuit and turning the whole system in a working state and the buzzer produces the corresponding tone. In another case, when the user halts or does not have to use the cane, and the cane is rested, it will be in another orientation opening up the ASS circuit, turning itself off and transiting the whole system to the idle state. Thus, the ASS user do not have to turn on or off the system, easing out the system usage comfort.

4.3 Ultrasonic sensor correction

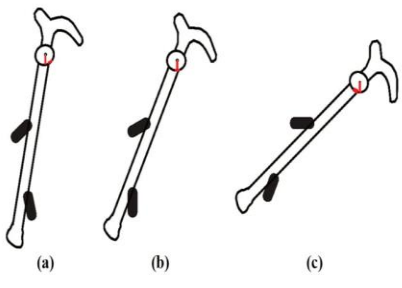
The ultrasonic sensor does not always provide ideal readings like the one shown in Figure 3, because the pulse sent by the sensor may be received back after multiple reflections through different objects in its environment as shown in Figure. To overcome this issue, a method is devised to discard the readings above 4 m as the readings in our set up are not expected to

Figure 7 System in action



Notes: (a) Bump detection; (b) pothole detection

Figure 8 (a) System "off", (b) System "on" and (c) System "off"



reach 4 m reading and using the average of four distances around median distances among 10 successive sensor readings. The control flow diagram shown in Figure 9 depicts in detail the steps involved.

Before starting the control flow diagram, we introduce the below notations. QuD, is the queue of size 10, to store distances read from the ultrasonic sensor. Once 10 readings are stored in the queue successively, the standard deviation of the stored readings are calculated. If the SD is more than the cutoff value of 5, it indicates noisy readings and all the readings in QuD are discarded. The process of storing the readings to the QuD is started again.

4.4 Uneven surface detection algorithm

We now discuss the uneven surface detection method, for detecting pothole and bumps. Few other obstacles such as four-wheeler, wall and speed breaker are categorized under bumps.

The method starts with checking for correct orientation in Step 1. Then, to correctly approximate the value of the actual distance of the surface from US1 denoted as D_a, continuous measurements of 1,000 readings are obtained and mode value is chosen to be Da. In Steps 6 and 8, readings from US1 and US2 are checked for the indication of false alarm. After the checks 20 continuous readings from US1 are processed with

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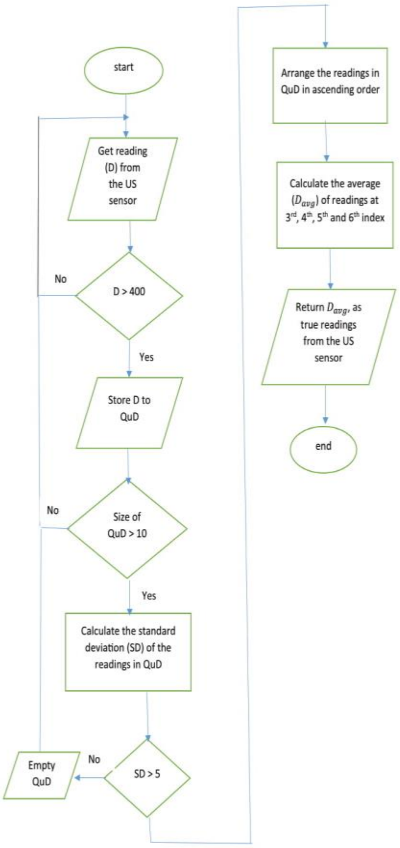
Figure 9 Control flow diagram for true reading



functions f_1 (n), f_2 (n) and f_3 (n) and the results are stored as sum_1, sum_2, sum_3, respectively. If the cane has encountered a pothole at least 12 out of 20 readings should satisfy the pothole condition (f_1 (n)). On the other hand, if the cane encounters a bump of height between 10 cm to 30 cm, at least 12 out of the 20 readings would qualify the condition of f_2 (n). Finally, if there are huge obstacles such as a four-wheeler, wall, at least 12 out of 20 readings would satisfy the condition of f_3 (n). The control flow diagram for the steps involved in the method is shown with Figure 10.

4.5 Feedback system

As the user picks the walking cane in the required orientation, the buzzer sends a sound signal, informing the user that the system is ready to be used and the whole system comes to a working state. The moment user orients the white cane moving to vertically downwards or moves it to a horizontal direction, which gets it oriented out of range of the ASS (as depicted by Figure 8), the buzzer produces an alarming sound to the user that the system is going to idle state. This way user does not have to take care of switching the system on and off. Feedback to the user about possible pothole or bump is provided with the usage of vibration sensors. The vibration sensor (vibrator) produces vibrations of different intensity levels depending upon the information to be conveyed to the user.

If there is a pothole detected by the system, the vibrator produces low-frequency vibrations with intensity depending upon the depth of the pothole as shown in Figure 11. Low intensity for low depth pothole and high-intensity vibrations for deep depth pothole detection.

If there is a bump detected by the system, the vibrator produces comparatively high-frequency sound with low in intensity for low height bump and high-intensity vibrations for high bump detection as shown in Figure 12.

For the case of larger obstacles such as wall and four-wheeler, the vibrator produces very high frequency intensity feed-back as shown in Figure 13. The intensity of vibration is directly proportional to the distance of the large obstacle from the user (Table 1).

The frequency of the vibrator is defined by the number of times the vibrations are produced in a given time. For example, Figure 11 shows a larger number of blocks than Figure 12 for the same amount of time duration.

