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ANALYSIS AND MODELING OF AUTOMATED WALKING GUIDE TO ENHANCE THE MOBILITY OF VISUALLY IMPAIRED PEOPLE

By

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Analysis and Modeling of Automated Walking Guide to Enhance the Mobility of Visually Impaired People

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A Thesis submitted in partial fulfillment of the requirements for the degree of

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Declaration

This is to certify that the thesis work entitled "**Analysis and Modeling of Automated Walking Guide to Enhance the Mobility of Visually Impaired People**" has been carried out by Md. Milon Islam in the Department of Computer Science and Engineering, Khulna University of Engineering & Technology, Khulna 9203, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

Signature of Supervisor

Signature of Candidate

Approval

This is to certify that the thesis work submitted by Md. Milon Islam entitled "**Analysis and Modeling of Automated Walking Guide to Enhance the Mobility of Visually Impaired People**" has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of Master of Science in Engineering in the Department of Computer Science and Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh in March, 2019.

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Abstract

The development of walking guides has become a prominent research due to the rapid growth of visually impaired people in recent decades. Although numerous systems have been developed to aid the visually impaired people, a considerable portion of these are limited in their scopes. This thesis has implemented a spectacle prototype to assist these individuals with safe and efficient walking in the surrounding's environment. The spectacle prototype is modeled in SolidWorks (3D model) considering the dimension of each electronic components. In the modeling, the front ultrasonic sensor is positioned in the spectacle to detect the front obstacles only, the left and right ultrasonic sensors are set to 45 degree from the spectacle center point in order to detect obstacles within the shoulder and arm of user; another ultrasonic sensor is positioned towards the ground facing for the detection of pothole. The Rpi camera is positioned at the center point of the spectacle. In addition, the right and left temple of the spectacle is designed to position the raspberry pi and battery respectively. The usage of spectacle based walking guide would help the visually impaired people to scan the surroundings. Three pieces of distance measurement sensors (ultrasonic sensor) is used in the walking guide in order to detect the obstacle in each direction including front, left and right. In addition, the system detects the potholes on the road surface using sensor and convolutional neural network (CNN). Overall, the spectacle prototype consists of four ultrasonic sensors; raspberry pi, Rpi camera and battery. CNN technique, runs on raspberry pi, is used to detect the pothole on the road surface. The pothole images are trained initially using convolutional neural network in a host computer and the potholes are detected by capturing a single image each time. The experimental study demonstrates that 98.73% accuracy is achieved by the front sensor with an error rate of 1.26% when the obstacle is at 50 cm distance. In addition, the results reveal that the system obtains the highest accuracy, precision and recall 92.67%, 92.33% and 93% respectively for potholes detection. The electronic spectacle gives a direct audio signal to the user via headphone for avoiding hindrances effectively.

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Nomenclature

BGMM	Bivariate Gaussian Mixture Model
CNN	Convolutional Neural Network
CSI	Camera Serial Interface
CRC	Co-Robotic Cane
DG	Deformable Grid
DPU	Data Processing Unit
PLD	Position Locator Devices
EOA	Electronic Orientation Aid
ETA	Electronic Travel Aid
FMCW	Frequency Modulated Continuous Wave
GMM	Gaussian Mixture Model
GPIO	General Purpose Input Output
GPRS	General Packet Radio Services
GPS	Global Positioning System
GSM	Global System for Mobile Communications
IMU	Inertial Measurement Unit
IR	Infrared
LED	Light Emitting Diode
LIDAR	Light Detection and Ranging
MAD	Mobility Assistive Devices
MEMS	Micro-Electro-Mechanical Sensors
OST	Optical See-Through
PLA	Polylactic Acid
PLD	Position Locator Devices
POI	Point of Interest
PWM	Pulse Width Modulation
RADAR	Radio Detection and Ranging
RANSAC	Random Sample Consensus
RFID	Radio Frequency Identification
ROI	Region of Interest

SLAM	Simultaneous Localization and Mapping
SoC	System on Chip
SURF	Speeded Up Robust Features
TTS	Text to Speech
UWB	Ultra-Wide Band
WHO	World Health Organization

CHAPTER I

Introduction

1.1 Introduction

This chapter describes the motivation, research questions, objectives, scope and organization of the thesis. In motivation, reasons for performing the thesis i.e. why the thesis is undertaken with some background information is discussed in detail. The specific questions that are addressed in this thesis are highlighted in Research Questions section. Then the objectives of the thesis are outlined followed by the scope. Finally, it presents the organization of this thesis.

1.2 Motivation

Recent statistics from the World Health Organization (WHO) have shown that approximately 253 million people in the world are visually impaired, of which 217 million have a slight vision and 36 million are blind [1]. The problem is becoming a matter of concern because the number of visually impaired is increasing by 2 million per decade. An estimation has shown that the number of blind people may be doubled in 2020 [2]. Furthermore, WHO reports that about 90% of the visually impaired population is in developing countries. For instance in Bangladesh, where this thesis is carried out, there are around 800,000 blind people, of whom 40,000 are children whose age are below fifteen [3]. In this developing country, 75% of the population live in remote areas with few basic facilities, therefore blind or semi blind residents of these areas face greater challenges in accomplishing day to day tasks. Due to the low income status of these regions, such a significant portion of the visually impaired population do not have access to technology that could otherwise aid in mobility and increase their productivity.

Blindness is the imbalance of physiological or neurological components that is called the condition of lacking discernment [4]. However, many people have vision problems due to birth defects, uncorrected errors, work nature, accidents, and aging. The visually impaired people need assistance to find their way in unfamiliar places. One of the major exigent daily events met by the visually impaired people in the real world environment is safe and independent mobility

[5]. They face serious problems to detect and avoid obstacles in their path, thus causing them emotional suffering, undercuts their independence, and exposes them to fracture [6]. People influenced by visual deficiency and visual ailments need assistance to triumph over day to day assignments e.g., moving and exploring unfamiliar environments [7]. When visually impaired people are in new or unknown places, the most important thing for them is to know the position of the obstacle and other interference to enable a safe navigation [8].

Conventionally, popular assistance methods used by visually impaired people to detect and avoid obstacles through their paths are white cane and Guide dog. These methods are limited with regard to the information that they provide in real-time scenarios; this information cannot ensure safe mobility and a clear path to the user as it would for a sighted person [9], [10]. A white cane is designed to detect close objects with physical contact requirements. A white cane can also alert people about the presence of visually impaired people and enable sighted people to yield the path to visually impaired people. However, a white cane cannot detect head level barriers and their danger levels. A guide dog is a good navigation solution compared to the white cane but it is an expensive solution. Intensive training is required for dogs that serve as guide dogs.

K-Sonar Cane [11], that can identify floor and head level hindrances, uses adjustable frequency sound forms to deliver the distance of barriers. CyARM [12] is a handheld obstacle recognition system. Most of the walking guides are developed based on obstacle detection with feedback signal [13], [14], [15]. The available devices for these individuals are in various forms like smart canes, smart glasses, hand-held tools etc. However, the acceptance rate of the available devices among the visually impaired is relatively low [16]. The walking guides that are developed with the combination of multiple electronic sensors tried to enhance the visually impaired individual’s daily activities [17]. The computer vision based electronic tool [18] can detect hindrances more simply and exactly than sensor based electronic device. However, the depth sensor works within a limited range in computing the distance of the hindrance.

There are also some existing technologies which are commonly used for navigation purposes such as GPS, active RFID, mobile phone, etc. However, the usage of each technology has its limitations based on indoor or outdoor application. Based on some studies, GPS [19] and smartphones [20] have quite a big error margin in which they can guide a visually impaired person to walk on the road, but not the walkway side of the road since their error could be varied from 5 meters to 10 meters. Besides these, active RFID has also been studied [21]. However, the accuracy of active RFID is also quite high, but the energy consumption with installation areas are limited. It is still now a challenging issue for the visually impaired individuals to attain the safe mobility. Despite numerous evolutions in innovation, blindness remains a critical issue [22], [23].

To enhance the mobility of the visually impaired people, previously few approaches have been developed in the Department of Computer Science and Engineering, Khulna University of Engineering & Technology which are described in brief as follows. Sadi et al. [24] proposed a system for visually impaired people to aid them in walking by identifying an object and creating an audio signal as per the distance of the object. The system is designed similar to a spectacle and can detect obstacles under 3 m distance and 60° angle. The spectacle consists of an ultrasonic sensor, a microcontroller, and an alarm generator. The ultrasonic sensor generates an ultrasound wave that is reflected to the sensor by observing the obstacle's location within 3 m. The microcontroller measures the distance by manipulating the time between the back and forth travel of ultrasound from the obstacle. A signal is transferred to the alarm generator with the presence of obstacles, and it generates an alarm based on the signal from the microcontroller. The ultrasonic sensor is positioned at the middle of the spectacle, and the microcontroller, alarm generator, and battery are attached to the temple. The developed scheme is a low-cost and straightforward strategy but bulky. Temperature, density, and weight also limit the ultrasonic sensor. Moreover, system accuracy varies at near and far distances. However, the system is able to detect the obstacles in front of the visually impaired people. Tanveer et al. [25] introduced a walking assistance tool for blind people. The system allows blind people to navigate by using a spectacle interfaced with a smartphone. The smartphone application generates Bengali/English voice signals with the detection of the obstacle's location. Visually impaired people establish a voice call to a fixed number by clicking the headset button. Latitude and longitude are measured through GPS, and tracking of blind people is handled by using another application based on Google maps. The overall error rate is approximately 5% for concrete and floor tiles. The system provides the location of the users using Google maps with front obstacle detection only.

However, this system fails to perform in certain circumstances, such as elevations. Kamal et al. [26] developed a walking assistant for the visually impaired people to aid them in navigation by avoiding obstacles around them. The system consists of two modules such as wearable spectacle module and smartphone module. The wearable spectacle module perceives the obstacles from the environment and receives the road surface as images for processing. The smartphone module obtains the images sent from the wearable spectacle module and then processes the images and finally computes the smoothness of the surface. The developed module is small, wearable and light weighty. However, the system obtained limited accuracy rate with error rate of about 31% at some area for both obstacle detection and surface smoothness detection.

In order to guide and navigate visually impaired people to reach their desired destination, a reliable method and device should be investigated. Hence, we have developed a spectacle prototype that can detect the obstacles in left, right and front directions of the users. In addition, we propose a strategy to detect the pothole on the road surfaces. The convolutional neural network approach has been used to classify the road surfaces with pothole or not. Furthermore, an ultrasonic sensor is also used to generate immediate alert about the pothole on the way of walking. The main contribution of the thesis is develop a spectacle prototype that is able to hold the all electronic components in a single system. In addition, the developed system utilize convolutional neural network for pothole classification which runs on a single chip. Overall, the developed system captures the environment using ultrasonic sensors and Rpi camera; and process the data in a single board and notifies the user within a fewer time.

1.3 Research Questions

During the completion of the thesis, several research questions are addressed. These questions are outlined shortly as follows.

- What kind of walking guide is suitable to acquire the information from the environment with respect to the visually impaired needs?
- How can the learning system for obstacle and pothole detection be designed to guide visually impaired people?
- How can the information of the surroundings be made accessible for visually impaired people?

- What types of responses are suitable for the users and how the responses can be passed to them?

1.4 Objectives of the Thesis

The goal of the thesis is to develop a walking guide that can be used by disabled people, especially the visually impaired. The thesis intends to investigate how the walking guide can be used effectively, so that the design requirements for the development of this walking guide could be formulated. To fulfill the goal, this thesis has the following specific objectives.

- To design and implement the spectacle prototype to guide the visually impaired people.
- To develop a walking guide to reduce collision with obstructions for the visually impaired people.
- To develop a method for pothole detection on the road surface.
- To evaluate the performance of the developed system with real time environments.

1.5 Scope of the Thesis

There are many issues and problems which are faced by the visually impaired people. For example, mobility problem, reading problem, location identification problem, employability problem, etc. The mobility issues are mainly studied and explored in this thesis, since the visually impaired people could not get the information about obstacles surrounding them. This thesis also explored pothole detection system on the road surface. The developed system can easily detect both static and dynamic obstacles in indoor and outdoor environments in any weather conditions. The male or female knowing any language is appropriate to wear the spectacle prototype but the people who don't know English needs some training before use. Some critical hindrances that are available in surrounding's environment like humps on the road surface, staircase situation, road surface smoothness, water on the road surface etc. are not detected by the developed walking guide.

1.6 Organization of the Thesis

The thesis is organized as follows.

- **Chapter I** presents the overview of the thesis including the introduction, motivation, research questions, objectives and scope.

- **Chapter II** demonstrates the literature review of walking guide in the area of computer vision, smartphone, sensors, etc. The performance of the existing systems are outlined shortly in here.
- **Chapter III** illustrates the proposed methodology for obstacle and pothole detection using sensors and convolutional neural network.
- **Chapter IV** describes the implementation details including the construction of the prototype. In addition, the experimental results are elaborated in order to evaluate the effectiveness of the developed assistive walking guide for both obstacle and pothole detection.
- **Chapter V** concludes this thesis together with the outline of open scopes to enhance this thesis in future.

CHAPTER II

Literature Review

2.1 Introduction

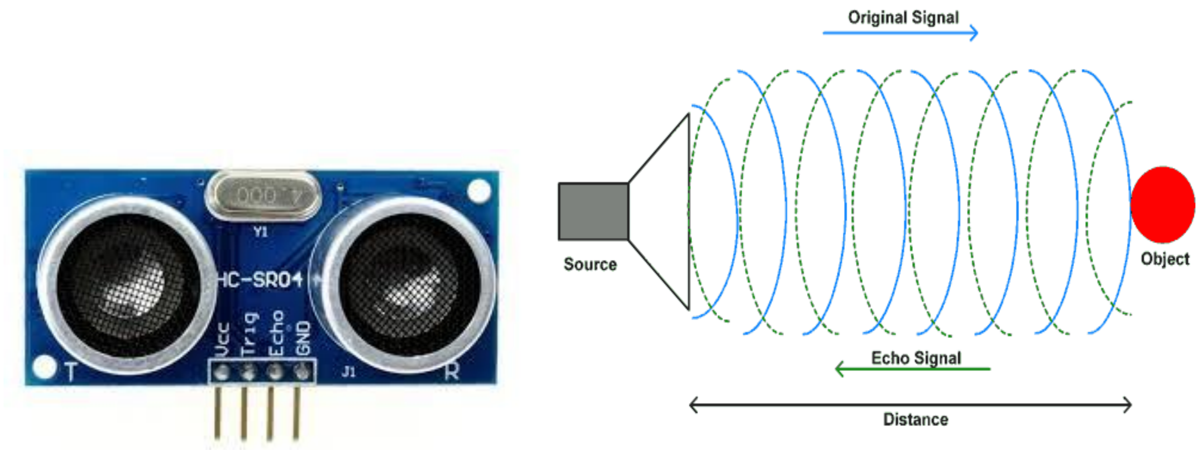
This chapter encompasses background information about hardware components that are used in the implementation of the proposed spectacle. These include ultrasonic sensors, raspberry pi, Rpi camera and power supply. The review on related work associated with the area is also described here.

2.2 Technical Background

The development of hardware for wearable walking guide involves four ultrasonic sensors, a Rpi camera, a raspberry pi and a battery. The background knowledge that are working for proper functioning of the spectacle is also described. The fundamentals of these components and key ideas of their operations are outlined in brief as follows.

2.2.1 Ultrasonic Sensors

The ultrasonic sensor is commonly applied in many applications since it functions by transmitting an ultrasonic sound through a transmitter and measures the required time for the sound to return back to the sender being reflected by the receiver. The range can be 2 cm to 4 m and can cover up to 15 degrees. It consists of only 4 pins. The pins are VCC, trigger (transmitter), echo (receiver) and ground (GND). VCC pin is used to power-up the sensor. It accepts up-to +5V, and ground pin is connected with ground. It sends ultrasonic pulse continuously through trigger pin. When any obstacle reflects the signal, the Echo pin receives the message and a control circuit measures the distance of the obstacles. The ultrasonic sensor and its working principle are illustrated in Figure 2.1 (a) and Figure 2.1 (b) respectively.



(a) (b)

Figure 2.1: Sensors. (a) Ultrasonic sensor (HC-SR04) (b). Distance measurement process [27].

2.2.2 Rpi Camera

The camera consists of a small (25mm x 20mm x 9mm) circuit board, which connects to the Raspberry Pi's Camera Serial Interface (CSI) bus connector via a flexible ribbon cable. The camera's image sensor has a native resolution of five megapixels and has a fixed focus lens. The software for the camera supports full resolution still images up to 2592x1944 and video resolutions of 1080p30, 720p60 and 640x480p60/90. It is attached with Pi by one of the small sockets on the board's upper surface and uses the dedicated CSi interface, designed especially for interfacing to cameras. The Rpi camera is shown in Figure 2.2.

Figure 2.2: Raspberry pi camera to capture the real world environment.

2.2.3 Raspberry Pi

Raspberry pi is mini sized single board computer that is used to conduct real time research. It has 17 GPIO pins that can easily connect with electronic devices (LEDs, switches etc.). The raspberry pi B+ model contains four USB ports, an audio jack port, two ports for camera interfacing, a HDMI port and an Ethernet port. The logic level of raspberry pi is approximately 3.3v. It is compatible with operating system Raspbian. It supports Python, Java, C, and C++ as programming languages and has a 700MHz single core processor. The different parts of raspberry pi are shown in Figure 2.3.

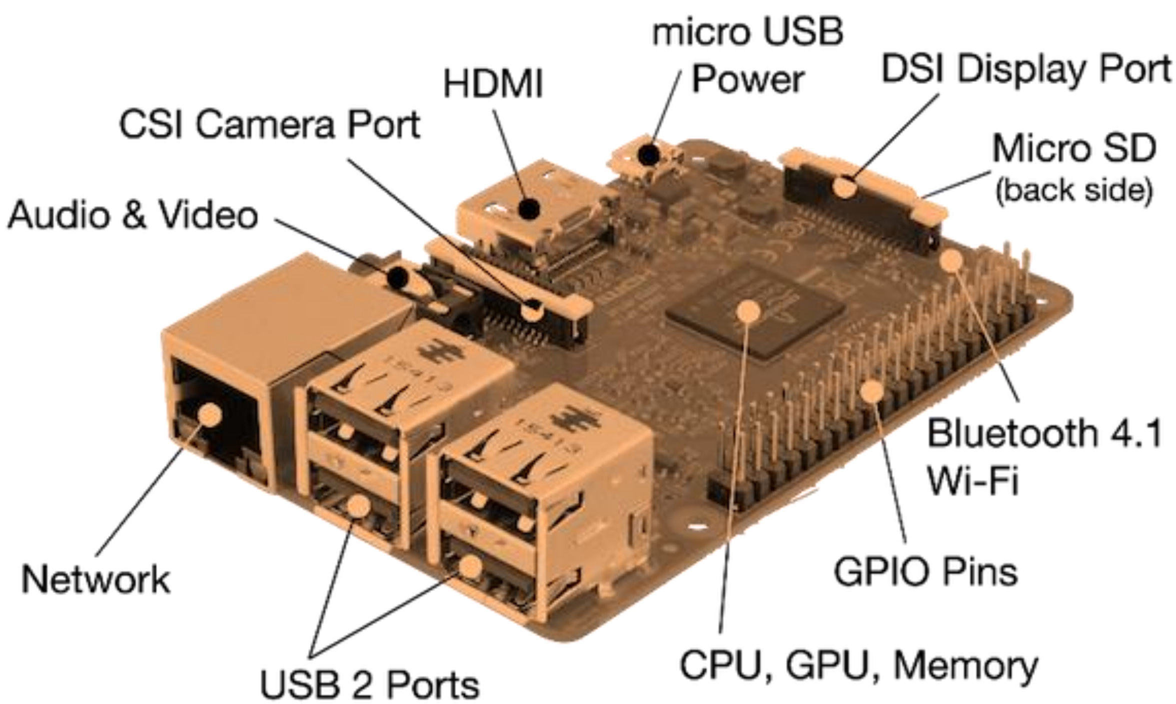


Figure 2.3: Raspberry pi and its different components.

2.2.4 Battery/Power Supply

In this thesis, Lithium-ion (Li-ion) battery is considered. If the battery capacity increases, the battery size also increases and longer lifetime can be provided. On the other hand, the volume of each rechargeable battery is also considered in order to select the best rechargeable battery for the system. The Lithium-ion battery has the lowest weight among all categories. The Lithium-ion battery is shown in Figure 2.4

Figure 2.4: Lithium-ion battery to power on the raspberry pi.

2.2.5 Brief Theory of Convolutional Neural Network

Convolutional Neural Networks (ConvNets or CNNs) [28] are a category of neural networks that have been well demonstrated in the fields of image recognition and classification. Because of its classifying visual patterns such as pixel images with a very few pre-processing, it has added a new dimension to image classification tasks [29]. Digital filtering technique is used to acquire the features of the data when the data propagates through the multiple layers in CNNs. Convolution and subsampling are the main process of CNNs. A CNN entails of some layers which are multiple convolution and subsampling layer, hidden layer and output layer.

The basic role of convolution process in case of a CNN is to excerpt features from the raw/input images. Convolution preserves the spatial connection between pixels by learning input image features with trivial squares of input data. Convolution is a numerical term applying a function on the output of other functions recurrently. Convolution will generate a direct change of the input data corresponding to the spatial information from the filter. The weights on that layer whether determine the convolution kernel is utilized or not. In this layer, a convolved feature value is developed with the use of kernel from the input feature value that is a preceding layer feature value. Hence, the convolution kernel may be trained in view of input on CNN. Sub-sampling layer [30] diminishes the spatial size and number of parameters in the system and quickens computing and controls the event of over fitting. Spatial blocks move along the feature pattern which is the main working principle of sub-sampling layer. A sub-sampling layer is followed by each convolutional layer that clarifies the data generated by the convolutional operation and generates sub-sampled feature value in CNN.

