A Finger-mounted Obstacle Detector for People with Visual Impairment

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Abstract

Visual impairment is the functional limitation of the eyes that may cause difficulties in performing normal daily activities such as walking. People with low vision have limited mobility as they have limited vision to move safely without colliding against obstacles. There are many research on developing obstacle detector for the visually impaired. However, there is still a lack of good obstacle detectors for people with visual impairment because most existing prototypes are in experimental stage without evaluation for their performance and usability. Some of the existing obstacle detectors have issues like bulky in size, heavy to carry on continuously, obstructive, high cost, and/or high maintenance.

As a result of analysing the research problems, this research proposes a low cost, low computational power, small and compact, lightweight, non-obstructive and non-vision based obstacle detection model for the visually impaired.

The prototype is built with an ultrasonic sensor to obtain real time information of distance between sensor and obstacles. This information is processed using a distance measurement algorithm and translated into an audio feedback which will alert a user of the presence of obstacles in the path. The prototype is small, compact and lightweight so it can be worn on the finger. Thus, it is flexible to allow the user changing the direction of the detection by pointing.

Three experimental testing were conducted to evaluate the prototype. First laboratory experiment was to determine the detection rate on indoor and outdoor obstacles of different sizes and shapes in a controlled environment. Second laboratory experiment was to test the prototype with participants wearing blindfolds (no vision simulator) and walking in the laboratory filled with real life obstacles. Third experiment was conducted with participants wearing low vision simulators walking in an uncontrolled outdoor environment. The results showed the prototype work well for people with low vision in an uncontrolled outdoor environment.

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Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university, and to the best of my knowledge contains no material previously published or written by another person, except where due reference is made in the text of the thesis. Work based on joint research or publications in this thesis fully acknowledges the relative contributions of the respective authors or workers.

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Chapter 1 Introduction

This thesis describes a research on the design and development of an obstacle detector model for the people with visual impairment using a low cost ultrasonic sensor and microcontroller. The proposed model includes an ultrasonic sensor based distance measurement module and an audio feedback module. It is designed in the form of a wearable, to help people with visual impairment to “sense” and “avoid” obstacles around them. This chapter discusses mainly on the research background, research problem, research goal and objectives, and proposed solution.

1.1 Research Background

Visual impairment is a defect of sight which decreases an individual’s ability to see. Vision is important because it allows human to connect with their surroundings. Up to 80 percent of impressions are perceived by sight (Politzer 2008). Furthermore, sight provides the best protection from danger when compared to other senses like taste and smell. The loss of sight result in problem such as difficulty in walking, navigating to a certain location and working.

Visual impairment can be classified into four categories including the mild visual impairment, moderate visual impairment, severe visual impairment and blindness (Mandal 2013). Visual acuity and visual field are the factors used to determine the class of visual impairment. The reduction of visual acuity and visual field can be caused by injury of the eyes, infections from disease, inherited genetic disorders, age-related and health conditions.

Most of the visual impairments can be prevented or cured with various treatment. For instance, refractive errors can be cured by using glasses, contact lens and surgery while as eye infections are treated using antibiotics. Unfortunately, some incurable visual impairments do exist such as retinal degeneration disorders.

Many products and tools are made to assist people with visual impairment in everyday life such as white cane, cash reader and Global Positioning System (GPS) navigation. Most of existing working products were outdated, standalone and costly (Humanware 2017). In addition, many research projects designed and developed obstacles detectors for the visually impaired, but they were not available commercially or stopped at experimental stage without detailed testing. In general, there is still a lack of small, compact, low cost and effective obstacle detector that can help the visually impaired in sensing and avoiding surrounding obstacles.

1.2 Research Problem

Advancement of technology creates opportunity to improve the wellbeing of people with visual impairment. However, the advancement is still not significant when it comes to the creation and implementation of assistive devices for helping people with visual impairment in detecting obstacle surrounding them.

Currently, there are many research works on obstacle detector using vision-based sensors, ultrasonic sensors, infrared sensors and fusing of multiple sensors. Vision-based systems may have better accuracy over other non-vision based systems, but they require higher computational resources to work in real time. For low cost and low computational power, non-vision based sensing system, ultrasonic sensor is one of the feasible choices.

In fact, there is a lack of commercially available and low cost non-vision based wearable detectors that can work in both indoor and outdoor conditions. This could mainly due to many conceptual models and prototypes that stopped at experimental stage without evaluation for their performance and usability.

An ideal obstacle detector for the visually impaired would be the one that can work in both indoor and outdoor environments, lightweight, compact, non-obstructive, low computational power and low cost. Thus, the research problems are identified as below:

1. There is a lack of non-vision based wearable obstacle detector which can work in both indoor and outdoor environments.

2. There is a lack of light-weight, portable and non-obstructive wearable obstacle detector.
3. There were a lot of conceptual models and prototypes being published but the products were not commercially available to the visually impaired. In addition, the performance and usability evaluation results of those obstacle detectors were not available.

1.3 Proposed Solution

As a result of analysing the research problems, this research proposes a low cost, low computational power, small and compact, lightweight, non-obstructive and non-vision based obstacle detection model for the visually impaired which includes a distance measurement sensor to obtain the distance between sensor and obstacle in real time, then this information is conveyed to user using audio feedback.

1.4 Research Goal and Objectives

Problem creates opportunity for improvement. Current models and prototypes can be questioned to determine the feasibility on improving the functionality such as designing a non-vision based wearable obstacle detectors which can work both indoor and outdoor environments for people with visual impairment. Not only that, development of prototype that meets the criteria such as light-weight, portable and non-obstructive needs to be considered as well. If the proposed non-vision based wearable obstacle detector is developed, the performance in detecting indoor and outdoor obstacles needs to be evaluated. The research questions are:

1. What are the limitations of the existing non-vision based obstacle detectors for the visually impaired?
2. How to design and develop a non-vision based obstacle detector which can achieve the criteria of low cost, low computational power, small and compact, light-weight and non-obstructive for the visually impaired?
3. How effective a non-vision based obstacle detector work in detecting indoor and outdoor obstacles?

Thus, this research aims to deliver a non-vision based, wearable obstacle detector model for the visually impaired with the research objectives as below:

1. To study the limitations in the existing non-vision based obstacle detectors for the visually impaired
2. To design and develop an enhanced non-vision obstacle detector which is low cost, low computational power, small and compact, light-weight and non-obstructive for the visually impaired
3. To evaluate the performance of the proposed non-vision obstacle detector

1.5 Thesis Organization

This thesis contains five chapters which discuss about the entire research project as shown below.

Chapter 1 introduces the general information relating to this research which includes background of the study and purpose and motivation to do the research.

Chapter 2 discusses the literature reviewed in this research which includes visual impairment, types of visual impairment, causes of visual impairment, ways of people with visual impairment navigate, and existing research work on obstacle detections.

Chapter 3 presents the proposed solution and also discusses on the implementation of prototype.

Chapter 4 contains the experimental evaluation of the prototype's performance which includes the procedure and setup of the experiments and discussion on the experimental findings.

Chapter 5 concludes the research with recommendations for improvement of this work.

Chapter 2 Literature Review

This chapter reviews the existing research of obstacle detection for people with visual impairment. It begins by firstly reviewing the definition of visual impairment, the types of visual impairment, causes of visual impairment and treatment for visual impairment. A discussion on how people with visual impairment navigate is also reviewed. Existing research on obstacle detection is discussed. This is followed by the selection rationale for sensors and requirements of a good obstacle detector for the people with visual impairment. Lastly, a critical review is presented.

2.1 Visual Impairment

Visual impairment is a reduction in vision which effects the function of eyes and cannot be corrected to normal vision. Visual impairment affects visual acuity, visual field and colour perception.

Visual acuity is a term describing the sharpness or clarity of the image seen by an individual. Snellen eye chart, shown in Figure 2.1, is a standardized test used to measure the visual acuity of an individual (Segre 2017). The measurement is represented by the fraction of two numbers. The numerator represents what an individual will see from the stated distance. The denominator represents what a normal people can see at the stated distance. Having a 6/6 vision means the person can clearly see what should be seen at 6 meters away. Visual acuity measurement of 6/60 means that the person must be at 6 meters to see what people with normal vision can see at 60 meters away. In United States, measurement of visual acuity is in feet, so a 20/20 vision means the person can clearly see what should be seen at 20 feet (60 meters in SI unit) away. Visual field is a term to describe the total area or range an individual can see.

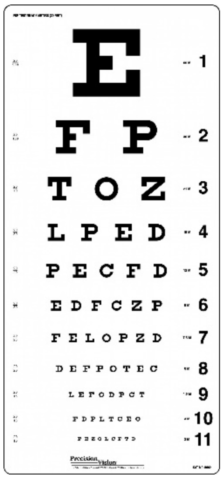

Figure 2.1: Snellen Chart (Segre 2017)

2.1.1 Types of Visual Impairment

According to World Health Organization (WHO 2016) International Classification of Diseases (ICD), visual impairment can be classified as normal vision, moderate visual impairment, severe visual impairment and blindness. The classification of visual impairment (Table 2.1) is based on the visual acuity and visual field of an individual. Visual acuity between 6/5 and 6/9 is defined as normal vision with no impairment and visual acuity between 6/9 and 6/18 is defined as mild visual impairment and these two are classified under Category 0. Visual acuity between 6/18 and 6/60 is classified under Category 1. Visual acuity between 6/60 and 3/60 is classified under Category 2. Visual impairment under Category 1 and 2 is defined as low vision. Visual acuity worse than 3/60 or beyond Category 2 is defined as blindness. Profound visual impairment with visual acuity between 3/60 and 1/60 and visual field of less than 10 degrees in radius around central fixation is classified under Category 3. Near total visual impairment is defined as visual acuity that is worse than 1/60 but better than no light perception and this is classified under Category 4. Total blindness or total visual impairment is defined as a complete loss of vision with no light perception and is classified under Category 5. Any undefined, undetermined, or unspecified visual impairment is classified under Category 9.

Table 2.1: Classification of visual impairment (WHO 2016)

Category		Worse than		Equal to or better than	
		meter	feet	meter	feet
0	No visual impairment	6/5	20/15	6/9	20/30
	Mild visual impairment	6/9	20/30	6/18	20/70
1	Moderate visual impairment	6/18	20/70	6/60	20/200
2	Severe visual impairment	6/60	20/200	3/60	20/400
3	Profound visual impairment	3/60	20/400	1/60	20/1200
4	Near total visual impairment	1/60	20/1200	Light perception	
5	Total visual impairment	No light perception			
9		Undetermined or unspecified			

2.1.2 Causes of Visual Impairment

There are many causes that may lead to visual impairment. It can happen before or after birth. Some of the causes are listed in Table 2.2.

Table 2.2: Known causes of visual impairment (Mandal 2012)

Condition	Causes
Refractive error	• The most common cause of visual impairment • It is caused by inflexible and irregular shaped lens • Common refractive errors are Myopia (near-sightedness), Hyperopia (farsightedness) and Astigmatism
Cataract	• Leading cause of visual impairment • Eye lens are clouded which prevents light from entering
Glaucoma	• It is caused by pressure in eye which damage the optic nerve
Trachoma	• An inflammation in the eye caused by contagious microorganism called chlamydia trachomatis
Diabetic retinopathy	• It is caused by damaged small blood vessel in retina due to diabetes
Accident	• Direct injury to the eye

2.1.3 Treatment for Visual Impairment

It is possible to change the quality of life of people with visual impairment by treatment which include teaching and guiding them on what to do or reduce the severity of impairment or obtaining a normal vision. Some of the available treatments are medical treatment, surgical treatment, and non-medical treatment (My Child without Limits 2017). Medical and surgical treatment can correct the vision loss or impairment. Medical treatment includes the use of medicine such as antibiotics to treat eye infections and the use of corrective lenses to treat refractive errors. Surgical treatment involves the use of technology such as laser surgery for retinography and removal of cataract by surgery.

Although there are impairments that can be treated, there are also impairments that cannot be treated and non-medical treatment is available to help the people with visual impairment. Non-medical treatment involves training the disabled to improve their sensory awareness, spatial concepts, searching skills and independent movement by attending orientation and mobility training. Vision and navigation aid such as white cane is also one of the non-medical treatment, learning to use them can benefit the disabled to walk and move around more independently.

2.2 Common Ways of Navigating and Avoiding Obstacles

People with visual impairment have difficulty in travelling from one place to another. They usually use some gadgets to help them to move around. Commonly used navigation aids to help them moving around are white cane, guide dog and human guide. Only about 20 to 30% of the totally blind people can use echolocation to travel (Thaler 2013).

White cane is a long rod that people with visual impairment use to assist them in navigating safely (Bhatlawande et al. 2014; Ong, Zhang & Nee 2013; Villamizar et al. 2013). It acts as limb extension where user can feel what is ahead. The cane is swept from side to side on the ground. This allows user to detect obstacles, pits, holes or stairs that is in the path. The cane is good to detect obstacles on the ground but it is not able to detect aerial obstacles that is above waist level.

Another way of navigating by people with visual impairment is by following a guide dog (Bai et al. 2017; Ong, Zhang & Nee 2013). Guide dogs are trained to guide the handler around obstacles and stop at curbs and stairs. Guide dogs can also judge the height of handler which is useful in preventing bumping to obstacles above waist level. However, guide dogs can be costly and high maintenance.

From the issue encountered by people with visual impairment in navigating, an assistive device that is capable of detecting obstacle and alert user could be a good alternative to avoid obstacles during real time walking and navigating (Ong, Zhang & Nee 2013; Villamizar et al. 2013).

2.3 Smart Technology for Obstacle Detection Using Ultrasonic Sensors

With the advancement in hardware and software at affordable prices, a lot of smart devices are designed, prototyped or developed for the blind. They are divided into vision and non-vision based devices.

Vision based obstacle detector uses camera as the main component (Amin & Borschbach 2015; Bhatlawande et al. 2014; Costa et al. 2012; Grassi & Guaragnella 2014; Jafri et al. 2017; Lee, Su & Chen 2012; Lee & Medioni 2016; Peiris et al. 2016; Pundlik, Tomasi & Luo 2013; Rizzo et al. 2017; Saputra, Widyawan & Santosa 2014; Tapu et al. 2013). It is used to capture live image and the data is then processed by a relatively strong processor such as ARM Cortex used in Beagleboard (Bhatlawande et al. 2014). There are many ways the data can be processed which is dependent on the desired results. For instance, some of the algorithms can detect stairs, path and obstacles (Silva & Wimalaratne 2016). The major advantage of using vision based sensors is the large amount of visual information that can be obtained and interpreted from the images, and may also result in more objects being detected. Image recognition is also possible when using vision based system. The disadvantage of vision based system is the need of using strong processor which tends to be power hungry and big in size (Li et al. 2015; Saputra, Widyawan & Santosa 2014; Tapu, Mocanu & Zaharia 2013).

A smaller built is possible if the system is not vision based. Non vision based obstacle detector uses less extensive sensors such as laser (Saffoury et al. 2016), infrared (Al-

Fahoum, Al-Hmoud & Al-Fraihat 2013; Kumpakeaw 2012; Niitsu, Taniguchi & Kawashima 2014) and ultrasonic (Abu-Faraj et al. 2012; Agarwal et al. 2017; Bahadir, Koncar & Kalaoglu 2012; Bahadir, Koncar & Kalaoglu 2016; Bhatlawande, Mukhopadhyay & Mahadevappa 2012; Chung, Kim & Rhee 2014; Earshia, Kalaivanan & Dayana 2014; Gao et al. 2015; Gürkan & Akan 2013; James & Harsola 2015; Khampachua et al. 2016; Laubhan et al. 2016; Menikdiwela, Dharmasena & Abeykoon 2013; Murali et al. 2016; Mustapha, Zayegh & Begg 2012; Mutiara, Hapsari & Rijalul 2016; Nayan & Latchmanan 2016; Niharika, Heena & Jaint 2015; Niitsu, Taniguchi & Kawashima 2014; O'Brien et al. 2014; Parmar & Inkoolu 2017; Rey et al. 2015; Saaid, Mohammad & Ali 2016; Sharma et al. 2017; silva & Dias 2015; Toha et al. 2015; Vorapatratorn & Nambunmee 2014; Yiting & Lunfu 2015). The power consumption and processing power is also less when compared to camera sensors. As this research aims is to assist the visually impaired with a lightweight and portable assistive device, the non-vision based obstacle detector is more desirable.

2.3.1 Smart Cane

There have been ongoing research in improving the function of assistive devices. Some of the attempts in making an obstacle detector was to turn a regular cane into smart cane by embedding electronics components into the white cane.

Menikdiwela, Dharmasena and Abeykoon (2013) designed an ultrasonic haptic based obstacle detector. Ultrasonic sensors were used for detecting obstacle and it is located near the bottom of the cane. Haptic feedback was implemented to notify the users and the mechanism was located on the handle. The haptic feedback mechanism was produced by using vibration motors. Placement of electronic components are shown in Figure 2.2. User does not have to swing the cane for detecting obstacle but it does require user to carry the cane to avoid the cane touching the ground. Swinging the cane could produce wrong feedback to user. Storing the designed cane in a small case is not possible as it is not foldable. The prototype is only designed to replace white cane in detecting ground level obstacles and is not capable of detecting head level obstacles or pits on the ground. The prototype was tested by blindfolded participant and based on the experiment, height of the obstacle above 0.1 meter can be detected but the maximum height was not evaluated.

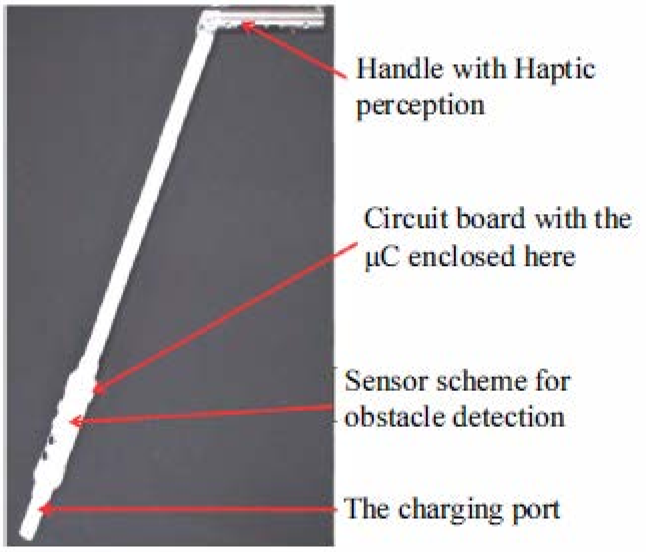

Figure 2.2: Placement of electronics on the cane (Menikdiwela, Dharmasena & Abeykoon 2013)

Another smart cane proposed by Mahmud et al. (2014) uses three sensors for detecting left, front and right plane obstacle which can be seen in Figure 2.3. Two feedbacks system were implemented which are vibration and audio. For example, when obstacle is detected by the left sensor, left arm vibration motor will operate and 'left obstacle detect' audio sound is produced. As this was a partially completed prototype, wires and electronics connection are visible making the cane vulnerable to situation where short circuits or open circuits could happen due to the exposure to water and damages of wires. Similar to the previous built, it is only capable of detecting ground level obstacles, leaving user vulnerable to head level obstacle such as overhanging tree branch. The performance and reliability of the prototype is undetermined because the researchers did not perform the evaluation.

Figure 2.3: Vibration and voice operated smart cane (Mahmud et al. 2014)

Mutiara, Hapsari and Rijalul (2016) developed an ultrasonic sensors based obstacle detecting cane, designed to detect holes and give direction of qibla through audio feedback system. The sensors are located near the bottom of the cane. It uses button to activate either the ultrasonic obstacle detection mode or compass qibla direction mode. Despite having the cane being foldable, there are wires running around the cane which could cause malfunctions in the electronics due to potential wire disconnection as seen in Figure 2.4 and Figure 2.5. The prototype was designed to detect hitch and holes only. The prototype was evaluated by six peoples and performed well in detecting and alerting the presence of hitch and holes. However, four of the six participants found the prototype difficult to use and the response time of the cane is slow.

Figure 2.4: Placement of sensor (left), microcontroller and energy storage system (right) (Mutiara, Hapsari & Rijalul 2016)

Saaid, Mohammad and Ali (2016) designed a prototype that is capable of detecting obstacle from waist-to-ground level with no swinging motion. Ultrasonic sensor (white box in Figure 2.5) is placed near the handle and is positioned on specific angle so that it does not detect the cane. Earphone is used to feedback information to user. The sensor and feedback system are externally connected to the processor using wires which however is not an ideal idea as it is more prone to wire disconnection. The prototype lacks of a proper testing and its usability is questionable because earphone blocks noise from surrounding, which can endanger the life of the user.

Figure 2.5: Prototype of smart cane using audio cue (Saaid, Mohammad and Ali (2016)

James and Harsola (2015) took a step further and developed a smart cane that can detect obstacles and provide navigation. Three ultrasonic sensors are used, two sensors are placed near the handle to detect left and right obstacles and one is placed near the bottom to detect obstacle in front as shown in Figure 2.6. GPS module and magnetometer are implemented and made the navigation possible. Although the prototype is designed to work in both indoor and outdoor environments, the electronic components which are not properly encased might decrease its likelihood of functioning in an outdoor environment. The researchers did not evaluate its performance with any user.

Figure 2.6: Smart cane with GPS function (James & Harsola 2015)

Murali et al. (2016) also implemented GPS module into their smart cane as shown in Figure 2.7. The purpose is to obtain and send the coordinates of user to other people during emergency. Global System for Mobile communications (GSM) module was used to provide the function of sending the coordinates in the form of text message. Besides that, the cane can detect obstacles, terrain change and presence of water on the ground. Haptic feedback is used for notifying presence of any obstacle to a user and audio feedback is used to convey terrain information. The prototype stopped in the experimental stage and wires are visible as shown in Figure 2.7. The researchers did not evaluate the prototype so the usability and performance of the prototype is unknown.

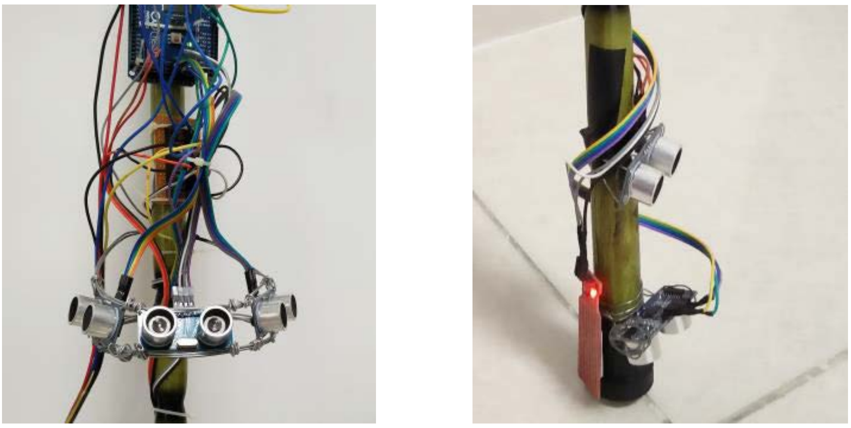

Figure 2.7: Sensor for over waist detection (left) and sensor for hitch, hole and moisture sensor detection (right) (Murali et al. 2016)

2.3.2 Robots

Toha et al. (2015) proposed a path guidance robot that can detect obstacle and follow path. Ultrasonic and infrared sensors are used for obstacle detection and path guidance respectively. The robot is attached to a white cane to eliminate the swinging motion during travelling (Figure 2.8). The proposed robot has motors that move the robot itself and this provides navigational cue to user. However, this feature may not work if there is no path. It detects ground level obstacle only and does not stop user from colliding with head or waist level obstacles. The prototype was not evaluated with users, thus the performance and usability could not be determined.