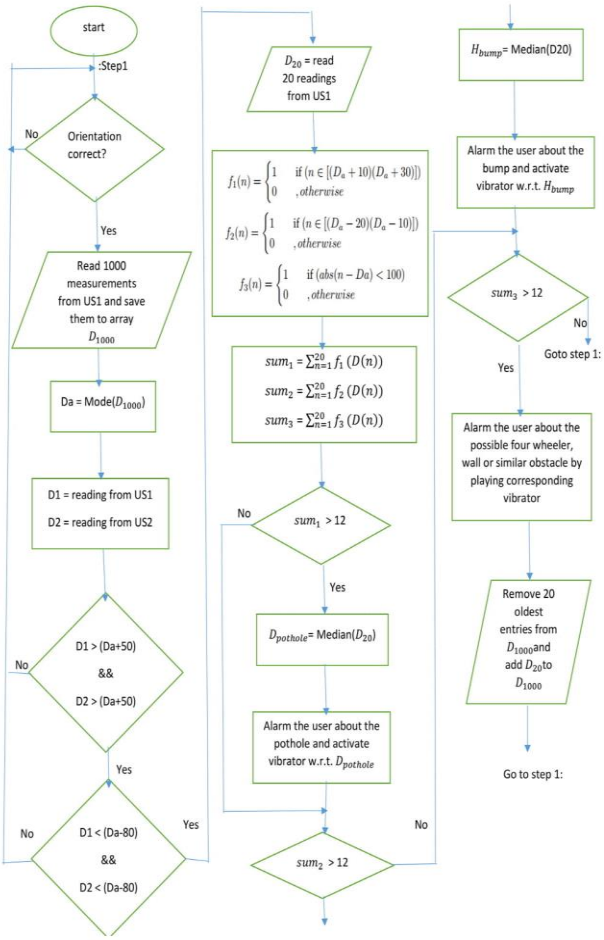
To provide ergonomic and more sensible feedback to the user a total of four vibration sensors are used, which are attached to the handle of the walking cane 1 b. The four vibrators are placed in vertical order [1], which defines the amount of depth of the pothole or the height of the bump. For example, if low height bump is detected, the vibrator with low height is activated. Similarly, if the depth of the pothole is not much, the vibrator placed high in vertical order is activated with a defined feedback pattern. The defined range of activation of different vibrators is shown in Table 1.

5. Experimental set up

To test the effectiveness of the system, an experimental route of a total length 200 m containing obstacles of different types were set up in the university campus. Two mounted stones in the form of a box of size 10 cm * 10 cm * 10 cm and 10 cm * 10 cm * 20 cm, two potholes of varying diameter one of diameter 10 cm with depth 10 cm and other with diameter 20 cm and depth 40 cm. A speed breaker, normally used for braking down speeding vehicles of dimension 20 cm height and 300 cm in length, two four-wheelers, hatchback type both of same model one facing front and other facing back is also used, and finally, wall-like structures one of height 80 cm and the other of height more than 200 cm is used. The experimental set up of the obstacles with their placements are represented diagrammatically in Figure 14.

With available resources, 40 undergraduate students were recruited as test subjects for the study with age 19–20, all men. To mimic VI persons all the test subjects were blindfolded by covering cloth around their eyes. The route is traversed by the subjects in five trips to check for improvement in the time required to traverse the same route by of the proposed system with increased usage. Further, the entire route is also covered in three conditions first, without using any type of aid by a normal person without blindfolding their eyes. Second, by blindfolding both eyes and using our system in OFF state as an assistive cane

Figure 10 Control flow diagram for pothole and bump detection



and third, blindfolding both eyes and traversing the path with the assistance of the proposed system. To avoid memorizing the path, the user is asked to move around and rotate several times while traversing the route. The users are also directed to walk left, right or straight whenever required, to stick them to the designed route. Training of 1 h is also undertaken before the start of actual experimentation, to acquaint the subjects with the proposed cane and traveling in the route, blindfolded.

6. Assessment score for obstacles

A total of five different obstacle types are incorporated in our study. The obstacles ranged from Mounted stones of different height to stationary four-wheeler. As these obstacles vary in importance, for example, a speed breaker is less harmful in comparison to mounted stones. Similarly, potholes of varying depth are dangerous as per their depth. There are also few obstacles such as stationary four-wheeler and walls, which can also be detected by the usage of the white cane itself, thus making usage of assistive systems unnecessary. To evaluate these different obstacle types with our system and draw inferences; a score-based approach is devised. In this approach, the obstacle, which is more dangerous is assigned higher weight as compared to the obstacle with lesser danger. A sum of 100 is divided among the different obstacle types used in our study. The details of these obstacles and their assigned score are

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Figure 11 Feedback for Pothole warning

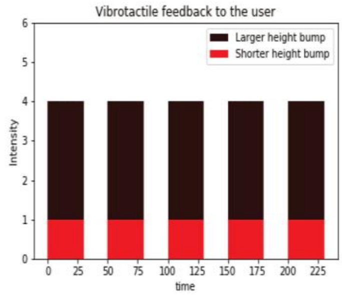


Figure 12 Feedback for bump warning

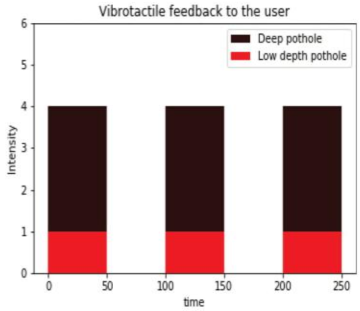
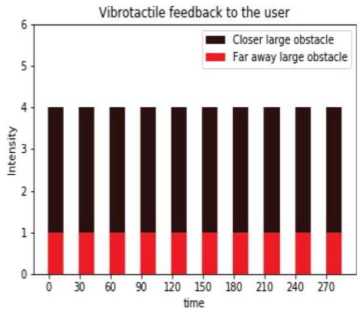


Figure 13 Feedback for large obstacle warning



shown in Table 2. Upon experimentation, if the proposed system is able to detect an obstacle, the corresponding assigned score is given to the system otherwise 0 is assigned if the system fails to detect the encountered obstacle.

7. Results and discussion

The system is tested inside the university campus with most obstacles placed at an uneven distance. The test subject is supported by a person walking just behind to avoid any injury on collision with the obstacles. If the test subject collides with the obstacle he is asked to take a few steps back and then turns left/right as per the designated route. Two scenarios are considered for the experiment. In the first, the blindfolded subjects walked with the stick in off state and moving it from left to right in an arc, the way white cane is used. In the second scenario, the stick is held firm by the test subject at an angle (the same actually used by the VI persons) without moving it while walking. Thus, a total of 40 trials (one for each subject) for both scenario i.e. walking with a normal cane and walking with our proposed system are available.