In CNN, a hidden layer before output layer is investigated after multiple times of convolution-subsampling operations. The output layer is a traditional multi-layer perceptron that uses a softmax or sigmoid activation function in the output layer. It implies that every neuron in the previous layer is connected to every neuron on the next layer. The output from the convolutional and pooling layers represent high-level features of the input image. The purpose of the output layer is to use these features for classifying the input image into various classes based on the training dataset.

2.3 Related Work

Several assistants have been developed to guide visually impaired people for easy walking. Many organizations have been working for an extended period to make low-cost and well-organized tools for them. The visually impaired people face much difficulties in their daily lives for losing their vision. The obstacles around the surroundings and pothole on the road surface are the major hindrances to their walking.

There are three parts of visual assistance technology. These are the vision enhancement, vision substitution, and vision replacement [31], [32], [22], [33], [34]. The first two categories are almost same in functionality. The captured image is processed, and the output is displayed in a monitoring device in vision enhancement whereas the production of the vision substitution is taken through vibration or with the aid of alarming devices that can generate a sound which has inferior information capability rather than vision. Vision replacement deals with medical technology and is comparatively more complicated than others. The information is displayed straight to the humanoid intelligence through the optic nerve.

The purpose of our review is to focus on the vision substitution that includes Electronic Travel Aid (ETA) [35], Electronic Orientation Aid (EOA) [36], and Position Locator Devices (PLD) [31], [32]. Among them, Electronic Travel Aid is the most promising in the review which collects information from the interior environment and handover it using sensors, cameras, and smartphone. A few ETAs are available in a wearable format, and few others are available in hand-hold format depending on the user's nature. The review discusses the challenges met by the blinds and the real-life solutions corresponding to the problems. It also explains the recent technology adopted in this field for aiding the visually impaired people for safe mobility.

2.3.1 Obstacle Detection System

Obstacle detection systems are generally developed based on some techniques. For instance, some systems are designed by combining different techniques. However, in this review, the categorization is done based on the priority, i.e., which method contributes more than the others. Therefore, on the basis of the existing methods, the developed obstacle detection system can be divided into three categories as follows.

- Sensor-based obstacle detection
- Computer vision-based obstacle detection
- Smartphone-based obstacle detection

The taxonomy of the reviewed obstacle detection system is depicted in Figure 2.5.

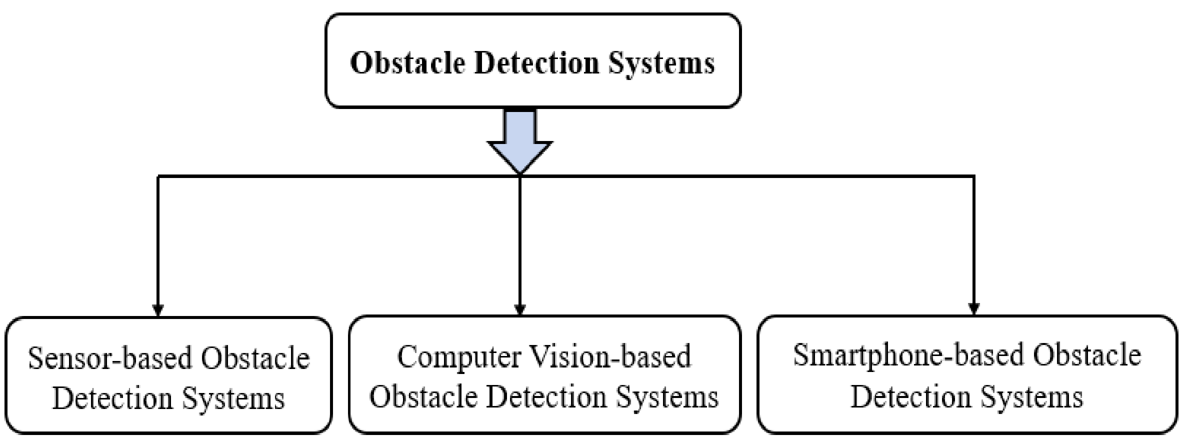


Figure 2.5: Taxonomy of the reviewed obstacle detection system for the visually impaired people.

A. Sensor-based Obstacle Detection

Sensor-based obstacle detection system provide surrounding information to visually impaired people through audio signal, vibration, and/or both [37]. These frameworks depend on the gathered information to recognize an obstacle and avoid it by calculating the distance between the users and obstacles using the velocity of the environment. The system architecture of sensor-based obstacle detection system for visually impaired people is illustrated in Figure 2.6. Several sensors are used to construct different types of assistants to provide obstacle detection and avoidance services.

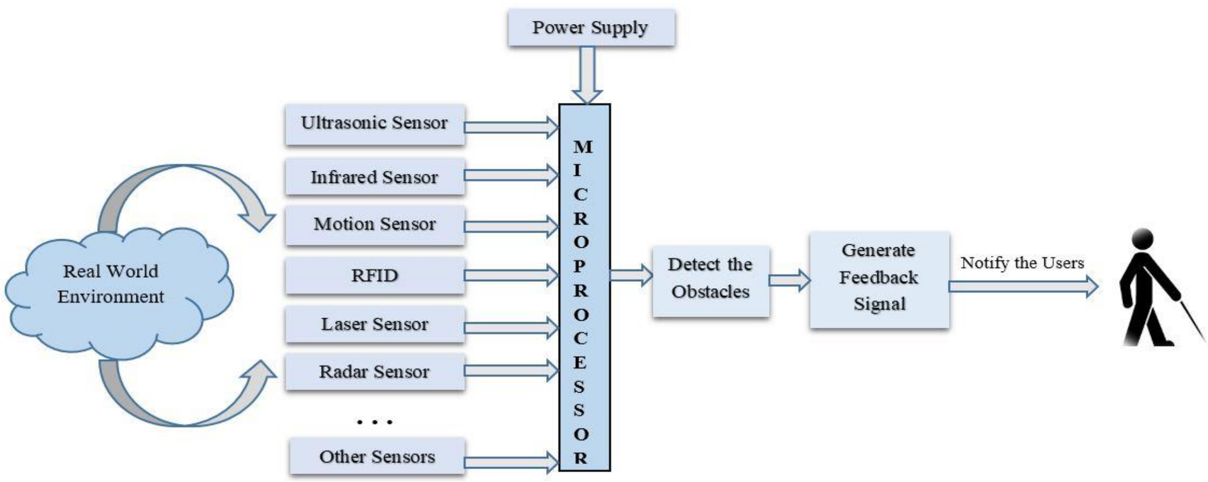


Figure 2.6: System architecture of sensor-based obstacle detection system for the visually impaired people.

Among the different sensors, ultrasonic sensors are widely used. Most of the obstacle detection systems for visually impaired people are developed using ultrasonic sensor [38-47]. Some of the obstacle detection systems are developed on the basis of other sensor-based technology, such as infrared (IR) [6], [48], [49], [50], laser [51], dynamic vision [52], [53], Ubisense compass [54], and time-of-flight distance [55] sensors. The system developed by different types of sensors are reviewed and these are outlined in brief as follows.

(I) Radar-based Navigation Device

Cardillo et al. [7] proposed an electromagnetic sensor device using a microwave radar that aids visually impaired people by notifying the presence of obstacles in the way. The system comprises TX and RX antennas and stigma. The TX and RX antennas are connected to the transceiver board. The target distance is calculated by digitizing and applying the Fourier transform on the output of the homodyne receiver. The laboratory prototype of the system is depicted in Figure 2.7. The system is noise tolerant and small in size. However, the subunits of the system are not integrated into a single circuit board and cover a short range of radar system.

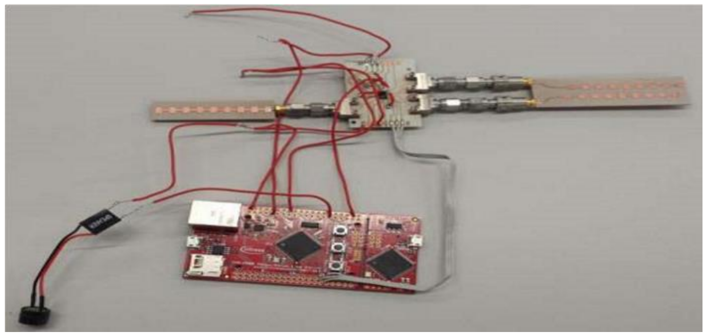


Figure 2.7: A laboratory prototype of the system proposed in [7].

Kwiatkowski et al. [56] investigated a radar-based navigation tool for blind people in unfamiliar surroundings. The tool perceives the environment information and transfers the distance into an acoustic signal that is used as feedback. The sensor includes Frequency Modulated Continuous Wave (FMCW) radar with a center frequency and bandwidth of 80 GHz and 24 GHz, respectively. The system is partitioned into three parts. The data are collected through the sensor unit and fed to the processing unit. The initial radar data are evaluated and compared with the sensor data, and a virtual map of objects is found. The virtual map is converted into a 3D audio signal, which alerts the blind person for the presence of obstacles. The setup of the developed system is illustrated in Figure 2.8. The system is beneficial for visually impaired people for way finding; however, the design of the antenna is a critical issue and makes the system bulky.

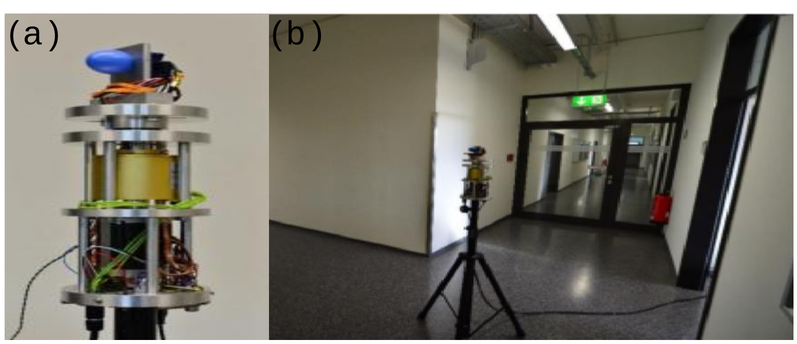


Figure 2.8: (a) 360 degree rotation radar setup. (b) Radar-captured state inside a house [56].

(II) Wearable Navigation Device

Patil et al. [17] proposed an ETA named NavGuide to aid the visually impaired and blind people in their navigation by avoiding the obstacles on the way. The system comprises six ultrasonic sensors, four vibration motors, a wet floor detector sensor, microcontroller circuits, a step-down button, and a battery. The prototype of the NavGuide is shown in Figure 2.9. The ultrasonic sensor emits high-frequency sound waves and calculates the time for the reflected sound waves. The distance of an obstacle is calculated using the speed of the waves and the total time elapsed. The data collected from the environment are sent to the logical map construction unit. This unit includes microcontroller circuits that decide on the position of the obstacles. The wet floor detector sensor senses any fluid dropped on the floor on the users' walkways. The system alerts the users by generating vibration and audio alert signal as feedback. Moreover, the NavGuide can detect knee- and floor-level obstacles, as well as the condition of the floors. However, the system cannot detect human impediments that communicate in the form of motion and touch.

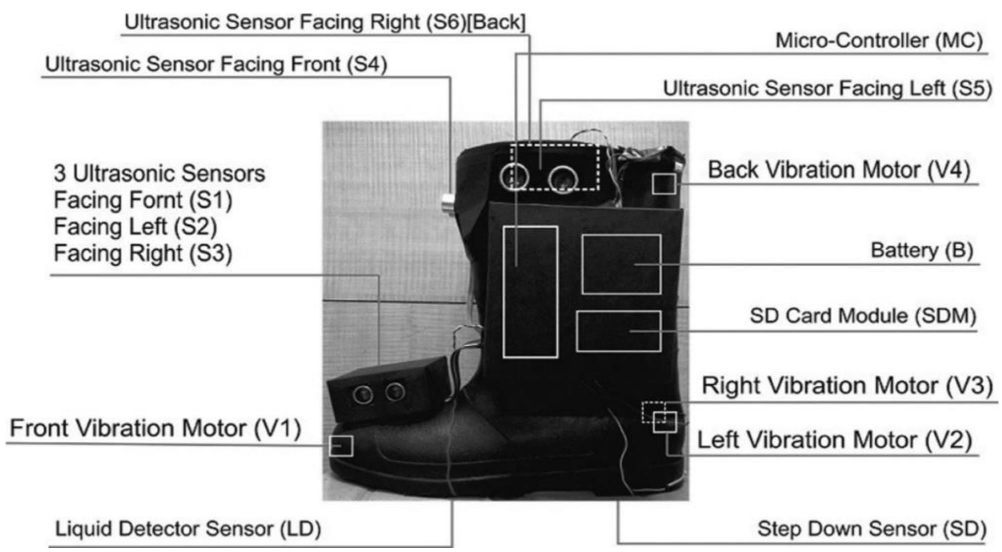


Figure 2.9: A prototype of NavGuide [17].

Bai et al. [57] proposed a new wearable device for aiding visually impaired people to reach the destination and avoid the collisions with obstacles during navigation by using a dynamic subgoal selection strategy. The device consists of a depth camera, a fisheye, an embedded CPU board, an earphone, an ultrasonic rangefinder, and a pair of optical see-through (OST) glasses. The prototype of the proposed system is illustrated in Figure 2.10. The rendering unit generates the audio signal that alerts visually impaired people of the presence of obstacles. The visual simultaneous localization and mapping part builds the virtual-blind-road using the RGB and depth image. The system detects the shortest path from the source to the destination using a point-of-interest graph, which is formed by an A*-based way-finding algorithm. The device proposed by the authors is low cost, small in size, and easy to wear. However, the ultrasonic sensor readings change with temperature and humidity, which may misguide the users.

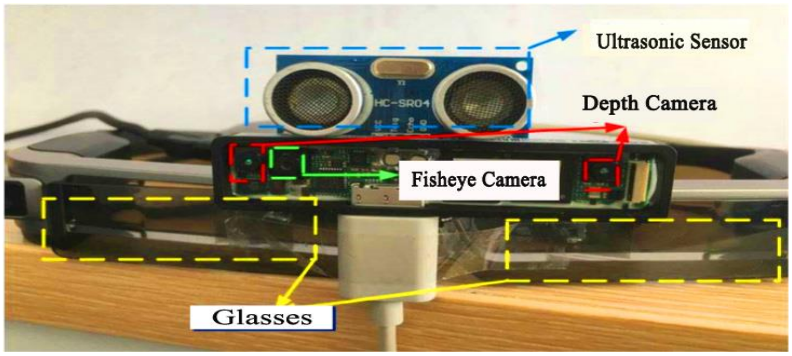


Figure 2.10: A prototype of the navigation tool proposed in [57].

Ton et al. [58] proposed a Light Detection and Ranging (LIDAR) assist sensing system for the visually impaired people which provide the spatial information to these individuals using a LIDAR sensor and the feedback signal is achieved through stereo sound. The wearable prototype of the developed lass system is shown in Figure 2.11. The system is able to detect obstacles in different angular direction and horizontal distance. However, the system cannot return better signal in case of body movement and needs long time training for usability.

Figure 2.11: Participants wearing the LIDAR assist spatial sensing system and equipped with a laser pointer [58] .

A. J. Ramadhan [59] proposed a wearable system for the visually impaired people to aid them in walking through streets, public places etc. The system comprised of microcontroller board, Global System for Mobile communications (GSM) and Global Positioning System (GPS) modules, various sensors, buzzer and a solar panel. The wearable prototype is depicted in Figure 2.12. The system used ultrasonic sensor to detect the obstacles on the track and notified the users through alarm generated by buzzer. The users can send a phone message along with their location to their family members when they are in stumbles. However, the system cannot detect the presence of water and fire, potholes and staircases as well as head level obstacles.

Figure 2.12: User wearing the prototype as proposed in [59].

Rizvi et al. [60] presented a technique for blind people, which can be helpful in their daily living by detecting the obstacles using voice feedback and haptic. The system is used by blind people for navigation and locate their position using global positioning system (GPS) and global system for mobile communications (GSM). The main hardware components used are sequentially as follows: Arduino UNO, sonar sensor, LV-MaxSonar-EZ, VoiceBox Shield, GSM SIM900 and

GPS modules, and Buzzer and DC motor. The final prototype of the system is depicted in Figure 2.13. In the described scheme, the microcontroller sends a signal to the ultrasonic sensor, and the sensor transmits the command and receives a pulse in the form of Pulse Width Modulation (PWM). Meanwhile, the microcontroller calculates the distance of obstacles and generates an alert signal using alert modules. The technique does not only provide information on the obstacles but also locates the user position. However, the weight and size of the wearable globe become comparatively large.

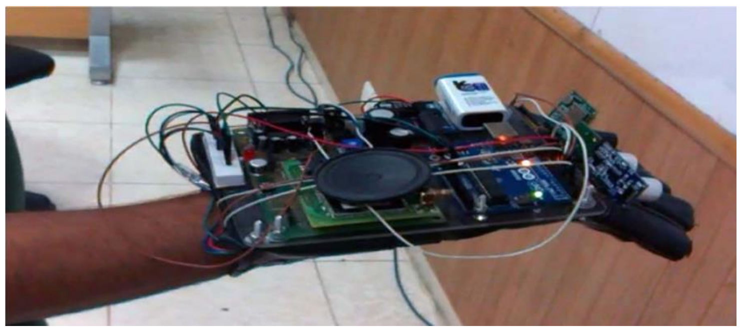


Figure 2.13: The final prototype of the wearable glove [60].

Prattico et al. [61] developed an ETA using IR–ultrasonic sensors to aid visually impaired and blind people in their navigation. The system consists of two IR sensors, an ultrasonic sensor, a microcontroller, and four vibrating motors. The microcontroller is used to receive the input signs and decide. The vibrator motors are used to reply feedback signs to the user with the presence of obstacles. All the apparatuses are combined in a belt. The initial prototype and human-device positioning are depicted in Figure 2.14. Although, the device is comfortable, it is not wearable. Moreover, the system can detect positive and negative obstacles.

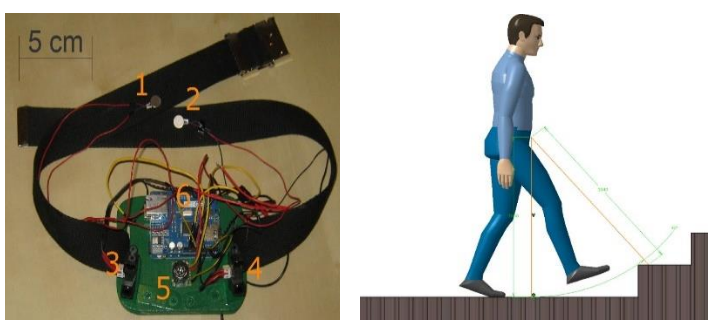


Figure 2.14: (a) Initial prototype: vibrating motors, infrared sensors, ultrasonic sensor, microcontroller are denoted by 1, 2, 3 and 4, 5, 6 respectively (b) Human-device positioning [61].

Vera et al. [62] proposed a framework called Blind Guide for visually impaired people to navigate them in interior and exterior environment using wireless sensor networks. The system consists of various wireless sensors that can be utilized in various portions of the body. The sensors can detect obstacles and provide an audio signal as feedback. The hardware components used in the scheme are external sensor; ultrasonic sensor; Wi-Fi microcontroller; and a central device that includes a camera module, a Raspberry Pi, and a speaker. An audio signal is sent to the central device when an object is detected. The primary device then captures an image of the object with the aid of the camera module, and the image is sent to the cloud image recognition service. The central device prototype and the volunteer test cases are depicted in Figure 2.15. The system can identify chairs, tables, doors, walls, and ordinary objects in the interior environment and avoid the common obstacles in the exterior environment. However, the system cannot label the images for processing.

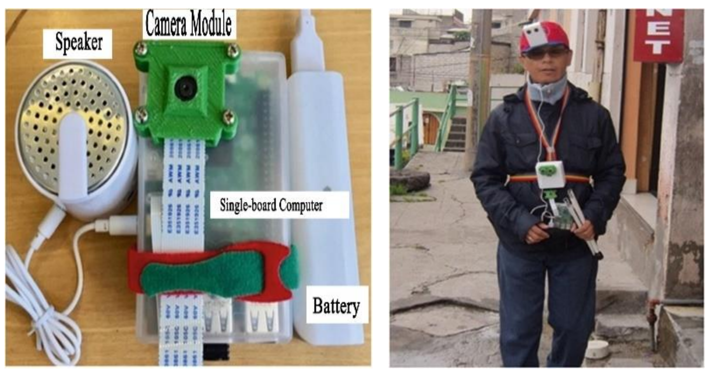


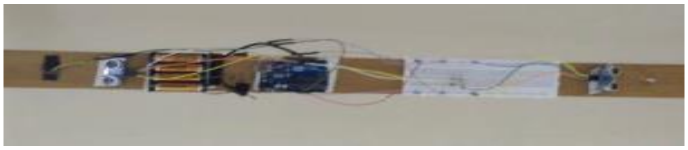
Figure 2.15: (a) Central device. (b) A volunteer tries the model of the Blind Guide [62].

Tsirmpas et al. [63] proposed an excellent and sophisticated construction of an indoor navigation system for visually impaired people. The system can detect the position of the user and provide suggestions for self-movement by perceiving the obstacles from the surroundings. The system uses Bluetooth, ultra-wide band, Wi-Fi, or radio frequency identification (RFID) technologies. The information from the environment is gathered through micro-electromechanical sensors (MEMS), and the data are processed using microcontroller ATmega328. The system covers a distance between 1 m and 2 m in indoor surroundings. The wearable module is presented in Figure 2.16. The system can localize the position of the user and detect the obstacles in indoor environments. However, it does not work in outdoor environments because the RFID tags provide a small range of coverage.