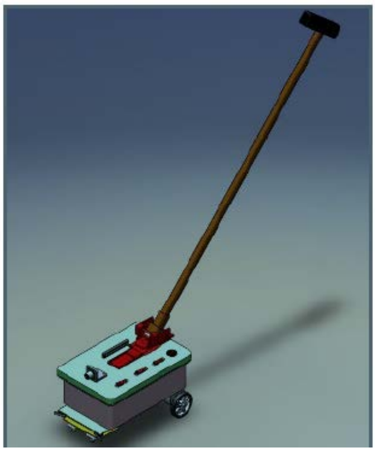

Figure 2.8: 3D design of the path guidance robot (Toha et al. 2015)

2.3.3 Wearable

There were also attempts in making a wearable obstacle detection device which could be worn on head, body, hand or legs. Aymaz and Çavdar (2016) designed a wearable headset that uses solar to power up the device (Figure 2.9). Ultrasonic sensors are used to detect obstacles. Audio feedback is implemented in this prototype and is relayed through the headset itself. The prototype however only relies on solar energy and is not capable to work indoor as it has no battery. Given the low output power of solar panels, the prototype may only work during a bright day environment. Using headset to provide feedback could be dangerous because it covers the entire ear and reduces the alertness to surrounding sounds.

Figure 2.9: Solar headset based obstacle detector (Aymaz & Çavdar 2016)

A wrist-based obstacle detector was developed by Khampachua et al. (2016) which incorporated ultrasonic sensor and smartphone together (Figure 2.10). Distance information from an ultrasonic sensor is processed by a microcontroller and is relayed to the smartphone using Bluetooth. The detector works in two modes which are ground and above ground level obstacle detection. Above ground detection mode uses the data from ultrasonic sensor only while the ground detection mode uses data from ultrasonic sensor and accelerometer found in the smartphone. Speaker and vibration motor are used as the feedback system. Evaluations were conducted on some blindfolded participants and it reduced the collision against obstacles when compared to using only white cane. The learning curve is low as participants navigate faster on their next trial. The response time was, however, not tested. There could be potential delay during the transfer of information from microcontroller to smartphone via Bluetooth. In the event that one of the devices powered down, the prototype is left unusable. No user evaluation has been performed to validate the usability and performance of this prototype.

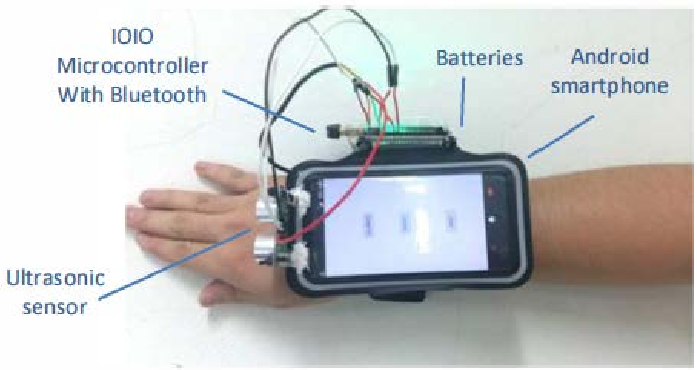

Figure 2.10: Smartphone based obstacle detector on wrist (Khampachua et al. 2016)

Vorapatratorn and Nambunmee (2014) designed and developed iSonar, a small size obstacle detector that can be worn around the neck. The researchers designed the ultrasonic module using two transducers and information is processed by a microcontroller. The prototype uses the haptic feedback to alert a user of any obstacle above the waist level. The electronic components used were shown in Figure 2.11. The prototype was evaluated and it was found that the collision rate was reduced from 33.33% to 6.67%. However, placing the device on the neck can cause false reading during movement because the device is not fixed and will swing unnecessarily.

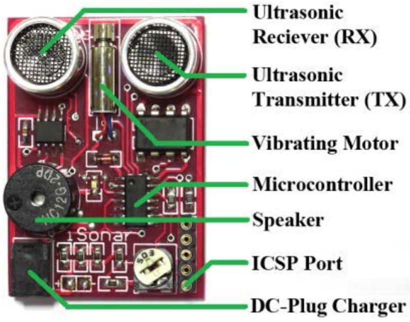

Figure 2.11: iSonar, a neck strap based obstacle detector (Vorapatratorn & Nambunmee 2014)

Using arrays of ultrasonic sensors on different body parts may solve the issue of not detecting obstacles on different height level. In such practice, Bhatlawande, Mukhopadhyay and Mahadevappa (2012) implemented arrays of sensors fitted on spectacle and belt (Figure 2.12). The spectacle detects the head-level obstacle and the belt detects the waist-level obstacle. The two input devices are connected to a microcontroller using wires and the processed feedback signal is announced through earphone. The wire connections make this prototype less user friendly. This concept requires some thorough testing because the ultrasonic pulses from different sensors interfere with one another. No user evaluation has been performed to validate the usability and performance of this prototype.

 

Figure 2.12: Ultrasonic sensor on glasses (left) and belt (right) (Bhatlawande, Mukhopadhyay & Mahadevappa 2012)

2.4 How Does Ultrasonic Sensor Work in Obstacle Detection

Penny Cup Game is a simple experiment that test whether one or two eyes is better (Home Science Tools n.d.; PBS KIDS n.d.). This simple game requires individual to drop a penny into a cup in two different setups; first with one eye open and second with two eyes open. It was more difficult to drop penny into the cup with one eye open only. Eyes can only see things in 2D. But with two eyes, there is two 2D images and brain is able to put together this two images into one 3D image. This is called stereoscopic vision (Becky n.d.). With this vision, human can perceive depth and has higher chance of putting the penny into the cup. Being able to perceive depth is how human can tell if an object or obstacle is near or far. However, people with visual impairment most likely cannot perceive depth. Thus a substitute equipment or device must be able to perceive depth or distance and notify people with visual impairment. One such device that can perceive distance is ultrasonic sensor.

Ultrasonic sensor is an electronic device that uses sound wave to measure distance. The sound wave is generated by a vibrating device called transducer which then emits ultrasonic pulses. After the pulse is emitted, the transducer is used to listen for echo or reflection of the pulse. The time taken to receive the reflected pulse is used to calculate the distance between the object and the sensor as shown in Equation 1.

$$distance = \frac{speed\ of\ sound \times time\ taken}{2} \quad (1)$$

According to Collins Dictionary (2018), there are two definitions for obstacle: obstacle as an object that blocks a path, making it difficult to go somewhere and obstacle as anything that makes doing something difficult. Obstacle as an object is used in this context where an object becomes an obstacle when a person approaches the object whereas the distance between the object and person decreases. By measuring the distance to an object, it is possible to find obstacle in an environment. Since ultrasonic sensor can measure the distance between an object and the sensor itself, it is suitable for detecting obstacles.

2.5 Advantages of Using Ultrasonic Sensor Compared to Laser and Infrared Sensor

There are a few sensors that could be used to measure distance such as laser, infrared and ultrasonic sensors. Each sensor has its own field of application due to its distinctive characteristics and limitations.

Laser sensor is highly accurate in detecting objects, and has high measurement resolution. It is also a low energy consumption device which is good for application requiring long term usage. Laser emits visible light spot which serves as an indicator but this feature would be disturbing to some people in a crowded environment. In addition, laser sensor lacks the capability to measure transparent objects and is considered sensitive to work in full sunlight environment. High sensitivity of laser sensor causes it to detect even dust particle which can be unnecessary in detecting obstacles for the visually impaired.

On the other hand, there are two types of infrared sensor, reflective sensor for a short distance and sharp sensor for a long distance. Infrared sensor has a narrow range of detection, resulting in good accuracy for detecting objects and it is inexpensive for its function. However, the sensor does not function well in outdoor environment during daytime. Infrared can be found in sunlight, thus it causes interference that may result in false reading. Reflective infrared sensor has a short distance range that is less than 10mm. Sharp sensor has a larger distance range and higher minimum distance. However, it is not able to detect anything below the minimum distance. It has difficulty in detecting object with dark surface and the colour of an object influences the distance measurement.

The main advantage of using ultrasonic sensor is its insensitivity towards light condition. It works in the dark and also in the area exposed with sunlight. It is also insensitive to dust, smoke, mist, and vapour. Colour, reflectivity and transparency of an object do not affect the ultrasonic reading but the shape, density, and texture of an object may affect the reading. In addition, object angle affects the reading accuracy, an object that is perpendicular to the sensor can be sensed accurately.

As ultrasonic sensor uses sound wave, noises in the environment can affect the accuracy. In addition, speed of sound changes in different environment factor such as temperature, pressure and humidity may affect the accuracy as well. Ultrasonic sensor may have a lower accuracy in detecting the exact object position when compared to the other two sensors due to its wider angle range detection.

Ultrasonic sensor is a good choice for developing a low cost, low computational power and low energy consumption obstacle detector. In addition, the sensor's insensitivity towards light condition enables the obstacle detector to work in both indoor and outdoor environment.

2.6 Attributes of a Good Obstacle Detector for the Users with Visual Impairment

The most important requirement in developing a good obstacle detector for people with visual impairment is the ability to detect and notify the user with the presence of obstacle accurately. Unreliable obstacle detector defeats the purpose of helping people with visual impairment to walk or navigate confidently. It should also contain a feedback system that provides easily interpreted cues to reduce unnecessary thinking time (Kim & Cho 2013).

It is also important to make the assistive device which has good portability (Kim & Cho 2013). Thus, the size and weight has to be taken into consideration when building an obstacle detector for the visually impaired. Small size and lightweight device has higher portability and is more likely to attract people into using it.

Most of the existing prototypes require user to walk slowly (Vorapatratorn & Nambunmee 2014). However, a good obstacle detector should not change or hinder the way people normally behave such as walking. It is possible that the people with visual impairment are not experienced in using an obstacle detector. Thus, a device that is easy to use would be beneficial to reduce any long and intensive learning curve like learning the Braille (Kim & Cho 2013).

Electronic device, to a certain degree, requires maintenance. Portable electronic devices are often powered by batteries which deplete after being used for a period of time. To reuse the device, batteries are either replaced with new one or recharged. Thus, maintaining a device such as recharging or replacing the battery has to be made easy for the people with visual impairment (Kim & Cho 2013).

Few additional desirable attributes such as low cost, low computational power and low energy consumption would contribute to a good obstacle. People of different backgrounds from low-income to high-income groups may suffer from visual impairment. While the people from high income group can afford to use assistive device that cost USD 700, people from low income group might take years of saving to get hold of such device. The benefit of developing a low cost obstacle detector includes giving the people with visual impairment in low income group an opportunity to use the assistive device without years of saving. Devices with low computational power is desirable to avoid overheating because processor with high computational power produces more heat (Dechaume 2003) which can be uncomfortable to be worn. Furthermore, a processor with high computational power consumes more energy and is not ideal for a portable device using battery which has limited energy storage. Thus, a portable device with low computational power and low energy consumption would be desirable for comfort and longer usage period.

As an obstacle detector is expected to be used frequently to assist people with visual impairment, low maintenance and high durability of the device in terms of wear and tear should be considered during the design and development phase.

2.7 Critical Review

People with visual impairment lacks the ability to see how normal people work. This restricts them in doing most of the things that require vision including walking. Walking without colliding to objects is a challenge for them. People with visual impairment require an assistive device that can detect obstacle to help them walk.

Many researchers designed and developed obstacle detectors to help people with visual impairment. Most prototypes are designed to replace white cane but many are still at experimental stage and not practical enough to be implemented in real life. Reliability of the reviewed prototypes were not documented or not thoroughly tested. In some cases, prototypes were not properly encased which increased the chance of damages on the electronic components.

Most smart cane prototypes were only used for ground level obstacle detection (Mahmud et al. 2014; Menikdiwela, Dharmasena & Abeykoon 2013; Mutiara, Hapsari & Rijalul 2016). It may replace white cane but it is not sufficient to provide the full experience of obstacle avoidance. Full obstacle detection should be considered starting from head to ground level obstacles. The reviewed smart cane prototypes were not able to detect obstacle above waist level.

The robotic guide dog (Toha et al. 2015) may look impressive but it has limited functionality. It can only follow a fixed line path which is uncommon to be found on the ground. The prototype is bulky and has to be carried by the user when he/she is not using it.

Wearable design obstacle detector come in different shapes. However, wrist-mounted or glove design which occupies one hand is obstructive to certain people (Khampachua et al. 2016). Headset-based design may block the user from hearing the ambient sound such as incoming vehicle sound which is important for their safety (Aymaz & Çavdar 2016), thus triggering the safety issues in an outdoor environment. Neck-strap based design can detect head level obstacle but due to its positioning on the chest, the device may swing as a user walks, which can lead to false detection (Vorapatratorn & Nambunmee 2014).

Following the guidelines of a good obstacle detector for the visually impaired and considering all the problems found from the literature reviews, a good obstacle detector must be low cost, low computational power, low energy consumption, portable, lightweight, non-obstructive and flexible to detect obstacles at different heights when needed.

In short, this chapter reviews the types of visual impairment, their way of navigating, existing research on obstacle detection for the visually impaired, distance measurement technologies in detecting obstacles, methodologies and models of existing non-vision based obstacle detection devices.

Chapter 3 Prototyping

3.1 Introduction

This chapter introduces the concept of prototyping of an obstacle detector, the methods and materials required to turn the concept into a working prototype. Development of the prototype in the aspects of hardware and software are documented and following that, some laboratory tests were documented to gather the specifications.

3.2 Conceptual Modelling

The ultimate aim of the obstacle detector is to be able to detect, identify and notify user of the existence of obstacles in front of it, in real time. The prototype is designed as a wearable in the form of a finger-mounted ring. Thus, a user can wear the prototype on his/her finger. User may point his/her finger with the obstacle detector to change the detection trajectory. If an obstacle is detected, the obstacle detector will beep to alert the user.

The concept behind the design of the prototype is to use ultrasonic sensor in measuring the distance between sensor and objects. Then, the signals are relayed to a user using the audio or haptic feedback. For this to happen, the interaction between the detection module and feedback module is made possible using a microcontroller. The microcontroller gets distance information from the ultrasonic sensor, processes the information, makes a decision based on the frequency, generates and sends the appropriate signal to the output module. A speaker is connected to the output module and an alert will occur when an obstacle is detected. This process run continuously to achieve a real-time obstacle detection. The prototype works as presented in Figure 3.1.

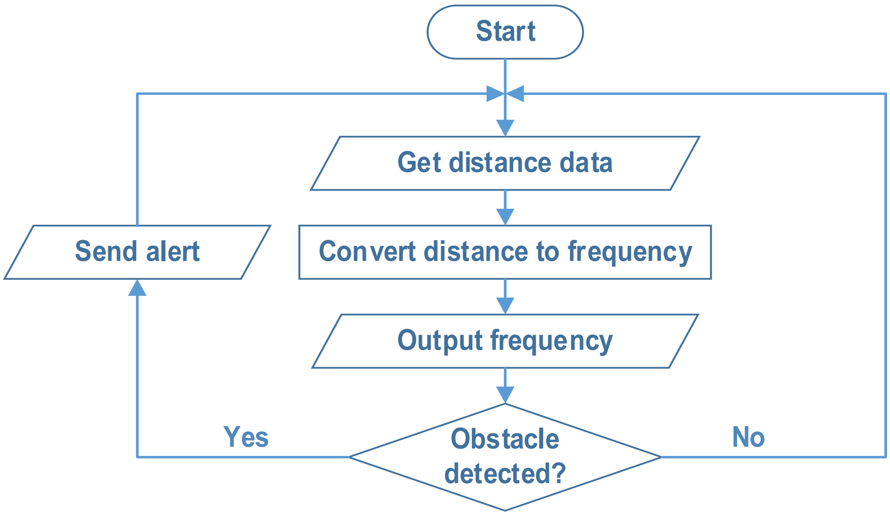

Figure 3.1: Conceptual Overview

3.3 Component Selection

When building the prototype, it was made sure that the electronic components used in the prototype are available commercially and selected properly to suit the desired requirements such as small, compact and lightweight, as discussed in Section 2.6.

One of the key components in the proposed prototype is the distance measuring sensor such as laser, infrared and ultrasonic. Each sensor has its own advantages and disadvantages as discussed in Section 2.5. Laser sensor emits visible light that may be interrupting to people, especially in the crowded environment. Although infrared sensor emits invisible beam, it does not perform well in outdoor environment due to the infrared interference from sunlight. Due to the issues of the laser and infrared sensors, an ultrasonic sensor is selected as the distance measuring sensor for the proposed prototype. As the form factor is critical in this prototype, Maxbotix HRLV-Maxsonar-EZ1, a small, compact and high detection accuracy ultrasonic sensor (Figure 3.2) was selected. The sensor has a distance detection range of 30cm to 5m with the resolution of 1mm. The sensor has multiple output options such as the analog voltage, pulse width and serial output. Pulse width output was used as the input signal to the microcontroller.

Figure 3.2: Maxsonar EZ1

As mentioned earlier, microcontroller obtains information from input source and converts the information into a desired output signal. It is the most crucial component in this project as it is the brain that controls and processes all the signals received. The microcontroller used in this prototype is an atmega328-based microcontroller board, Arduino Pro Mini (Figure 3.3).

There are many different Arduino models such as Arduino UNO, Arduino Mega, Arduino Leonardo as shown in Table 3.1. Arduino Mini has the smallest form factor of 30mm (L) × 18mm (W) among all boards but it is rather uncommonly used and not easily found in the local and online stores. The next smallest boards are Arduino Pro Mini and Pro Micro with dimensions of 33mm (L) × 18mm (W), it is 3mm larger that Arduino Mini. Both Pro Mini and Pro Micro are readily available in stores but Pro Mini was chosen because the cost of Pro Mini controller is lower and this in fact, helped to achieve the low cost requirement mentioned in Section 2.6.

Table 3.1: Comparison of Arduino models (Arduino n.d.; Sparkfun n.d.)

Model	Operating voltage	CPU Speed	Analog In	Digital IO/ PWM	Dimension L x W (mm)
UNO	5V	16MHz	6	14/6	68.6 x 53.4
Mega	5V	16MHz	16	54/15	101.52 x 53.3
Leonardo	5V	16MHz	12	20/7	68.6 x 53.3
Nano	5V	16MHz	8	14/6	45 x 18
Mini	5V	16MHz	8	14/6	30 x 18
Pro Mini	3.3V/5V	8MHz/16MHz	6	14/6	33 x 18
Micro	5V	16MHz	12	14/6	48 x 18
Pro Micro	3.3V/5V	8MHz/16MHz	9	12/5	33 x 18

Arduino Pro Mini (Figure 3.3) features a 14 digital input/output (I/O) pin, 6 of them can be used as the Pulse Width Modulation (PWM) pin. The PWM pin helps to control the speed of a component. It switches on and off instantly, thus it contributes to the effect of a speed control. A duty cycle determines the speed of switching. When a duty cycle reaches 100%, the speed is the maximum but the speed is halved when the duty cycle is reduced to 50%. Some examples of its usage are for controlling the motor speed and controlling the brightness of Light Emitting Diode (LED). A digital pin can be used as the input or output, depending on the command. When it is used as input, it can receive the digital or pulse signal. This pin mode is used to receive data from the ultrasonic sensor.

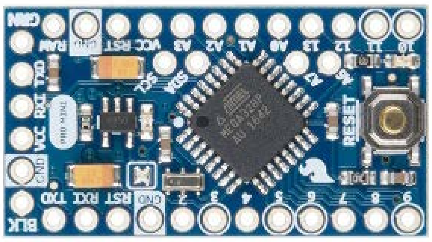

Figure 3.3: Arduino Pro Mini

Battery and Universal Serial Bus (USB) connection can be used to power up Arduino. For the proposed obstacle detector, battery is used to store and provide the energy source, thus it achieves the requirement of portability mentioned in Section 2.6. Some commonly used battery types for Arduino are lithium-ion, lithium-polymer and lead-acid. Coin cell-sized battery is selected for the prototype to reduce the overall size and weight. Other types of battery often require extra circuitry to properly power up Arduino and this is undesirable as it may consume more space on a compact prototype. A switch is implemented to turn on and off the prototype.

There has to be a feedback module for the interaction between the user and the proposed obstacle detector. Like how smartphone relays information to the visually impaired user using audio, an assistive device particularly for people with visual impairment requires feedback system that uses senses such as sound, touch or haptic. The feedback module implemented for the proposed obstacle detector delivers audio alert and it was done by using a smartphone speaker (Figure 3.4) as it is smaller than an ordinary buzzer.

Figure 3.4: Smartphone internal speaker

There are a few ways to relay information using audio feedback such as changing the sound intensity, frequency and beeping rate. For example, sound can be made louder, higher frequency and rapid beeping to indicate something urgent. The alteration of sound frequency was utilized in the proposed obstacle detector. Table 3.2 shows the frequency signal emitted in correlation with the distance measured from the sensor. The relationship between those two are inversely proportional. A higher frequency is emitted if the distance is shorter and vice versa, no signal is emitted if the distance is over the threshold of 5 meters.

Table 3.2: Frequency emitted for various distance ranges

Distance range	**Frequency (Hz)**
x < 0.5m	3000
x < 1m	2500
x < 2m	2000
x < 3m	1500
x < 4m	1000
x < 5m	500

3.4 Development

All the electronic components were initially tested to make sure they work properly. During the initial testing, fluctuation was observed based on the distance readings taken from the ultrasonic sensor. Filtering techniques were implemented to reduce the fluctuation. In this particular case, a hardware-based low pass filter shown in Figure 3.5 was implemented.

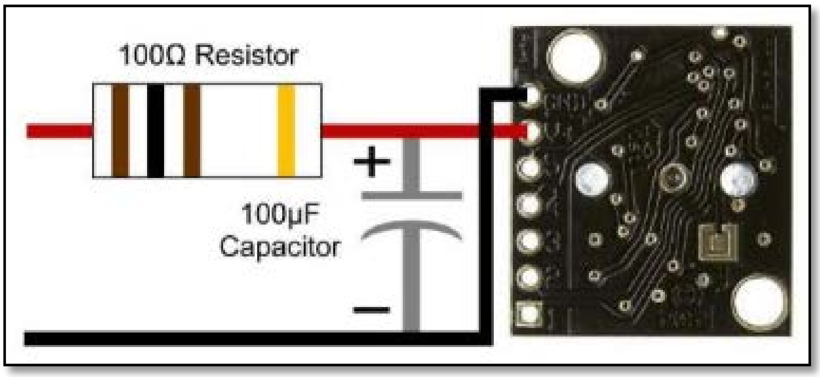

Figure 3.5: Controlling noise by filtering

After assembling, testing and ensuring all the parts worked properly, the electronic layout was sketched to keep track of all the connections and enabling the assembly of components to be easier and more systematic. The schematic layout of electronic components was drawn using Fritzing as shown in Figure 3.6.