Table 1 Vibration sensor activation

S. No.	Vibration sensor	Pothole depth (in cm)	Bump height (in cm)
1	VS-01	<10	30–80
2	VS-02	10–20	20–30
3	VS-03	20–30	10–20
4	VS-04	30–80	<10

Figure 14 Experimental route

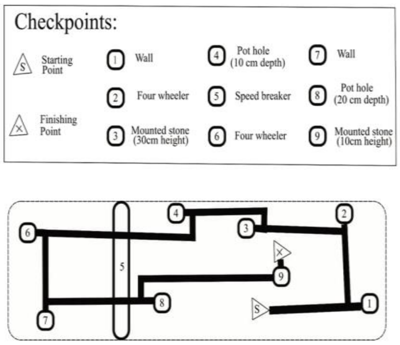


Table 2 Obstacle assessment score

S. No.	Obstacle type	Obstacle feature	Obstacle score
1	Mounted stones	Height (cm)	
		10	10
		30	20
2	Potholes	Diameter (cm)	
		10	10
		20	30
3	Speed breaker	Dimension	10
		20 cm height, 60 cm wide	
		Same attributes	
4	Four wheeler	Front facing	5
		Back facing	5
		Same attribute	
5	Wall	Wall 1	5
		Wall 2	5

The results of the subject's collision with obstacles obtained are shown in Table 3 (the obstacle detected by 40 trials are averaged and presented as 10 to obtain final score out of 1,000), which shows the number of times the obstacles are detected by our system in comparison to the normal cane. On comparing the results in terms of assigned assessment score, our system achieved 24.88% higher score, in comparison to normal cane or white cane. Obstacles types such as wall and four-wheeler have been detected by both the systems but potholes are detected better by our assistive cane.

On looking at the results in Table 4, it is quite clear that the strategy of using two US sensors at opposite directions to each other works considerably well. The pot-holes of diameter 10 cm are detected more than 6 times in comparison to normal cane

Table 3 Obstacle detection test

S. No.	Obstacle type	Obstacle feature	Obstacle detected (Averaged out of 10) Proposed cane	Normal cane
1	Mounted stones	Height (cm)		
		10	6.25	4.25
		30	7.5	7.75
2	Potholes	Diameter (cm)		
		10	6.5	1
		20	8.5	3.25
3	Speed breaker	Dimension		
		20 cm height 300 cm wide	5	4.25
		(Same attributes)		
4	Four wheeler	Front facing	9.25	9.5
		Back facing	9.5	7.5
	Wall	(Same attributes)		
5		Wall 1	10	10
		wall 2	10	9

Table 4 Achieved score

S. No.	Obstacle type	Obstacle feature	Achieved score Proposed cane	Normal cane
1	Mounted stones	Height (cm)		
		10	62.5	42.5
		30	150	155
2	Pot holes	Diameter (cm)		
		10	65	10
		20	255	97.5
3	Speed breaker	Dimension		
		20 cm height 300 cm wide	50	42.5
		(Same attributes)		
4	4 wheeler	Front facing	46.25	47.5
		Back facing	47.5	37.5
5	Wall	(Same attributes)		
		Wall 1	50	50
		Wall 2	50	45
		Final score (1,000)	776.25	527.5

whereas potholes of diameter 20 cm are detected 2 times in comparison to the white cane. The usage of the proposed ASS also effectively reduced the false rate as further discussed in Section 7.1. The proposed ASS also helps in orienting the cane in the desired orientation, which makes it easy for the VI persons as they do not have to concern about holding the cane inappropriately.

In comparing our work with similar work by Shripad Bhatlawande *et al.* (2014), they have attached the sensors to the walking cane itself without causing the user to carry additional equipment. The accuracy reported by them for bump like obstacles is 80% for blind persons in comparison to white cane with only 55% accuracy. In comparison, the accuracy of our system for detecting bump (mounted stones and speed breaker) is 65%, which is lower. However, they do not have devised any method for detecting potholes. This makes our system more functional. Moreover, their system has to be held straight upright at 90 with the floor to get consistent results, otherwise, the obstacles may be missed. However, practically walking with this constraint is very difficult without the person knowing if the orientation is correct if the usage time is very high. In our system, results are already presented with the cane oriented within the same range as being held while using white cane by the VI users. In addition, there is also a unique mechanism of keeping the check on the orientation with the help of novel ASS, which alarms the user if required, to keep the cane in the desired orientation. This significantly helps in achieving consistent results. Additionally, we have not used any complex audio feedback for the user to comprehend, thus the comparative travel time by our system is expected to be less.

In comparison to the work by Kailash Patil *et al.* (2018), they have used the same strategy of using multiple US sensors 3 of them facing front while three facing back and one to the left and one to the right, to get the complete obstacle presence detection. However, all these sensors are installed in a designed shoe, which poses an acceptance challenge from the VI persons as they need no additional equipment to carry at best.

In similar work by Arnesh Sen *et al.* (2018), the idea of attaching the sensors to the body of the user makes it less ergonomic and also not much acceptable by the user in practical conditions. In comparison, we have attached the sensors to the cane itself, which the VI persons already use for their travel purposes.

Thus, the comparison with the state of the art results demonstrates the efficacy of our system in providing unique functionality of detecting obstacles on the surfaces as well, thus avoiding any injury from potholes and bumps. The addition of the proposed ASS makes it easy for the users to walk with the cane in their usual fashion without any unnecessary concern of the orientation of the cane, which is completely missing in the literature. The proposed system architecture is also ergonomic in usage in the sense that all the proposed system components can be attached to the walking cane itself requiring the user to carry no additional equipment. While many researchers have proposed systems, which has to be additionally carried on by the user or wear in their body, making them less acceptable.

7.1 False rate reduction

In the trial runs, it was observed that the user moves the cane upwards or downwards 2–3 times in every single usage run of around 20 min. The two ultrasonic sensors approach by our system helps in detecting these situations and ignores these scenarios as being a false alarm. Similarly, the user orients the cane almost horizontally in 5–6 times in every single usage run of around 20 min. Here, the proposed ASS switch accurately detects these situations and alarms the user for possible orientation deviation, which needs to be maintained. Thus, on average for every 20 min usage of our cane, the system removes 7–9 false rate alarms. These two novel features help in reducing a considerable amount of false rates, which are not proposed by any reviewed system.