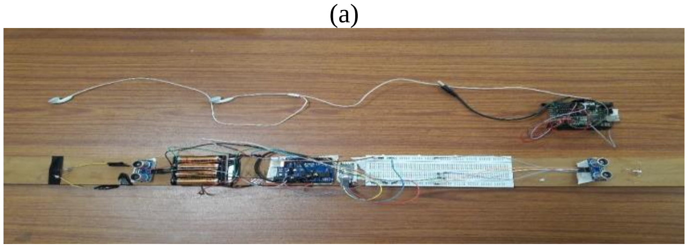
Figure 2.16: The wearable prototype in testing case as shown in [63].

(III) Smart Stick

Sharma et al. [64] developed a smart stick that is low cost but durable and assists visually impaired people in their movements. The stick provides pure knowledge about the distance and the location of the obstacle through vibration and audio in hand and ear, respectively. Bluetooth dongle has been used to establish a connection between the earphone and the smart stick. The proposed scheme can detect static and dynamic obstacles, downstairs, and upstairs. The main hardware components used in the system are a microcontroller, an ultrasonic sensor, and HC-05 master–slave Bluetooth modules. The simple prototype of the smart scheme is illustrated in Figure 2.17. However, the smart stick cannot detect objects in all surroundings, that is, it can only detect obstacles in front of users, and the error rate becomes high with the increment in distance.



(a)



(b)

Figure 2.17: (a) Smart stick frame and (b)The connection between stick and earphone as shown in [64].

Kaushalya et al. [65] developed a walking assistant called AKSHI to aid visually impaired people. The system uses Raspberry Pi 2, ultrasonic sensor, GSM module, and RFID reader and tags. The simple prototype of AKSHI with location tracker and stick is presented in Figure 2.18. The RFID reader is attached with the bottom part of the stick that can detect the obstacles using RFID tags. The ultrasonic sensor is placed below the circuit box on the track of 45° angles. Another box, including Raspberry Pi, GSM, and GPS modules, is attached to the stick. A mobile application was also developed to keep track of the user location using GSM and GPS modules. Users can access the GPS location interface that displays the current location of the visually impaired. However, the RFID tags work within a short range, and the stick cannot work in dirty and muddy environments.

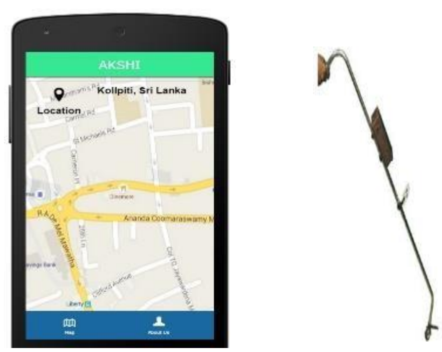


Figure 2.18: (a) The AKSHI location tracker. (b) The prototype of the AKSHI stick [65].

(IV) Electronic Mobility Cane

Aljahdali et al. [66] proposed a smart assistive walker device that decreases the risks of accidents of the visually impaired people. The hardware parts of the system are sensor, controller, output and the software part of the system are "Map" and "Find Me" Apps. The sensors collect the real time data and when the system detects an obstacle, the controller sends it via IoT signal to the output to avoid collision. However, the system is not able to measure the distance from the user to obstacle and unable to alert the authority. Andò et al. [67] developed a haptic tool to provide the notification to the visually impaired people with the presence of obstacles. The system is integrated with short cane, ultrasonic sensors and vibration motors. The sensitivity of the right, left and center positions obstacles are achieved 0.830, 0.735 and 0.803 respectively whereas the specificity are 0.827, 0.924 and 0.835 individually. The system is tested with few number of trials.

Bhatlawande et al. [16] proposed an electronic mobility cane for way finding and obstacle detection of visually impaired people. The system constructs a logical map of the surroundings and maintains them based on priority. The system provides the priority information to users by using feedback signals, such as voice, vibration, or audio, and detects staircase and floor statuses. The system consists of ultrasonic sensors, liquid, metal detection sensor, wireless transceivers, battery, and microcontroller circuits. The prototype of the proposed mobility cane is illustrated in Figure 2.19. Furthermore, the system collects and categorizes the information of surroundings. However, the system cannot identify overhanging obstacles and requires excessive training that might be expensive for visually impaired people.

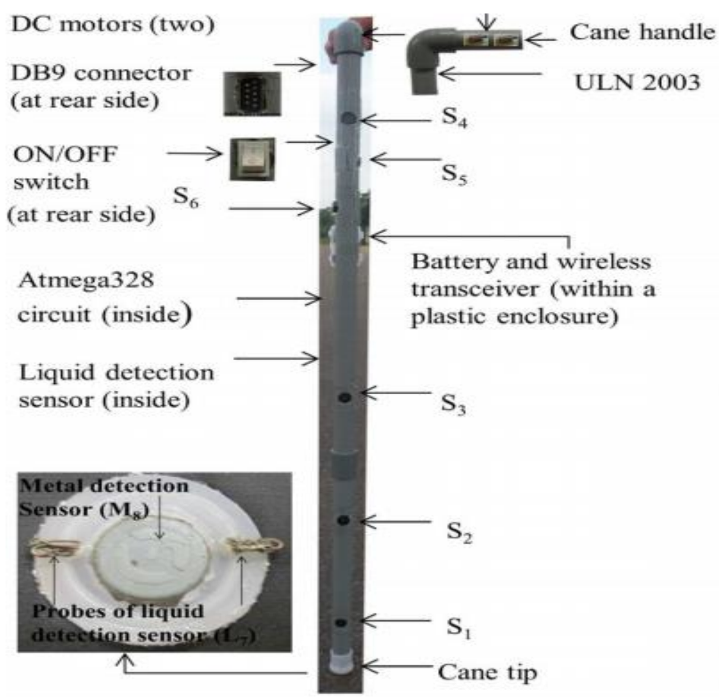


Figure 2.19: Assembling of the hardware components of the cane proposed in [16].

O'Brien et al. [68] discussed a low-cost electronic tool integrated with a conventional cane that provides an alarm signal when obstacles are detected. A custom-built printed circuit board embedded with a microcontroller drives the sensor and the motor. The designed prototype is shown in Figure 2.20. Its weight with battery is approximately 110 g. The system calculates the distance during the notification of obstacles. An alarm signal is generated when the calculated distance is between 0.2 m and 0.6 m, and another signal is generated when the distance is between 0.6 m and1 m. Moreover, the system searches for another obstacle when no obstacles are observed between 0.2 m and 1 m.

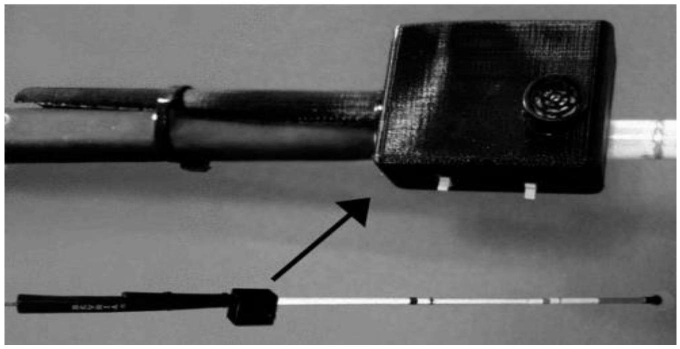


Figure 2.20: The prototype of the electronic travel aid [68].

(V) Smart Virtual Eye

Lee et al. [69] designed a device mounted on a pair of glasses for the visually impaired people using camera and ultrasonic sensors. The system recognized certain color-coded markers within a 15m range using recognition algorithm. The ultrasonic sensors are used to detect obstacles in front, left and right directions. The sensor layout on the actual glasses is drawn in Figure 2.21. The detection rate for obstacles is achieved about 80% and 70% for normal and faster speed respectively. However, the system has a tradeoff alongside the power demand.

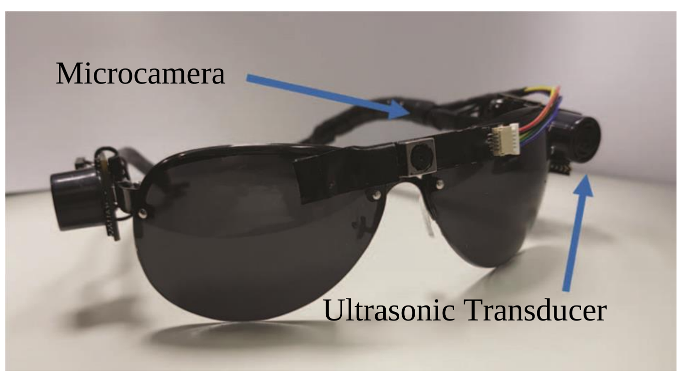


Figure 2.21: The sensor layout on the actual glasses [69].

Khan et al. [70] developed a mini hand-carrying device that can be used as an alternative of smart stick/cane. The system can detect the obstacles, manholes as well as potholes and notified the users by alarming buzzer. The system used Arduino UNO, two sonar sensors, two buzzers, 9v battery and a voltage converter. The finally implemented system is shown in Figure 2.22. However, the performance of the system has not been assessed by the blind users.

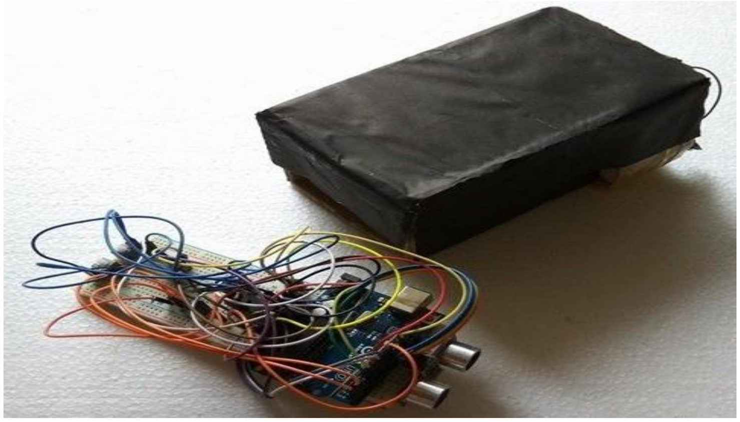


Figure 2.22: A pictorial view of the developed system [70].

Sharma et al. [71] developed a smart stick for the visually impaired people in order to provide independent mobility. The system can detect the ground level and knee level obstacles, potholes and staircases. It provides vibration signal with the presence of hindrances. The system is comprised of three sonar sensors, a moisture sensor, two vibration motors, two buzzers and Arduino microcontroller. Figure 2.23 shows smart stick. However, the detection range of pothole is approximately 30 cm which is too small to avoid risks of accidents.

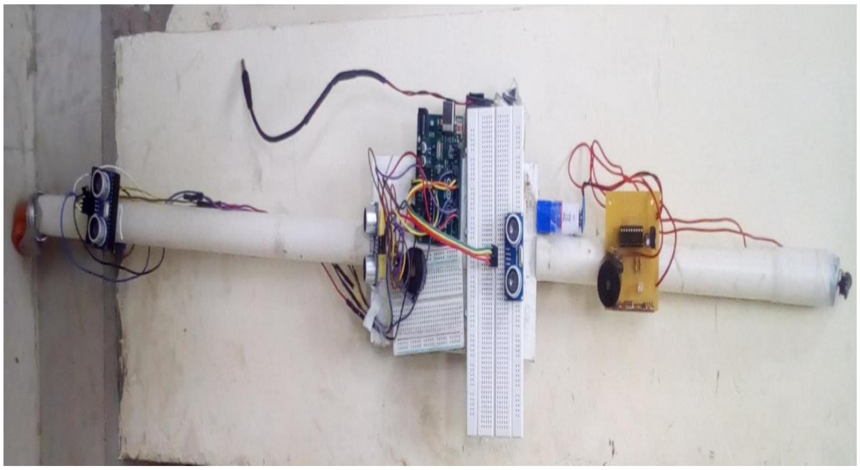


Figure 2.23: Embedded stick proposed in [71].

Zhou et al. [72] developed a smart system called Smart Eye to aid visually impaired people by providing them with information on the surroundings. The system has two modules, namely, embedded wearable sensor and smartphone modules. The wearable sensor module consists of power (9 V DC battery), CPU (32 b mbed NXP LPC1768), sensors (ultrasonic and motion sensors), and communication (Bluetooth or Wi-Fi chip) parts. An Android application was developed to provide distance notification to users that is returned by using an ultrasonic sensor. The embedded module and smartphone communicate through Bluetooth or Wi-Fi. The hardware configuration of the proposed system is shown in Figure 2.24. The developed application is vigorous and detects obstacles at approximately 10 ft away. This process is conducted in a laboratory and cannot interact with the real world along with real-time obstacles.

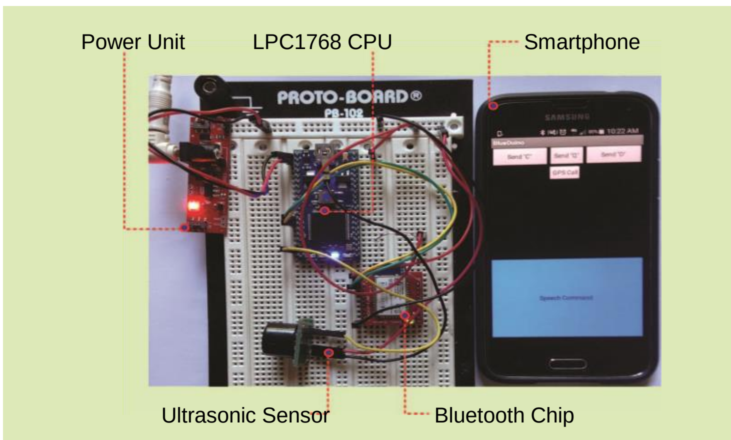


Figure 2.24: Hardware prototype of the system proposed in [72].

Sohl-Dickstein et al. [73] presented a tool called Sonic Eye based on ultrasonic echolocation and spatial hearing principles that aid visually impaired people for their safe mobility. The tool comprises an ultrasonic emitter, stereo microphones, and a wearable headset. The resonance of ultrasonic pulses is noted, and a feedback signal (human auditory range) is then provided to the users with the presence of obstacles. The tool with tested users is illustrated in Figure 2.25. The tool can be used efficiently to observe the surroundings, and the human auditory structure may swiftly adapt to artificial echolocation signals. However, the system is not precisely contactless as the users should wear the echolocation device.

Figure 2.25: Assembling of hardware components as shown in [73].

Bharambe et al. [74] introduced a low-cost and supportive tool for visually impaired people that can be used as an artificial eye. The embedded tool in the proposed system is used to detect obstacles using ultrasonic sensors, and vibrator motors generate the feedback. An Android device is used for navigation. An Android application is used to track the position of blind people using GPS and General Packet Radio Services (GPRS) and guide them in the proper direction. The final prototype of the proposed scheme is shown in Figure 2.26. The system is used to detect and locate obstacles. However, the system is only a prototype in the laboratory.

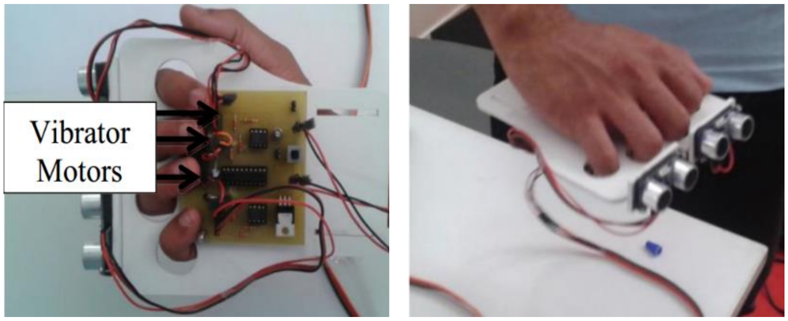


Figure 2.26: The final prototype of the eye substitution device [74].

Table 2.1 summarizes the aforementioned sensor-based obstacle detection system for the visually impaired people and evaluates some of the significant parameters i.e. capturing and feedback devices, major hardware components and its detection/coverage range, weight, and cost-effectiveness.

Table 2.1: Summary of the sensor-based obstacle detection system for the visually impaired people

Authors	Year	Capturing Devices	Feedback Devices/ Types	Major Hardware Components	Coverage Area	Detection Range	Weight	Cost
Cardillo et al. [7]	2018	Radar sensor	Vibrational and/or acoustic warning	TX antenna, RX antenna, Stigma	Indoor and outdoor	1m-5m	A few hundreds of grams	Low cost
Kwiatkowski et al. [56]	2017	Radar sensor	Hearing device	Stepper motor, FMCW radar, slippery ring	Outdoor	N/A	Bulky	High cost
Patil et al. [17]	2018	Ultrasonic sensors, wet floor detector sensor	Vibration and audio signal	Four vibration motor, microcontroller circuits, a step-down button and a battery	Indoor and outdoor	0.26m-3m	Lightweight	Low cost
Bai et al. [57]	2018	Depth camera, ultrasonic sensor	Audio signal	A fisheye, an embedded CPU Board, an earphone, a pair of OST glasses	Indoor	0.26m-1.34m	Less weight	Low cost
Ton et al. [58]	2018	LIDAR sensor	Stereo sound	a computer, a Hokuyo URG-04LX Scanning Laser Rangefinder	Indoor	2m-4m	170 gram	High cost
A. J. Ramadhan [59]	2018	Ultrasonic sensors, Accelerometer	Buzzer, Vibration Motor	Microcontroller board, Global System for Mobile communications (GSM) and Global Positioning System (GPS) modules, various sensors, and a solar panel	Outdoor	0.02m-4 m	Lightweight	High cost
Rizvi et al. [60]	2017	Ultrasonic sensors, Sonar sensors	Buzzer	Arduino UNO, microcontroller, GSM and GPS Module, DC motor	Indoor and outdoor	0.09m- 0.20m	Bulky but wearable	High cost

Authors	Year	Capturing Devices	Feedback Devices/ Types	Major Hardware Components	Coverage Area	Detection Range	Weight	Cost
Prattico et al. [61]	2013	Infrared sensors, ultrasonic sensor	Vibrating motors	Microcontroller, Filters	Outdoor	0.2m-1.5m	Low weight	Low cost
Vera et al. [62]	2017	Peripheral Sensor, Ultrasonic sensors, Camera	Speaker	Wi-Fi microcontroller, Raspberry Pi 3	Indoor and outdoor	1m-2.5m	Bulky	Low cost
Tsirmpas et al. [63]	2015	RFID tags	Voice controller	Microcontroller ATmega8	Indoor	1.2m-2m	Lightweight	Low cost
Sharma et al. [64]	2017	Ultrasonic sensors	Vibration Motor	Microcontroller and Bluetooth modules	Indoor and outdoor	0.05m - 3.5m	High weight	Low cost
Kaushalya et al. [65]	2016	Transducer Sensor	Voice signal	Raspberry Pi 2, 5V-2V Rechargeable Battery, GSM module, RFID Reader, RFID Tags.	Outdoor like as Pedestrian crossing,	0.05m-0.07m	Bulky	Low cost
Aljahdali et al. [66]	2018	Ultrasonic sensor	Piezoelectric speaker	Arduino Uno, ESP8266	Indoor and outdoor	N/A	Lightweight	Low cost
Andò et al. [67]	2015	Ultrasonic sensors	Vibration motors	Microcontroller	Indoor	N/A	Lightweight	Low cost
Bhatlawande et al. [16]	2014	Ultrasonic sensor	Audio, vibration or voice signal	Liquid and metal detection sensor, wireless transceivers, battery and microcontroller circuits.	Indoor and outdoor	1m-4m	Weight (0.503 kg)	Low cost
O'Brien et al. [68]	2014	MB1200 sensor	Pulsed vibration	Microcontroller, motor, 9V battery	Indoor and outdoor	0.2m-1m	110 g	Low cost

Authors	Year	Capturing Devices	Feedback Devices/ Types	Major Hardware Components	Coverage Area	Detection Range	Weight	Cost
Lee et al. [69]	2018	Ultrasonic sensor, microcamera	Audio signal, vibration	Intel Edison board	Indoor	0.02m-4m	Lightweight	Low cost
Khan et al. [70]	2018	Ultrasonic sensor	Alarm generated by buzzer	Arduino UNO, 9v battery and a voltage converter	Indoor and outdoor	0.02m-4m	Lightweight	Low cost
Sharma et al. [71]	2018	Ultrasonic sensor, moisture sensor	Vibration motor and buzzer	Arduino microcontroller, battery	Indoor and outdoor	0.02m-0.70m	Lightweight	Low cost
Zhou et al. [72]	2016	Ultrasonic sensor	TTS	Power, CPU, Bluetooth chip	Outdoor	0.30m-3.04m	Bulky	Low cost
Sohl-Dickstein et al. [73]	2015	Ultrasonic emitter	Stereo microphones	Artificial pinna, ultrasonic microphone and speaker, chirp	Outdoor	N/A	Heavy weight	High cost
Bharambe et al. [74]	2013	Ultrasonic Sensors	Vibrator Motors	Microcontroller, register divider, op-amp, 5V power supply, Oscilloscope, and voltage regulator	Outdoor	2m – 3m	Lightweight	High cost

***Not Appropriately Defined: N/A**

B. Computer Vision-based Obstacle Detection

At present, computer vision [75-84] has attracted considerable attention for the development of different types of obstacle detection system for visually impaired people. The systems developed based on computer vision technology provide exact services but the response time is comparatively high. The system architecture of computer vision-based obstacle detection system for visually impaired people is shown in Figure 2.27. In these approaches, different types of camera are used to capture the images from real-world environment, and computer vision-based algorithms are used to detect obstacles. However, computer vision-based systems are affected with soft real time.