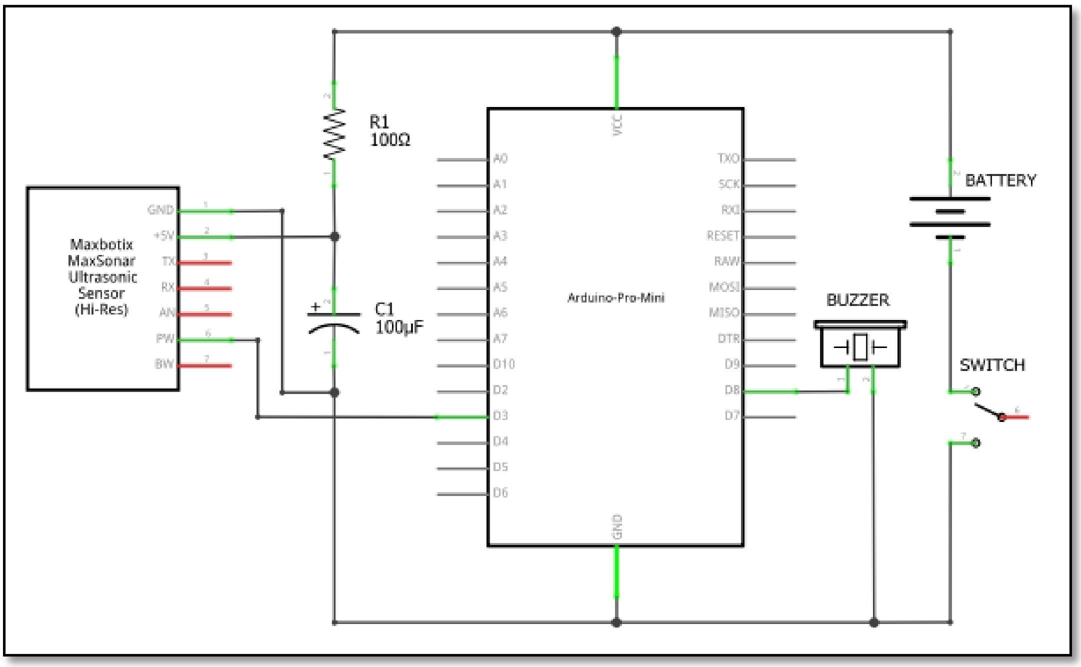

Figure 3.6: Schematic layout of components

Testing was done on breadboard before soldering the components into its compact form shown in Figure 3.6. A few things were taken into consideration when soldering the components such as leaving enough space to make sure there will not be short circuit. Figure 3.7 shows the assembled electronic parts of the prototype.

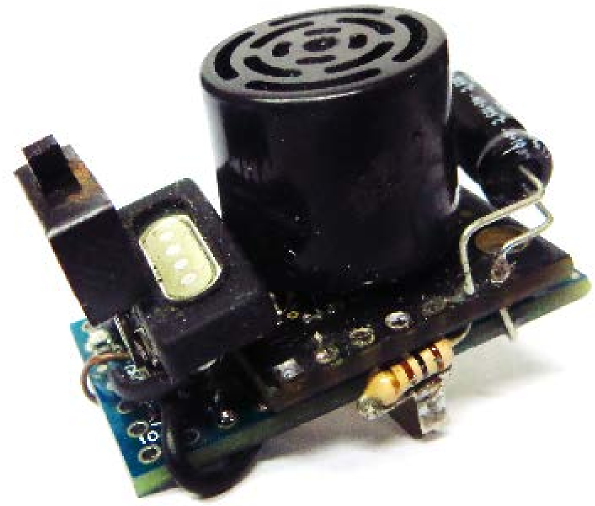

Figure 3.7: Assembled electronic components

The normal operating voltage of Arduino Pro Mini is either 3.3V or 5V which depends on on-board crystal clock. In this prototype, coin cell battery (CR2032) was used and the output voltage is 3V. Since no converter is implemented and the voltage is not boosted up to 3.3V or 5V, the fuse setting of the microcontroller is changed. Modifying the fuse setting changes the way the microcontroller operates which includes changing the operation speed of microcontroller and minimum voltage required to operate (Currey 2014). By default, the fuse settings for Pro Mini is to operate using external crystal clock and minimum voltage requirement of 2.7V. The default voltage requirement is close to the battery voltage. Thus, the new fuse setting lowers the minimum voltage requirement to 1.8V allowing more battery chemical to be depleted which can increase the time usage of the prototype.

In order to make the obstacle detector non-obstructive as mentioned in Section 2.6, the detector is made in the form of a wearable. For prototyping purpose, a cardboard casing was designed. The dimensions of the assembled electronic components were measured, marked and cut on a cardboard as shown in Figure 3.8.

Figure 3.8: Prototype – Casing design (left) front view (center) and side view (right)

Caliper is a device that can measure the distance and thickness of an object and it was used to measure the dimensions of the prototype. The dimensions are 37.60mm × 24.89mm × 27.34mm as shown in Figure 3.9. The compactness of the prototype is shown in Figure 3.10.

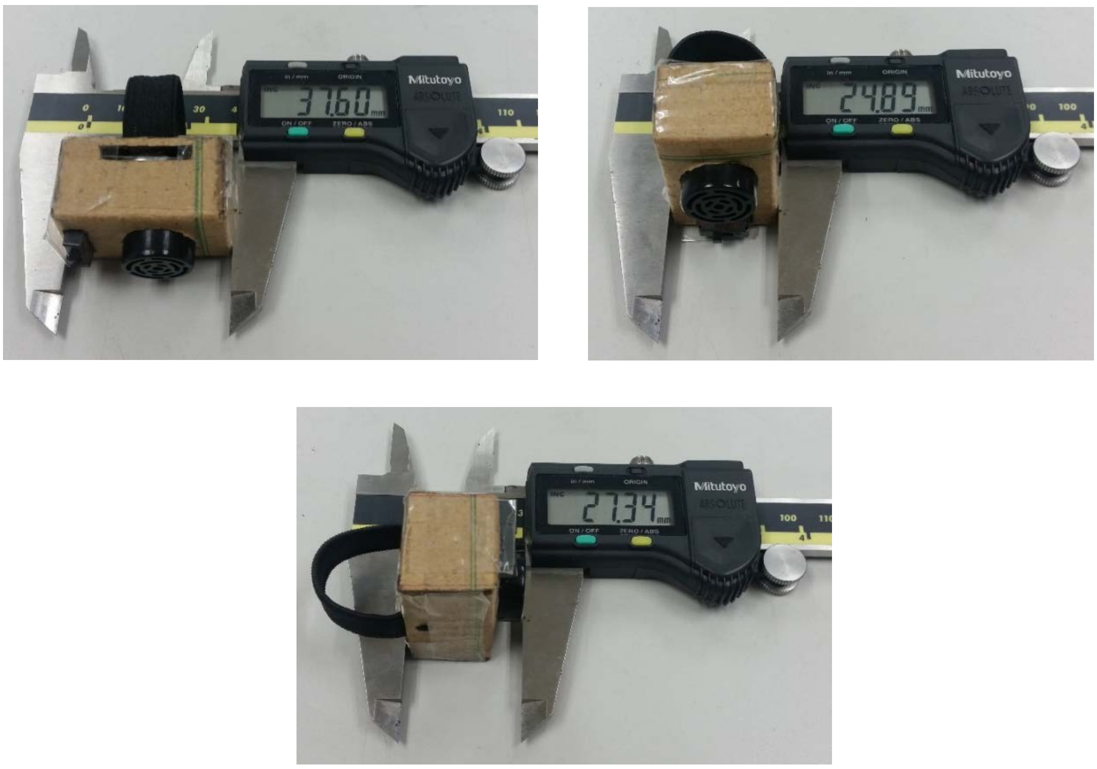

Figure 3.9: Dimensions of prototype; height (upper left), length (upper right) and base (bottom center)

Figure 3.10: Casing with electronics removed (left) and attached (right)

The weight of the prototype is 15.7g and it was measured by using an electronic weighing scale shown in Figure 3.11.

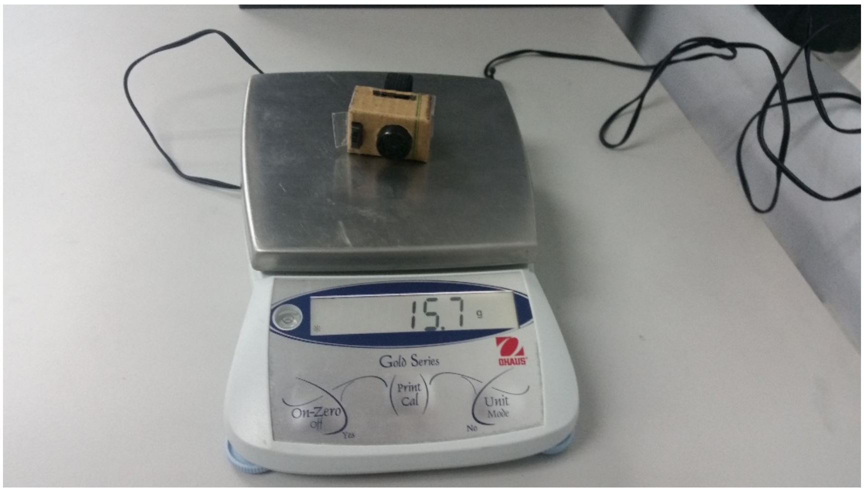

Figure 3.11: Prototype on an electronic weight scale

3.5 Algorithm for Obstacle Detection

The advantage of using an atmega328p-based microcontroller is the years of research and development invested by the Arduino community for making a user-friendly software environment. Arduino IDE enables user to program and use the microcontroller easily. The community also developed a wide variety of libraries that allows compatibility of various sensors and actuators available in the market. The development of this prototype utilized some of the features such as compatibility of ultrasonic sensor and tone generator library.

The algorithm to detect obstacles is written in the programming environment and the flow of the processing algorithm is shown in Figure 3.12. It starts with the initialization of all input and output pins. Then, it moves into a loop and runs the main logics. In the loop, there are three main processes: capture signal, process signal and relay signal. At the input stage, ultrasonic sensor captures and measures the distance, then passes the distance information to the processing stage. At the processing stage, the distance data is compared with the pre-coded conditions. It returns a numeric figure representing the frequency. At the output stage, this number representing the frequency is converted to a tone which is emitted through the internal speaker. Once the process is completed, it loops back to the capturing signal stage. This algorithm shown in Figure 3.13 is simple and straightforward. Thus, it does not impose high computation resource and power.

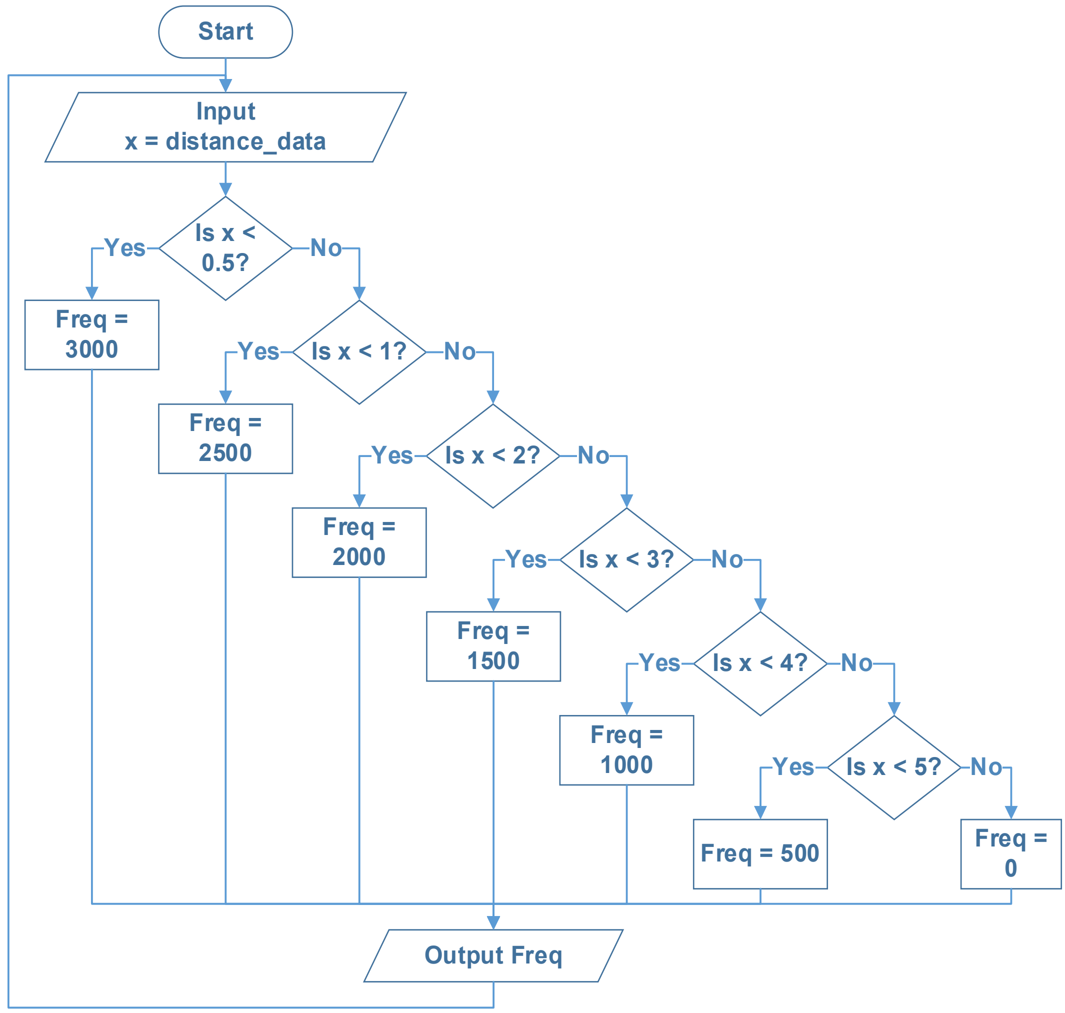

Figure 3.12: Flowchart representing procedures of obstacle detection

Algorithm 1 Range detection
Read input from sensor, x
if *x < 0.5m* ***then***
Generate 3000Hz tone
else if *x < 1m* ***then***
Generate 2500Hz tone
else if *x < 2m* ***then***
Generate 2000Hz tone
else if *x < 3m* ***then***
Generate 1500Hz tone
else if *x < 4m* ***then***
Generate 1000Hz tone
else if *x < 5m* ***then***
Generate 500Hz tone
else
Do nothing
end

Figure 3.13: Algorithm 1 for determining an obstacle and alerting at different frequencies

3.6 Prototype Testing

The prototype was designed to be mounted on the finger. From previous measurements, the prototype is small and lightweight. These features allow users to use the prototype for a period of time without having to feel their hands being obstructed as they can still open and close their hands freely, move and direct their hands towards the direction they wish to check for obstacle. Flexibility of the prototype was demonstrated in Figure 3.14, Figure 3.15 and Figure 3.16. Participant pointed to his left and right in Figure 3.14 and Figure 3.15 respectively. Users can lower their hand or raise their hand to detect obstacles. Figure 3.16 shows participant raising his hand to detect head-level obstacle.

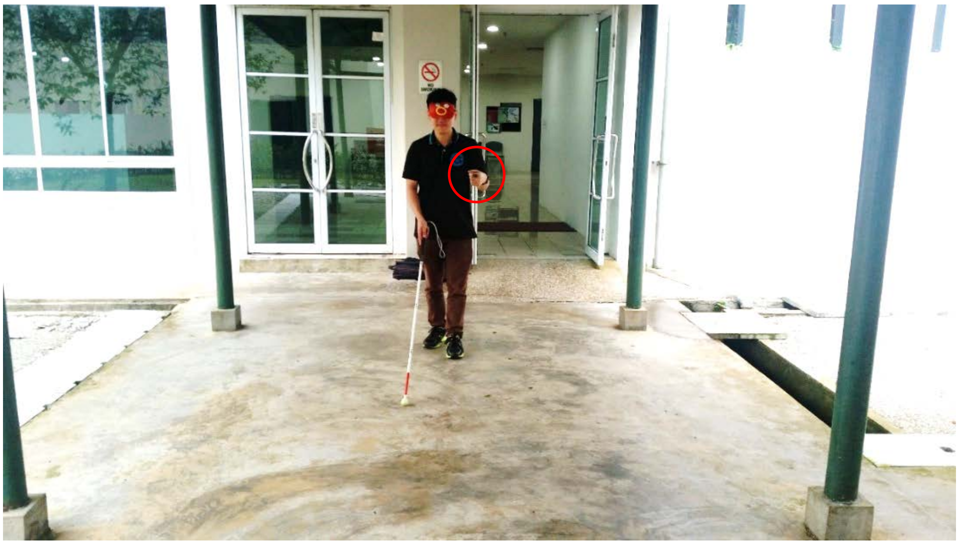

Figure 3.14: User pointed the prototype to detect obstacles on his left

Figure 3.15: User pointed the prototype to detect obstacle on his right

Figure 3.16: User raised the prototype to sense the obstacle above his head level

The developed prototype consists of a microcontroller with low computational power and it requires low power to operate. The prototype operates continuously and the power consumption differs according to the presence of obstacle. When there is no obstacle being detected, the power consumption is 5.97mA. When an obstacle is detected, the power consumption is 15.37mA. The difference of power consumption is due to the energy used by the speaker to generate the alerts upon detecting the obstacles. The difference can be seen in Figure 3.17. Based on the calculation, the prototype should be able perform continuous detection for 9.375 hours on a new CR2032 battery with a capacity of 150mAh in an ideal situation until the remaining voltage is 1.8V.

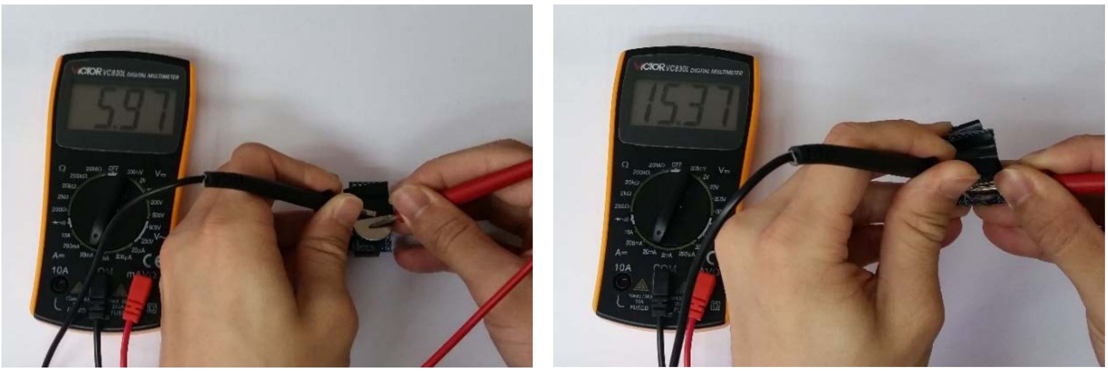

Figure 3.17: Power consumption in the idle (left) and active (right) state

As portability of the prototype is an important feature, an additional experiment was conducted to verify the duration of a new CR2032 battery with a capacity of 150mAh when the prototype is turned on continuously for obstacle detection. An obstacle was placed in front of the prototype and a smartphone was used to record and monitor the battery depletion process. The experimental setup is shown as in Figure 3.18. From the recording, the audio generated by the prototype deteriorated to an unacceptable alert quality (both alert sound and distance frequency) by the 4^{th} hour of usage where the remaining voltage was 2.9V, voltage lower than that did not permit the prototype to perform any obstacle detection. Thus, the experiment indicated that the duration of usage of a new battery when the prototype is turned on continuously is approximately 4 hours. With this small sized battery (20mm × 3.2mm, 2.9 gram) lasting up to 4 hours, the prototype can give the people with visual impairment sufficient service needed without carrying bulky and obstructive batteries.

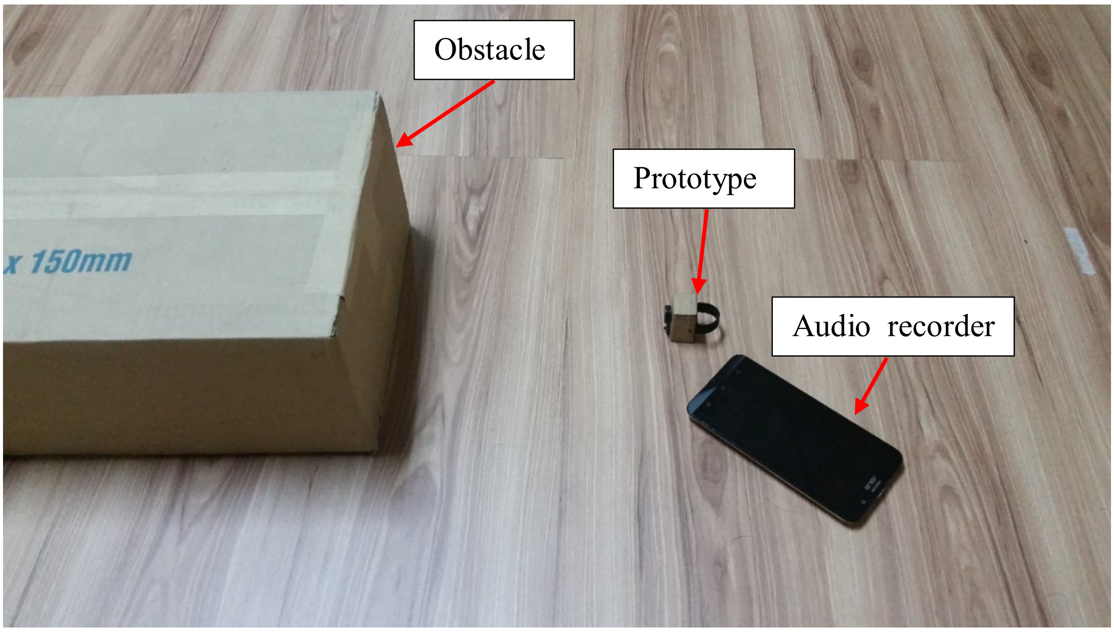

Figure 3.18: Experimental setup to determine the estimated duration with a new battery

Kim and Cho (2013) stated that an obstacle detector with fast response is vital for the safety of people with visual impairment so they can have more time to make decisions and avoid obstacles. The time taken for the developed prototype to detect an obstacle is around 0.179s. Video recording technique was used to collect the response time of the prototype and the averaged result value is shown in Table 3.3. There are many factors that may affect the reaction time of human such as age, gender, dominant hand, activity level and many more (Census at School 2018; Jain et al. 2015) and the fastest reaction time is around 0.219s. The response time of the prototype is sufficient to detect obstacle and provide feedback cue within the reaction time of human.