8. Conclusion

In this paper, the problems faced by VI persons are presented along with currently available ETAs. Our proposed method of detecting obstacles (potholes and bumps) is explained with the necessary details. Our work relied on the usage of ultra-sonic sensors and proposed an Alignment Sensor Switch to restrict the orientation of white cane when used by the user. The US sensor's noisy distance readings are also corrected with the described algorithm, for possible multiple reflection infused noise. Information about the potential obstacle is provided to the user by defining different vibrotactile feedback mechanism. All the emphasis of the work is based on unfaltering user's acquaintance of white cane. The effectiveness of the system is tested on the outdoor environment having different sizes of potholes and bumps. The results obtained after experiments show the effectiveness of our method. The results are assessed on the basis of an obstacle hazard score-based approach and compared with the similar works available in the literature. The effectiveness of ASS in reducing the false-positive rate is also discussed. Any future attempts in developing any assistive devices should focus on simple to use methods to get acceptance from the Visually Impaired user.

Note

1 Though the handle of the cane in standing position is horizontal, the working orientation of the cane is slightly titled and not exactly vertical or horizontal.

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Corresponding author

Bhupendra Singh can be contacted at: bhupendrabisht59@gmail.com

Annexure VIII

Publication 3 [135]

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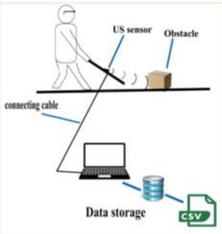
A Framework for the Generation of Obstacle Data for the Study of Obstacle Detection by Ultrasonic Sensors

Bhupendra Singh and Monit Kapoor

***Abstract*—In addition to numerous problems faced by the Visually Impaired persons, navigation through the outdoor environment is one of them, as the terrain is unknown with surfaces filled with obstacles of different heights. Several Electronic Travel Aids are proposed in the literature, and the methodology is evaluated by placing different types of the obstacle, traveling through them blindfolded, and counting the number of times obstacles are de-tected or not by the system. In our view, this approach helps little for further advancing the current system as the experimental scenario is not repeatable entirely and makes it difficult to compare new research findings with any existing one. We therefore, present a model inspired by the real world settings for detecting low-lying obstacles, considering few assumptions and constraints. The simulations are also proposed based on the model to generate obstacle data any number of time. Furthermore, to validate our model and simulations, field experiments are conducted, and the results obtained are compared with the simulation result. The evaluation parameter in terms of standard deviation, accuracy, false positive, errors encountered suggest that the proposed model and simulations effectively encapsulates the real-world parameters and thus can be explored and utilized further by the research community.**



***Index Terms*—Assistive technology, electronic travel aids, healthcare, modelling, simulation, sensors, visual impairment.**

I. Introduction

EYES are one of the essential part of our body and plays an important role in our daily living. Visual Impairment (VI) is the inefficiency of one's eyes to view the environment in front of it up to some clarity even with the usage of eyeglasses. Similar term visual acuity defined as the clarity of vision is measured with the help of psycho-physical test. A normal person has visual acuity as 6/6 but in case of VI persons it can worsen upto 20/60. For a blind person there is complete loss of vision. Without the vision a person is unable to perceive its environment and travel through it, resulting in injury while navigating through an unknown environment.

As per fact sheet provided by WHO [1], August 2014

- 285 million people are approximated to be visually impaired worldwide. With 39 million are blind and 246 million having low vision.
- About 90% visually impaired of the world lives in low-income settings.
- 82% of blind people are aged 50 and above.
- 80% of cases of visual impairment are preventable or curable.

There are a variety of aids employed by the VI persons for their safe travel around their environment ranging from white cane, travel dogs, GPS devices, white cane, and Electronic Travel Aids (ETA). White cane is very commonly used by them because of its simplicity and ease of use. The ETAs are the electronic devices which senses information about their surroundings with the help of sensors, pro-cesses the acquired information through micro-controllers and provides feedback to the user through either, audible or haptic means. The sensing system may consists of camera, Ultrasonic(US) Sensors, infrared sensors, motion sensors, laser or others. There are a number of ETAs proposed in the literature as discussed in section 2. As per WHO fact-sheet [1], around 90% of the VI persons come from low-income settings. This fact supports the use of the US sensors over camera-based

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The authors are with the School of Computer Science, University of Petroleum and Energy Studies, Dehradun 248007, India (e-mail: bhupendra.bisht.59@gmail.com; kapoor.monit@gmail.com).

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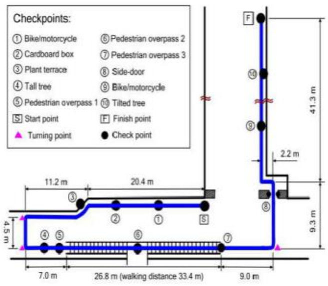

Fig. 1. Experimental Route [3].

computer vision approach because of their ultra-low-cost. However, the downside with the US sensor is the reduced accuracy, if the angle of orientation deviates from 0 among many others, this problem is discussed further in section 3.4.

In most of the proposed works focus has been either on Computer Vision approach or US sensor based approach, the results of the proposed system are analyzed based on some experimental setup and not on any benchmark dataset. The latter is not available for the problem of detection of an obstacle for VI persons. For e.g., the assessment of the developed system by [2] is done in the environment where obstacles are placed at different positions and consists of boxes, blocking rod, crossbar, hanging objects. Similarly, in the evaluation of the system by [3], a route for experimentation and validation is designed as consisting of different obstacles like a motorcycle, tall tree, side door, plant terrace and others, as shown in Fig. 1.

On reviewing these works, the problem of repeating the experimental scenario can be observed. To overcome these challenges we provide a solution in the form of real world working model and generating the obstacle data with the help of proposed simulations. The major contributions of our works are: 1) We present a model which encapsulates real-world parameters along with some constraints and the simulations which are based on the proposed model to generate obstacles data. We call this USODataGen (USsensor Obstacle Data Generator) 2) The simulation based on the proposed model is validated with the data collected through ground experiments. The validation is performed on the parameters of similarity in standard deviation, accuracy rate, false positive and, errors encountered 3) The model and simulation thus presented can be used to generate obstacle data multiple times and can be used as a benchmark to be used by the research community in their endeavor for result comparisons. 4) We release the simulated data, experimental data as well as the source code for the simulations on the publicly accessible online repository. 5) We provide results based on three different obstacle detection methods in order to benchmark the baseline of the introduced method of obstacle data generation through proposed simulations. This will give guidance to fellow researchers in the community for future research directions.