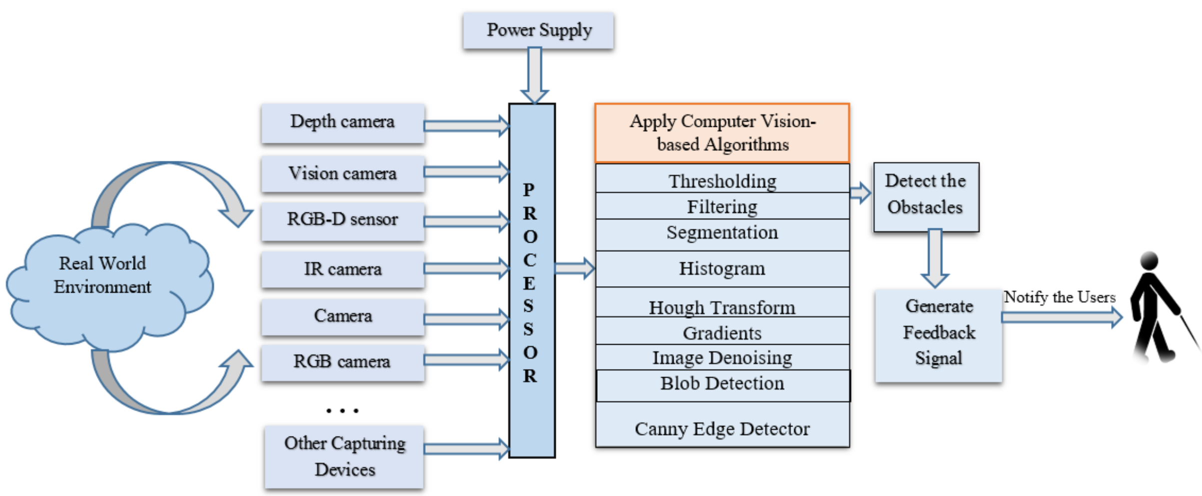


Figure 2.27: System architecture of computer vision-based obstacle detection system for the visually impaired people.

A hard-real time system guarantees that critical tasks are completed on time, whereas a soft real-time system prioritizes a critical real-time task over other tasks and retains that priority until its completion. A computer vision system requires time to capture images, process the images, and generate an alert signal. However, a hardware system uses the input from the real-time environment and provides the results within a few instances. Result analysis requires time to solve the problem, which should be considered. The obstacle detection systems developed based on computer vision technology in recent years are as follows.

(I) Wearable Navigation Tool

Mancini et al. [85] introduced a monocular vision-based system to aid visually impaired people in walking, running, and jogging. The authors presented some algorithms to extract lines/lanes to follow. The wearable prototype of the proposed system is illustrated in Figure 2.28. The system comprises a camera, a board, and two gloves equipped with vibration motors. The system detects the right track with speed greater than 10 km/h by using the gloves. An RGB camera captures the images, a processing unit processes the images and extracts the lines/lanes, and a haptic device generates an alert signal and provides the command to users to move left or right. However, the system is unsuitable in crowded scenarios.

Figure 2.28: A wearable prototype of the system proposed in [85].

Pissaloux et al. [5] proposed a system that assists users in walking with obstacle avoidance, orientation, real physical displacement, etc. It is based on the real gist. The system consists of TactiPad for obstacle detection and tactile gist for display. The wearable prototype with users is shown in Figure 2.29. The system is beneficial for the visually impaired people in their mobility in an unfamiliar environment, but the system is comparatively bulky.

Jiang et al. [86] proposed a wearable system to assist the visually impaired people using binocular vision sensors. The images from the real world environment are captured and sent to cloud for computing. The data are processed using convolutional neural network and the results are returned back to the users that can help them in navigation. The system can detects around

10 objects. The precision and recall obtained by the system are 0.675 and 0.287 which are comparatively low.

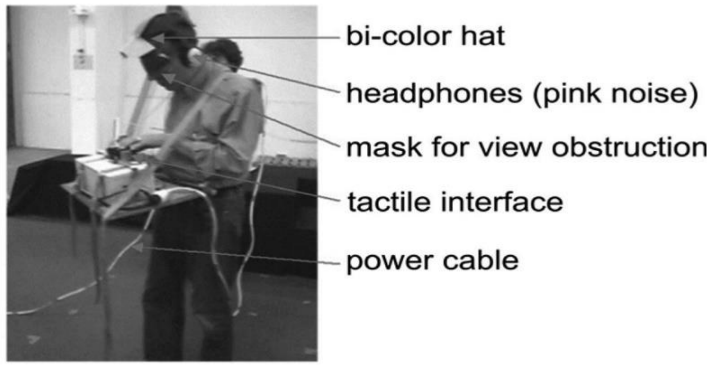


Figure 2.29: Initial prototype with users including all components [5].

Li et al. [87] presented vision- based navigation system to aid the visually impaired people in indoor environment. The system proposed an obstacle detection and avoidance technique with the use of a time-stamped map Kalman filter (TSM-KF) algorithm using RGB-D camera. The users are notified with speech, audio and haptic signal with the presence of obstacles. The system cannot perform at transportation terminals and cognitive mapping.

Ye et al. [88] proposed a navigation tool named as co-robotic cane (CRC) to assist the visually impaired people in navigation. The cane comprised of a 3-D camera, a Gumstix Overo AirSTORM COM computer and a three axis gyro. The system is able to detect staircases, doorways, tables, computer monitors etc. in indoor environment using Gaussian mixture model (GMM). The prototype of the developed system is shown in Figure 2.30. However, the performance of the system degrades when the swing speed become higher (>30°/s).

Mulky et al. [89] developed an autonomous scooter that can aid the mobility challenges people to navigate individually and securely in unknown environment. The system provides the current location, maps, and nearby obstacle's location to the users. The autonomous scooter prototype is illustrated in Figure 2.31. The system used stereo camera and raspberry pi as sensing and processing device respectively. However, the scooter provides short-range vision-based mapping.

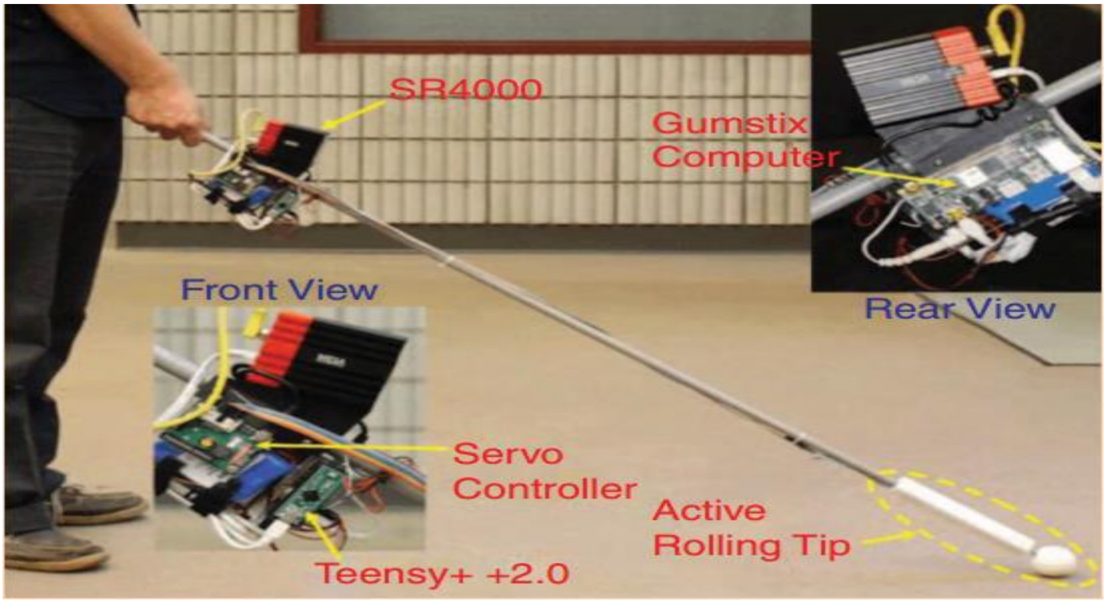


Figure 2.30: The co-robotic cane (CRC) prototype [88].

Figure 2.31: The autonomous scooter prototype [89].

Xiao et al. [90] proposed a low cost system to aid the visually impaired people using raspberry pi. The system used magnetic compass and gyroscope to measure the forward direction of the users. In addition, the users can provide input their address through a microphone. The device is light weight and wearable at waist. The overall production cost of the proposed system is approximately $138. The system provides 3-D sound as a feedback signal. However, the system cannot recognize landmarks and the position as well as the velocity of the users is not addressed in here.

Aladrén et al. [18] introduced a novel navigation system for blind or slightly blind people by using an RGB-D camera that collects visual and range information from the surroundings. The developed system not only detects obstacle-free paths but also classifies them, which is valuable for the safe navigation of visually impaired people. The sound map created by stereo beeps and voice commands is used as a feedback signal to alert the users with the presence of obstacles. The system uses a floor-based segmentation technique. The setup of the proposed scheme is shown in Figure 2.32 where the camera hangs from user's neck and the laptop is in users backpack. The developed tool is light and easy to wear for blind people. However, the system only operates in indoor environment, and its performance is degraded in sunlight, that is, during daytime because the readings of RGB-D camera vary with sunlight.

Figure 2.32: A wearable device with users [18].

Khade and Dandawate [91] developed an obstacle detection framework for the visually impaired people in unknown surroundings using Raspberry Pi. The system perceived the obstacles in the ROI without the help of cameras. The hardware used in this scheme is 'Raspberry Pi 2-B', a wearable camera with 5MP resolution and the overall system is simulated in MATLAB as well as Python language. The authors generated the database by visiting a school for the blinds. The database is retrieved by capturing the video of the blind head, and approximately 25 videos are taken for the research purpose. The database is converted into a video frame initially, and the motion vectors are used for the obstacle detection. The segmentation is done using background subtraction procedure. Finally, the Region of Interest (ROI) is created to detect the obstacles. The captured frame and the corresponding ROI are illustrated in Figure 2.33. The system is cost-effective and has lesser weight, but the illumination and brightness situations are constant. However, in the real-world scenario, these properties change frequently. So, the prototype is not compatible with the real world. The system can detect the obstacles only, but is not able to categorize them.

(a) (b)

Figure 2.33: (a) The setup of the line of sight camera (b) Corresponding Region of Interest as shown in [91].

Kammoun et al. [92] developed a system called NAVIG project to aid visually impaired people. The system localizes particular objects in the surroundings. It is composed of stereoscopic cameras, GPS, sensors, microphone, headphones, and a computer stored in a backpack. The system also uses a head-mounted stereoscopic camera to capture images from the environment. The captured images are processed by using machine learning approaches, such as object localization algorithms. The prototype and system testing for NAVIG are shown in Figure 2.34. The NAVIG operates under indoor and outdoor environments.

(a) (b)

Figure 2.34: (a) Prototype including all hardware components (b) Initial system testing in outdoor environment as shown in [92].

(II) Smart Guiding Glasses

Yang et al. [93] proposed a wearable tool that utilizes pixel-wise semantic segmentation to aid visually impaired people. The system notifies individuals about traversable areas, stairs, water hazards, and sidewalks. In addition, the prototype avoids fast-approaching pedestrians, short-range hindrances, and vehicles. The system uses an in-depth learning approach with an encoder that generates down-sampled feature maps and a corresponding decoder that up-samples the feature maps to match the input resolution. ADE20K dataset, which incorporates indoor and outdoor images, is used to train the system. The system comprises an IR camera, an RGB camera, and a RealSense image processor. The prototype of the system with users testing is illustrated in Figure 2.35. However, the system cannot work in zebra crosswalks, traffic lights, hazardous curbs, and water puddles.

Figure 2.35: Prototype with users testing in real time scenario proposed in [93].

Bai et al. [94] developed a smart guiding tool similar to an eyeglass to aid visually impaired people for their safe movement. The system comprises a pair of display glasses and some developed sensors that are cost effective. The developed system comprises a depth camera to gather information from the surroundings, ultrasonic sensor and microprogrammed control unit for obstacle distance measurement, and a CPU for image processing and sound analysis. The initial prototype is shown in the Figure 2.36. Audio instructions are provided as feedback with the presence of obstacles. The system is evaluated in home, office, and supermarket environments. The proposed glass is efficient and supports the eye vision of visually impaired people in indoor environment. However, the system cannot provide the location information and does not have way finding and way-following functionalities.

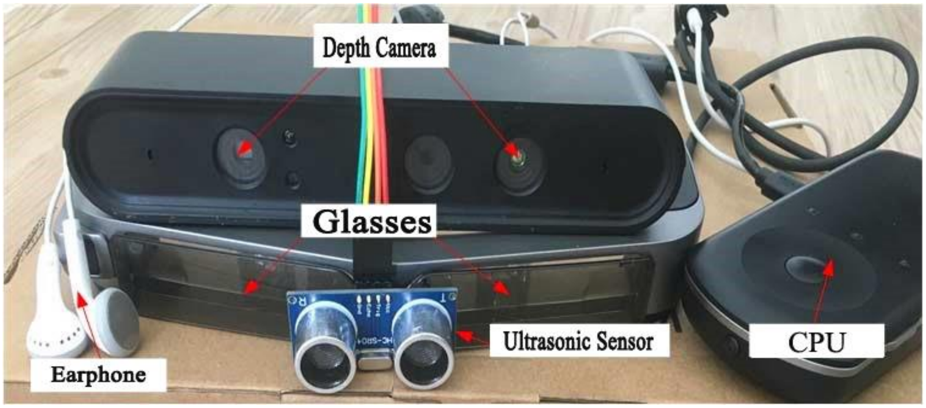
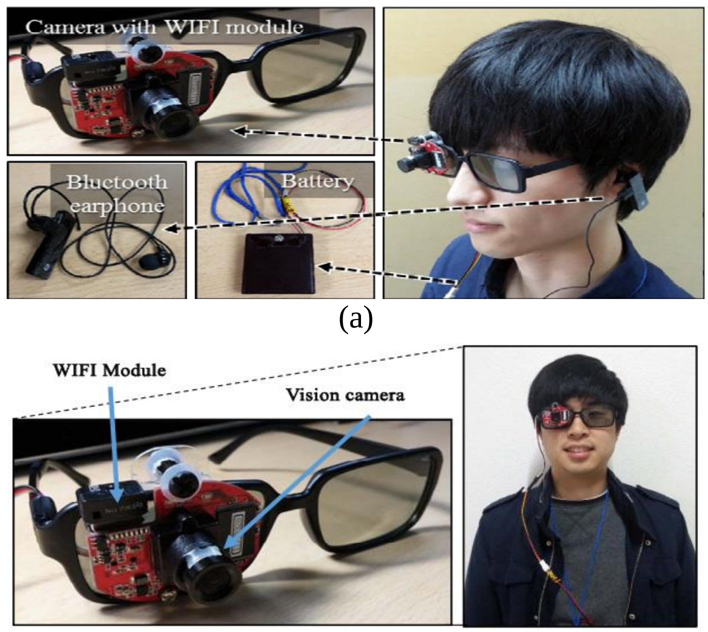


Figure 2.36: A prototype of the system proposed in [94].

Sareeka et al. [95] developed a wearable device named as pseudoEye that captures the texts from the environment and converts it to voice signal which is delivered to users. The system used a mini camera, a push button, raspberry pi and a SoC (System on Chip) attached to a cap. The raspberry pi captures the data from the environment using camera and extracts texts from the images and generates voice signal corresponding to texts. A portable power bank is used to power on the raspberry pi. The final setup of the proposed system is shown in Figure 2.37. However, the system can recognize few numbers of texts and fails to detect handwritten character.

Figure 2.37: The final setup of the system proposed in [95].

Kang et al. [96, 97] proposed a new obstacle detection modality in a deformable grid (DG) structure to aid visually impaired people. The proposed modality perceives an obstacle in danger of a crash due to the level of DG deformation. The system uses a vision camera that captures video sequence with 320×240 resolution at 30 fps. The captured sequences are sent to a laptop via a Wi-Fi module. The system notifies the users of the obstacle's position before 2 s. The output signal is conveyed to the user's earphone by using a Bluetooth module. In [96], the authors used a vertex deformation function to improve the performance of a previous work [97] in terms of accuracy and processing time. The wearable prototype is shown in Figure 2.38. The developed method is comparatively better than the previous one. However, the system cannot detect obstacles that are closed to a door or a wall.



(a)

(b)

Figure 2.38: (a) Wearable vision camera module proposed in [96] (b) Wearable vision camera module proposed in [97].

Yang et al. [98] also proposed a wearable prototype to assist visually impaired people by using an RGB-D sensor and an Intel RealSense R200 that expands the detection of the traversable area. An RGB image-guided filtering is used to enhance the real sense of the depth image. In addition, random sample consensus segmentation and surface normal vector estimation are used to cover the traversable area. The system comprises RealSense R200, IR camera, RGB camera, processor, attitude sensor, and bone-conducting headphone. The wearable prototype of the proposed system is shown in Figure 2.39. The proposed wearable prototype operates on indoor and outdoor environments. However, its operation is not optimized because the proposed wearable prototype has low speed and only covers a short area.

Figure 2.39: Wearable prototype with visually impaired volunteers proposed in [98].

(III) Eye Sight

Mekhalfi et al. [99] developed a prototype for blind people that automatically moves and recognizes objects in indoor environment. The system is integrated into a module with a headset, camera, marker, inertial measurement unit (IMU), and laser sensors that are positioned on the user's chest. The system is divided into different modules, such as egomotion, path planning, object detection, and object recognition modules. Communication between the prototype module and users is performed through speech recognition and synthesis modules. The system uses machine learning approaches for recognition. On this basis, some image datasets are trained with machine learning approaches. The laser sensor provides information about the distance to be covered. The camera captures the scenes and sends it for navigation or recognition. The portable device prototype is shown in Figure 2.40. The prototype module avoids static and dynamic obstacles.

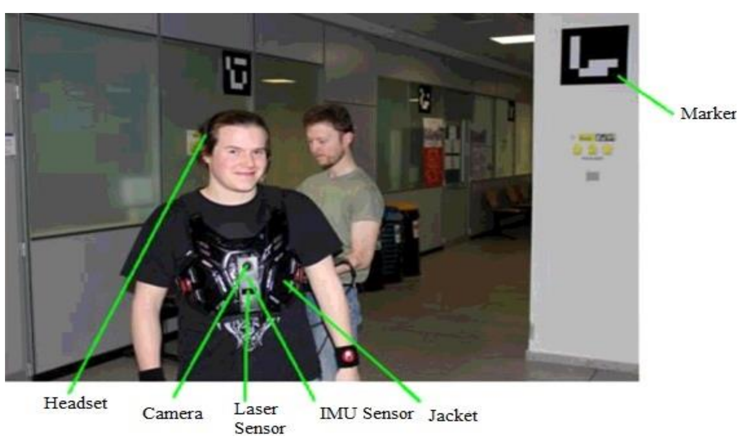
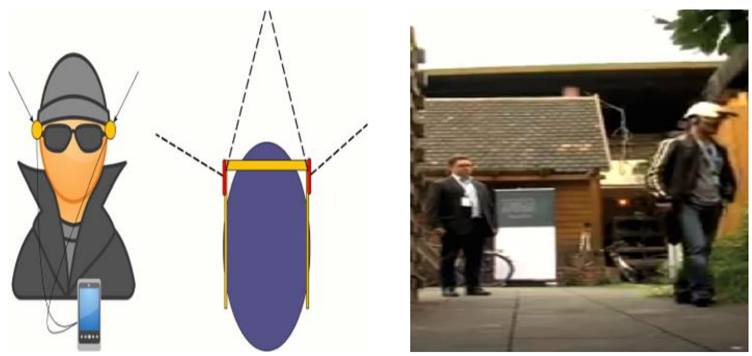


Figure 2.40: Hardware components of the portable device as shown in [99].

Sövény et al. [100] designed a wearable tool to aid visually impaired people in interior and exterior navigations by perceiving the environment. The system can detect traffic lamps, street crossings, cars, and other obstacles located on the street. The scheme uses real-time data by using camera and sensors and generates audio signals with the presence of obstacles. The simple prototype for the capturing images is shown in Figure 2.41. A motion vector is used to identify the obstacles. A label based on the key track of the obstacle is acquired by fitting a route on the basis of the obstacle's size, movement speed, and its location in the image. A slow movement speed is recognized as a pole by using a vertical key track. An object with a fast movement speed and same property as before is recognized as a passerby. An obstacle with horizontal key track and high motion vector is recognized as a vehicle. The data processing unit (DPU) in the current prototype is limited to video inputs, and the system is loud and obsolete.



(a) (b)

Figure 2.41: (a) Image capturing scenario using head-mounted cameras. (b)Testing the prototype in public place [100].

Table 2.2 summarizes the aforementioned computer vision-based obstacle detection system for visually impaired people and evaluates some important parameters, such as capturing and feedback devices, major hardware components, and their detection/coverage range, weight, and cost-effectiveness.