The codes for obstacle detection is shown in Figure 3.19. This is aligned with the algorithm shown in Figure 3.13 which is simple and straightforward thus, it does not impose high computation resource and power. The input and output pins used in this prototype are shown in Line 2 to 5 which are initialized in the setup function shown from Line 9 to 15. Line 7 contains the variables used to temporarily store the data such as ultrasonic reading and frequency value. The program runs infinitely in the loop function shown from Line 56 to 61. There are three functions inside the loop function which run infinitely: read sensor function, output comparison function and output buzzer function. The read sensor function obtains distance measurement reading from the ultrasonic sensor (Line 17 to 27). Output comparison function maps out the appropriate output frequency according to the distance readings obtained from the ultrasonic sensor (Line 29 to 46). Output buzzer function sends the output frequency value to the output pin that is connected to a smartphone speaker and this generate alerts (Line 48 to 54).

Table 3.3: Response time of prototype in 20 samples

Sample	Start (s)	End (s)	Duration (s)
1	4.770	5.016	0.246
2	6.288	6.337	0.049
3	7.535	7.678	0.143
4	9.025	9.133	0.108
5	10.284	10.426	0.142
6	11.983	12.129	0.146
7	13.072	13.325	0.253
8	15.473	15.602	0.129
9	16.586	16.814	0.228
10	17.790	17.902	0.112
11	20.400	20.673	0.273
12	22.037	22.265	0.228
13	23.698	23.905	0.207
14	25.370	25.560	0.190
15	27.343	27.462	0.119
16	28.744	28.928	0.184
17	30.411	30.688	0.277
18	32.189	32.370	0.181
19	33.581	33.687	0.106
20	34.720	34.977	0.257
Average time			0.179

```
// Declare pin
const int sonarpin = 3;
const int rangepin = 4;
const int motorpin = 6;
const int speakerpin = 8;

long sensor1, cm, inches, motorval, toneval;

void setup () {
  // Configure GPIO
  pinMode(sonarpin, INPUT);
  pinMode(rangepin, OUTPUT);
  pinMode(motorpin, OUTPUT);
  pinMode(speakerpin, OUTPUT);
}

void read_sensor(){
  // Generate pulse
  digitalWrite(rangepin, LOW);
  delayMicroseconds(5);
  digitalWrite(rangepin, HIGH);
  delayMicroseconds(30);
  digitalWrite(rangepin, LOW);
  // Obtain reading
  sensor1 = pulseIn(sonarpin, HIGH);
  sensor1 = sensor1 * 1.068745;
}

void output_compare(){
  // Allocate reading to specific frequency
  if (sensor1 < 500){
    toneval = 3000;
  } else if (sensor1 < 1000){
    toneval = 2500;
  } else if (sensor1 < 2000){
    toneval = 2000;
  } else if (sensor1 < 3000){
    toneval = 1500;
  } else if (sensor1 < 4000){
    toneval = 1000;
  } else if (sensor1 < 5000){
    toneval = 500;
  } else{
    toneval = 0;
  }
}

void output_buzzer(){
  // Output frequency
  if (toneval == 0){
    noTone(speakerpin);
  } else
  tone(speakerpin, toneval);
}

void loop () {
  read_sensor();
  output_compare();
  output_buzzer();
  delay(30);
}
```

Figure 3.19: Codes for obstacle detection

From the aspect of costing, the total cost to produce and develop the prototype is only RM166.43. The cost of electronic parts is tabulated in Table 3.4. The cost can be further reduced by 50% if the prototype is produced in bulk. When compared to existing ultrasonic obstacle detectors such as UltraCane (UltraCane n.d.) and Bawa Cane (Bawa 2017) which costs £635.00 and USD699.00 respectively. Thus, the prototype is considered to be low cost.

Table 3.4: Cost of developing one set of the prototype

Electronic parts	**Cost (RM)**
Arduino Pro Mini	9.50
Maxsonar EZ1	153.70
Resistor	0.05
Capacitor	0.21
Slide switch	0.85
CR2032 battery	2.12
Total	166.43

3.7 Summary

This chapter contains the design and development of the proposed obstacle detector for the visually impaired. The idea and concept of the prototype operation is first realized based on the research problems identified in Section 1.2 and attributes in Section 2.6. After that, the appropriate electronic components were researched to satisfy the small form factor requirement. Ultrasonic sensor with one transducer, Arduino Pro Mini and smartphone speaker were selected as they have the attributes mentioned in Section 1.2 and Section 2.6. Following that, the connection of those components were firstly drawn into a schematic diagram which was then used as the reference during the actual hardware assembly. The final assembled prototype was measured and a case was designed to house the electronics components. The prototype was implemented with the algorithms to detect obstacle before housing it.

Chapter 4 Testing and Evaluation

This chapter evaluates the proposed obstacle detector's capability by testing it on both indoor and outdoor scenarios. This chapter describes the procedures taken when conducting the experiments, categorization of experimental results and performance evaluation of obstacle detector. Three experiments were carried out. The first experiment involves functional testing of the prototype with common indoor and outdoor obstacles of different sizes and shapes. The second experiment was a pilot test conducted in a controlled indoor environment which also involved human participants with blindfolds to simulate no vision. Third experiment involves human participants with low vision goggles in an uncontrolled outdoor environment.

4.1 Experiment 1 Functional Testing of the Prototype

The first experiment was conducted in a controlled environment that involved testing on the detection of the prototype against some common indoor and outdoor obstacles. The experimental testing was conducted consistently according to the flow shown in Figure 4.1 to avoid human misreading error.

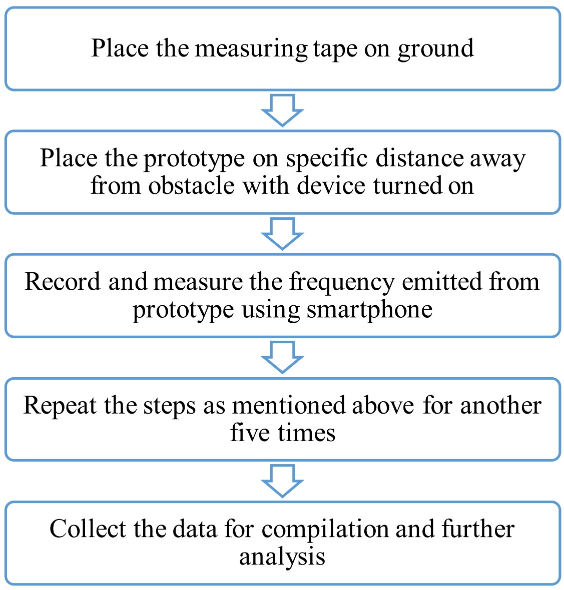

Figure 4.1: Flowchart of the entire testing and evaluation process

A few factors that affects the reliability of the collected data were the reading distance, height and speed of the moving prototype. The prototype is heavily dependent on the ultrasonic sensor in detecting obstacles and measuring distance. To assess the accuracy of the prototype in detecting obstacle, a proper distance measurement technique is required to ensure reliable data reading. Not only that, due to the characteristic of ultrasonic sensor, it has a limited range of detection. Anything outside the detection boundary will not result in obstacle detection. So proper height placement is necessary for consistent assessment of the prototype. A consistent and systematic experiment approach can ensure the reliability of the data. The reading distance between an obstacle and the prototype was consistently collected by observing the values from a measuring tape that was placed on the floor. According to Beardmore (2013), the fingertip height can be categorized into different percentiles as tabulated in Table 4.1. The percentile indicates the amount of people that are smaller than the given size. For example, men in the 5% percentile category indicates that 5% of men is smaller than 600mm, measuring from ground to fingertip as shown in Figure 4.2 with the label number 7. Based on that, the height of the prototype was maintained at 700mm.

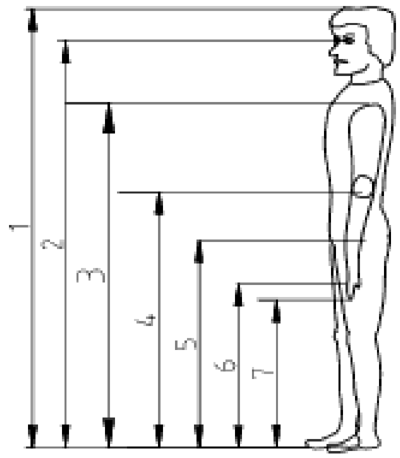

Figure 4.2: Average human heights (Beardmore 2013)

Table 4.1: Average fingertip height (Beardmore 2013)

Dimension	**Men (Percentiles)**			**Women (Percentiles)**		
	5%	50%	95%	5%	50%	95%
7 – Fingertip Height	600mm	675mm	730mm	560mm	620mm	680mm

In a dynamic environment, average moving speed of sighted people and people with visual impairment were simulated. This was done by holding the prototype and walking at the speed of approximately 1.2m/s and 0.8m/s which is the average walking speed of people with normal vision and people with visual impairment respectively (Schellingerhout et al. 2001). Video camera was particularly used in recording any changes of prototype output in relation to the distance. Repetitive readings were taken to normalize the possible human error when carrying out the experiment.

There are five indoor obstacles and eight outdoor obstacles all together in this experiment. The obstacles were chosen due to its common availability in the respective environments. Wall, table, chair and box can be easily found in indoor environment while as door, signboard, traffic cone, lamp post, car, human and post can be found in outdoor environment. Stairs can be found in both indoor and outdoor environment, but it is easier to conduct the experiment in outdoor environment because of wider area when compared to stair in indoor environment that can be quite compact and lack of space to properly measure the distance between obstacles and prototype. Criteria such as the size and shape of an obstacle were also taken into consideration. This is evident from the selected obstacles which varied in sizes and shapes.

4.1.1 Obstacles in an Indoor Environment

This section contains the data on the obstacle detection rates collected in an indoor environment. Obstacles with different sizes and shapes were tested. All the obstacles were placed in front of the obstacle detector when conducting the test. The selected obstacles were also used in other research works such as car, chair, table, box, flat concrete wall and lamppost (Baliga et al. 2015; Nayan & Latchmanan 2016; Parmar & Inkoolu 2017; Villamizar et al. 2013). As stated in the previous section, the tests were recorded by using video camera of smartphone device. The data collected represents the frequency emitted by the prototype at the particular distance. For each range of distance, detection rate were evaluated based on the expected frequency value. For example, the expected frequency emitted when the distance of obstacle from the obstacle detector is between four to five meters is 500Hz. If the detected frequency is not 500Hz, then it is ignored and not recognised as an obstacle.

4.1.1.1 Wall

A big obstacle was first tested to make sure that the prototype could detect obstacle properly within the expected range. Wall, floor and ceiling were the obstacles with bigger surface area so wall was chosen for practicality (Figure 4.3). The dimension of the wall is 2950mm (L) × 2420mm (H).

Figure 4.3: Obstacle – A wall

Table 4.2 contains the frequencies emitted by the device when the walking speed was 1.2m/s and obstacle was the wall. It is graphically represented as in Figure 4.4. The prototype could detect the wall in all five tests with a detection rate of 100% for distance between zero to five meter. This indicates the prototype can function properly and can further be tested on other obstacles.

Table 4.2: Test results on average walking speed of people with normal vision against the wall

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	1000	1000	1000	1000	1000	100%
4 to 4.99	500	500	500	500	500	100%

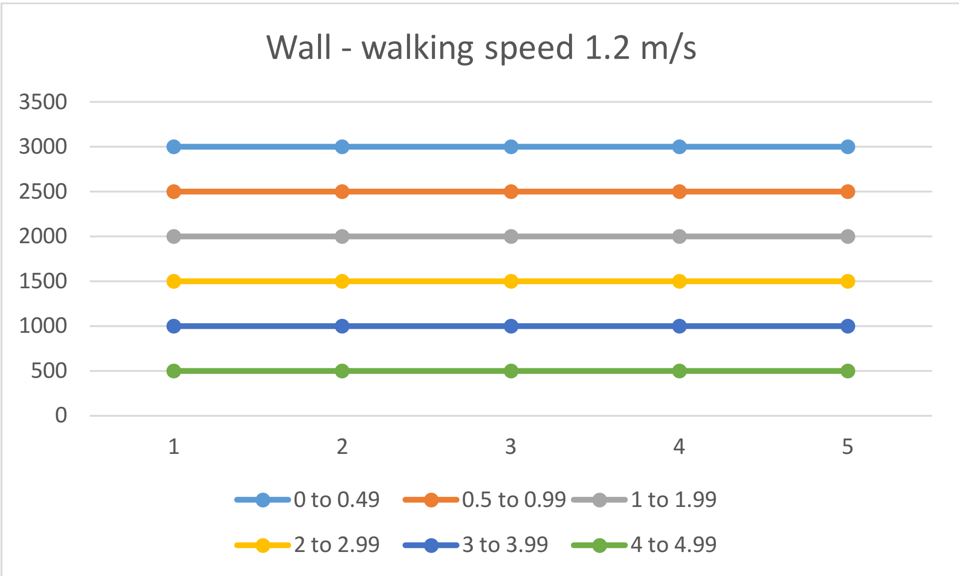

Figure 4.4: Average walking speed of people with normal vision against the wall

Table 4.3 contains the frequencies emitted by the prototype when the walking speed was 0.8m/s and obstacle was the wall. It is graphically represented as in Figure 4.5. The prototype detected the wall successfully in all five tests with the detection rate of 100% for distance up to five meters.

Table 4.3: Test results on average walking speed of people with visual impairment against the wall

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	1000	1000	1000	1000	1000	100%
4 to 4.99	500	500	500	500	500	100%

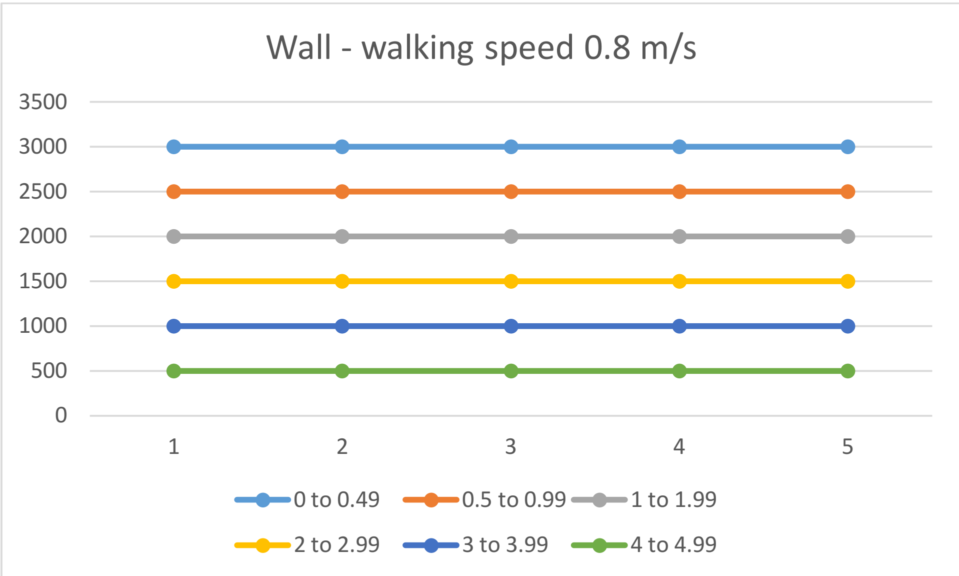

Figure 4.5: Average walking speed of people with visual impairment against the wall

4.1.1.2 Table

The next tested obstacle is a table (Figure 4.6) which is relatively large with a dimension of 1200mm (L) × 1200mm (H). It has a shiny surface and it was slightly tilted.

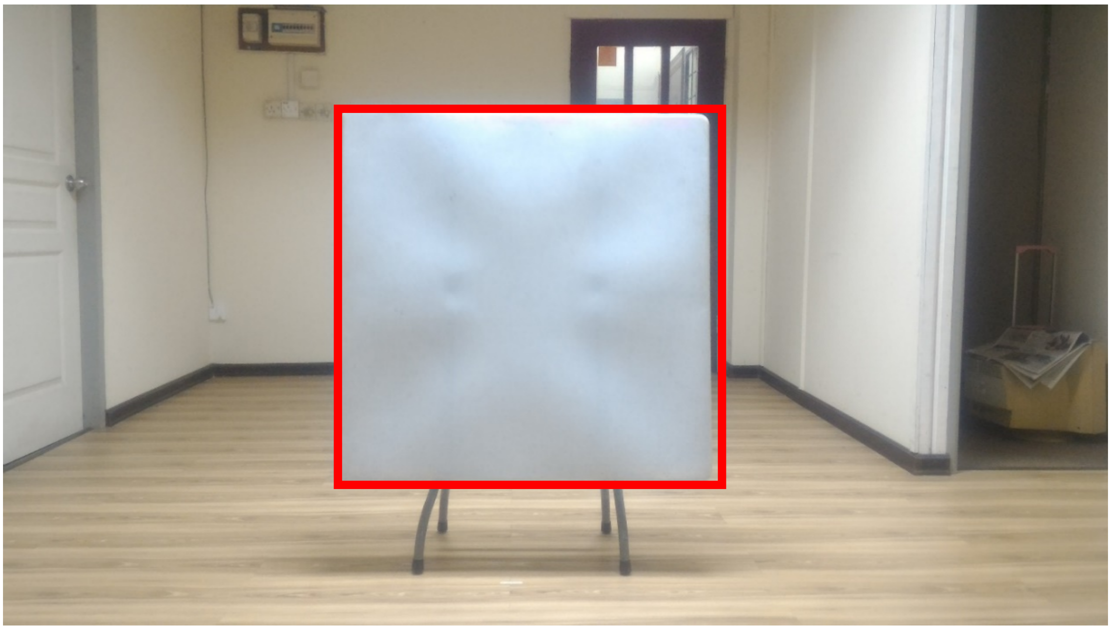

Figure 4.6: Obstacle – A table

Table 4.4 contains the frequencies emitted by the prototype when the walking speed was 1.2m/s and obstacle was table. It is graphically represented as in Figure 4.7. The prototype detected the table in all five tests with detection rate of 100% for distance up to five meters.

Table 4.4: Test results on average walking speed of people with normal vision against the table

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	1000	1000	1000	1000	1000	100%
4 to 4.99	500	500	500	500	500	100%

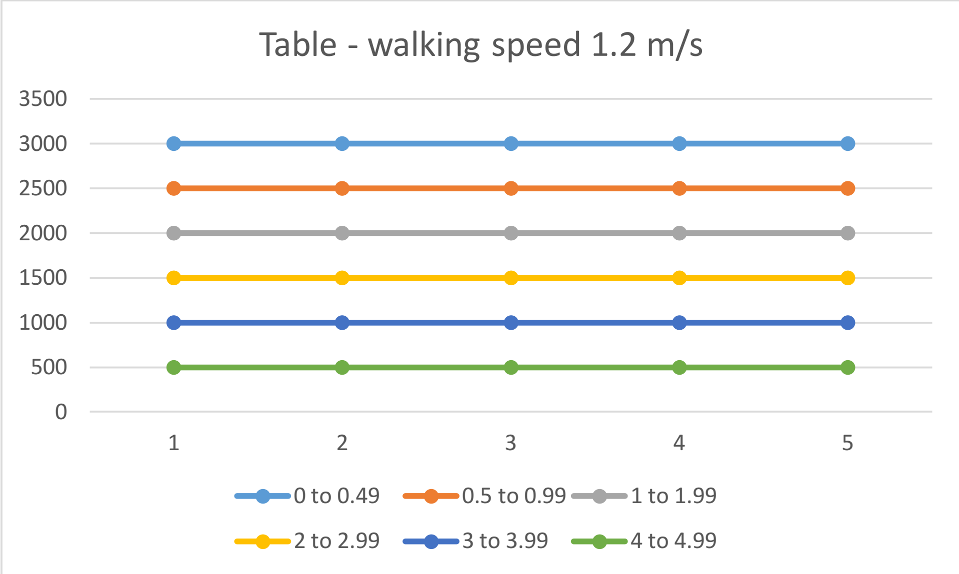

Figure 4.7: Average walking speed of people with normal vision against the table

Table 4.5 contains the frequencies emitted by the prototype when the walking speed was 0.8m/s and obstacle was a table. It is graphically represented as in Figure 4.8. The prototype detected the table in all five tests with detection rate of 100% for distance up to five meter.

Table 4.5: Test results on average walking speed of people with visual impairment against the table

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	1000	1000	1000	1000	1000	100%
4 to 4.99	500	500	500	500	500	100%

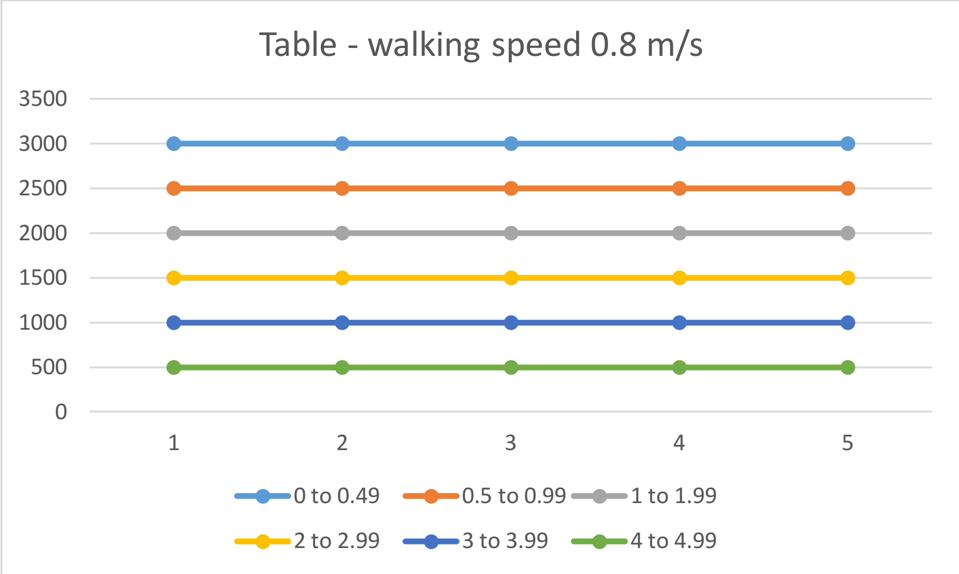

Figure 4.8: Average walking speed of people with visual impairment against the table

4.1.1.3 Chair

Chair is a common household obstacle that was tested as well. It has a shiny surface with odd shape which reduced the detection rate. Dimension of the chair used in this experiment is 390mm (L) × 785mm (H) × 482mm (W).