The rest of the paper is organized as:- first the model with assumed constraints and US sensor characteristics are presented in section 3, next the simulations with different obstacle scenarios are implemented in section 4, then implementation of the model in terms of field experiments is discussed and performed in section 5, following with the comparative study of the results obtained with simulations and the actual field experiments in section 6., the benchmark results based on three different methods are provided in section 7. The paper is finally concluded at the end in section 8.

II. Related Work

A survey with apt details is discussed in work by [4] and [5] Among popular ETA proposed in the literature, some of them are based on Computer Vision. In the work by [6], monocular vision camera is used,[7] proposes a method which analyzes received laser pattern of the emitted laser beam for the detection of uneven surfaces and potholes,[8] used laser together with smartphone camera, to calculate the distance of the obstacle in front of it. In [9] the image obtained by the camera is over segmented into subpixels for collision detection, [10] provides vision based mobile assistive navigation system to help indoor navigation, [11] provides robotic navigation aid using 3-D camera for pose estimation and object recognition in an unknown environment. In the work on US sensors, [2] uses multiple US sensor strategy employing seven US sensors attached to the cane pointing at different direction for obstacle detection, [12] uses three US sensor attached at chest, knee and toe of the user to detect obstacle in front of the user, [13] uses an US sensor to detect knee above obstacles in front of the user, [3] developed an assistive cane based on US sensor and explored its ergonomic aspects, [14] developed a Nav Guide shoe to assist VI persons in navigating through their environment, similar assistive devices have been developed by [15], [16] and [17]. Few authors have also studied hybrid use of both camera and US sensors [18], [19], [20].

For the problems where to extract or obtain actual data from the system is not possible, Modeling and Simulation plays an important role in those scenarios. In work by [21], they carried out experiments to study and analyze the mobility pattern when aged and younger persons are mixed. Based on the experimental results model and simulations are created, which further helped in suggesting the separation of the walking lane for slow and regular speeding pedestrians. Similarly, in work by [22], to detect the problem of detecting changes in a video, a unified depth data model mixing multiple device information cues are used. Results on implementation of widely used datasets show the approach handling several practical situations. In another work by [23], a mathematical model for the piezoresistive accelerometer is presented, which is further validated with actual experiments, and the comparison between the proposed model and experiments are conducted.

US sensors hold a number of applications in robotics and other related fields. In [24], the authors presented the sens-ing device which is the combination of the US sensor and passive infrared sensors to simultaneously monitor traffic congestion and urban flash floods. The sensing device is used for real-time vehicle detection, vehicle classification, and also speed estima-

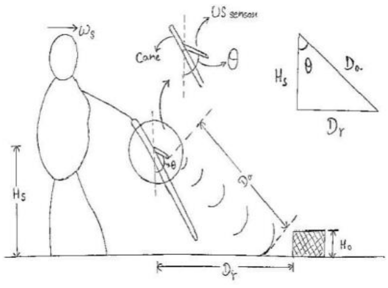

Fig. 2. System Working.

tion. As per [25], a measurement system is constructed which can perform 3D environment mapping and self-localization with the help of a small flying robot which consists of movable US range sensor and a ground-facing US range sensor for the purpose of altitude measurements. In the work by [26], a new positioning method is presented for the purpose of autonomous mobile robots based on multiple US sensors. Unlike the conven-tional positioning methods, the proposed method realized higher accuracy positing with US sensors without requiring additional temperature information. A total of three US sensor are used for the purpose of positioning. The work by [27], presents acoustic scanning for reconstructing obstacles with the help of array of sensors. When using multiple US sensors simultaneously, the signal from one sensor may interfere with the signal from other sensor. To avoid this interference a method is presented by [28].

III. Modelling the System

Inspired by the real-world scenario, a model is encapsulated, which depicts the VI person walking with the assistive cane with US sensors attached to it and facing forward direction. An illustration of the model along with obstacle lying on the ground is shown in the Fig. 2.

A. Working Scenario

With the help of simple trigonometrical formula, it can de deduced from Fig. 2 as

$$D_r = Hs * tan\theta \quad (1)$$

$$D_a = Hs/cos\theta \quad (2)$$

Here,

- θ is the angle at which the US sensor is oriented;
- H_o is the height of the obstacle in front of the user; H_s is the height of the US sensor above the ground surface;
- D_r is the distance, of the obstacle from the user;
- D_a is the distance of the US sensor from the obstacle/surface in front of it;

B. Constraints and Assumptions

To build a predictive system following assumptions are considered in our model.

TABLE I
α(I) Calculation

Sampling Rate (SR)	Mode	Average	Max (D_{mx})	Min (D_{mi})	SD	$\alpha(\Theta)$
195	80	80.45	94	45	2.5	97.4%

- W_s, the walking speed of the VI persons as 62cm/sec[1];
- H_s is fixed to 82 cm;
- The desired range of D_r is fixed to 82 cm;

To achieve the desired range D_r, is calculated with the help of equation 1, as $\theta = 35$

Similarly, D_a, the actual distance of the US sensor from the ground at angle $\theta = 35$, is calculated with the help of equation 2 as 80cm.

The low-lying obstacles are considered to be of three types as mentioned below:-

- Ob_{lg}, the obstacle of height around 40 cm;
- Ob_{md}, the obstacle of height around 20 cm;
- Ob_{sm}, the obstacle of height around 10 cm;
- Ob_{NO}, the obstacle of height below 10cm, or no obstacle at all;

C. Ultrasonic Sensors

Our work rely much on the US sensor. It usually consist of two transducers, one for transmitting US pulse (usually slightly above 20KHz) in front of it, and the other for receiving the transmitted pulse. The total time taken by the pulse until it is received back by the other transducer is known as the time of flight (ToF). The distance is thus calculated as

$$Distance = (ToF/2) * speed\_of\_US\_pulse \quad (3)$$

The speed of the pulse is assumed to be the same as the speed of sound (334m/s).