Table 2.2: Summary of the computer vision-based obstacle detection system for the visually impaired people

Authors	Year	Capturing Devices	Feedback Devices/ Types	Major Hardware Components	Coverage Area	Detection Range	Weight	Cost
Mancini et al. [85]	2018	Camera	Vibration	BLE device and vibration motor	Outdoor	2–3 m	Lightweight	High cost
Pissaloux et al. [5]	2017	Camera	Discrete tactile	TactiPad, headset, tactile gist	Indoor	0m-6m	200g	High cost
Jiang et al. [86]	2018	Binocular vision sensors	Audio	Cloud computer	Outdoor	N/A	Lightweight	High cost
Li et al. [87]	2018	RGB-D camera	Speech-audio interaction	Google Tango device	Indoor	N/A	Lightweight	Low cost
Ye et al. [88]	2016	3-D camera	Vibration	Gumstix Overo AirSTORM COM computer and a three axis gyro	Indoor	N/A	Lightweight	High cost
Mulky et al. [89]	2018	Stereo camera	Vibration	Inertial Measurement Unit, Proportional Integral Derivative (PID) controller	Indoor	7m-10m	Lightweight	Low cost
Xiao et al. [90]	2013	Magnetic compass and gyroscope	3-D signals using audio bone headphones	Raspberry pi, Bluetooth, GPS receiver	Indoor and outdoor	N/A	Lightweight	Low cost
Aladrén et al. [18]	2016	RGB-D sensor	Stereo beeps and voice commands	Laptop	Indoor	0–3 m	Lightweight	Low cost
Khade and Dandawate [91]	2016	Camera	Vibration	Raspberry Pi 2-B	Indoor and outdoor	N/A	Less Bulky	Low cost
Kammoun et al. [92]	2012	Stereoscopic cameras	Audio-augmented reality	GPS, sensors, microphone, headphones, and laptop equipped with an Intel i7 quad-core processor	Indoor and outdoor	N/A	Bulky	High cost

Authors	Year	Capturing Devices	Feedback Devices/ Types	Major Hardware Components	Coverage Area	Detection Range	Weight	Cost
Yang et al. [93]	2018	RGB and IR cameras	Stereo sound and audio signal	RealSense image processor and bone conduction headphones	Indoor and outdoor	N/A	Lightweight	Low cost
Bai et al. [94]	2017	Depth camera and ultrasonic sensor	Audio signal	Microprogrammed control unit and embedded CPU	Indoor	0.952–2.692 m	Lightweight	Low cost
Sareeka et al. [95]	2018	Mini camera	Voice signals	Raspberry pi, power bank	Indoor	N/A	Lightweight	Low cost
Kang et al. [96, 97]	2017, 2015	Vision camera	Stereo	Bluetooth chip, Wi-Fi module, laptop, and earphone	Indoor and outdoor	N/A	Bulky	High cost
Yang et al. [98]	2016	RGB-D sensor and IR camera	Audio signal	RealSense R200, processor, attitude sensor, and bone-conducting headphone	Indoor and outdoor	N/A	Lightweight	Low cost
Mekhalfi et al. [99]	2016	Camera and IMU sensor	Speech synthesis module	Dell laptop with 4 GB RAM	Indoor	N/A	Lightweight	Low cost
Sövény et al. [100]	2015	Logitech QuickCam Pro 9000 USB cameras	Audio module	Laptop computer with Intel Core i5 3210M 2.5 GHz processor and 8 GB RAM	Indoor and outdoor	N/A	Lightweight	Low cost

***Not Appropriately Defined: N/A**

C. Smartphone-based Obstacle Detection

The advancement of smartphones has created a new era of research in different fields. Currently, smartphones have become common toward nearly all types of people. Thus, obstacle detection systems developed based on smartphones [101-110] are comparatively easy and comfortable. The system architecture of smartphone-based obstacle detection system for visually impaired people is shown in Figure 2.42.

In these approaches, different types of smartphone camera or sensor are used to capture data from real-world environment, and the processors of smartphone are used to process the data and generate alert signals in detecting obstacles/objects. The obstacle detection systems developed based on smartphones are as follows.

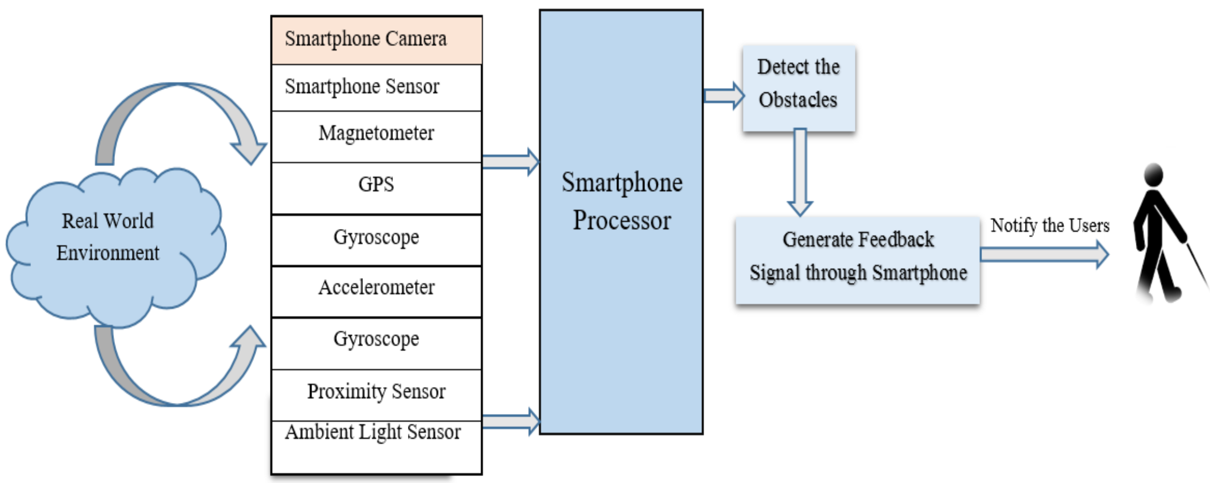


Figure 2.42: System architecture of smartphone-based obstacle detection system for the visually impaired people.

(I) Guide Beacon

Cheraghi et al. [111] developed a system called Guide Beacon, which can be used for indoor way finding of visually impaired people to assist them in navigation within interior surroundings. The working procedure of the system is illustrated in Figure 2.43. A smartphone application declares the name of interior space and directs the user in the desired goal for the first time. However, the system is not wearable similar to spectacles, and Guide Beacon is not configured with respect to users' demand.

(a) (b)

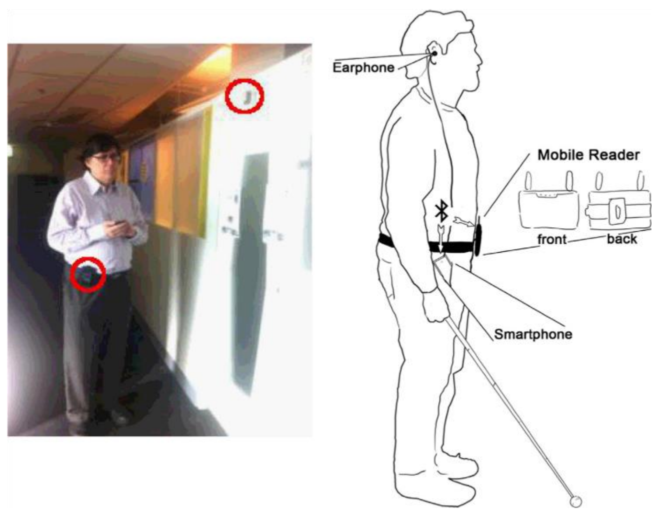
Figure 2.43: Guide Beacon. (a) Navigation using cane (b) Navigation using guide dog [111].

(II) Head Mounted Device

A smartphone-based navigation system for blind people was presented in [112]. The system utilizes MEMS that are integrated in a smartphone. Other sensors are also used to perceive information from environments. The smartphone communicates with external modules through Bluetooth and Wi-Fi. Communication between users and mobile application is performed through TTS. A battery with 3800 mAh rating is attached to the smartphone as a backup, and external sensors are connected with a solar charged battery with 5600 mAh rating. The testing issues in outside environment are shown in Figure 2.44. The proposed portable system is efficient, low cost, and small in size. The application enables book reading, easy setup of phone calls, and date and time searching. However, the proposed system is not evaluated in buildings and outdoor environments.

Figure 2.44: Test cases in exterior surroundings as shown in [112].

Alghamdi et al. [113] presented a novel technique for visually impaired and blind people to aid them in their indoor and outdoor navigations by demonstrating their position and guiding them to reach their goal. The system is based on RFID technology and approximately covers 0.5 m distance. The system aids in finding offices, laboratories, and theaters. The system comprises a smartphone, a mobile RFID reader, and an earpiece. The RFID reader is linked to the smartphone through Bluetooth. Communication between the smartphone and RFID reader is performed through Wi-Fi to obtain tag locations. The positioning diagram of the system is illustrated in Figure 2.45. The successful detection rate obtained by the system is 93.5%, and the false positive rate is only 1%. However, RFID tags work within a short range. Thus, users cannot obtain an alert signal for obstacles that are in long distances.



(a) (b)

Figure 2.45: (a) System components with mobile reader and tags (b) Components position diagram proposed in [113].

Nakajima and Haruyama [114] proposed an indoor mobility system for blind people. A visible light ID is transmitted to a portable tool that is worn by a blind person through LEDs. The ID receives the latitude and longitude information for blind people. The system is evaluated in an interior navigation system by using LED lights and a geomagnetic sensor combined with a smartphone. The prototype of the system is shown in Figure 2.46. The test outcomes show an accuracy of 1–2 m acquired by the proposed framework. However, an accuracy detection method of the system is not well-defined.

Figure 2.46: Test Prototype device proposed in [114].

Table 2.3 summarizes the aforementioned smartphone-based obstacle detection system for visually impaired people and evaluates some important parameters, such as capturing and feedback devices, major hardware components, and their detection/coverage range, weight, and cost-effectiveness.

Table 2.3: Summary of the smartphone-based obstacle detection system for the visually impaired people

Authors	Year	Capturing Devices	Feedback Devices/ Types	Major Hardware Components	Coverage Area	Detection Range	Weight	Cost
Cheraghi et al. [111]	2017	Camera	Smartphones	Beacon	Indoor	N/A	Light-weight	Low cost
Ţepelea et al. [112]	2017	Camera and MEMS sensors	Audio module	Light sensor, orientation sensor, GPS sensor, accelerometer, GSM module, Arduino nano, and Raspberry Pi board	Indoor and outdoor	N/A	Light-weight	Low cost
Alghamdi et al. [113]	2014	RFID tags	Audio of tag locations	Mobile reader and smartphone	Indoor and outdoor	0–0.5 m	Light-weight	High cost
Nakajima and Haruyama [114]	2013	Geomagnetic sensor	Feedback sound	LED lights and headphone	Indoor	1–4 m	Heavy-weight	High cost

***Not Appropriately Defined: N/A**

2.3.2 Pothole Detection System

A suggestion from orientation and mobility experts is [115] that there is an absence of tools to distinguish pothole and uneven asphalts which restrains safe mobility. Potholes are the primary cause of accidents, hence identification of it is very important. The systems that are developed for pothole detection are outlined as follows.

Ponnada et al. [116] proposed a manhole and staircase detection system for the visually impaired people that can help the individuals to avoid the manhole and staircase in the way of walking. The system used the ultrasonic sensor for the detection of manhole and staircase, and computer vision-based technique also used to detect the hindrances. The SURF algorithm extracts the features from the real-time images, and Bivariate Gaussian Mixture Model (BGMM) is used to detect the staircase and manhole. The main components used the scheme are Arduino Kit, ultrasonic sensor, vibrator, HC-05 Bluetooth and camera. The proposed device is small and lightweight and will be effective for the blind and deaf people as the system will give notification to these about the current position they are in right now and give direction to them about the stairs. However, the system may faultier in the dark or in a place where there is so much sound. The system fails to categorize the moving obstacles in case of staircase detection. Madli et al. [117] presented an automatic pothole and humps detection system for autonomous vehicles. The presented system used a global positioning system to take the geographical position coordinates of the potholes and humps which includes the depth and height of the potholes and humps. The data that are sensed are stored in a cloud database. For a particular location, the data of the road remain stored in a database. When tracking on the road, an alert signal with the depth and height of the potholes and humps are sent to the driver using an android application. The ultrasonic sensors are used to collect data but the sensors readings are changed with the variation of temperature and humidity which misguide the vehicles.

Rao et al. [118] proposed a computer vision based pothole detection system for the visually impaired people that is helpful in their safe mobility. The scheme records the pattern and extract the features from the pattern and give the proper way of waking by analyzing the features. The data was collected by a camera with a laser. The system detects the pothole with 90% accuracy. The system worked in the real-time environment. The major limitation of the system is that it is only appropriate for the dark environment as the laser patterns are visible only in dark.

Harikrishnan et al. [119] introduced a road monitoring system that is able to detect the pothole and humps on the road surface and predict their harshness from vibration signal generated by vehicles. The smartphone accelerometer is used to capture vehicle vibration along z-axis and the pothole or humps are detected using x-z ratio filtering. The system also estimated the depth and height of the potholes and humps respectively. The system is able to detect the pothole and hump but can't detect Expansion joints, Manhole and Pipeline holes etc. The authors in [120] evaluated the performance of pothole detection system with an image classification modality using deep convolutional neural networks. The system is evaluated in terms of grayscale and color image. The system used 3028 images for training and 159 images for testing with 5000 iterations. The experimental results show that the classification accuracy obtained by the system is 96.5~97.5%. The system used some deep learning toolbox which is not best practice to evaluate the performance of a system.

2.4 Area of Coverage by Existing Work

The features that we consider here are the types of capturing device used, types of feedback signal provided, the coverage area, the weight, and the cost. These features are key concerns for measuring the efficiency and reliability of any walking guide that is developed for visually impaired people. The reviewed walking guides are classified in Figure 2.47 based on the aforementioned features. From Figure 2.47, no system offers all features to a reasonable degree. Each framework offers something unique over the others but cannot address every feature because a perfect framework ought to have every one of the features and numerous functionalities. The most significant conclusion is that no framework can fully assist visually impaired people.

The prototypes mentioned in [57], [92] , [94], and [97] used cameras and sensors as capturing devices. Some systems provide tactile feedback [63], [16], [68], [18], [100] and some provide audio and tactile feedback [7], [56], [17]. The framework developed in [16] works in outdoor scenarios but is unsuitable indoors. The system can detect static obstacles within a 5 m distance but is inappropriate for dynamic obstacles. Some systems provide indoor coverage, whereas some provide outdoor coverage. Nevertheless, the user demand is indoor and outdoor.

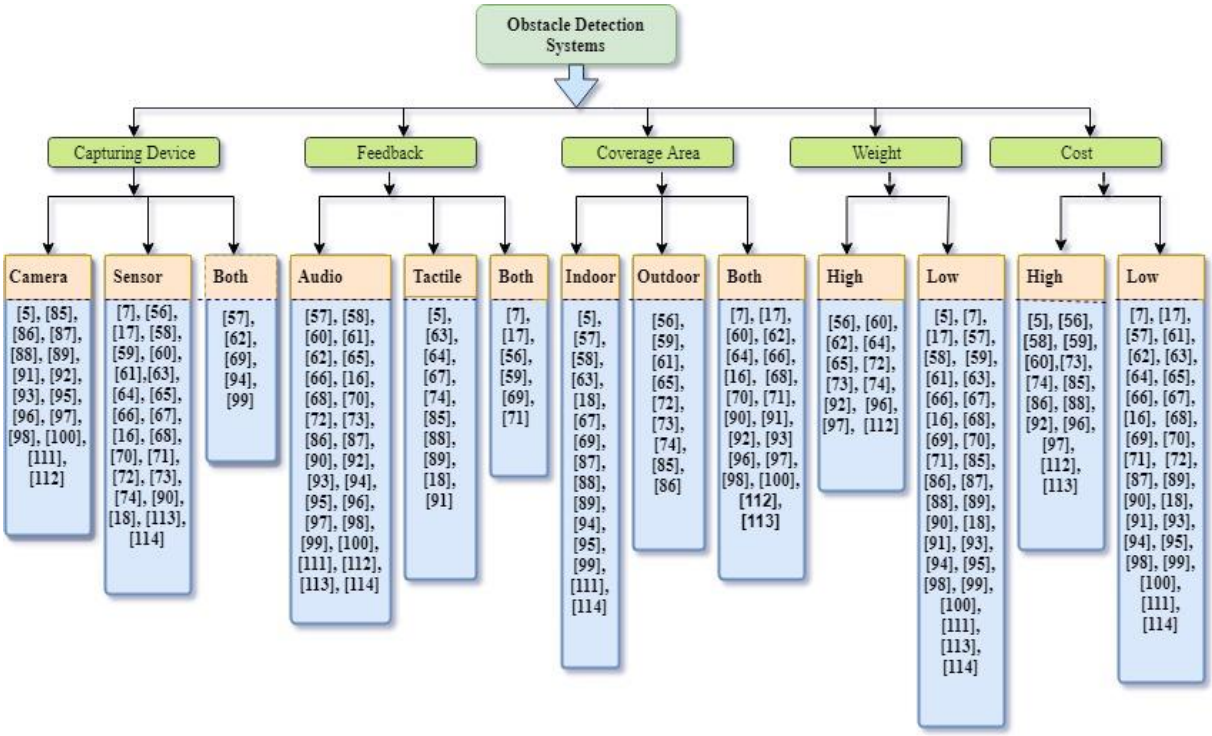


Figure 2.47: Classification of reviewed walking guides based on scopes.

2.5 Conclusion

The review discusses the recent innovative technologies developed for the visually impaired to aid them in walking with their merits and demerits. This review presents the modern assistive technologies for visually impaired people in the area of computer vision, embedded system, and mobile platforms. Although all the studied tools are in their early stages, many of them are interpreted into everyday life with the use of recent technologies (i.e., mobile phones). On the basis of the review, sufficient explanation of the major features that should be incorporated in any framework that can assist visually impaired people is provided. However, no single system can categorize the obstacles, which are essential for visually impaired people during navigation. Some critical hindrances that are faced by blind people are pothole on the road surface, staircase situation, road surface smoothness, water on the road surface, and different roads. Thus, the development of walking guides considering the previously described issues may contribute in the novel research for aiding visually impaired people during navigation. This review presents the majority of the issues of such frameworks to serve as a basis for different researchers to develop walking assistants that ensure movability and safety of visually impaired people.

CHAPTER III

The Proposed Methodology for Obstacle and Pothole Detection

3.1 Introduction

In the proposed system, the real world data are collected using ultrasonic sensors and pi camera. The collected data are processed using raspberry pi for obstacle and pothole detection. The overall system architecture of the proposed system is illustrated in Figure 3.1. The system generates feedback signal with the presence of obstacles and potholes and send it to the users for notification. The system comprised of two modules which are described as follows.

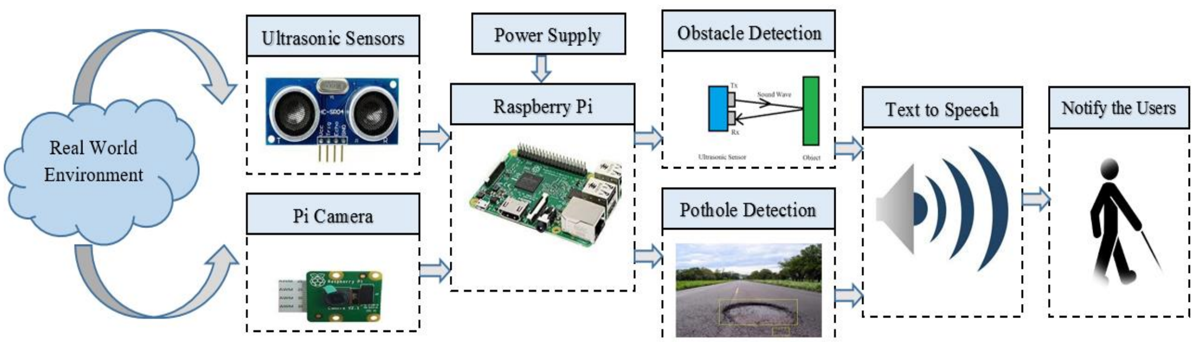


Figure 3.1: System architecture of the developed automated walking guide for the visually impaired people.