Figure 4.9: Obstacle – A chair

Table 4.6 contains the frequencies emitted by the prototype when the walking speed was 1.2m/s and obstacle was chair. It is graphically represented in Figure 4.10. The prototype could correctly detect the chair when distance was not more than two meters. When distance was between two to three meters, the detection rate decreased as shown in Table 4.6. In the first test, the prototype detected the chair but the feedback generated was not desired. The frequency generated is supposed to be 1500Hz but 1000Hz was recorded. Beyond three meters, chair was not detected at all.

Table 4.6: Test results on average walking speed of people with normal vision against the chair

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1000	1500	1500	1500	1500	80%
3 to 3.99	0	0	0	0	0	0%
4 to 4.99	0	0	0	0	0	0%

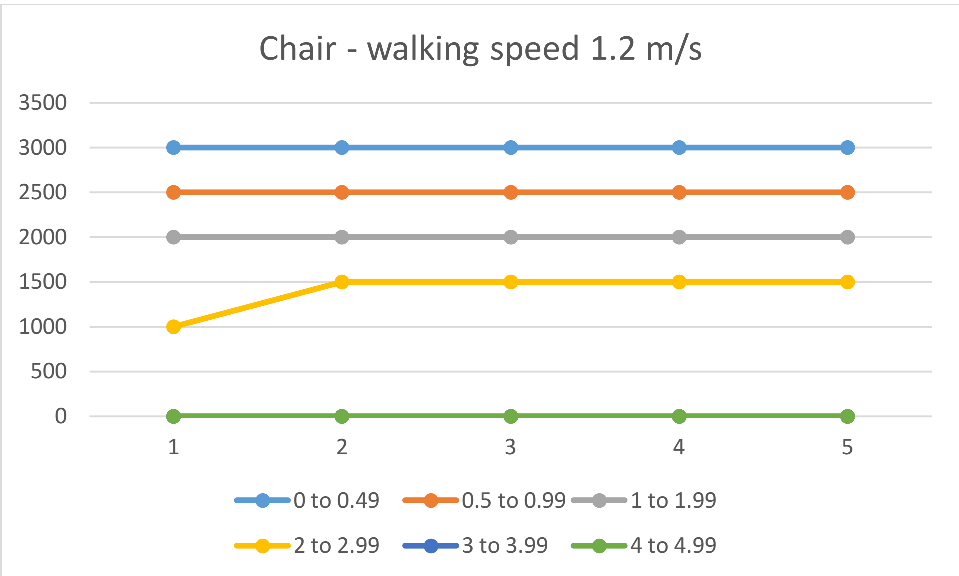

Figure 4.10: Average walking speed of people with normal vision against the chair

Table 4.7 contains the frequencies emitted by the prototype when the walking speed was 0.8m/s and obstacle is chair. It is graphically represented in Figure 4.11. Similar to when walking speed is 1.2m/s, the prototype can correctly detect the chair when distance is between zero to two meters. When the distance was between two to three meters, the detection rate dropped. Beyond three meters, chair was not detected.

Table 4.7: Test results on average walking speed of people with visual impairment against the chair

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1000	1000	60%
3 to 3.99	0	0	0	0	0	0%
4 to 4.99	0	0	0	0	0	0%

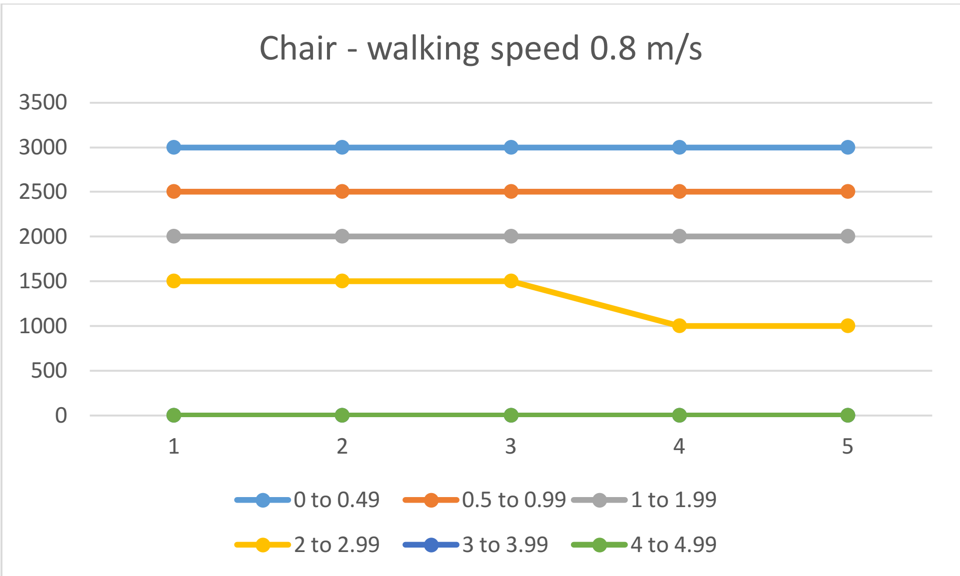

Figure 4.11: Average walking speed of people with visual impairment against the chair

4.1.1.4 Box

Table 4.8 contains the frequencies emitted of the prototype when the walking speed was 1.2m/s and obstacle was a box (Figure 4.12). It is graphically represented as in Figure 4.13. Dimension of the box is 510mm (L) × 600mm (H) × 400mm (W). The prototype could correctly detect the box in all five tests with the detection rates of 100% for distance between zero to five meter, even though it was smaller in surface and size when compared to the table.

Figure 4.12: Obstacle – A box

Table 4.8: Test results on average walking speed of people with normal vision against the box

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	1000	1000	1000	1000	1000	100%
4 to 4.99	500	500	500	500	500	100%

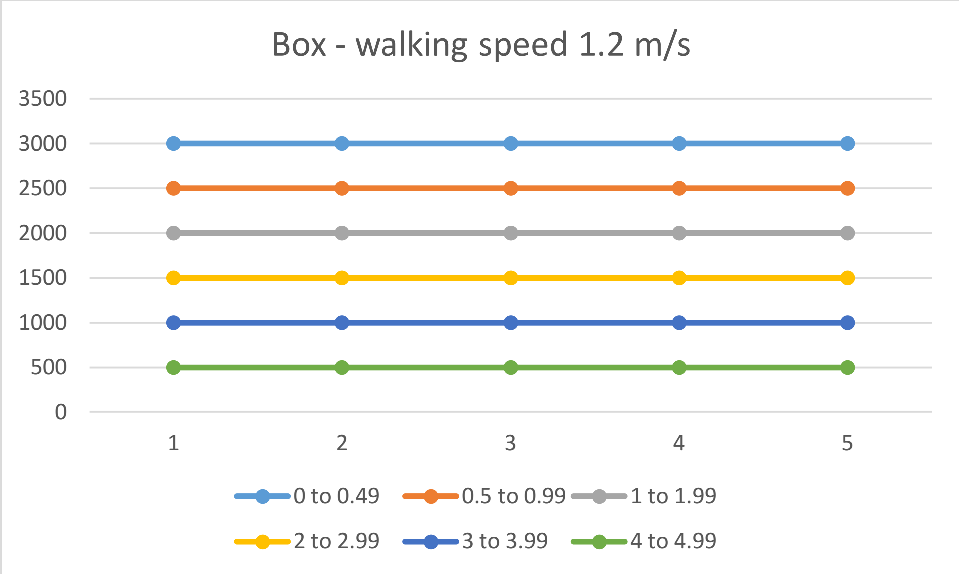

Figure 4.13: Average walking speed of people with normal vision against the box

Table 4.9 contains the frequencies emitted by the prototype when the walking speed was 0.8m/s and obstacle is box. It is graphically represented as in Figure 4.14. The prototype could detect the box in all five tests with the successful detection rate of 100% for distance between zero to five meters.

Table 4.9: Test results on average walking speed of people with visual impairment against the box

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	1000	1000	1000	1000	1000	100%
4 to 4.99	500	500	500	500	500	100%

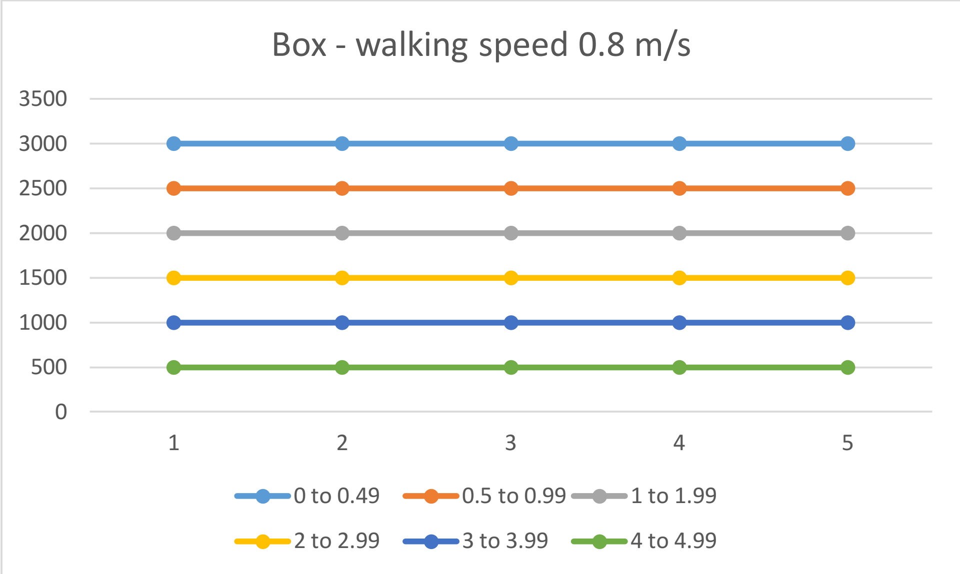

Figure 4.14: Average walking speed of people with visual impairment against the box

4.1.1.5 Luggage

Table 4.10 contains the frequencies emitted by the prototype when the walking speed was 1.2m/s and obstacle is luggage (Figure 4.15). It is graphically represented as in Figure 4.16. Dimension of the luggage is 590mm (L) × 400mm (H) × 370mm (W). The prototype could correctly detect the luggage when distance was between one to five meters. The prototype failed to detect the obstacle when it was less than one meter from the obstacle detector.

Figure 4.15: Obstacle – A luggage

Table 4.10: Test results on average walking speed of people with normal vision against the luggage

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	0	0	0	0	0	0%
0.5 to 0.99	2000	0	0	0	0	0%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	1000	1000	1000	1000	1000	100%
4 to 4.99	500	500	500	500	500	100%

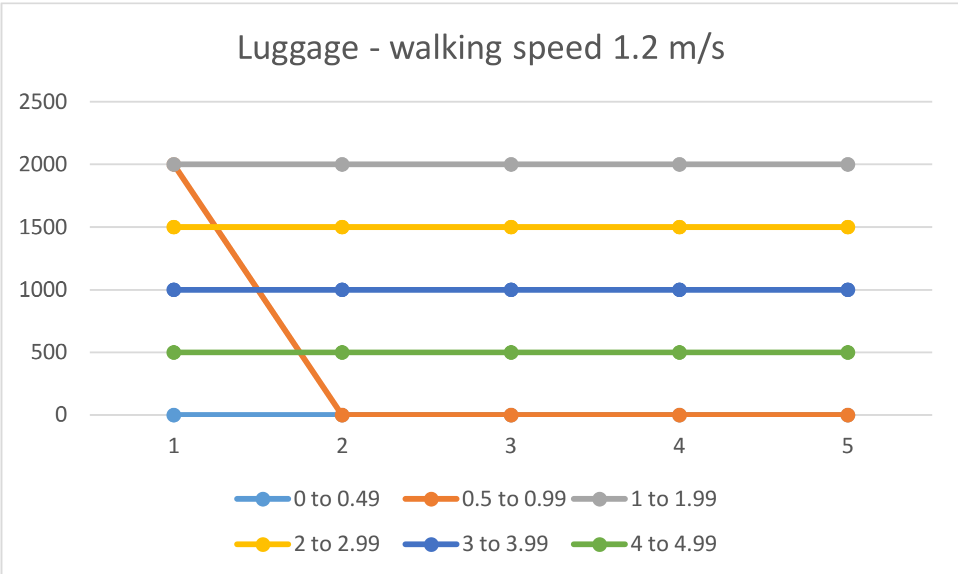

Figure 4.16: Average walking speed of people with normal vision against the luggage

Table 4.11 contains the frequencies emitted by the prototype when the walking speed was 0.8m/s and obstacle was luggage. It is graphically represented as in Figure 4.17. Similar to previous results, the prototype could correctly detect luggage when it was within one to five meters. Luggage was not detected when the prototype was less than one meter away from it.

Table 4.11: Test results on average walking speed of people with visual impairment against luggage

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	0	0	0	0	0	0%
0.5 to 0.99	0	0	0	2000	0	0%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	1000	1000	1000	1000	1000	100%
4 to 4.99	500	500	500	500	500	100%

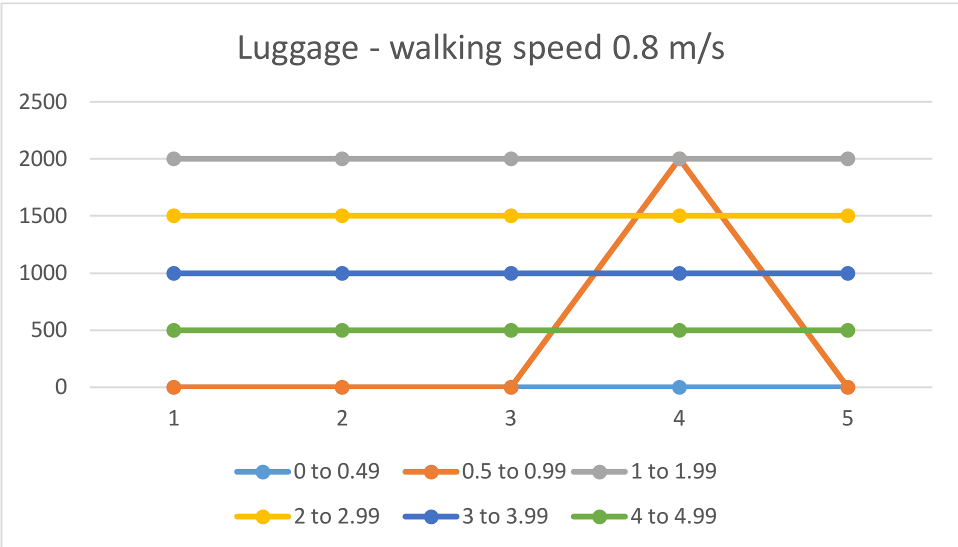

Figure 4.17: Average walking speed of people with visual impairment against the luggage

4.1.2 Obstacle in Outdoor Environment

This section contains data of the obstacle detection rate in an outdoor environment. Common outdoor obstacles were tested. The prototype is placed in front of the obstacle with the sensing unit facing the obstacle when conducting the test. The same test setup and procedure from indoor environment was carried out.

4.1.2.1 Entrance door

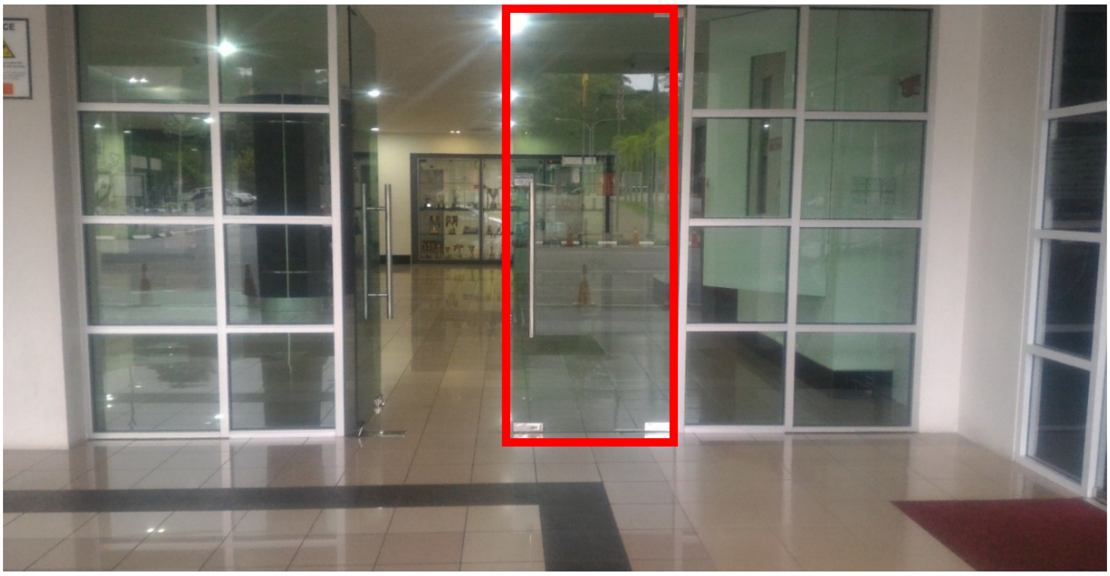

Figure 4.18: Obstacle – An entrance door

Table 4.12 contains the frequencies emitted by the prototype when the walking speed is 1.2m/s and obstacle is entrance door (Figure 4.18). It is graphically represented in Figure 4.19. The prototype can detect the door from zero to four meters. Beyond four meter, the detection rate decreases. Nothing is detected in Test 2,3 and 4.

Table 4.12: Test results on average walking speed of people with normal vision against the entrance door

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	1000	1000	1000	1000	1000	100%
4 to 4.99	500	0	0	0	500	40%

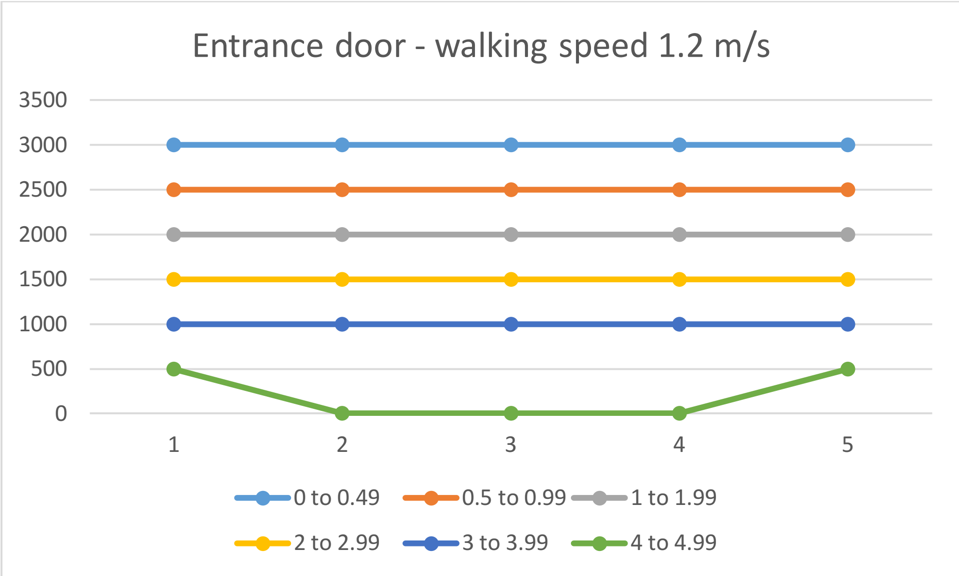

Figure 4.19: Average walking speed of people with normal vision against the entrance door

Table 4.13 contains the frequencies emitted by the prototype when the walking speed is 0.8m/s and obstacle is entrance door. It is graphically represented in Figure 4.20. The prototype can detect the door from zero to five meter with 100% detection rate.

Table 4.13: Test results on average walking speed of people with visual impairment against entrance door

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	1000	1000	1000	1000	1000	100%
4 to 4.99	500	500	500	500	500	100%
5 to 5.99	2000	0	2000	2000	2000	

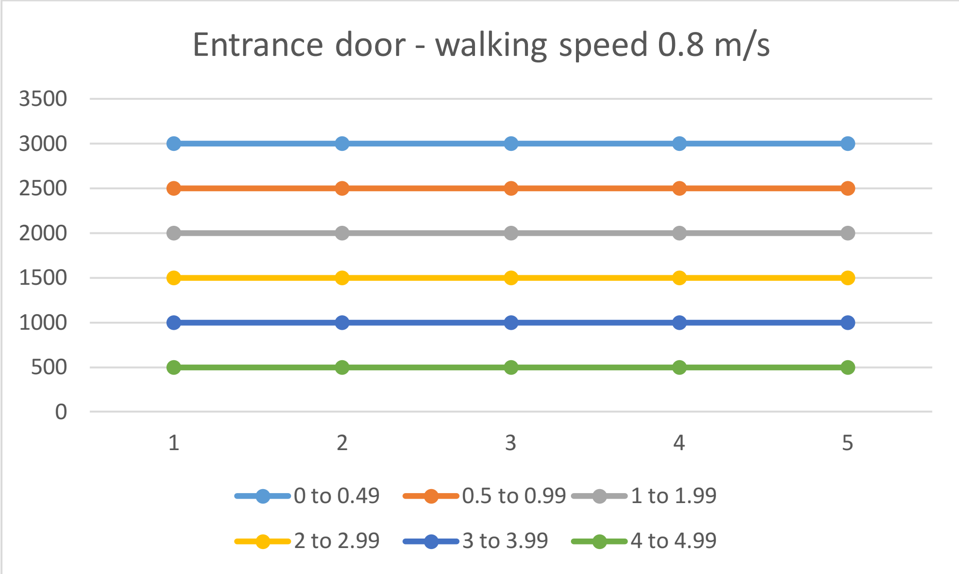

Figure 4.20: Average walking speed of people with visual impairment against entrance door

4.1.2.2 Signboard

Table 4.14 contains the frequencies emitted by the prototype when the walking speed was 1.2m/s and obstacle was a signboard (Figure 4.21). It is graphically represented in Figure 4.22. The prototype could correctly detect the board from zero to five meter in all five tests.

Figure 4.21: Obstacle – A signboard

Table 4.14: Test results on average walking speed of people with normal vision against the signboard

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	1000	1000	1000	1000	1000	100%
4 to 4.99	500	500	500	500	500	100%

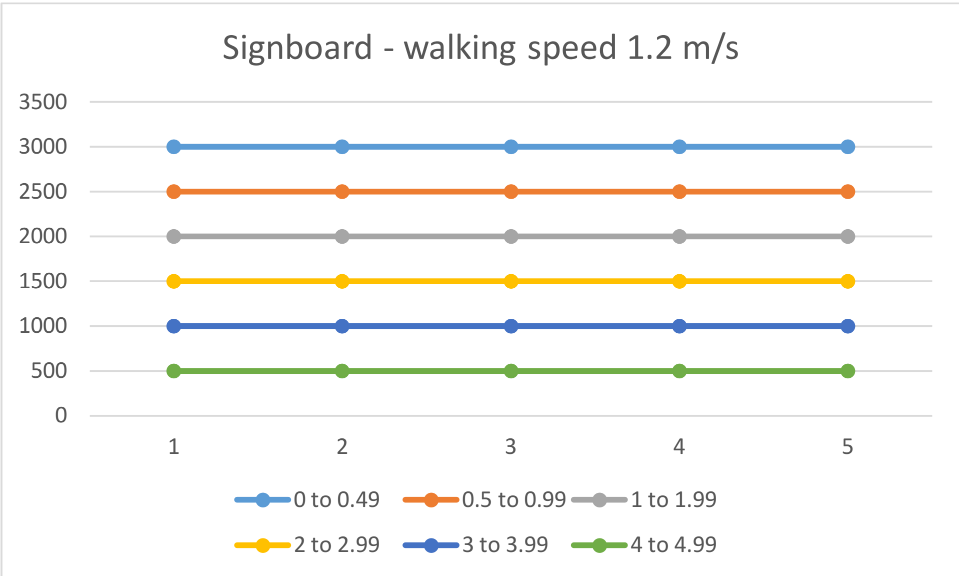

Figure 4.22: Average walking speed of people with normal vision against the signboard

Table 4.15 contains the frequencies emitted by the prototype when the walking speed was 0.8m/s and obstacle was a signboard. It is graphically represented in Figure 4.23. The prototype could correctly detect the board from zero to five meter in all five tests.