Thus, the distance is then calculated as

$$Distance = (ToF/2) * 334 \quad (4)$$

The US sensor used in our work is the popular and low cost HC-SR 04, the technical details of the sensor can be found in [29].

D. Ultrasonic Sensor Characterization

The low-cost US sensor comes with some highly unreliable measurements when it comes to measuring the distance at an orientation angle, as shown in Fig. 3. The accuracy of the US sensor is inversely related to the angle.

The reason for the phenomenon can be described with the help of 3. In Fig. 3a) if the US sensor is oriented correctly against the obstacle, i.e., at $\theta = 0$, almost all the transmitted US pulses are received back without interfering with the environment resulting in accuracy approximately to be 100%. On the other hand, as seen in Fig. 3 b) if the US sensor is oriented against the obstacle too away it will

[1]obtained after conducting several experiments with blindfolded users

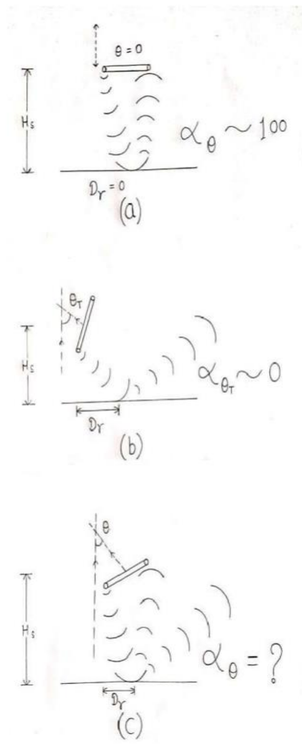

Fig. 3. US sensor characterization.

result in the transmitted US pulse diverging towards another direction away from the US sensor and none reaching it, resulting in accuracy approximately to be around 0. In our case, the US sensor is oriented against the obstacle at an angle as shown in Fig. 3b), such that few of the transmitted US pulses are reflected away from the US sensor or received back after some interference with the environment resulting in less than 100%.

For the US sensor operating at angle, the corresponding operational results can be characterized as,

- the accuracy of the sensor at angle;
- SD, the standard deviation in the readings of the sensor at angle θ;
- D_{mx}, the maximum distance measured by the US sensor in error, against actual distance, D_a;
- D_{mi}, the minimum distance measured by the US sensor in error, against actual distance, D_a;

To find out these characteristics, an experiment is conducted where is set to 35, Hs is set to 82cm and D_a is known to be 80cm. Next, the US sensor readings are measured con-tinuously with New Ping library [30], for 10,000 runs. The results are shown in Table I, at the sampling rate(SR) of 195 samples/sec. These results will be exploited to designing the simulations which are discussed next.

IV. Designing Simulation

The three scenarios, which are assumed to be followed while the VI person walks with the US sensor attached to the stick as per Fig. 2 are simulated in this section.

Given below are few common parameters of these simulations:-

$$E_t = N * (1 - \alpha(I)/100) \quad (5)$$

- α(I), as 97.4%
- N: the total number of distance measurements as desired in the simulation run
- Q_n: the queue holding the N distance measurements sequentially
- E_t: total error available for the given sensor characteristics and given N number of points to be gener-ated
- E_c: the amount of error occurred for the current reading of the US sensor
- E_r: remaining errors, out of E_t after the start of measurements by the US sensor

A. No Obstacle Scenario

This scenario is considered to be followed for the case when there are no obstacles in front of the user. The distance reading thus to be obtained should have been constant value. But because of the noisy reading by the US sensor the actual distance reading is not always the same. To generate N points, Algorithm 1 is used in conjunction with Table I.

Algorithm 1 No Obstacle Scenario

Result: Q_n, Distance data points

Step 1: Initiate a loop upto N

Step 2: for each iteration, generate a random number D_i, within range of $[D_{mi}\ D_{mx}]$

Step 3: Add D_i to Q_n

Step 4: E_c is computed as abs(D_a − D_i) and $E_r = E_t$ - E_c

Step 5: Break the loop if $E_r = 0$, and assign D_a to the rest of the elements of Q_n

B. Ideal Obstacle Scenario

This scenario is considered for the case, = 100% i.e., the US sensor is working with absolutely no error. The distance readings in this case would follow constant values as the US sensor points to the ground. And as soon as the obstacle is encountered the distance readings starts decreasing in value first, then some constant value which is equal to the height of the US sensor minus the height of the obstacle encountered is obtained and finally as the sensor walk over the obstacle is complete, the distance readings are again constant.

The total no. of points for which the US sensor walks over the obstacle, can be calculated as

$$N_t = SR * H_o / W_s \quad (6)$$

The first distance D_0, by the US sensor, is assumed to be $D_0 = D_a$ The last distance D_1, measured by the US sensor at

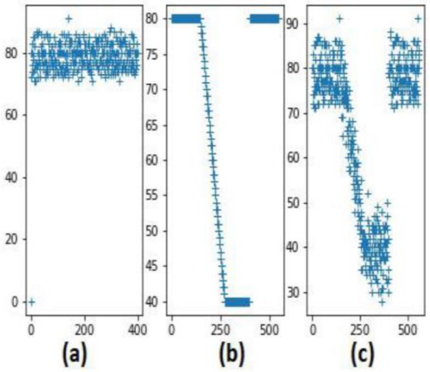

Fig. 4. Simulated data for a) No Obstacle Scenario b) Ideal Obstacle Scenario c) Noisy Obstacle Scenario.

the end of the walk over the obstacle can be computed as

$$D_{-1} = D_a - H_o \tag{7}$$

The sampling interval distance, i.e., the discrete distances measured by the sensor between D_0 and D_1, can be computed as

$$\Delta = (D_0 - D_1)/N_t \tag{8}$$

On simplification using equation 5, we get

$$\Delta = H_o/N_t \tag{9}$$

The N points for the ideal scenario are computed with Algorithm 2 below:-

Algorithm 2 Ideal Obstacle Scenario

Result: Q_n, Distance data points

Step 1: Save D_a as first value to Q_n
Step 2: Initiate a loop upto N - 1
Step 3: Compute, $D_i = D_i$ - Δ
Step 4: Save D_i to Q_n
Step 5: Repeat till loop ends

C. Noisy Obstacle Scenario

Since the accuracy of the US sensor ( ) is below 100%, the obstacle data is expected to deviate from the ideal scenario as discussed in section 4.2 in accordance to the US sensor characteristics captured in Table I. The input data Q_{idn}, for this scenario, is obtained using Algorithm 2. Fig. 4 shows the data generated from the simulations, USODataGen, for the user moving at the speed of 62.3cm/s and for the obstacle of height 40cm.