3.2 Obstacle Detection Module

In the proposed system, three ultrasonic sensors are used for obstacle detection to assist the visually impaired people. These sensors detect the obstacles towards the left, front and right directions respectively. The distance from the obstacle to the individuals is determined. The ultrasonic sensor sends a sound wave at a specific frequency toward the obstacle and receives the wave reflected by the obstacle. It archives the travel time of sound wave for forth and back. By using the travel time, sensor calculates the distance between the user and the obstacle. The distance of an obstacle is calculated using (1).

$$Distance = (Speed\ of\ Sound * Elapsed\ Time) \quad (1)$$

In the dry air, the speed of sound is 343.2 m/s and the distance between the obstacle and sensor become half of the distance covered by the sound wave. Hence, the distance looks like as follows.

$$Distance\ (D) = ((343.2\ m/s) * \Delta t)/2 \quad (2)$$

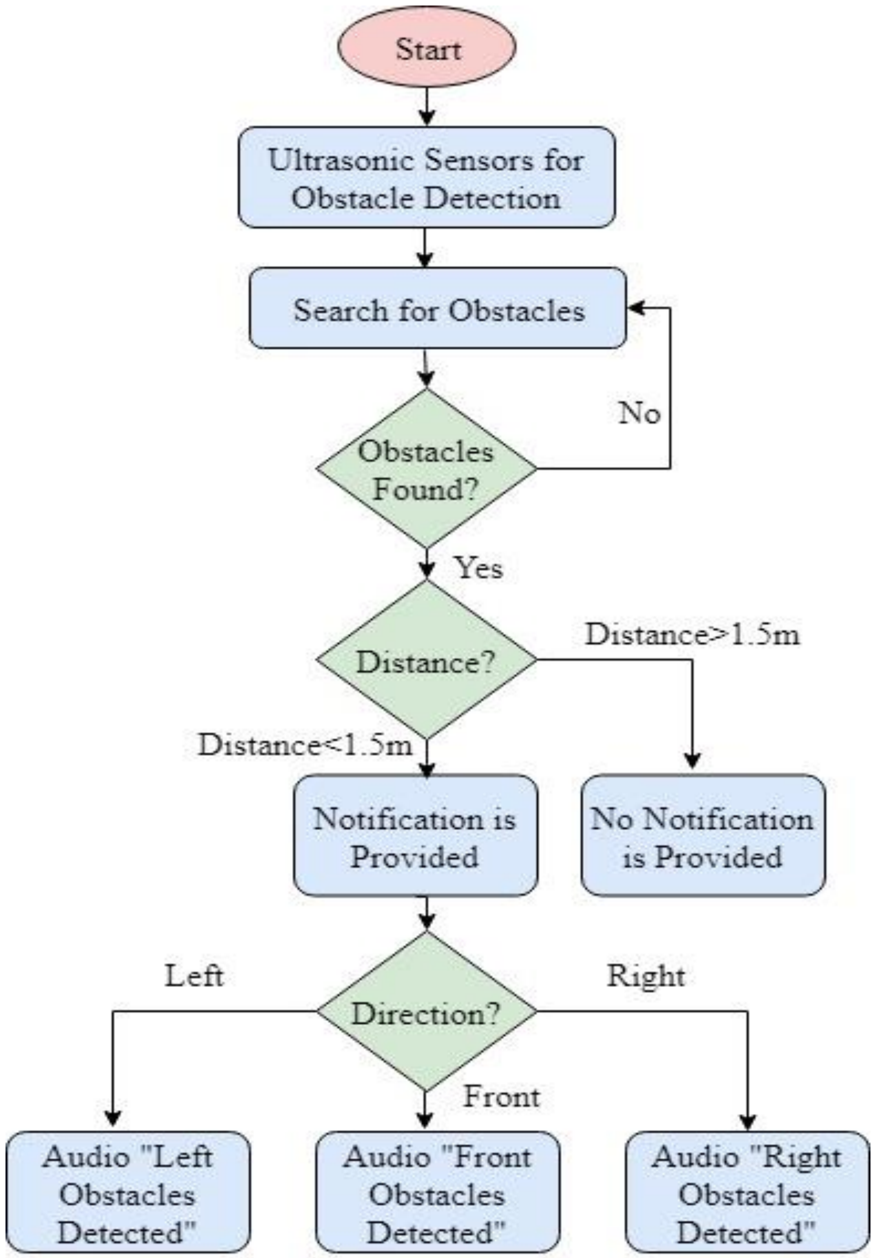


Figure 3.2: The flowchart for obstacle detection.

The safety zone threshold for each ultrasonic sensor is decided based on human walking speed, which is 4 km/h ≈ 1 m/s in general. Thus, the threshold or limit is 1.5 m in order to ensure safety for the visually impaired while using the electronic spectacle. In addition, the threshold or limit needs to be more than 1 m based the results and surveys from [121]. Hence, the notification system is developed to notify the user when the distance between the user and the obstacle is about 1.5 m. The system flowchart for the obstacle detection system is illustrated in Figure 3.2.

3.3 Pothole Detection Module

For pothole detection, a hybrid approach with the combination of sensor and CNN is used. The pothole sensor facing towards the ground is attached with the spectacle prototype. The Rpi camera captures the images and the images are checked with pertained model if it contains potholes or not. The pothole detection procedure of the developed system is shown is Figure 3.3.

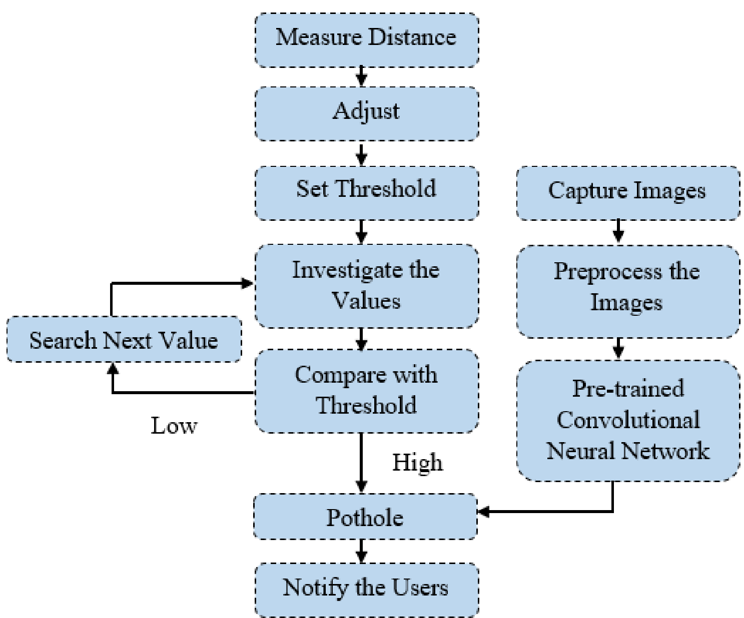


Figure 3.3: The flowchart for pothole detection.

3.3.1 Pothole Detection using Threshold Values

The pothole detection sensor measures the distance from wearable prototype to smooth surface using (2). A threshold value is set initially and compared with the distance. When the distance value become greater than the threshold value, then it is considered as pothole otherwise not.

The threshold value calculation procedure considers the different scenario of wearing the prototype.

It is considered that a single value can misguide the setting of the threshold value. Hence, a sequence of values are noted in different directions in front of the pothole. We have considered ten values to set the threshold. The average value for setting the threshold is calculated by (3).

$$Avg = \sum_{i=1}^{n} distance_i /n \qquad (3)$$

where, n is the number of distances.

The threshold value is set by repeating the procedure several times (randomly) and maximum average is set as threshold as shown in (4).

$$Threshold = Maximum\ (Avg) \qquad (4)$$

3.3.2 Pothole Detection using Convolutional Neural Network

The pothole detection using CNN consists of several steps: dataset collection, convolutional neural network, and performance evaluation. Each step is described briefly as follows.

A. Dataset Collection and Preparation

The road surface dataset with non- pothole is retrieved from KITTI ROAD dataset [122] that contains 289 images. The road surface dataset with pothole is retrieved from pothole detection dataset [123] that contains 90 images. The total number of images in the dataset is 379. The size of the retrieved non-pothole images is 1242×375. However, the pothole images are of different sizes. In addition, the data from the real world environment are collected using Rpi camera having size of 3280×2464 pixels. These cover images which have horizontal and vertical field view of 62.2 and 48.8 degrees respectively. The data are collected in different weather conditions at different days having different time slots. The urban-like areas are considered for data collection. The datasets contain road surfaces with pothole and non-pothole. The road surface dataset with pothole and non-pothole contains 200 and 100 images respectively. The total number of images in the dataset 679. Among these images, some images are shown in Figure 3.4 as examples.

(a) (b) (c) (d)

Figure 3.4: Sample images from the dataset: (a) Dataset non-pothole [122] (b) Collected non-pothole (c) Dataset pothole [123] (d) Collected pothole.

As the overall dataset contains only 679 sample images, we have applied data augmentation technique in order to prevent the network from over fitting. Data augmentation [124] is a way of creating new data with rotation of the image, shifting the image left/right/top/bottom by some amount, flip the image horizontally or vertically, shear or zoom the image etc. The data augmentation process is illustrated in Figure 3.5. Finally, we have generated 3000 images from the dataset. Now, the datasets contain 1500 images for non-pothole and 1500 images for pothole.

The datasets are partitioned into (80-20) % training-testing partition. The training set consists of 2400 images and the testing set consists of 600 images. The collected data are in different resolutions, shapes and sizes. Hence, pre-processing is done on the collected data to bring them to same format that makes it easy to fit into CNN. At last, all images are resized into 32×32 dimension for proper input.

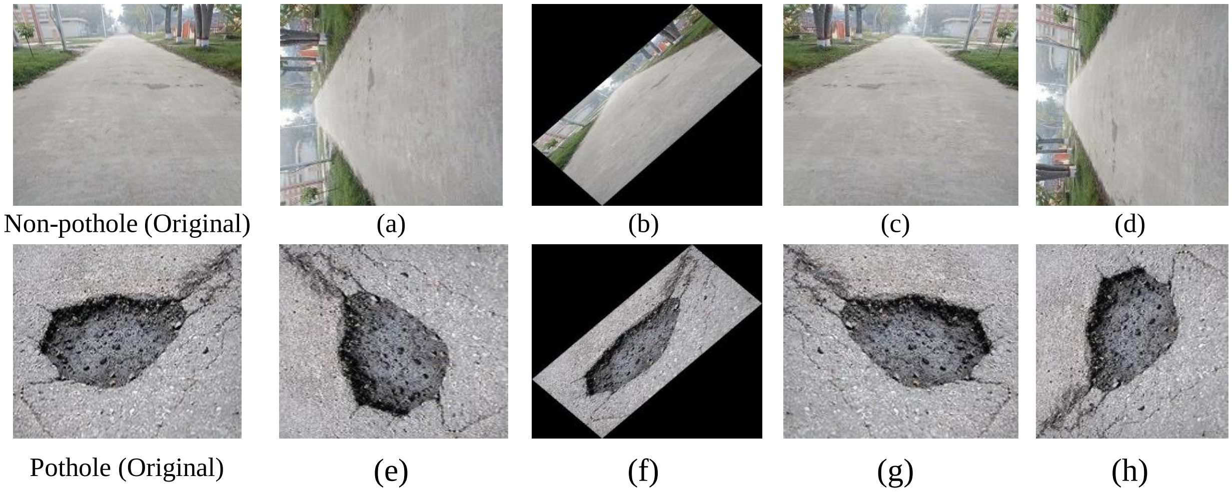


Figure 3.5: Sample images after applying data augmentation technique. (a), (e). 90^0 rotation (b), (f). 45^0 rotation (c), (g). Flip left to right (d), (h). Transpose

B. Convolutional Neural Network

The convolutional neural network structure that we have used for pothole classification consists of two convolutional layers and two subsampling layers each following only one convolutional layer. Figure 3.6 shows the CNN structure for pothole classification considered in this work. For both convolutional layers, the kernel size remains fixed and is 5×5 where in both subsampling layers, the size of the pooling area is 2×2. The input images are in size of 32×32 that are considered as 1024 linear nodes on which convolution process are to be accomplished. Convolution operation with kernel spatial dimension 5 converts 32 spatial dimension to 28 (32-5+1) spatial dimension [124] where size of the image is 32 × 32 size of the kernel is 5 × 5. Hence, the convolutional layer (C1) with kernel size of 5×5 and 16 kernels give an output of 28×28 in first convolution. We have used max pooling operation with the size of 2×2 and ReLU as an activation function. In subsampling layer S1, the feature maps of size 28×28 is subsampled by a 2×2 window and 16 feature maps with size 14×14 is obtained. In convolution layer C2, the output data from S2 is convoluted with 32 filters of size 5×5. The output data in C3 are 32 feature maps of size 10×10. In subsampling layer S2, the output data from previous layer is subsampled by a 2×2 window to generate 32 new feature maps with size of 5×5. Finally, nodes of hidden layer are connected to the 2 neurons in the output layer for classifying images into 2 classes.

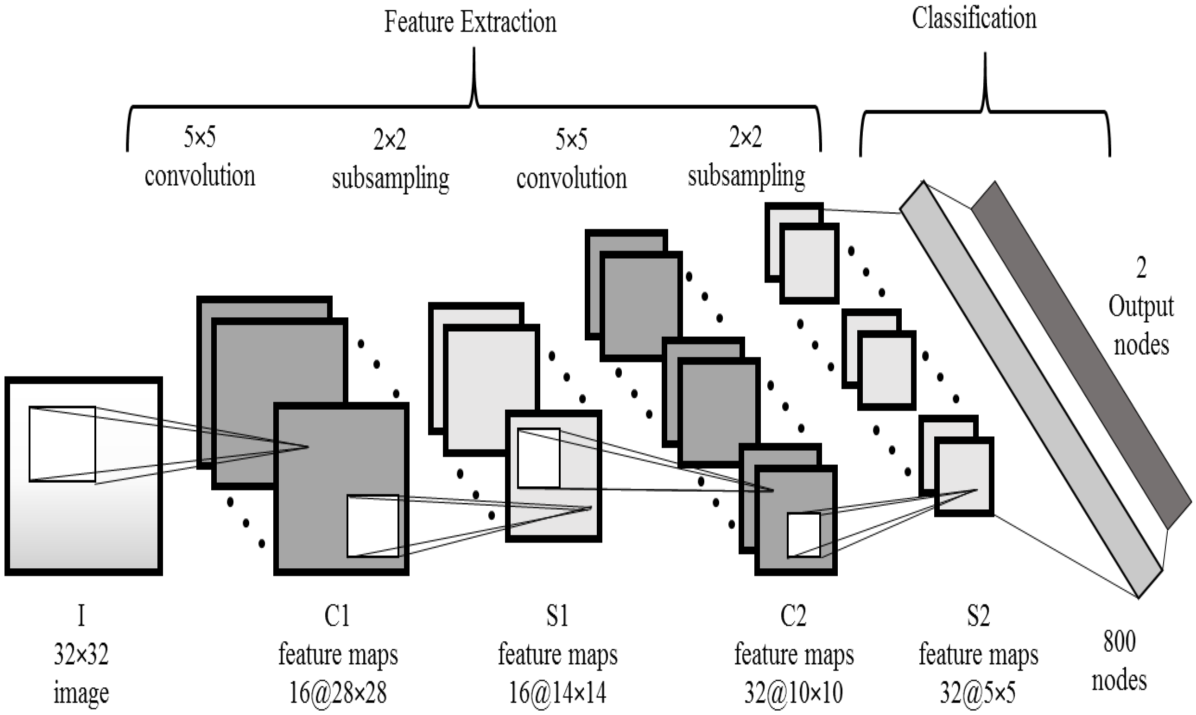


Figure 3.6: CNN structure for pothole classification.

The sigmoid classification is used in the output layer. Potholes are determined from a particular neuron in the output layer and non-potholes are determined from another neuron. When the pothole neurons' value outputs 1, other neurons' value become 0. The kernels, as well as the hidden-output weights, are updated while training process continues with 100 iterations.

C. Performance Evaluation

To measure the performance of the pothole detection system, some measures are used. In our study, the following parameters are used extensively to evaluate some terms by their corresponding formula to measure the performance of our system. Samples with absence of potholes are considered as negative class, and samples with presence of potholes are considered as positive class. Here,

True Positive (TP): Number of samples with presence of potholes predicted as presence of potholes.

False Positive (FP): Number of samples with absence of potholes predicted as presence of potholes.

True Negative (TN): Number of samples with absence of potholes predicted as absence of potholes.

False Negative (FN): Number of samples actually have presence of potholes predicted as absence of potholes.

Accuracy: Accuracy is the ratio of occurrences that are appropriately categorized by the classification learner i.e. the ratio of suitably predicted samples to total number of examples.

$$Accuracy = \frac{(TP+TN)}{(TP+TN+FP+FN)} \qquad (5)$$

Precision: Precision is the ratio of true positive (absence classified as absence) with all instances classified as positive (total samples classified as absence).

$$Precision = \frac{TP}{(TP+ FP)} \qquad (6)$$

Recall: Recall is the ratio of perceived positive instance with the total positive instances, i.e. the ratio of total predicted absence with total absence.

$$Recall = \frac{TP}{(TP+ FN)} \qquad (7)$$

F1 Score: F1 score is the harmonic mean among precision and recall. For the best performance, its requisite is one, and for foulest performance, it is zero.

$$F1\ Score = 2 * \frac{(Precision * Rcall)}{(Precision + Rcall)} \qquad (8)$$

3.4 Conclusion

This chapter covers the overall working principle of the developed walking guide for the visually impaired people. Each step for obstacles' and potholes' detection is discussed in detail. Three ultrasonic sensors are used to detect the obstacles in front, left and right directions respectively. The potholes are detected using ultrasonic sensors and camera. Convolutional neural network is used to classify the road surfaces with having potholes and non-potholes. The performance of the pothole detection system are measured with some performance measure parameters: accuracy, sensitivity, precision and F1 score.

CHAPTER IV

Prototype Development

4.1 Introduction

The prototype's finalization of the walking guide is discussed in this chapter. In order to ensure the safety and applicability of the developed walking guide, several experiments are systematically conducted. The discussions on system performance for obstacle and pothole detection are also presented in here.

4.2 Experimental Setup

The frame of the walking guide is designed in SolidWorks 2017 that runs on Microsoft windows. The design is printed in 3D printer named as Ultimaker 3 Extended having the dimension of 34.2 x 50.5 x 68.8 cm. We have used an Intel Core i7 powered computer with 8GB of RAM for developing the CNN model for pothole detection. In addition, Scikit-learn, an open-source machine learning library in Python programming language is used. Spyder is an integrated development environment which is also used to fulfill our goal. The overall system runs in raspberry pi.

4.3 Construction of the Prototype

The prototype consists of four ultrasonic sensors, a raspberry pi, a headphone to alert the users and a battery for power supply. The frame of the walking guide is shown in Figure 4.1. From Figure 4.5, it can be observed that the arm of the spectacle is in x- axis direction. The length, height and width of the arm are 11.40, 6.52 and 2.50 cm respectively in the exterior side. In the interior side, the length and height are of 9.75 and 5.54 cm individually. In the z axis, the height is about 5.33 cm. The upper and lower length along y-axis are 13.43 and 14.41 cm respectively. Four holes are created for ultrasonic sensors where three of them detect the obstacles in left, front and right directions. For pothole detection, one hole for ultrasonic sensor is created facing towards ground. The length, width and thickness of the hole, created for ultrasonic sensor is about 4.3, 2.0 and 1.5 cm respectively. At the middle of the frame, a hole is created for camera with 0.90 cm height and width and the thickness of this hole is about 0.37cm. The dimension of the camera board is about 2.5 cm x 2.3 cm x 0.9 cm which is located at the interior of the frame. Figure 4.2 shows the designed electronic spectacle which is designed by using SolidWorks 2017 tool.

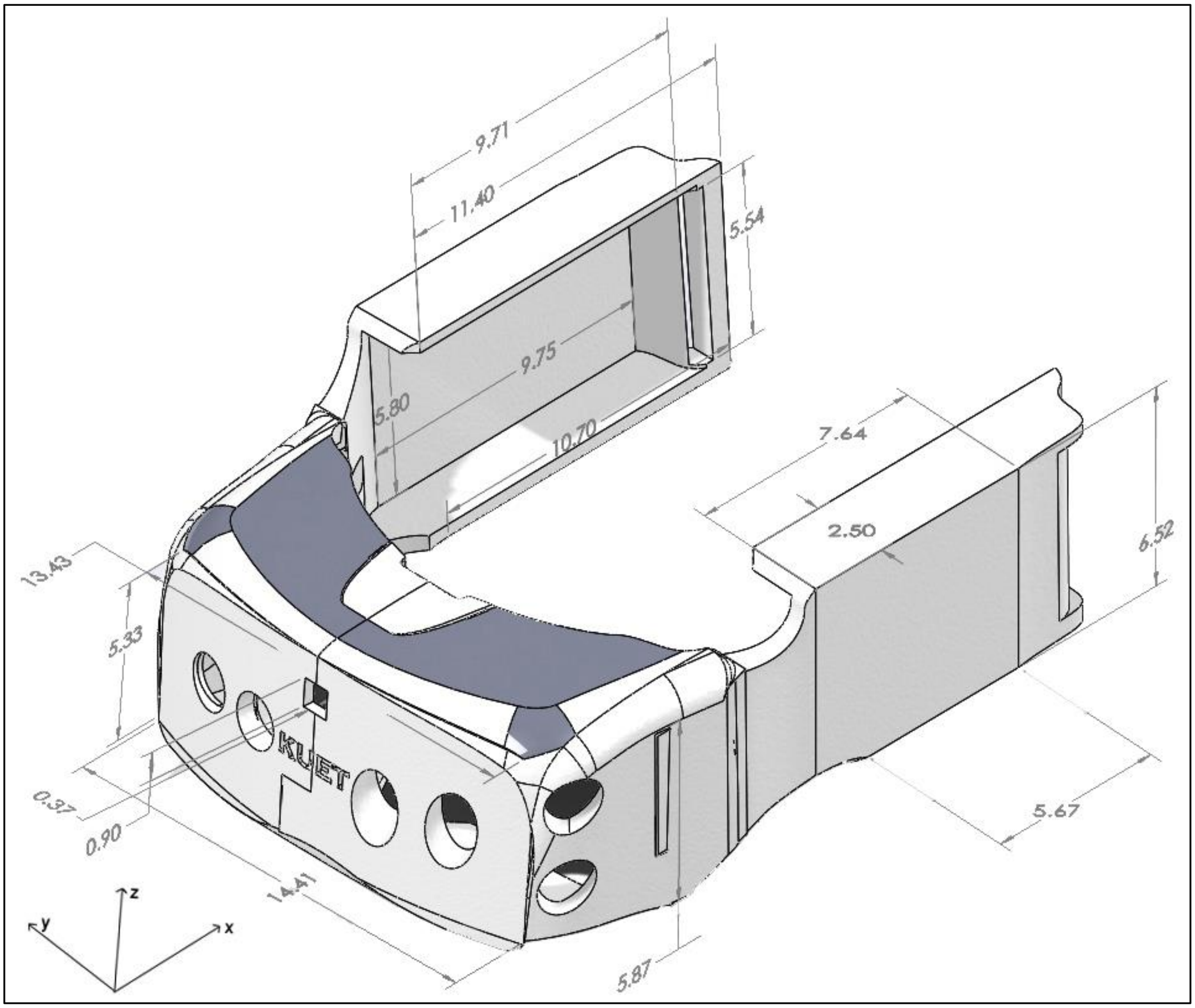
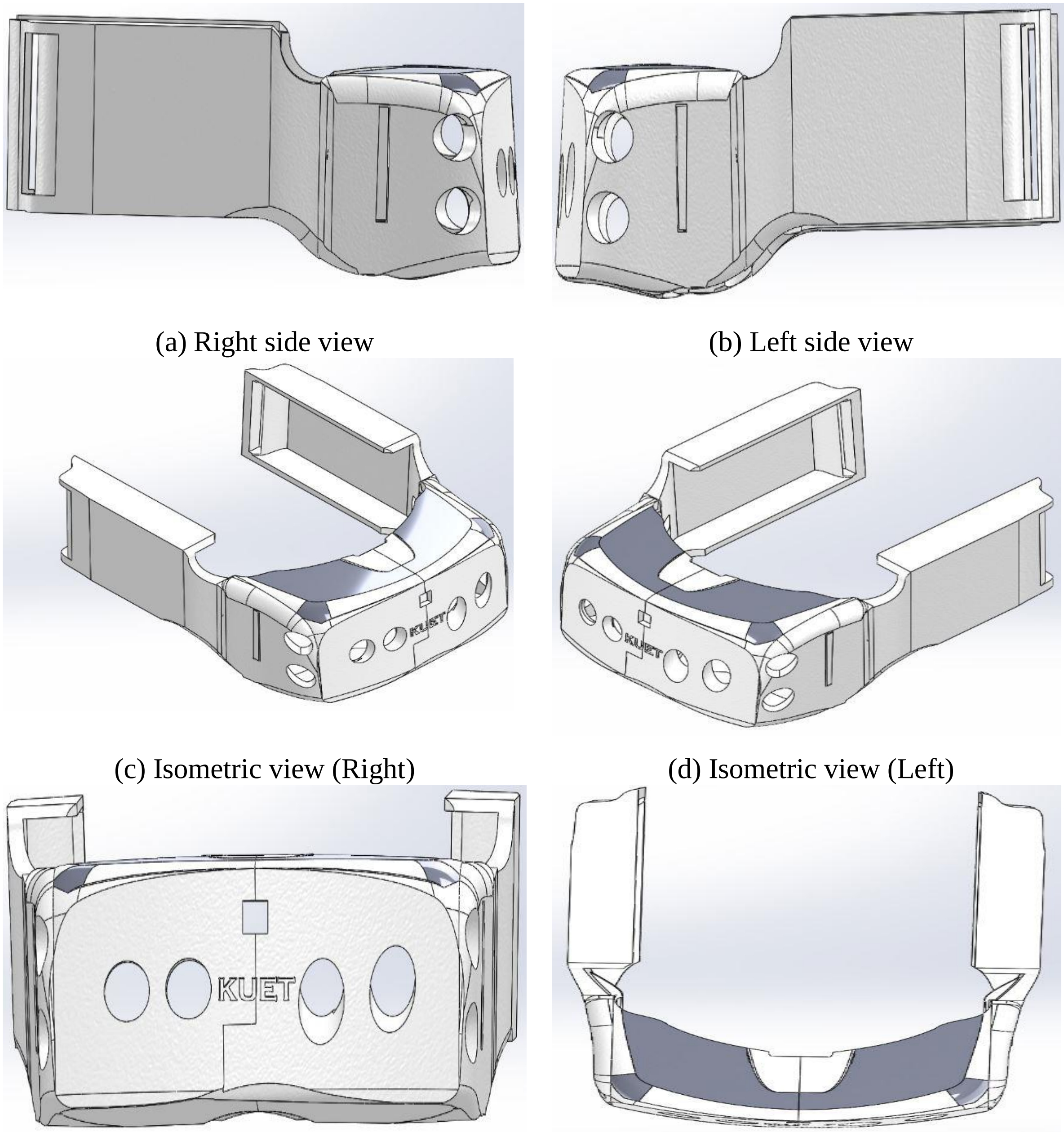