Table 4.15: Test results on average walking speed of people with visual impairment against the signboard

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	1000	1000	1000	1000	1000	100%
4 to 4.99	500	500	500	500	500	100%

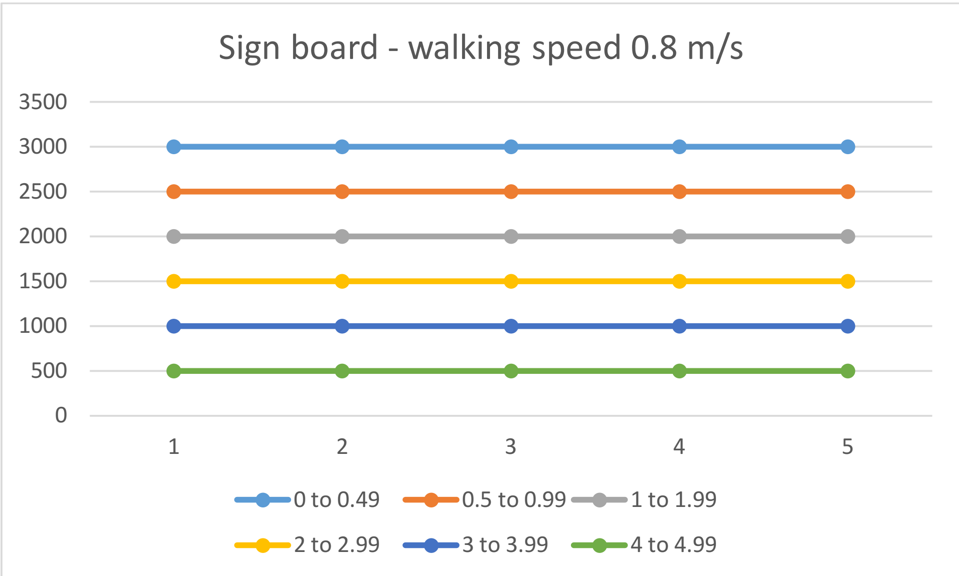

Figure 4.23: Average walking speed of people with visual impairment against the signboard

4.1.2.3 Traffic cone

Table 4.16 contains the frequencies emitted by the prototype when the walking speed was 1.2m/s and obstacle is traffic cone (Figure 4.24). It is graphically represented in Figure 4.25. The prototype could correctly detect the traffic cone from below one meter to two meters. It was still able to detect obstacle two to three meters away twice but failed thrice. Obstacle was not detected when it was beyond three meters away from the prototype.

Figure 4.24: Obstacle – A traffic cone

Table 4.16: Test results on average walking speed of people with normal vision against the traffic cone

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	0	0	0	40%
3 to 3.99	0	0	0	0	0	0%
4 to 4.99	0	0	0	0	0	0%

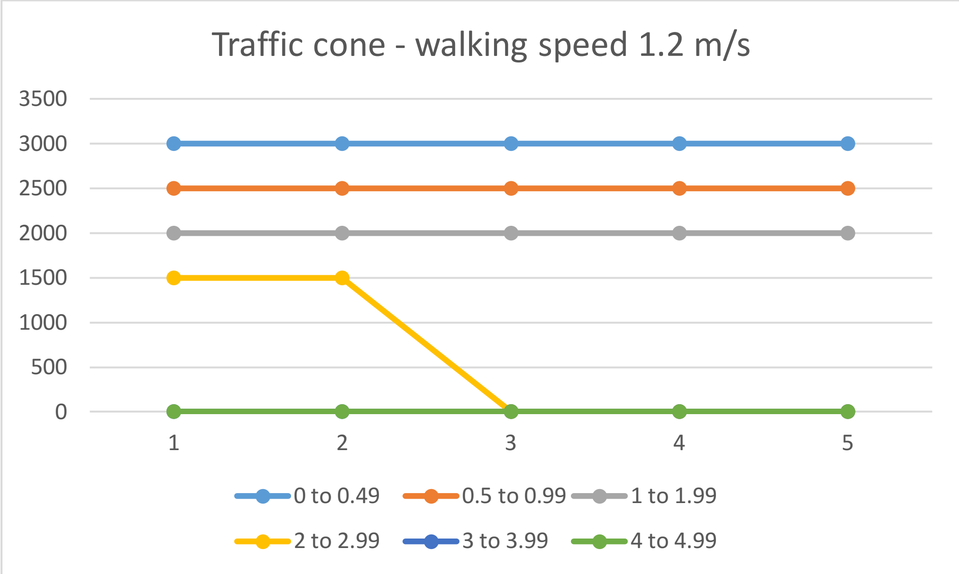

Figure 4.25: Average walking speed of people with normal vision against traffic cone

Table 4.17 contains the frequencies emitted by the prototype when the walking speed was 0.8m/s and obstacle was the traffic cone. It is graphically represented in Figure 4.26. The prototype correctly detected the funnel from zero to three meters in all five tests. The prototype was unable to detect the obstacle when the funnel is more than three meters away.

Table 4.17: Test results on average walking speed of people with visual impairment against the traffic cone

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	0	0	0	0	0	0%
4 to 4.99	0	0	0	0	0	0%

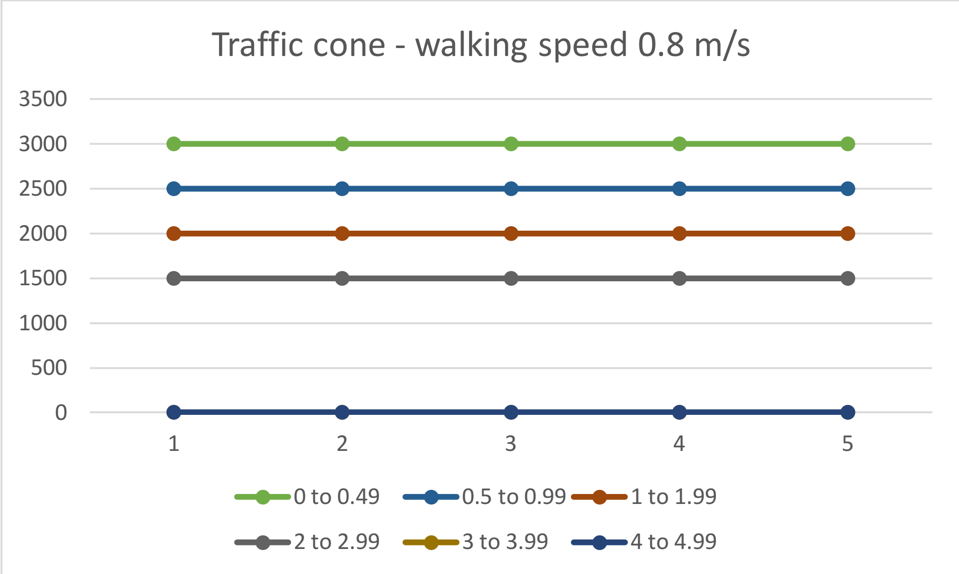

Figure 4.26: Average walking speed of people with visual impairment against the traffic cone

4.1.2.4 Stairs

Table 4.18 shows the frequencies emitted by the prototype when the walking speed was 1.2m/s and obstacle is stairs (Figure 4.27). It is graphically represented in Figure 4.28. The prototype can correctly detect the stairs from half a meter to five meter in all five tests. The obstacle was detected when the distance was between zero to half a meter but the frequencies generated was not the expected value.

Figure 4.27: Obstacle – The stairs

Table 4.18: Test results on average walking speed of people with normal vision against the stairs

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	2500	2500	2500	2500	2500	0%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	1000	1000	1000	1000	1000	100%
4 to 4.99	500	500	500	500	500	100%

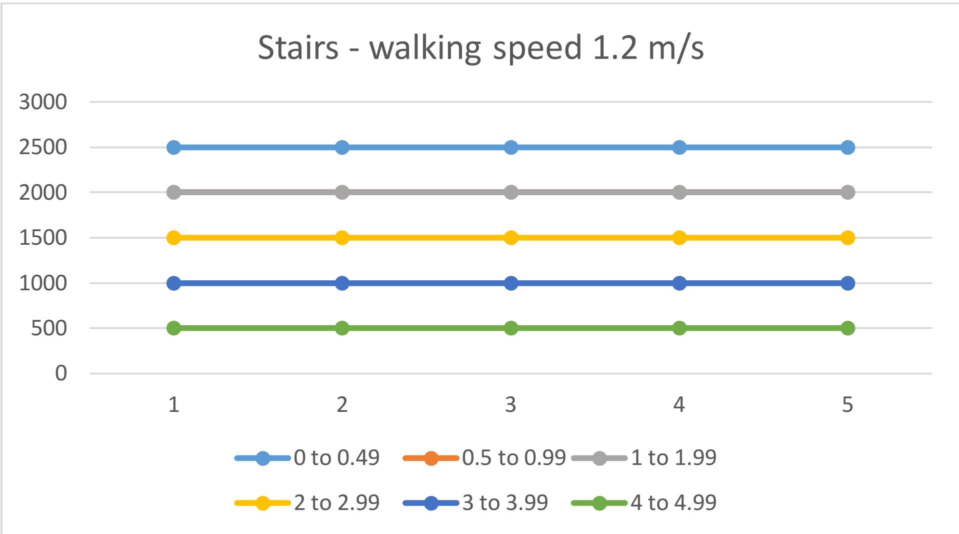

Figure 4.28: Average walking speed of people with normal vision against the stairs

Table 4.19 describes the frequencies emitted by the prototype when the walking speed was 0.8m/s and obstacle was the stairs. It is graphically represented in Figure 4.29. The prototype could correctly detect the stairs from half a meter to five meter in all five tests. Similar to the previous detection, undesired frequency values were generated when distance was between zero to half a meter.

Table 4.19: Test results on average walking speed of people with visual impairment against the stairs

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	2500	2500	2500	2500	2500	0%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	1000	1000	1000	1000	1000	100%
4 to 4.99	500	500	500	500	500	100%

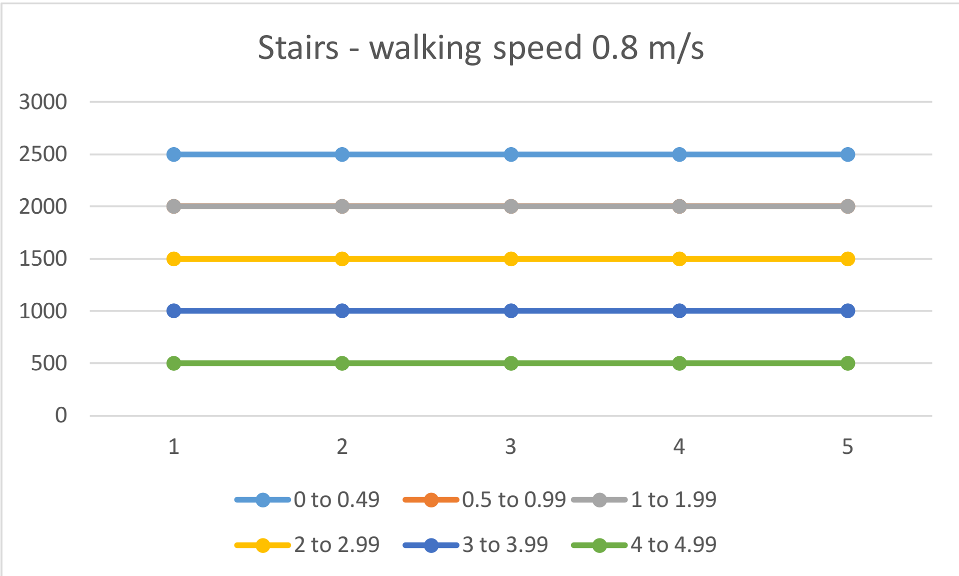

Figure 4.29: Average walking speed of people with visual impairment against stairs

4.1.2.5 Lamppost

Table 4.20 shows the frequencies emitted by the prototype when the walking speed was 1.2m/s and obstacle was lamppost (Figure 4.30). It is graphically represented in Figure 4.31. The prototype detected the lamppost in all five tests with detection rate of 100% for the distance between zero to five meters.

Figure 4.30: Obstacle – A Lamppost

Table 4.20: Test results on average walking speed of people with normal vision against the lamppost

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	1000	1000	1000	1000	1000	100%
4 to 4.99	500	500	500	500	500	100%

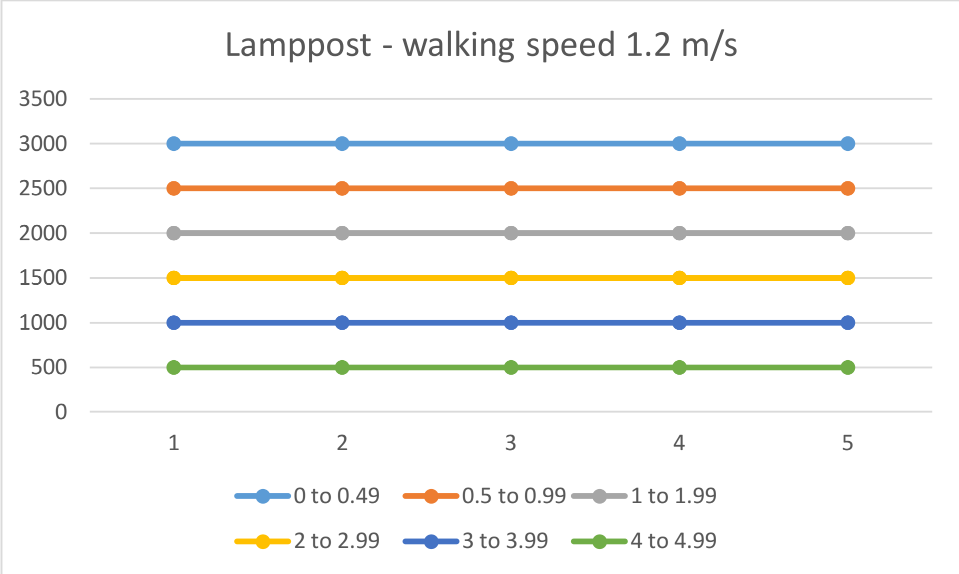

Figure 4.31: Average walking speed of people with normal vision against the lamppost

Table 4.21 contains the frequencies emitted by the prototype when the walking speed was 0.8m/s and obstacle was lamppost. It is graphically represented in Figure 4.32. The prototype detected the lamppost in all five tests with detection rate of 100% for distance between zero to five meters.

Table 4.21: Test results on average walking speed of people with visual impairment against the lamppost

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	1000	1000	1000	1000	1000	100%
4 to 4.99	500	500	500	500	500	100%

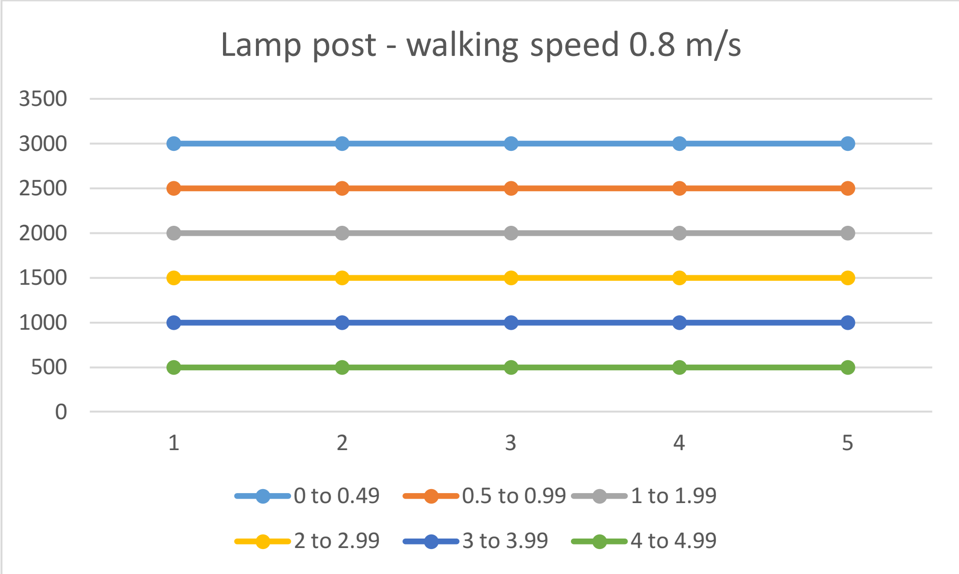

Figure 4.32: Average walking speed of people with visual impairment against the lamppost

4.1.2.6 Car

Table 4.22 contains the frequencies emitted by the prototype when the walking speed is 1.2m/s and obstacle is car (Figure 4.33). It is graphically represented in Figure 4.34. The prototype can detect the car in all five tests with detection rate of 100% for distance between zero to five meter.

Figure 4.33: Obstacle – A car

Table 4.22: Test results on average walking speed of people with normal vision against the car

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	1000	1000	1000	1000	1000	100%
4 to 4.99	500	500	500	500	500	100%

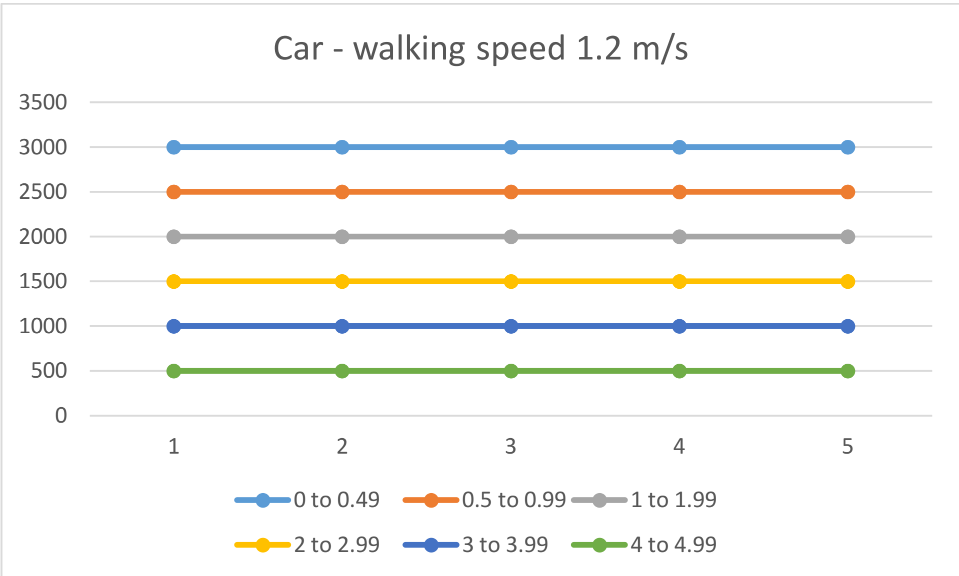

Figure 4.34: Average walking speed of people with normal vision against the car

Table 4.23 contains the frequencies emitted by the prototype when the walking speed was 0.8m/s and obstacle was car. It is graphically represented in Figure 4.35. The prototype detected the car in all five tests with detection rate of 100% for the distance between zero to five meters.

Table 4.23: Test results on average walking speed of people with visual impairment against the car

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	1000	1000	1000	1000	1000	100%
4 to 4.99	500	500	500	500	500	100%

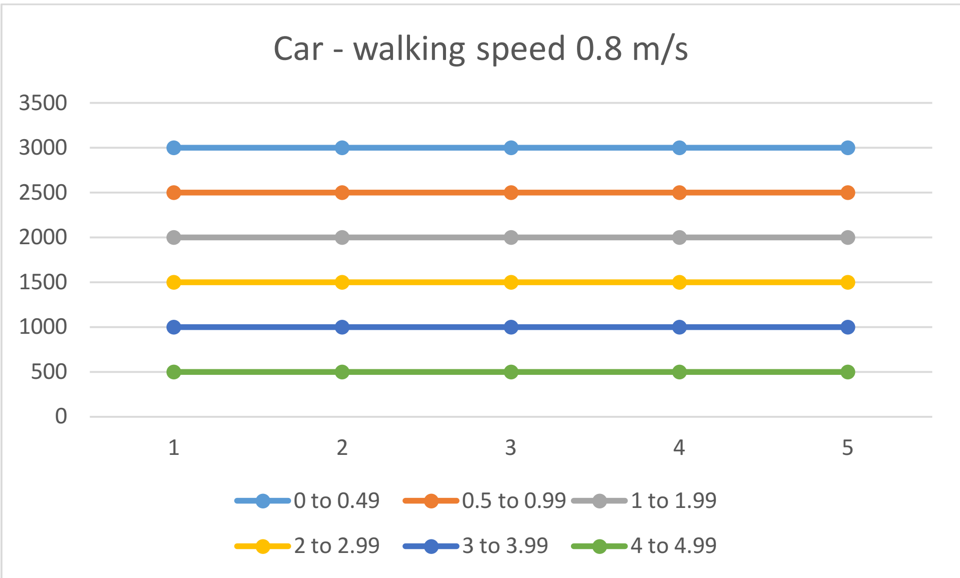

Figure 4.35: Average walking speed of people with visual impairment against the car

4.1.2.7 Human (Passer-by)

Table 4.24 contains the frequencies emitted by the prototype when the walking speed was 1.2m/s and obstacle is human (Figure 4.36). It is graphically represented in Figure 4.37. The prototype could correctly detect the participant from zero to one meters. From one to two meters, the detection rate was 80%. The prototype failed to detect correctly in one of the tests. No object was detected when distance is increased more than two meter.