V. Model Implementation

To test the effectiveness of the proposed model and simulation, field experiments are conducted to analyze whether the ground experiments are consistent with the proposed model.

Algorithm 3 Noisy Obstacle Scenario

Result: Q_n, Distance data points

Step 1: Initiate a loop upto N
Step 2: Fetch corresponding value D_{idn}, from Q_{idn}
Step 3: Generate a random number D_i, around D_{idn}, within range of $[D_{mi}\ D_{mx}]$
Step 4: Save D_i to Q_n
Step 5: Computer errors as
Ec = abs(D_{idn} - D_i)
Er = $E_t - E_c$
Step 6: Repeat till loop ends

A. System Prototype

A walking cane resembling the VI persons white cane is equipped with an US sensor attached at the front of it. The walking cane is also equipped with an Arduino microcontroller [31] for collecting the data from the US sensor and transmitting them to the laptop connected to the microcontroller via a USB cable. Every experiment runs, once complete transmits all the distances to the connected laptop which are then copy and pasted to a CSV file.

B. Environmental Set up

The obstacles are realized with cardboard boxes of height 10cm, 20cm and 40cm. Three test subjects in the ages 19-20 are tasked to walk with the walking cane in the route having cardboard boxes. As the subject walks over the obstacle, the readings are noted down. To, later on, compare experimental results with simulation results, the subjects are asked to walk in three different speed modes of slow, normal and fast, details in Table II, 10 times for each. In every single run, a total of 2000 readings are obtained at the rate of 235 samples per second. One such reading for a single experiment is shown in Fig. 5. As can be seen in the figure, up to the readings 980, the US sensor measured the distances about 62 cm with the deviation between 60 to 65 cm. Once the obstacle is encountered and passed upon the subsequent readings shows

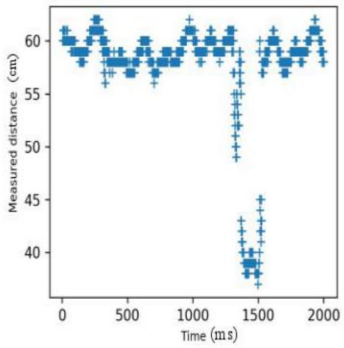

Fig. 5. Sensor walk over obstacle of height 20cm.

TABLE II
WALKING SPEED IN CM/SEC

Slow	Normal	Fast
62.3	95.7	122

the drop in measuring distances to the point around 45 cm which is when the US sensor's pulses reach the top of the obstacle and after readings 1300, the measuring distances is again restored to average 62 with intermittent noise in between.

C. Obstacle Identification Algorithm

To identify the obstacles, based on the pattern obtained, an algorithm based on clustering is devised, which helps in identifying the obstacle type is described below. The pattern for the data obtained for an obstacle of height 20cm is obtained for one experimental run is shown with Fig. 5. The pattern helps in deducing algorithm for finding the height of the obstacle as detailed by Algorithm 4 below:-

Algorithm 4 Obstacle Identification by Cluster Method

Result: Obstacle Type, Ob_{sm}, Ob_{md}, Ob_{lg}, Ob_{NO}

Step 1: Define four clusters corresponding to each obstacle type as $Cluster_{NO}$, $Cluster_{sm}$, $Cluster_{md}$, $Cluster_{lg}$

Step 2: Read obstacle data from i'th Experiment

Step 3: Assign individual data points to the cluster having closest distance

Step 4: Repeat Step No 3 for all the obstacle data points

Step 5: Finally, the cluster having the most number of data points assigned is the identified obstacle type

VI. COMPARATIVE STUDY

This section attempts to validate the model and simulation proposed earlier by the field experimental data recorded, with the help of different data analysis tools and methods.

A. Data Analysis With Standard Deviation

The data analysis in terms of standard deviation for the simulation vs experimental results are compared. The scenarios for the four obstacle types are considered with three speed types as shown in Table III. As the walking speed mode of the user increases from slow to fast, the error in measurement of the distance by the US sensor is theoretically expected to increase, similarly increasing in Standard Deviation. The same can be noted in the simulation results for all the obstacles excepts Ob_{NO}, which shows the reverse trend. In the case of experimental results, there is an inconsistent response; however, overall, it also depicts the same pattern of increasing the SD for higher speed modes.

B. Accuracy Comparison

The comparison in terms of accuracy is shown in Fig 7 which shows that though Ob_{NO}, Ob_{md} and Ob_{lg} obsta-cle are detected quite accurately with 91.1% and 93.9% and 95.8% accuracy respectively during simulations but detecting small obstacle accurately is a quite tough task with 88.5% accuracy during simulation. The reason can be found in Fig. 6, which demonstrates that for larger obstacle Ob_{lg} the number of obstacle data points (W1) is larger than medium-sized obstacle Ob_{md} (W2) and much larger than small-sized obstacles Ob_{sm} (W3). In fact W1 > W2 > W3. Both simulation and experimental results show similar trends; hence accuracy comparison study is passed.

C. False Positive Comparison

Ob_{NO} objects have a very high numbers of false-positive 15% during simulation, while Ob_{lg} shows the least 0.4% during simulation, in comparison to other obstacles, as shown in Fig 8. Both simulation and experimental results show similar trends; hence false positive rate comparison study is passed.

D. Errors Encountered Comparison

Fig. 9 shows the comparison between the two in terms of errors encountered in case of different walking speed by the test subjects. The figure clearly shows that as the speed is increased the number of errors are also increased, which can be attributed to an increase in SD, as noted in Table III Both simulation and experimental results show similar trends; hence errors comparison study is passed. Though the errors in case of experimental results are higher than simulation which is evident as the real experiments are more prone to unseen errors in comparison to the simulations.

VII. SETTING UP BENCHMARK

In order to set a baseline of the obstacle data generation simulation which are reproducible and comparable, two more methods have been presented in this section in addition to cluster method described by algorithm 4.