Figure 4.1: Schematic diagram of the developed walking guide for the visually impaired people.



(a) Right side view (b) Left side view

(c) Isometric view (Right) (d) Isometric view (Left)

(e) Front view (f) Top view

Figure 4.2: Designed electronic spectacle prototype using SolidWorks.

4.4 System Implementation

After selecting electronic components and detection range, the design and development of the spectacle are conducted. The placement of the ultrasonic sensors in this prototype refers to the angle range that the device should detect. Meanwhile, the left and right ultrasonic sensors are set to 45 degree from the spectacle center point in order to detect obstacles within the shoulder and arm of user. Therefore, collision between obstacle and both left and right shoulders can be avoided. In this thesis, we have used 3D printer to develop the 3D model of the spectacle. 3D printer can develop a prototype up to a maximum size of 34.2 x 50.5 x 68.8 (L x W x H) cm. Besides this, the material which is be used to develop the model of the spectacle is Polylactic acid (PLA) filament and it is easy to obtain and low in cost. All parts of the spectacle are produced in house and the assemble process can easily be done. In order to develop the model of the spectacle, the amount of PLA material is needed as approximately 254gm.

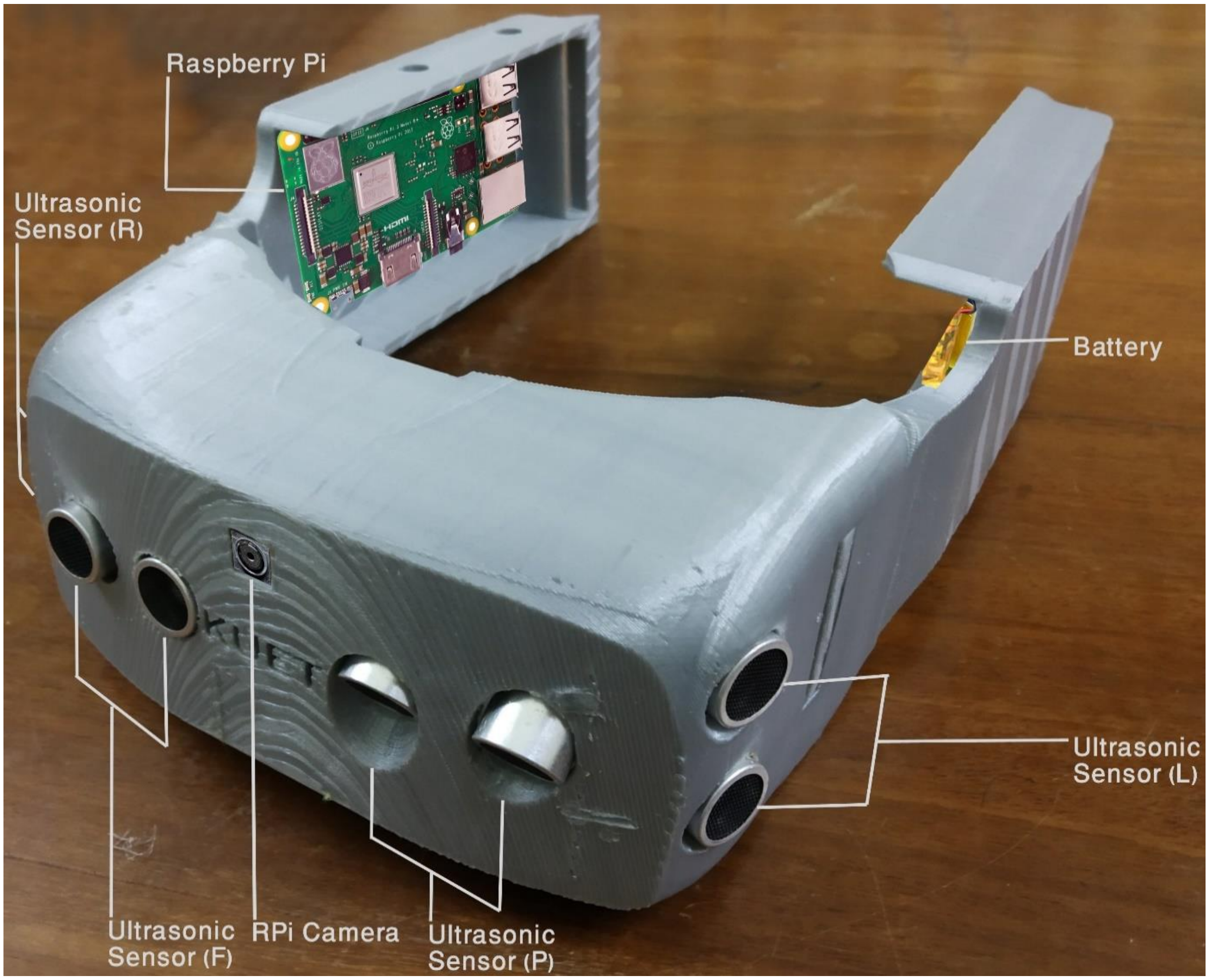


Figure 4.3: Prototype of the developed walking guide for the visually impaired people.

The walking guide was implemented in the form of spectacle prototype in which four ultrasonic sensors, an Rpi camera, raspberry pi, battery and headphone are used. The implemented prototype is shown in Figure 4.3. From Figure 4.3, it can be shown that three ultrasonic sensors are used for obstacle detection along the left, front and right directions and the remaining one is used for pothole detection facing towards ground. The Rpi camera is located at the middle point of the prototype. The raspberry pi and battery for power supply is positioned at the right and left arm of the spectacle.

The connection of each component is mapped with the raspberry pi which is shown in Table 4.1. From Table 4.1, it can be shown that the trigger and echo pin of the front sensor is connected with GPIO8 and GPIO7 pin of the raspberry pi. The GPIO14 and GPIO15 connect the trigger and echo pin of pothole detection sensor. The battery and headphone are connected with Micro USB power and Audio jack port of raspberry pi. The circuit diagram of the developed system is illustrated in Figure 4.4.

Table 4.1: Mapping between raspberry pi and other components

Raspberry pi pin	Connected device
GPIO 8	Trigger pin of front sensor
GPIO 7	Echo pin of front sensor
GPIO 23	Trigger pin of left sensor
GPIO 24	Echo pin of left sensor
GPIO 20	Trigger pin of right sensor
GPIO 21	Echo pin of right sensor
GPIO 14	Trigger pin of pothole sensor
GPIO 15	Echo pin of pothole sensor
5V	Common +5V for all device
GND	Common Ground(-) for all device
Micro USB power	Battery
Audio jack	Headphone
CSI camera port	Rpi Camera

The communication between the users and prototype is done using headphone which convey the audio message with the presence of hindrances on the way of walking. Text to Speech (TTS) module is used to generate audio message from text. Different kinds of audio messages, played as feedback, are shown in Table 4.2. If there is no obstacle found in any direction then that direction is suggested to be used for the navigation of the visually impaired. The developed system suggests the free path to the users in which direction they have to move.

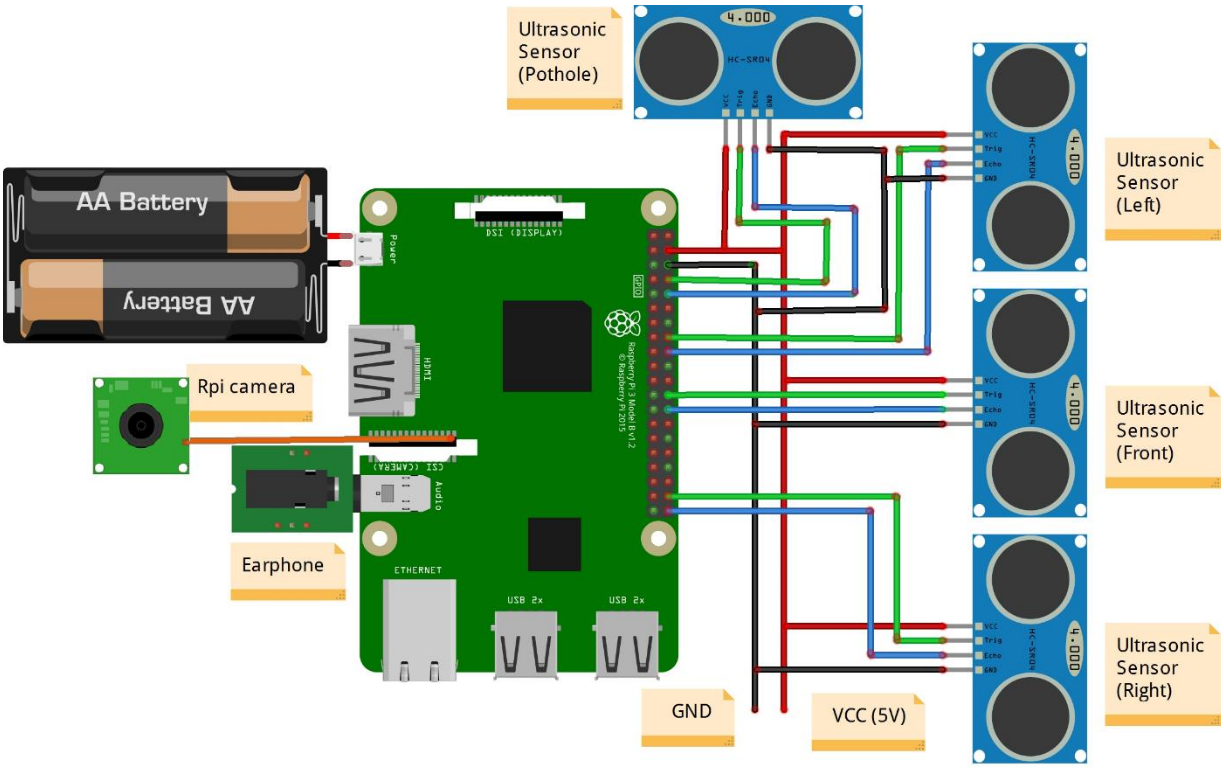


Figure 4.4: Circuit diagram of the developed walking guide.

Table 4.2: Audio feedback signals

Obstacle Situation	Audio Message
No Obstacle	Move any directions
Obstacle located on right	Move front or left direction
Obstacle located on left	Move front or right direction
Obstacle located in front	Move left or right direction
Obstacle located on left and right	Move front direction
Obstacle located in front and right	Move left direction
Obstacle located in front and left	Move right direction
Obstacle located in front, left and right	Stop. All directions are blocked
Pothole detected	Pothole

4.5 Results for Obstacle Detection

The experiment was performed in real environment to measure the performance of the system. The data are collected for front, left and right ultrasonic sensors by positioning obstacles in different orientations. For each interval, we have taken data for five times and calculated the average value of these data. We have also estimated the accuracy, error rate, standard deviation and variance of observed data. The collected data from each sensor (with aforementioned value) are represented in Table 4.3, Table 4.4 and Table 4.5.

Table 4.3: Real time data collected using front ultrasonic sensor

AD (cm)	Observed Distance (cm)					Average (cm)	Acc (%)	Error (%)	SD	Variance
	1	2	3	4	5					
50	49.01	50.07	49.09	49.75	48.92	49.368	98.73	1.26	0.51	0.26
100	97.32	98.25	99.08	97.86	96.1	97.72	97.72	2.27	1.11	1.23
150	148.15	147.41	144.29	145.29	146.15	146.25	97.50	2.49	1.55	2.43
200	196.17	192.17	195.25	193.13	193.19	193.98	96.99	3.00	1.66	2.75
250	242.35	240.29	244.12	243.01	241.19	242.19	96.87	3.12	1.50	2.25
300	291.8	286.55	292.07	285.1	283.44	287.79	95.93	4.06	3.94	15.52
350	331.07	337.14	332.21	339.16	333.22	334.56	95.58	4.41	3.43	11.82

*AD=Actual Distance, Acc=Accuracy, SD=Standard Deviation

Table 4.4: Real time data collected using left ultrasonic sensor

AD (cm)	Observed Distance (cm)					Average (cm)	Acc (%)	Error (%)	SD	Variance
	1	2	3	4	5					
50	49.74	50.01	49.77	48.06	49.08	49.33	98.66	1.33	0.79	0.62
100	99.26	98.24	98.06	97.55	95.32	97.68	97.68	2.31	1.46	2.13
150	148.07	145.08	143.28	147.4	146.64	146.09	97.39	2.60	1.92	3.71
200	195.7	192.15	190.38	194.1	196.61	193.78	96.89	3.10	2.55	6.50
250	245.27	237.12	243.19	238.19	243.41	241.43	96.57	3.42	3.56	12.69
300	290.09	284.34	291.37	288.58	285.06	287.88	95.96	4.03	3.08	9.50
350	340.43	333.76	331.45	330.18	335.14	334.19	95.48	4.51	3.98	15.90

*AD=Actual Distance, Acc=Accuracy, SD=Standard Deviation

Table 4.5: Real time data collected using right ultrasonic sensor

AD (cm)	Observed Distance (cm)					Average (cm)	Acc (%)	Error (%)	SD	Variance
	1	2	3	4	5					
50	49.06	49.67	50.22	49.17	48.48	49.32	98.64	1.36	0.65	0.43
100	99.08	96.38	98.36	96.37	97.39	97.51	97.51	2.48	1.20	1.44
150	143.31	146.44	148.17	145.46	147.23	146.12	97.41	2.58	1.86	3.46
200	192.46	194.15	190.17	196.29	195.26	193.66	96.83	3.16	2.41	5.83
250	245.11	236.07	237.24	244.12	242.15	240.93	96.37	3.62	4.07	16.59
300	290.94	284.19	287.06	285.3	291.24	287.74	95.91	4.08	3.22	10.37
350	341.63	331.75	330.06	329.58	333.95	333.39	95.25	4.74	4.91	24.12

*AD=Actual Distance, Acc=Accuracy, SD=Standard Deviation

The comparison between actual distance and observed distance for front, left and right sensors are depicted in Figure 4.5, Figure 4.6 and Figure 4.7 respectively. These representations show the distortion of the observed distance from the actual distance. It is shown that the deformity is not severe and the observed distance is acceptable. The distortion of the right sensor is comparatively higher than others sensors. In addition, the value of the distortion from the actual distance rises in a positive approach with the increment of actual distance.

The accuracy and error rate along with the distance for all sensors are shown in Figure 4.8 and Figure 4.9 respectively. From Figure 4.8, it can be observed that the highest accuracy of 98.73% is achieved by the front sensor when the actual distance is 50 cm. In addition, the highest accuracy obtained by the left and right sensors are 98.66% and 98.64% respectively at the same distance. The accuracy is decreased with the increase of distance. The highest error rate found at the actual distance of 350 cm which is about 4.74% for right sensor. The front and left sensors obtain the highest error rate of 4.41% and 4.51% respectively at the same distance (350 cm). From Figure 4.9, it can be observed that with the increase of distance, the error rate becomes high.

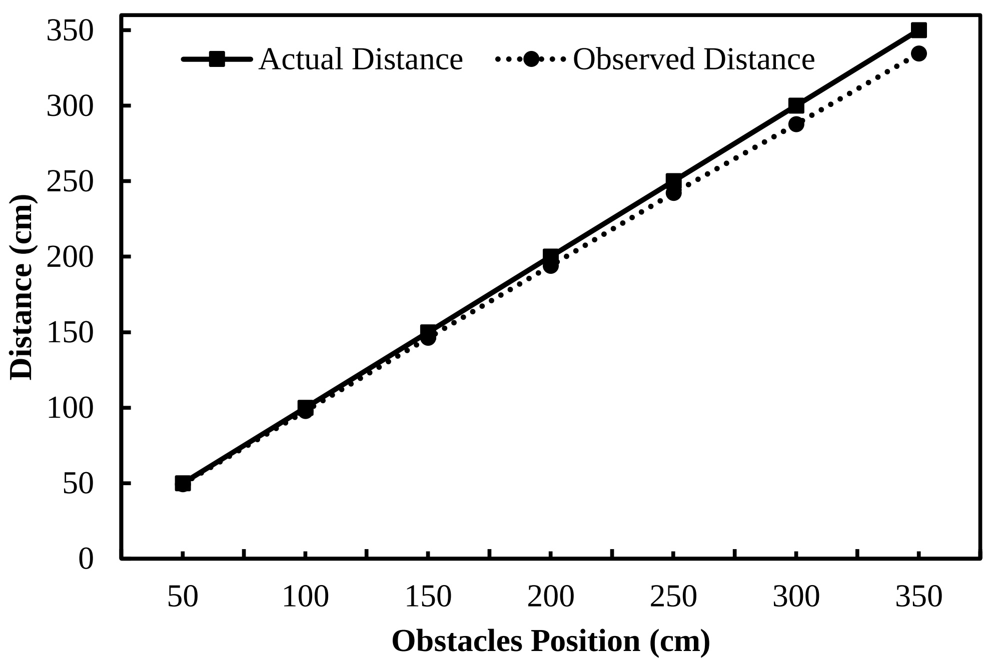


Figure 4.5: The comparison between actual and observed distance collected from front sensor.