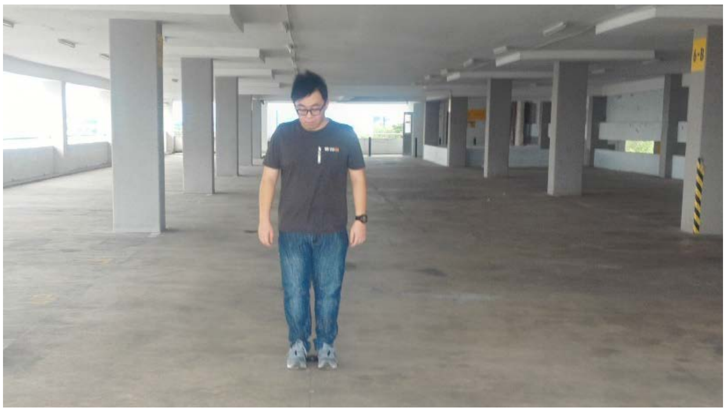

Figure 4.36: Obstacle – A Passer-by

Table 4.24: Test results on average walking speed of people with normal vision against the passer-by

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	1500	2000	2000	2000	80%
2 to 2.99	0	0	0	0	0	0%
3 to 3.99	0	0	0	0	0	0%
4 to 4.99	0	0	0	0	0	0%

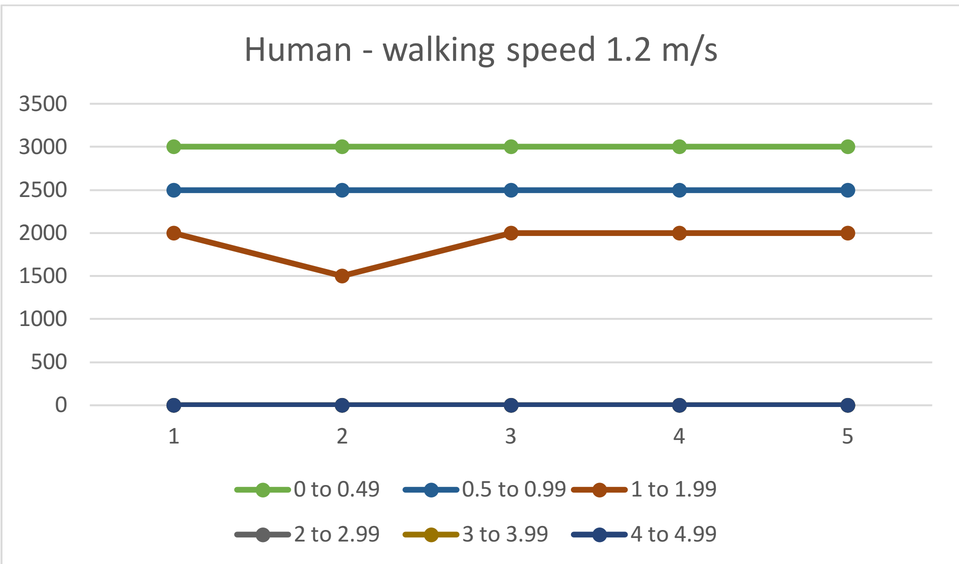

Figure 4.37: Average walking speed of people with normal vision against the passer-by

Table 4.25 contains the frequencies emitted by the prototype when the walking speed was 0.8m/s and obstacle was a human. It is graphically represented in Figure 4.38. The prototype can correctly detect the participant from zero to two meters. From two to three meters, the detection rate is 60%. The prototype failed to detect correctly in two of the tests. No object was detected when distance increased to more than three meters.

Table 4.25: Test results on average walking speed of people with visual impairment against the passer-by

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	0	1500	0	1500	1500	60%
3 to 3.99	0	0	0	0	0	0%
4 to 4.99	0	0	0	0	0	0%

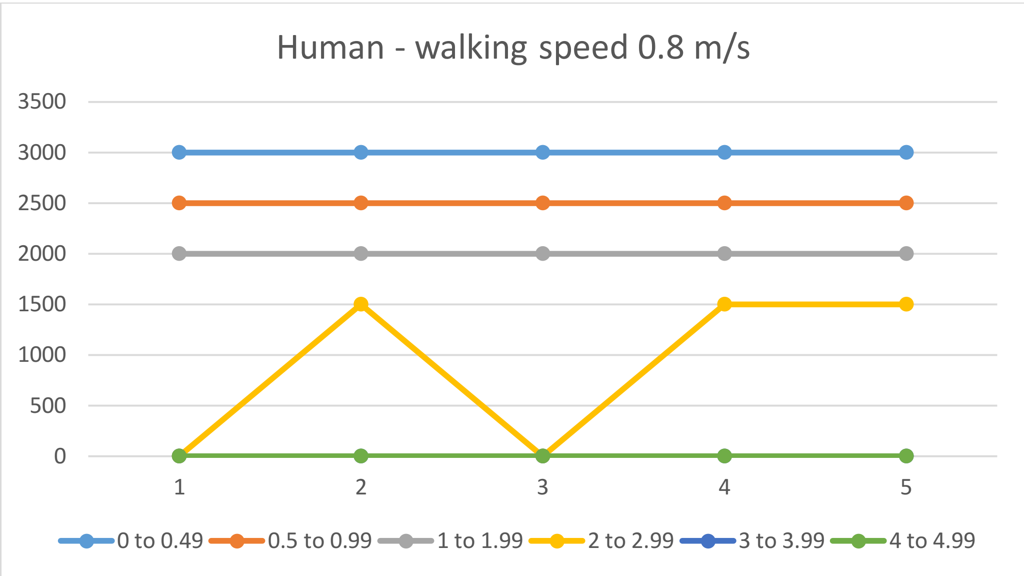

Figure 4.38: Average walking speed of people with visual impairment against the passer-by

4.1.2.8 Post

Table 4.26 describes the frequencies emitted by the prototype when the walking speed was 1.2m/s and obstacle was a post (Figure 4.39). It is graphically represented in Figure 4.40. The prototype could correctly detect the post from zero to three meters. From three to four meters, the detection rate was 60%. The prototype failed to detect correctly twice. Beyond four meters, the prototype could not detect the obstacle.

Figure 4.39: Obstacle – a post

Table 4.26: Test results on average walking speed of people with normal vision against the post

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	1000	1000	1000	0	0	60%
4 to 4.99	0	0	0	0	0	0%

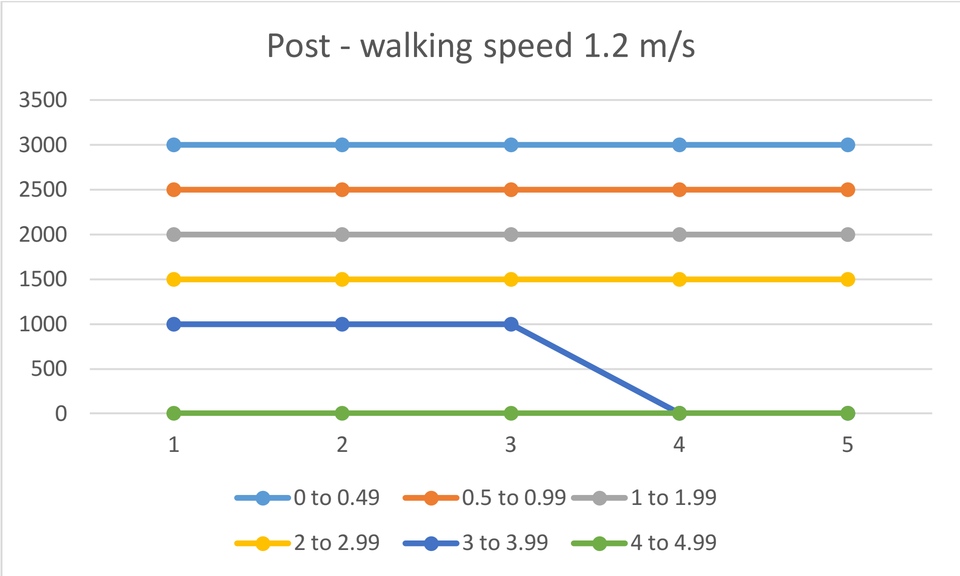

Figure 4.40: Average walking speed of people with normal vision against a post

Table 4.27 contains the frequencies emitted by the prototype when the walking speed was 0.8m/s and obstacle was the post. It is graphically represented in Figure 4.41. The prototype correctly detected the post from zero to three meters. Beyond three meters, the prototype could not detect the obstacle.

Table 4.27: Test results on average walking speed of people with visual impairment against the post

Distance (m)	Test (Hz)					Detection Rate
	1	2	3	4	5	
0 to 0.49	3000	3000	3000	3000	3000	100%
0.5 to 0.99	2500	2500	2500	2500	2500	100%
1 to 1.99	2000	2000	2000	2000	2000	100%
2 to 2.99	1500	1500	1500	1500	1500	100%
3 to 3.99	0	0	0	0	0	0%
4 to 4.99	0	0	0	0	0	0%

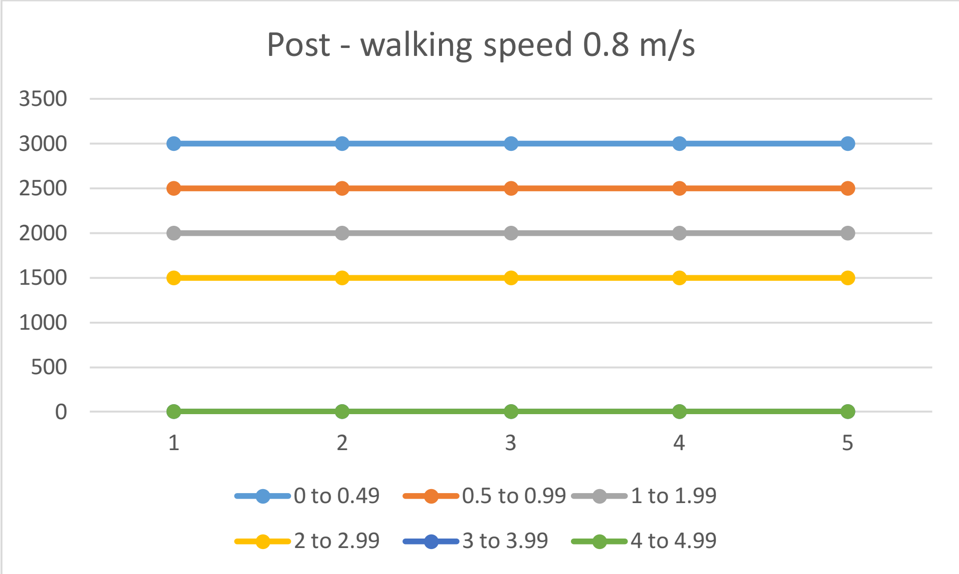

Figure 4.41: Average walking speed of people with visual impairment against the post

4.1.3 Results and Discussions

Table 4.28 shows the compiled detection rates for all the testing with various obstacles. The wall, table, box, signboard and entrance door were classified as large obstacles with even surface area. Large obstacles were correctly detected from below one meter to five meters in both walking speeds with the exception of entrance door. When walking at the speed of 1.2m/s and 0.8m/s and distance is between four to five meters, the detection rate was 40% and 100% respectively. The differences in walking speed may have caused the differences in successful detection rate. A slower walking speed gave the prototype more frequency samples to process and thus, increasing the rates of successful detection.

Irregular shaped obstacles such as the chair and human decreased the successful detection rate of the prototype. The accurate obstacle detection was possible up to approximately 2 meters distance between the obstacles and the prototype. The successful detection rate of a chair from a distance of two to three meters was 80% and 60% for walking speed of 1.2m/s and 0.8m/s respectively. This did not conform to the perception that slower walking speed increases the successful detection rate. However, a more significant result from the same irregular shaped obstacle which was the human could be compared. When the passer-by was approximately two to three meters away, the prototype could detect him at a slower walking speed but not when walking speed increased. Even though the detection rate was 60%, it signified that it was capable of detecting human at a slower walking speed.

Car was also considered as an irregular shaped obstacle but the prototype was able to detect it correctly in both walking speed tests. This means that size or large surface area affects the successful detection rate. The traffic cone and post had a lower successful detection rate when compared to large obstacles such as the wall. Both the obstacles were successfully detected at a distance up to three meters. Beyond that, it encountered false detection or no detection. The size and surface area of the traffic cone and post was considered small, thus this could have affected the successful detection rate.

Luggage and stairs' successful detection rate differed from other obstacles. Both the obstacles could be detected up to five meters but had trouble being detected within one meter. A possible explanation to this was due to the height of both obstacles. As the prototype approaching the shorter obstacles, the surface being exposed for detection decreased, thus reducing the successful detection rate.

From the results shown in Table 4.28, it proved that the obstacle detector prototype is fully functional, where the successful detection rates depend on the obstacles' physical characteristics such as size, surface area, shape and height. The prototype was able to detect large sized obstacles in most of the testing. Normal or small sized objects with normal or irregular shape such as chair, traffic cone and post could be detected by the prototype in a distance of two meters away from the obstacles. The prototype had no problem in detecting short obstacles which were one to five meters away, but it had problem when the short obstacles was less than one meter away from the detector. In short, at the walking speed of 1.2 meters per second, the average successful detection rate was 83% while the average successful detection rate at the walking speed of 0.8 meter per second was 85%.

Table 4.28: Successful detection rate of obstacles at two walking speed

Obstacle	Walking speed (m/s)	Detection rate						
		0m to 0.49m	0.5m to 0.99m	1m to 1.99m	2m to 2.99m	3m to 3.99m	4m to 4.99m	Avg.
Wall	1.2	100%	100%	100%	100%	100%	100%	100%
	0.8	100%	100%	100%	100%	100%	100%	100%
Table	1.2	100%	100%	100%	100%	100%	100%	100%
	0.8	100%	100%	100%	100%	100%	100%	100%
Chair	1.2	100%	100%	100%	80%	0%	0%	63%
	0.8	100%	100%	100%	60%	0%	0%	60%
Box	1.2	100%	100%	100%	100%	100%	100%	100%
	0.8	100%	100%	100%	100%	100%	100%	100%
Luggage	1.2	0%	0%	100%	100%	100%	100%	67%
	0.8	0%	0%	100%	100%	100%	100%	67%
Entrance door	1.2	100%	100%	100%	100%	100%	40%	90%
	0.8	100%	100%	100%	100%	100%	100%	100%
Signboard	1.2	100%	100%	100%	100%	100%	100%	100%
	0.8	100%	100%	100%	100%	100%	100%	100%
Traffic cone	1.2	100%	100%	100%	40%	0%	0%	57%
	0.8	100%	100%	100%	100%	0%	0%	67%
Stair	1.2	0%	100%	100%	100%	100%	100%	83%
	0.8	0%	100%	100%	100%	100%	100%	83%
Lamppost	1.2	100%	100%	100%	100%	100%	100%	100%
	0.8	100%	100%	100%	100%	100%	100%	100%
Car	1.2	100%	100%	100%	100%	100%	100%	100%
	0.8	100%	100%	100%	100%	100%	100%	100%
Human	1.2	100%	100%	80%	0%	0%	0%	47%
	0.8	100%	100%	100%	60%	0%	0%	60%
Post	1.2	100%	100%	100%	100%	60%	0%	77%
	0.8	100%	100%	100%	100%	0%	0%	67%
Average (Avg.)		85%	92%	99%	90%	72%	67%	-

4.2 Experiment 2 Pilot Test with Participants in a Controlled Indoor Environment

Experiment 2 was conducted as a pilot test conducted in a controlled indoor environment with two main goals; to ensure the prototype can perform in real-time with the help of participants and to obtain feedback so improvement could be made on the prototype. The prototype was tested on participants in an experimental controlled indoor environment. The convenience sample of ten participants recruited by word of mouth were all aged 18 years and above, and most were university students. Upon explaining the project and evaluation details, verbal consent was obtained from each participant prior to taking part in the process. The participants who had given consent were also advised that they could withdraw at any point of the evaluation process as the participation was completely voluntary. The participants had no experience in using the obstacle detector prototype and hence, a brief explanation on the functionality of the prototype and the way of functioning was given to the participants. As the prototype is usable on any finger, the participants could choose to mount the prototype on their preferred finger. The participants were blindfolded to simulate no vision and they were assisted to walk safely throughout the experiment, following the path shown in Figure 4.42. Each participant went through the path three times and each time the position between participant and obstacles differs slightly. Figure 4.43 shows a participant who was searching for obstacle in front of him.

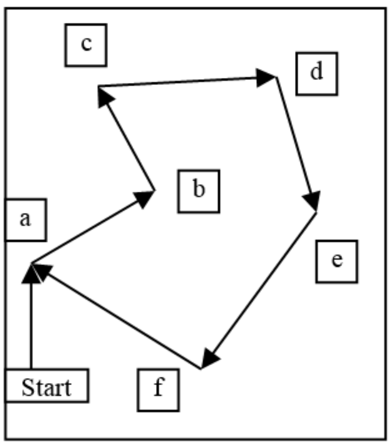

Figure 4.42: Placement of obstacles: Wall column (a), chair (b), waist-level box (c), small box on ground (d), table (e), head-level box (f)

Six obstacles were placed along the path and each obstacle has its own testing purpose. Wall column (Figure 4.44) was used to represent an object corner, the chair (Figure 4.45) to represent an irregular shaped obstacle, a hanging box to represent a waist-level (Figure 4.46) and another to represent a head-level (Figure 4.47) obstacle, small box (Figure 4.48) on the floor to represent an elevated step, and the table as shown in Figure 4.49 represents an obstacle with hollow body. The placement of these obstacles were found in some research works with similar purpose to test obstacles of different height level (Lee et al. 2014; Pyun et al. 2013; Vorapatratorn & Nambunmee 2014).

Figure 4.43: Participant in front of a waist-level obstacle

Figure 4.44: A wall column

Figure 4.45: A chair representing an irregular shape obstacle

Figure 4.46: A hanging box representing a waist-level obstacle

Figure 4.47: A hanging box representing head-level obstacle

Figure 4.48: A box on the floor representing an elevated step

Figure 4.49: A table representing obstacle with a hollow body

4.2.1 Results and Discussions

The detection rate of the prototype for different obstacles in Experiment 2 are shown in Table 4.29. As this was a pilot test with human volunteers, the highest detection rate among the six obstacles was the wall column with 90% of successful detection rate. Waist-level obstacle was successfully detected at 50%. Chair, table and head level obstacles were successfully detected at 36.67%. The least detected obstacle is the ground-level obstacle with only 20% detection rate.

There were some factors contributing to the success rates of detection such as size of the obstacle and the sensing angle of the prototype and obstacle. The height of the box used for ground-level obstacle was 16cm. The prototype is capable of detecting the obstacle of that height in an ideal testing scenario where the prototype is aligned perpendicularly to the obstacle. However, the motion of the volunteer is involved and this affected the detection rate of the prototype. When participants moved their hands or finger to detect an obstacle, the direction and angle between obstacles and prototype may not be aligned to face the sensor perpendicularly. From the observation made during the experiment, participants had a tendency to lift their hands slightly and point the prototype upwards. This reduced the possibility of detecting a small and short obstacle that could be the reason for a low detection rate of 20%. Due to unfamiliarity with the device, strong and quick swinging of the device was observed in some volunteers during testing. With the swinging, the prototype was not able to response fast enough to their changing directions.

The detection rate of irregular shape objects is lower as discussed in Experiment 1. The irregular shape of a chair and the constant movement of the prototype may result in low detection rate of 36.67%. The table used in this experiment has a hollow body. The surface area of the table exposed to the prototype is small that is the sides and legs of the table. The small surface area may have resulted in a low detection rate of 36.67%. The box was used as head-level obstacle and it had a relatively large surface area and is regular shaped. However, the detection rate was 36.67%. One of the possible explanations is the position and height difference between the prototype and obstacles. Similar with the ground-level obstacles, the prototype had no problem in detecting the obstacle in a scenario where prototype was directly perpendicular to the obstacle.

However, due to real time positioning of participant's finger, the prototype was not perpendicular to the obstacle in some testing.

Successful detection rate of 90% was observed when the obstacle was a wall column. It was detected the most when compared to the other five obstacles. The surface area of wall column was big and the plane of the surface was flat and regular. These characteristics increased the possibility of obstacles being detected by the prototype.

From the pilot test, the prototype was able to perform real-time detection. However, there were rooms for improvement. The participants had given their feedbacks to improve the functionality and aspects of the prototype after the testing. They suggested the prototype to have a faster response speed and this was important because in the observation made during the experiments, the prototype fail to detect obstacle when participants moved their hands too quickly. They also expressed that the unfamiliarity in using the prototype caused some confusion particularly on directing the prototype to perform the detection. The participants had also indicated that more prior training must be given before the actual usage of the prototype.

Table 4.29: Obstacle detection rate for various obstacles with participants wearing blindfolds

Obstacle	Column	Chair	Waist-level obstacle	Ground-level obstacle	Table	Head-level obstacle
Successful detection	27	11	15	6	11	11
Total detection	30	30	30	30	30	30
Successful detection rate	90%	36.67%	50%	20%	36.67%	36.67%

4.3 Experiment 3 Evaluation with Participants in an Uncontrolled Outdoor Environment

The third experiment was conducted in an outdoor uncontrolled environment with real obstacles along the walking path within the campus. Participants in this experiment wore a low vision simulator goggles and not blindfolded due to safety concerns when conducting the experiment in outdoor environment. The low vision goggles simulate cataract which is in the severe visual impairment category. Similar to the second experiment, six participants recruited into the third experiment were aged 18 years and above, all were university students, and had no experience in using the improved prototype with better response speed. Upon explaining the project and evaluation details, verbal consent was obtained from each volunteer prior to taking part in the process. Each participant was required to complete five different paths during the evaluation as shown in Figure 4.50, Figure 4.51, Figure 4.52, Figure 4.53 and Figure 4.54. The volunteers who had given consent were also being advised that they could withdraw at any point of the evaluation process as the participation was completely voluntary and time consuming. The prior knowledge of the volunteers about the path in the campus was not assessed during the experiment.

For this experiment, audio and video recorders were used to collect data because there were dynamic movement of participants and uncontrolled placement of obstacles. Dynamic movement of participant made it challenging to determine the alerts generated from the prototype without disturbing the participants by walking near them. Thus, the audio recorder was placed on the wrist of the participant to capture the alerts generated. There were many obstacles along the path taken by the participants such as building wall, metal handle, metal column, and trees as shown in Figure 4.55, Figure 4.56, and Figure 4.57. One of the paths taken by a participant is shown in Figure 4.58. However, not every obstacle was in the way of walking. This means the detection rate of obstacle is dependent on how the participant swing their hand or finger and where the prototype is being directed to. Hence, a video recorder was used to capture those obstacles. By syncing the audio and video files, a clear set of data on detection rate of obstacles can be obtained.

The prototype in this experiment was improved to increase the response speed. The default setting of ultrasonic sensor collects data every 100ms and the data passing through a 2Hz filter. The filter provides reliable readings by reducing the fluctuation of data. This however resulted in a slower response speed because the filter outputs reading every 500ms. This setting was selected in experiment 2 and participants realized the slow response speed as well. To overcome this problem, a signal was manually inserted into the ultrasonic sensor. The signal gave the instructions to the sensor on the timing of data collection. By using this method, data could be obtained every 100ms.