A. Quadratic Method

This method uses a curve fitting technique to fit a quadratic curve to the simulation data for different obstacle type. Curve

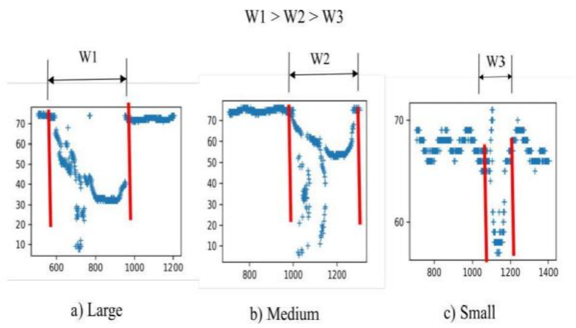

Fig. 6. Sensor walk over obstacle of different types.

TABLE III
STANDARD DEVIATION: SIMULATION VS EXPERIMENTAL

	No Obstacle			Small Obstacle			Medium Obstacle			Large Obstacle		
	slow	normal	fast	slow	normal	fast	slow	normal	fast	slow	normal	fast
Simulation	1.87	2.62	3.05	2.62	5.03	5.17	5.91	8.69	9.48	13.13	14.4	16.69
Experimental	2.88	3.31	3.34	7.61	9.59	12.32	11.84	12.99	10.65	13.81	14.25	18.85

TABLE IV
OBSTACLE DETECTION RESULTS BY VARIOUS METHODS

	No Obstacle			Small Obstacle			Medium Obstacle			Large Obstacle		
	Precision	Recall	Fscore	Precision	Recall	Fscore	Precision	Recall	Fscore	Precision	Recall	Fscore
Cluster Method	82.6	84.4	83.5	87.9	81.1	84.4	85.4	91.1	88.2	92.1	91.1	91.6
Quadratic Method	73.4	76.7	75.0	78.1	71.1	74.4	85.1	88.9	86.9	91.1	91.1	91.1
Histogram method	71.4	72.2	71.8	74.4	67.8	70.9	88.3	93.3	90.7	92.5	96.7	94.6

fitting is the mathematical process of best fitting a curve to a given series of data points. Once the equation of the quadratic curve is found, the height of the curve is then used as an indicator of the obstacle type. An example of the quadratic curve fitted over the simulated data of large, obstacle type is shown in Fig. 10.

B. Histogram Method

The histogram is a type of graph that represents numerical data in the form of bins which lie in a defined range. In this method of obstacle type detection, the histogram for the simulations obstacle data is explored. A histogram is first constructed for the simulation data with a total of bins restricted to 5. All the bins are then processed to find the number of data points. The bin containing the most number of data points is considered to be the candidate for obstacle type. The height of the corresponding bin is considered as the height of the obstacle.

The results obtained with the cluster, quadratic and the histogram method in terms of precision, recall and Fscore are shown in Table IV. In all three methods, the recall rate for small obstacles is found to be challenging while that of large obstacles is the best among all other obstacle types. The Histogram method has the least recall rate for small obstacles

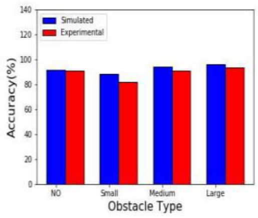

Fig. 7. Accuracy comparison.

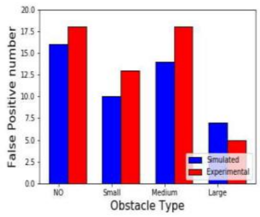

Fig. 8. False positive rate comparison.

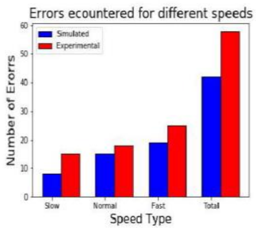

Fig. 9. Errors for different speed.

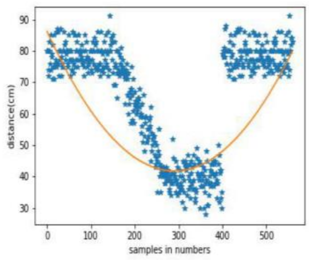

Fig. 10. Quadratic curve method.

but has the highest recall rate for large obstacles. The precision rate of No obstacle type is the least among all obstacle types while large obstacles have the highest precision rate. The cluster method has the highest precision for all the obstacle types except for large obstacles. The Histogram method has the highest precision rate for large obstacles among all the obstacle detection methods. Fig. 11, shows the accuracy plot for the three types of obstacle detection methods. Overall the cluster

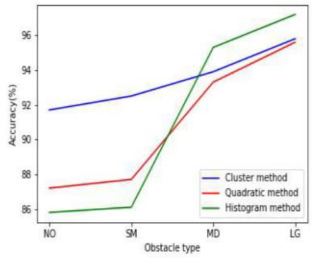

Fig. 11. Accuracy results for different methods.

method outperforms all other methods for different obstacle types except for large obstacles. The Histogram method has the highest accuracy for the large obstacles.

VIII. Conclusion

The problem of repeating experimental scenarios for the continuation of research is presented and the need for the solution for the same is stressed. A Model and Simulation, USODataGen, for the generation of obstacle data, based on US sensor while the person walks with a stick having the US sensor attached is presented. The proposed model is supported by conducting field experiments and comparing the simulation results with the experimental results in terms of standard deviation, accuracy, false detection rate and the total number of errors encountered. With comparison, both the simulation and field experimental results are found to follow the same trend. Thus validating the proposed model and simulation. The research community thus can use them for comparing their algorithm and results without having to create a scenario with physical obstacles.

IX. Current Limitations and Future Scope

The current setting of holding the cane by the test subjects in this study considered to firmly holding the cane, while in real world the cane is subjected to continuous change in orientation of the cane. This constraint needs to be taken up in future work. The example solution approach can consists of accelerometer which keeps track of the orientation of the cane.

Another limitation is the test subjects involved in this study. Each were having normal vision and blindfolded for the purpose of the study. In order to get more realistic results the actual VI or blind persons needs to be incorporated for the study.

Acknowledgment

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Analysis address	skumar.upes@analysis.urkund.com