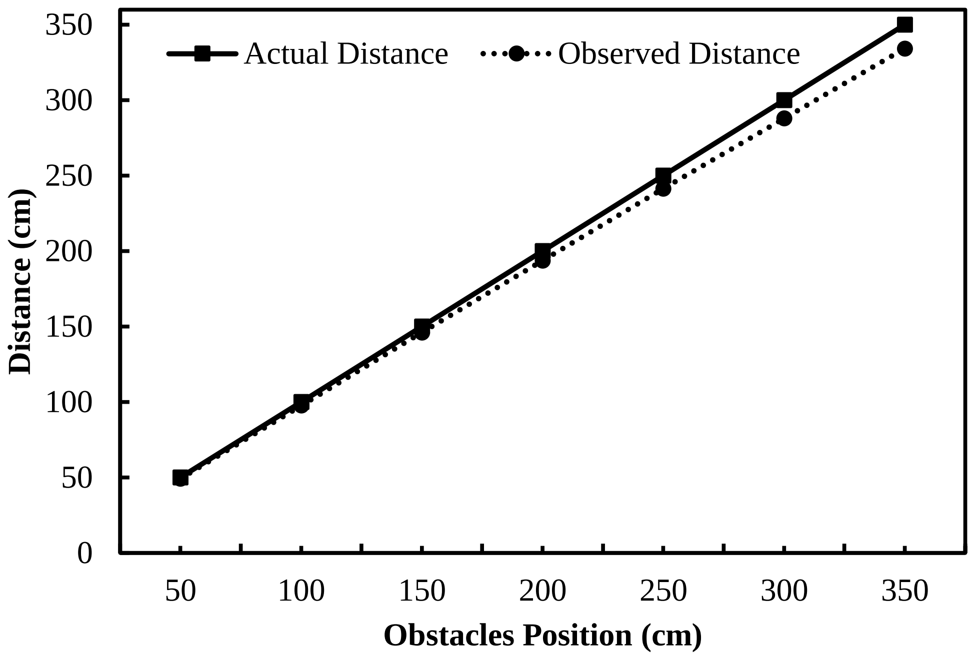


Figure 4.6: The comparison between actual and observed distance collected from left sensor.

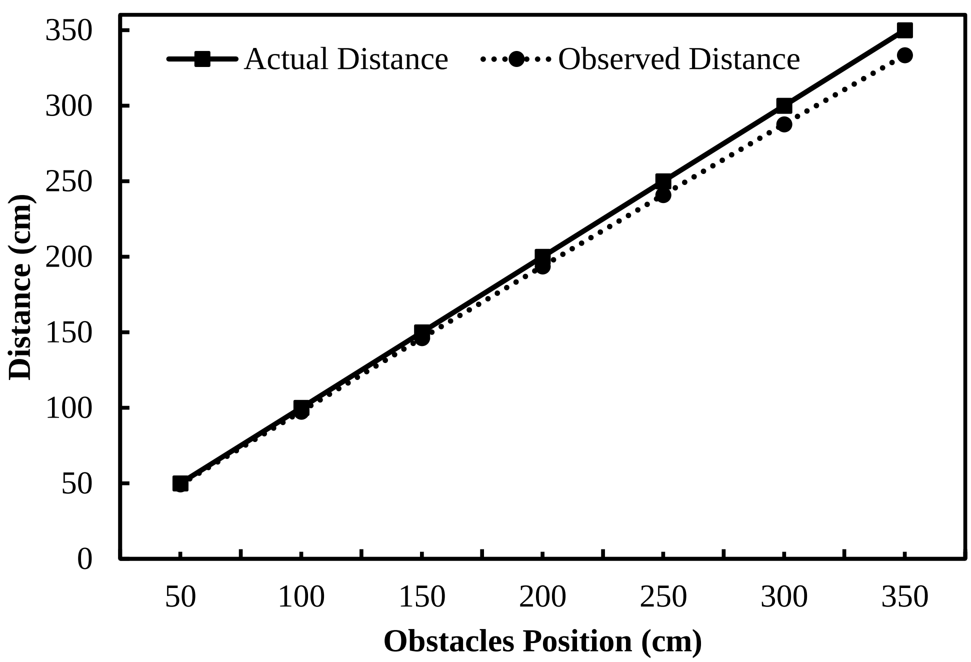


Figure 4.7: The comparison between actual and observed distance collected from right sensor.

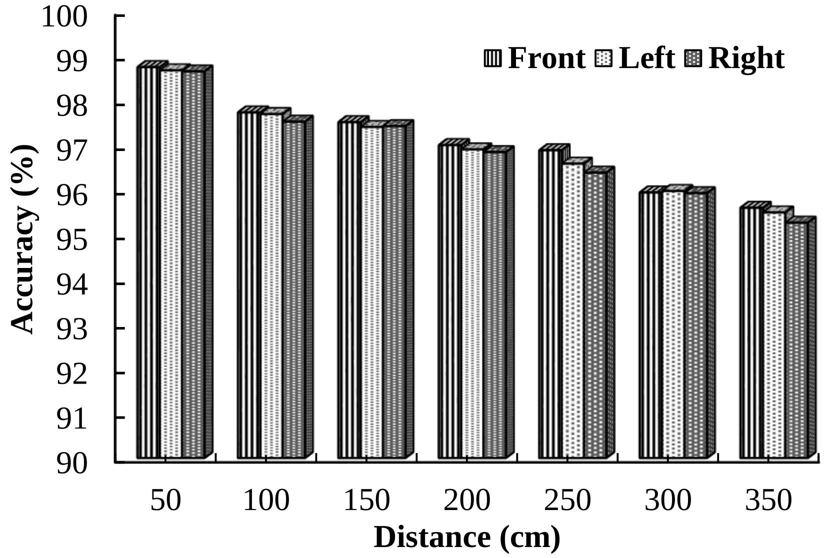


Figure 4.8: The accuracy achieved by the developed system.

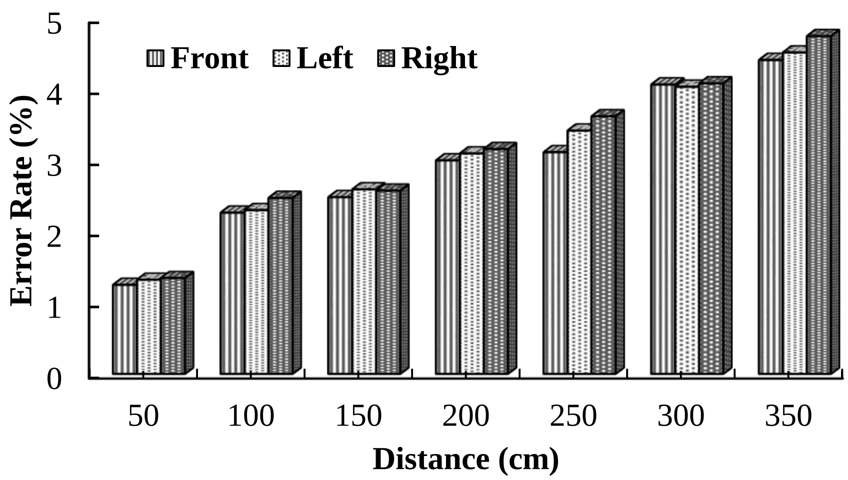


Figure 4.9: The error rate achieved by the developed system.

Standard deviation and variance are two closely associated measures of deviation. The lower value of standard deviation depicts the narrower deviation from the mean value. The variance measures the average unit to which each value varies from the mean. The larger value of the variance represent the greater data range in overall system. The standard deviation and variance of the data collected by the developed system is illustrated in Figure 4.10 and Figure 4.11.

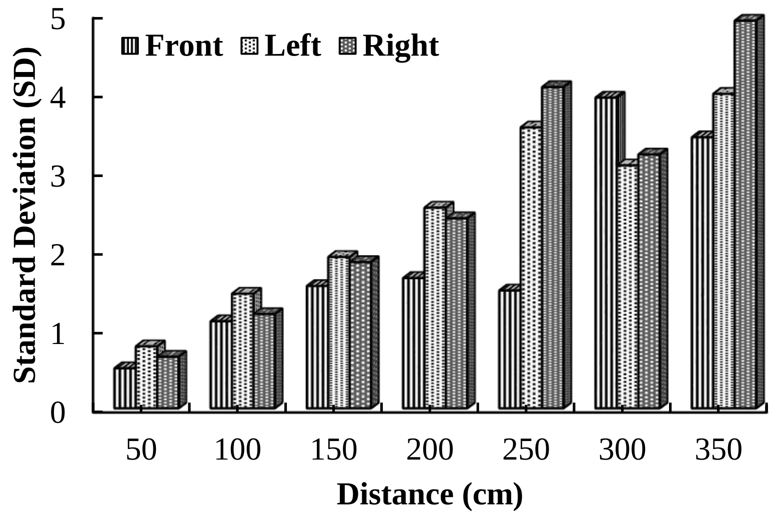


Figure 4.10: Standard deviation of the data collected by the developed system.

From Figure 4.10 and Figure 4.11, it can be observed that the lower values of standard deviation and variance are achieved when the obstacles are very close to the users. These values are increased with the increase of obstacles' distance. The lowest standard deviation and variance that are obtained by the front sensor of the system are 0.51 and 0.26 respectively. It represents that the observed distance, in case of front sensor, is very close to the average value. The highest value of standard deviation and variance are obtained 4.91 and 24.12 in case of right sensor which depicts comparatively higher distortion.

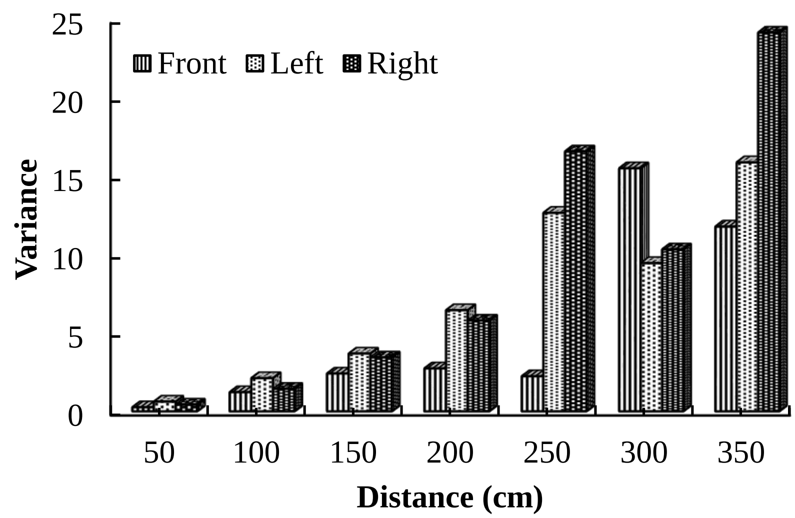


Figure 4.11: Variance of the data collected by the developed system.

4.6 Results for Pothole Detection

The pothole detection using sensor uses a generated threshold to flag potholes. The threshold values are set when the device is power on by averaging first 10 values from the pothole detection sensor. Table 4.6 highlights few trials of threshold values' measurement. From Table 4.6, it can be observed that the threshold values for 1st, 2nd and 3rd users are 192.98 cm, 188.71cm, and 181.86 cm respectively. The users' height that are considered for the experiment are 165 cm, 160 cm, and 152 cm for 1st, 2nd and 3rd users respectively. The threshold value varies due to the different height of the users. Any distance greater than the threshold values (192.98 cm for 1st user) depicts the presence of potholes.

Table 4.6: Measurement of threshold values

Users	Measurement of threshold values for different users	Threshold Values
1	192.29, 191.40, 193.87, 194.46, 194.20, 192.86, 192.02, 191.04, 193.87, 193.84	192.98
2	188.57, 186.90, 190.55, 187.81, 187.85, 189.29, 187.73, 190.26, 189.85, 188.26	188.71
3	180.59, 181.75, 181.93, 181.52, 182.81, 180.29, 181.89, 180.82, 183.38, 183.58	181.86

The convolutional neural network is trained with the sample images in a host computer. The developed model is transferred to raspberry pi that predicts the presence of potholes by capturing a single image each time. The experimental results show that the CNN generates a pothole detection system with high accuracy where the experiments are performed 100 iterations. In every iteration, we have measured the accuracy, precision, recall and F1 score both for training and testing phases. In training phase, among 2400 samples, 1195 are correctly identified as non-potholes, 1 is wrongly identified as non-potholes, 5 samples are wrongly classified as potholes, and 1199 are correctly identified as potholes. The overall accuracy obtained by the system is 99.75% in training phase. In addition, the precision, recall and F1 score achieved by the system are 99.58, 99.91 and 99.75% respectively. The performance measure parameters for training phase are shown in Figure 4.12.

In testing phase, among 600 samples, 277 are correctly identified as non-potholes, 21 are wrongly identified as non-potholes, 23 samples are wrongly classified as potholes, and 279 are correctly identified as potholes. Using the values from the confusion matrix, the performance measure parameters are calculated. The overall accuracy obtained by the system is 92.67% in testing phase. In addition, the other performance measures such as precision, recall and F1 score appraised by the system are 92.38, 93 and 92.68% respectively. The performance measure parameters for testing phase are illustrated in Figure 4.13.

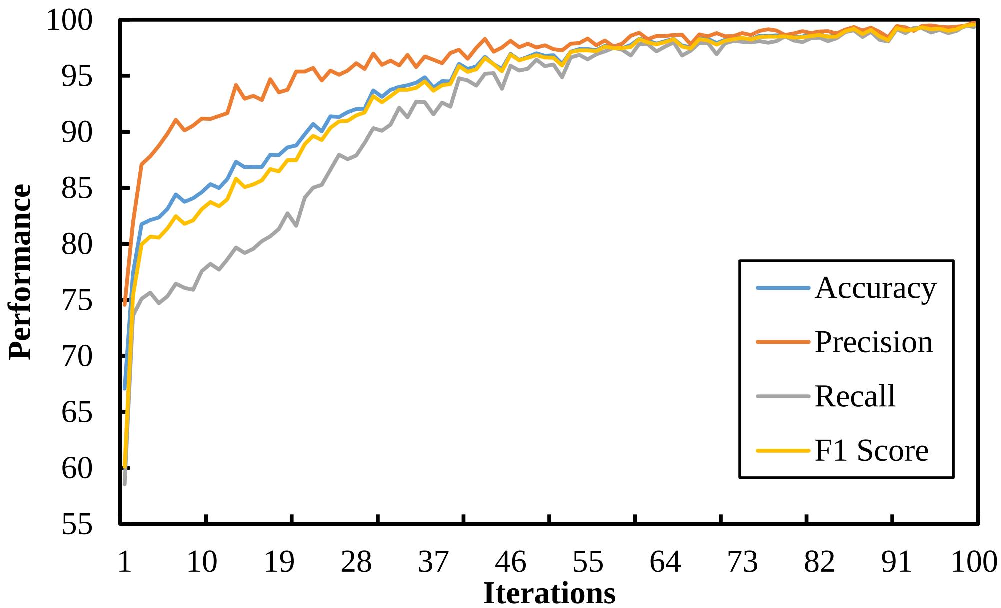


Figure 4.12: The performance measure parameters of the developed system in training phase.

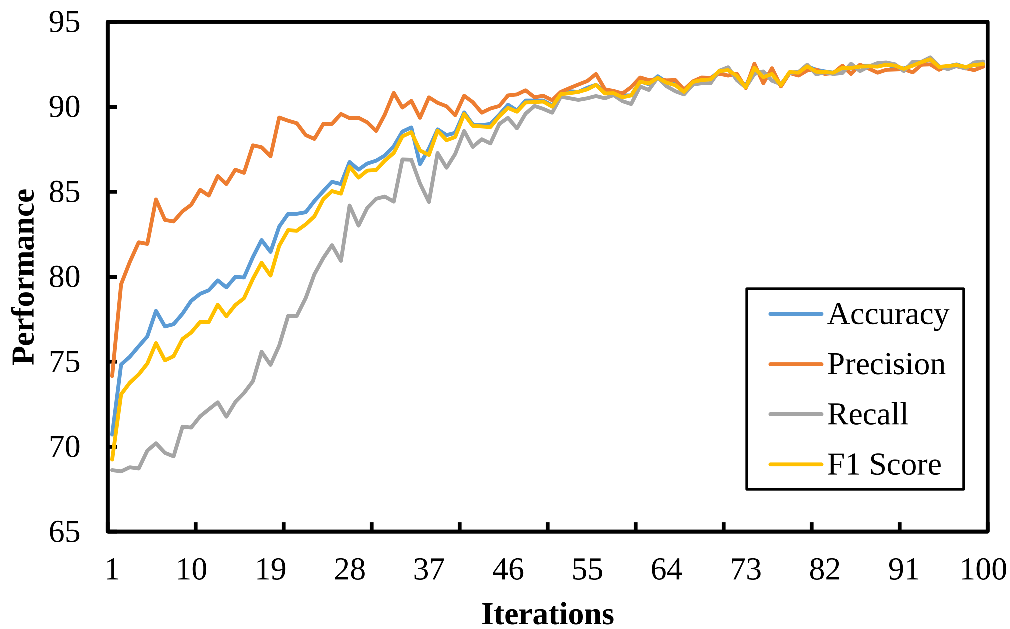


Figure 4.13: The performance measure parameters of the developed system in testing phase.

4.7 Comparative Analysis

A comparative analysis between the developed walking guide and the existing electronic travel aids is illustrated in this subsection. The common requirements of electronic travel aid that are suggested by the visually impaired people, their care patrons, and rehabilitation specialists [17] are proper information of the surroundings, light weight, low cost and simple carry technique.

Among existing electronic travel aids, few systems [12], [64], [125] can detect obstacles in front of the users only rather than detecting all objects in the surroundings. In case of cost analysis, the systems proposed in [65], [16], [68], [24], [126] and [74] showed the cost of the systems as approximately $290, $280, $40, $10, $150 and $1790 respectively. Some of the developed systems are in heavy weight and some of them are light weight. The weight of the systems [16], [68], [24] and [126] are of 0.503 kg, 110 g, 160 g and 1.57 kg (including a 800g vest) respectively. In accuracy comparison' the highest and lowest accuracies achieved by the system in [64] are approximately 98.8% (when the obstacle was close (5 cm) to users) and 62.8% (when the obstacle was far (350 cm) away from the users). The average accuracy obtained by the systems proposed in [24] and [126] are about 96% and 95% respectively.

The developed walking guide provides clear and concise information about the environment to the users in all directions. When an obstacle is detected, this prototype guides the individuals to an alternate direction. The overall cost of our developed prototype is approximately $140 and the weight is about 360 g including all electronic components. The developed walking guide is a spectacle prototype that provides easy carry facilities. In addition, the system is able to detect the obstacles within 3.34 m. The average accuracy obtained by the system is about 97.05% for obstacle detection and 92.67% for pothole detection. Table 4.7 illustrates the comparison of the developed walking guide with existing work. From Table 4.7, it can be observed that the developed walking guide outperforms the systems proposed by [16], and [126] in case of weight and cost. The system proposed in [24] has comparatively light weight and is less costly than our developed system. However, it can detect the front obstacles only.

Table 4.7: Comparison of the developed walking guide with existing work

Authors	Accuracy (%)	Weight	Cost
Bhatlawande et. al [16]	-	0.503 kg	$280
Sadi et. al [24]	96	160 g	$10
Kim et. al [126]	95	1.57 kg	$150
Developed Walking Guide	97.05	360 g	$140

4.8 Conclusion

This chapter illustrates the development of the spectacle prototype and its performance analysis. The spectacle prototype is designed in Solid works and fabricated using 3D printer. All the components are assembled with the prototype successfully. The testing and finalization of the designed walking guide for the visually impaired people are also described in this chapter. The key findings of the work in this chapter cover the system performance, accuracy and analysis in case of obstacles and potholes detection. The results of each of the steps are recorded, displayed and discussed in detail. From the measurement aspect of the obstacle detection, the functionality and accuracy of the distance sensors are of great importance and are discussed in detail. To verify this, the measured results are compared with the actual distance. The comparison shows acceptable distance measurement determined at the output of the obstacle detection sensors. The developed system detects the obstacles having the range of 0.02m-3.33m. The system can easily detect the potholes within certain time. Finally, the designed walking guide provide a knowledge about the surroundings that aid the visually impaired people in their way of walking.

CHAPTER V

Conclusions

5.1 Concluding Remarks

The main goal of this thesis is to develop a walking guide to assist the visually impaired people to navigate independently in environments. The developed system consists of two main parts that are obstacle and pothole detection. The obstacle detection system aims to indicate the presence of obstacles around the surroundings at the directions of front, left and right. The pothole detection system detects the potholes on the road surface. The walking guide is designed to guide the visually impaired people in their navigation. The overall electronic spectacle prototype, which can be used for guiding the visually impaired people, is constructed in this thesis. Some electronic components such as raspberry pi, distance measurement sensor (ultrasonic sensor), Rpi camera, single headphone, etc. have been selected systematically. Then, the prototype of the walking guide is developed successfully with a weight of about 360 g including all electronic components. In addition, evaluation processes have been successfully conducted for the developed spectacle. Notification systems are introduced inside the electronic spectacle in order to give a direct audio signal to the users for avoiding obstacles effectively. The ultrasonic sensor and Rpi camera are used to capture the real world environment of the developed walking guide. The distance between the obstacle and the user is calculated by analyzing the data from the ultrasonic sensors. The pothole images are trained initially using convolutional neural network and the potholes are detected by capturing a single image each time. The notification to the users are provided with the presence of obstacles and potholes through audio signals by headphone. The developed prototype is a bit bulky and it can only detect the obstacles but cannot categorize the obstacles except potholes. Despite of these limitations, the developed walking guide is supportive for the visually impaired people to avoid obstacles at any directions and potholes on the road surfaces while walking.

5.2 Future Recommendations

Based on the theoretical and experimental work carried out during this thesis, it is recommended that further research could be done to improve the efficiency of the walking guide by addressing the following points.

- The developed walking guide became slightly bulky due to the use of several electronic components. For example, the raspberry pi is used but all the functionalities of the raspberry pi are not used in here. Hence, developing an Application Specific Integrated Circuit (ASIC) with the functionalities of the developed walking guide can reduce the size, weight and cost of the prototype.
- In real world environment, some critical hindrances that are faced by the visually impaired people are humps on the road surface, staircase situation, road surface smoothness, water on the road surface etc. However, the developed walking guide only detect the potholes on the road surface. Thus, the enhancement of walking guide considering other critical hindrances may contribute in the further research for aiding visually impaired people.
- The system can detect the presence of obstacles but cannot categorize the obstacles, which are essential for the visually impaired people in navigation. Semantic pixel-wise segmentation of the surroundings may contribute to categorize the obstacles around environment.

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