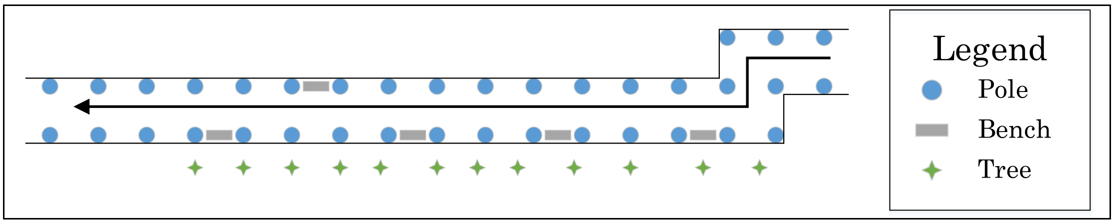

Figure 4.50: Path 1

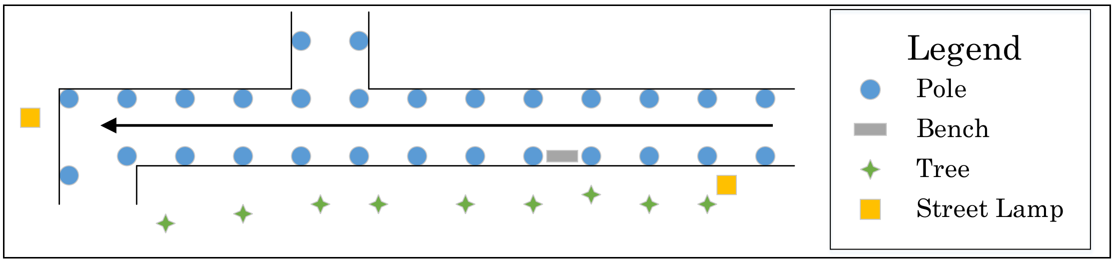

Figure 4.51: Path 2

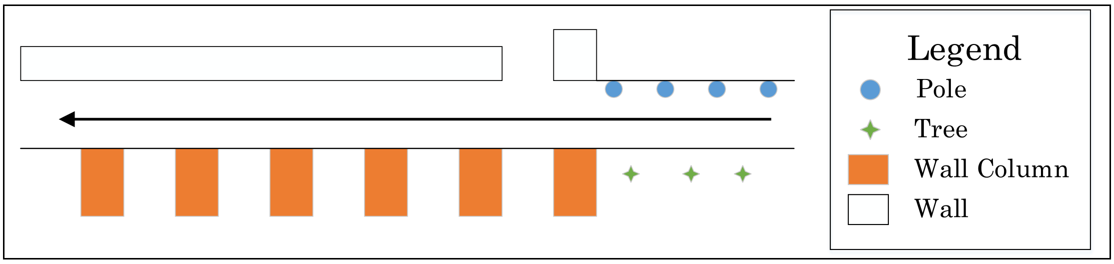

Figure 4.52: Path 3

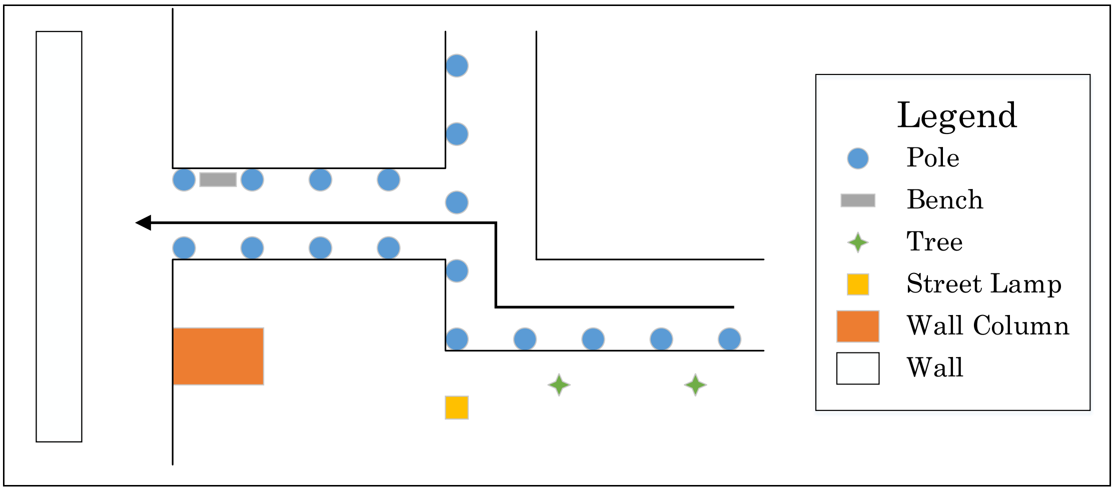

Figure 4.53: Path 4

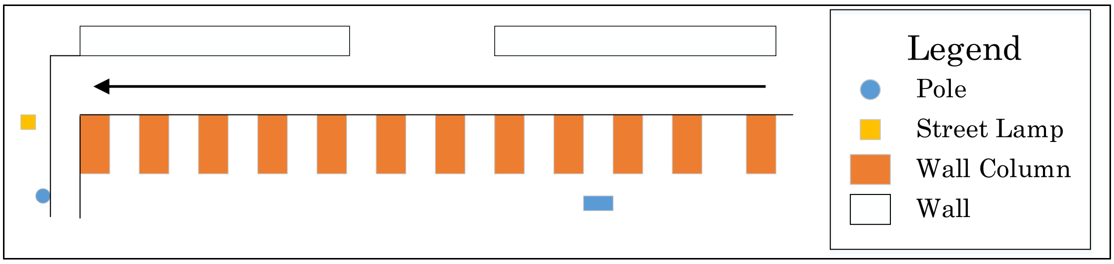

Figure 4.54: Path 5

Figure 4.55: Uncontrolled outdoor path in Path 1

Figure 4.56: Uncontrolled outdoor path in Path 2

Figure 4.57: Uncontrolled outdoor path in Path 3

Figure 4.58: Participant wearing low vision goggle at outdoor environment

4.3.1 Results and Discussions

From the audio and video recording, data regarding the rate of detecting obstacles and the time taken to complete the path were extracted and tabulated in Table 4.30. The average walking speed of the participants was calculated by dividing the distance of the path with the total time taken to complete the path.

The average successful detection rate of obstacle in this experiment was 86.58%. From the second experiment to the third experiment, the detection rate had increased by 42.58%.

Table 4.30: Detection rate resulted from participants with low vision simulator

Path	Total obstacle	Detected obstacle	Detection rate (%)	Time taken (s)	Distance travelled (m)	Average speed (m/s)
1	11	9	81.82	38	27.2	0.72
2	12	10	83.33	38	33.0	0.87
3	13	13	100.00	48	33.0	0.69
4	15	13	86.67	47	33.0	0.70
5	15	13	86.67	51	33.0	0.65
6	17	13	76.47	37	27.2	0.73
7	17	16	94.12	47	33.0	0.70
8	17	14	82.35	42	27.2	0.65
9	17	16	94.12	45	27.2	0.60
10	17	17	100.00	52	33.0	0.64
11	18	17	94.44	35	27.2	0.78
12	18	16	88.89	36	27.2	0.75
13	20	15	75.00	41	33.0	0.81
14	21	19	90.48	61	34.3	0.56
15	21	20	95.24	36	27.2	0.75
16	21	19	90.48	56	34.3	0.61
17	21	19	90.48	50	33.0	0.66
18	21	20	95.24	53	33.0	0.62
19	22	20	90.91	35	27.2	0.78
20	22	15	68.18	69	33.0	0.48
21	22	18	81.82	53	34.3	0.65
22	22	16	72.73	49	34.3	0.70
23	23	21	91.30	62	34.3	0.55
24	23	20	86.96	62	34.3	0.55
25	25	21	84.00	47	34.3	0.73
26	25	18	72.00	39	34.3	0.88
27	25	25	100.00	42	27.2	0.65
28	25	23	92.00	50	34.3	0.69
29	26	21	80.77	49	27.2	0.55
30	31	22	70.97	78	34.3	0.44
Average	20.10	17.30	86.58	48.27	31.50	0.67
Standard deviation	4.52	3.80	8.95	10.52	3.15	0.10

It was observed in this experiment that the size and distance of the obstacles from the prototype affect the successful detection rates as some of the detection rates were below 80%. In those path testing, it was observed that although the prototype was pointing towards the obstacles, it was around three to four meters and the width of the obstacles was 20cm. From the results in Experiment 1, it was found that the size of an obstacle affects the detection rate. Detection of small size obstacle was reduced when the distance increased. This could be the reason why some path testing had results with detection rates below 80%.

There were three tests with successful detection rate of 100%. In these path tests, it was observed that the participants pointed the prototype towards obstacles at around one meter distance. The width of the obstacles was still 20cm. However, due to the different distances, it resulted in a higher successful rate of detection.

There was no significant indication of a relationship between detection rate and average walking speed as shown in Figure 4.59. However, there was a subtle polynomial pattern found from the waveform presented as dotted line in Figure 4.59. This may suggest that the optimal walking speed for an optimal detection rate was around 0.68m/s, thus any walking speed faster or slower than that might result in a lower successful detection rate.

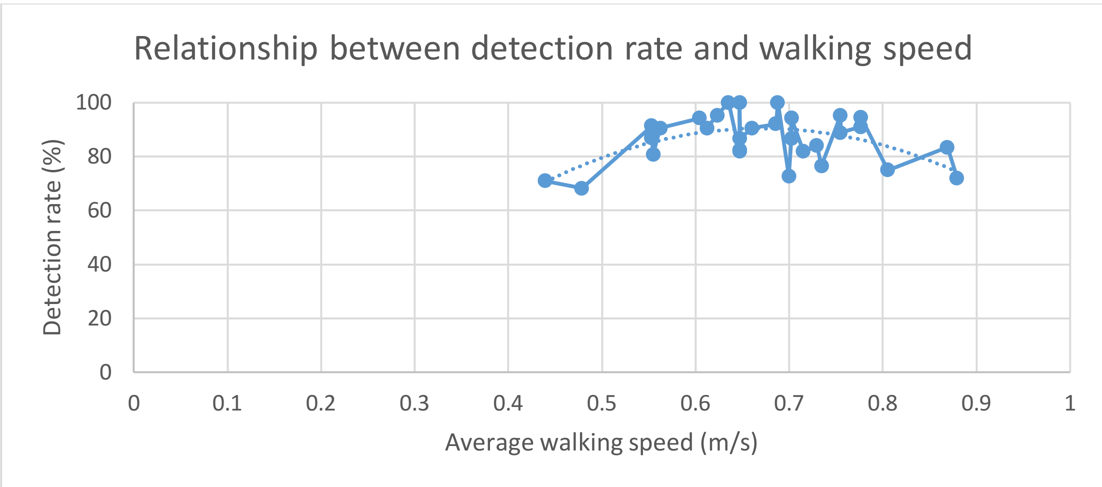

Figure 4.59: Relationship between detection rate and walking speed

Similar to the average walking speed, there was no significant relationship between the successful detection rate and the total time taken to complete the testing path (Figure 4.60). However, it was observed that the detection rate was lower when total time taken to complete the path was above 65s. In the experiment, the participants who took a longer period of time to complete the experiment as they tend to stop at a place and scan the prototype around to confirm the presence of obstacles. During those scans, the prototype was pointed not only towards obstacles along the path but also towards obstacles that were five meter away such as the scenarios mentioned previously. This reduced the detection rate because the prototype could not detect small obstacles that were more than 5 meters. They were still counted as obstacles in the data collection.

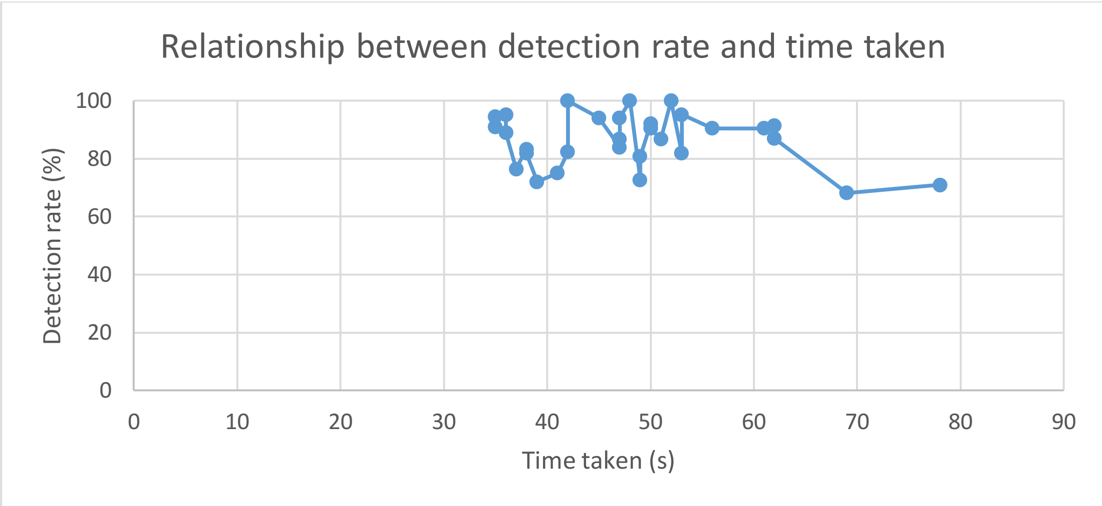

Figure 4.60: Relationship between detection rate and time taken to complete the path

4.4 Summary

In this chapter, the obstacle detection performance of the proposed prototype was evaluated with various volunteers. Experimental procedures were defined and followed throughout the prototype evaluation. Three experiments were conducted in both indoor and outdoor environments. Detection rate of the prototype on different obstacles and environments were discussed. In first experiment, data collected showed that there were multiple factors that affect the detection rate which were the size and shape of the obstacles, and the movement rate or walking speed towards the obstacle. Large obstacles could be detected easily when compared to normal or small obstacles. The prototype could not detect nearby short obstacles. Slow walking speed increased the rate of obstacle being detected by the prototype. The second experiment involved pilot testing with blindfolded participants in a controlled indoor environment and the average obstacle detection rate is 45%. Following that, improvement was done on prototype's response speed and prior prototype usage training given to the participants. As a result, participants with low vision goggles in the third experiment performed in an uncontrolled outdoor environment achieved the average detection rate of 86.58%.

Chapter 5 Conclusions

As mentioned in Chapter 1, an ideal obstacle detector for the visually impaired would be the one that can work in both indoor and outdoor environments, lightweight, compact, non-obstructive, low computational power and low cost. Thus, this research proposed, designed, developed and evaluated a finger mounted obstacle detector prototype for people with visual impairment to help them move and navigate to avoid collision.

5.1 Contributions

This research has completed and achieved the research objectives highlighted in Chapter 1. The following contains the summarised contribution for each research objective.

5.1.1 Research Objective 1: Study the limitations of the existing non-vision based obstacle detectors

People with visual impairment have trouble in moving easily from one place to another place. They usually require assistance to move around safely such as by using walking stick, guide dog or human companion. These options have limitations such as walking stick cannot detect hanging obstacle, guide dog has limited life span, and human cannot accompany people with visual impairment all the time.

From the literature review, observation and informal discussions with the orientation and mobility practitioners, the limitations in the existing non-vision based obstacle detectors were identified. In fact, numerous assistive mobility aids were designed and developed by researchers worldwide to help people with visual impairment. However, there was insufficient assistive device that could detect obstacles which can help people with visual impairment to avoid collision. Many obstacle detector prototypes were developed but they are either bulky or obstructive making it less likely to be used in daily life. There was also insufficient evaluation on the prototypes performance. The outcome of the study indicated that a low cost, low computational power, small and compact in size, lightweight, portable and non-obstructive obstacle detector was needed to overcome the problems faced by the visually impaired.

5.1.2 Research Objective 2: Design and development of an enhanced non-vision based obstacle detector

The research contributed the design of the proposed obstacle detector for people with visual impairment. From the literature review, it is an enhanced detector when compared to the existing mobility aids for the visually impaired are not widely implemented due to limitations such as bulkiness and obstructive. Thus, this research proposed an improved electronic obstacle detector that can be brought around easily and help people with visual impairment in avoiding collision.

This research has successfully developed the proposed obstacle detector. The prototype is designed to be mounted on the finger which is not obstructive to the white cane and walking speed, light weight i.e. 15.7g, small and compact i.e. 3.8cm × 2.7cm × 2.5cm, and can be carried around easily i.e. wireless, coin-sized battery operable. The prototype produces staged audio alerts (i.e. louder when the obstacle is nearer and vice-versa) to the user when an obstacle is detected in real time.

5.1.3 Research Objective 3: Evaluation of the proposed obstacle detector

The prototype was evaluated to ensure the performance of the obstacle detector was up to the usage needs of the visually impaired, in three experiments as discussed in Section 4.1, Section 4.2 and Section 4.3.

The first experiment proved the functionality of the obstacle detector in sensing various common objects in indoor and outdoor environment with two different walking speed of people i.e. with visual impairment at 0.8 meter per second and without any visual impairment at the speed of 1.2 meters per second. For the walking speed at 1.2 meters per second, the average detection rate was 83% while the average detection rate at 0.8 meter per second was 85%. This indicated that the obstacle detector was able to detect obstacle in real time at the common walking speed of the visually impaired.

The second experiment tested the prototype with participants in a controlled indoor setup to gather user feedbacks prior to testing in uncontrolled outdoor environment. The blindfolded participants gave some feedbacks on their experience when using the prototype to detect obstacle. They suggested to have a louder audio alert, a faster detection speed and a longer duration of training prior to using the obstacle detector.

The second experiment gave the researcher valuable user feedback for the third experiment. All the feedbacks were taken into improvement of the prototype used in the third experiment.

Lastly, the third experiment was conducted with participants wearing low vision goggles to simulate low vision type of visual impairment. With the experience learnt in the second experiment, all participants in the third experiment were given sufficient prior training on how to use the proposed obstacle detector. In addition, the detection speed was increased while the audio alert was also made clearer. They walked freely in paths which had various obstacles appearing along the paths. From the results collected, the prototype performed well with an average detection rate of 86.58%, in helping participants with low vision who walked and navigated successfully to the end of the paths at an average speed of 0.67 meter per second. This demonstrated the feasibility of using the proposed obstacle detector as a supplementary assistive tool for people who have various visual impairments causing the low vision.

5.2 Limitations

Throughout the evaluation, the proposed prototype was evaluated by six sighted participants wearing blindfolds to simulate no vision and low vision goggles to simulate low vision in various scenarios. This was due to safety concern for the people with visual impairment as the researcher is not a qualified orientation and mobility specialist. There is a lack of certified orientation and mobility specialist in this region.

From the evaluation, the prototype's performance in detecting obstacles can be affected by the characteristic of the obstacle. Large obstacle could be detected easily than the small and thin obstacle. A solid regular shape obstacle with flat surface was easily detected when compared to irregular shaped obstacle. This is unlikely to be resolved by ultrasonic sensors, unless a vision-based obstacle detection approach is used.

The sensing unit of the prototype can also affect the performance in detecting obstacle. Ultrasonic sensor which was used as the sensing unit can detect obstacle within a certain range of angle between the sensor and obstacle. Obstacle within the angle from range of 60 to 90 degrees could be detected. Beyond that range, the detection performance deteriorated particularly after 40 degrees when no object could be detected.

5.3 Future Improvement

There are some improvements for future works to improve the detection performance of the assistive device.

Firstly, it is good to upgrade the sensing module. The ultrasonic sensor used in this research is the smallest available in the market and it serves the purpose for prototyping. There are high end ultrasonic sensors that have narrow beam of detection which can provide a more accurate location of obstacles. The cost, size and power consumption will also be higher. It may also increase the weight, size, and computation resources while reducing the portability to the users.

In addition, it is good to increase the detection rate by increasing the processing speed of the microcontroller. Microcontrollers with faster processing speed will increase the rate at which an obstacle is detected and this will provide a faster response for the people with visual impairment to react when there is obstacle. However, more powerful microcontroller requires most cost and power consumption. It may also post an issue to the weight, size, computation resources and portability to the users.

Getting hold of a qualified orientation and mobility specialist is a good approach to further conduct experiments on real people with visual impairment. This allows the prototype to be tested on the targeted user and safety concern when dealing with people with visual impairment can be reduced with the help of the qualified specialist.

Future works have to probe into balancing the actual needs of the people with visual impairment. There is always a trade-off between getting a better detection rate and having all the other desired attributes of the obstacle detector.

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Further Readings

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Appendices

Appendix 1: Ethics approval

From: Astrid Nordmann
To: Denny Meyer
Cc: RES Ethics; Lil Deverell
Subject: SHR Project 2016/316 - Ethics clearance
Date: Monday, 20 February 2017 8:12:22 AM
Attachments: image001.png

To: A/Prof. Denny Meyer, FHAD

Dear Denny,

SHR Project 2016/316 – Optimising technology to measure functional vision, mobility and service outcomes for people with low vision or blindness
A/Prof. Denny Meyer *et al* - FHAD
Approved duration: 20-02-2017 to 18-10-2020 [adjusted]

I refer to the ethical review of the above project protocol by Swinburne's Human Research Ethics Committee (SUHREC). Your response to the review, as emailed on 09 February 2016, accords with the Committee review.

I am pleased to advise that, as submitted to date, the project may proceed in line with standard on-going ethics clearance conditions outlined below.

- The approved duration is 20 February 2017 to 18 October 2020 unless an extension request is subsequently approved.

- All human research activity undertaken under Swinburne auspices must conform to Swinburne and external regulatory standards, including the *National Statement on Ethical Conduct in Human Research* and with respect to secure data use, retention and disposal.

- The named Swinburne Chief Investigator/Supervisor remains responsible for any personnel appointed to or associated with the project being made aware of ethics clearance conditions, including research and consent procedures or instruments approved. Any change in chief investigator/supervisor, and addition or removal of other personnel/students from the project, requires timely notification and SUHREC endorsement.

- The above project has been approved as submitted for ethical review by or on behalf of SUHREC. Amendments to approved procedures or instruments ordinarily require prior ethical appraisal/clearance. SUHREC must be notified immediately or as soon as possible thereafter of (a) any serious or unexpected adverse effects on participants and any redress measures; (b) proposed changes in protocols; and (c) unforeseen events which might affect continued ethical acceptability of the project.

- At a minimum, an annual report on the progress of the project is required as well as at the conclusion (or abandonment) of the project. Information on project monitoring and variations/additions, self-audits and progress reports can be found on the Research Ethics Internet pages.

- A duly authorised external or internal audit of the project may be undertaken at any time.

Please contact the Research Ethics Office if you have any queries about on-going ethics clearance, citing the Swinburne project number. A copy of this email should be retained as part of project record-keeping.

Best wishes for the project.

Yours sincerely

Astrid Nordmann
Secretary, SUHREC

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Appendix 2: Information form

PARTICIPANT INFORMATION STATEMENT FOR IMPLIED CONSENT

SWINBURNE UNIVERSITY OF TECHNOLOGY

"Optimising technology to measure functional vision, mobility and service outcomes for people with low vision or blindness"

Principal Investigator: Prof Denny Meyer; **Project Manager:** Dr Lil Deverell

Introduction

We have completed the development of a smart technology for people with visual impairment to detect and avoid obstacles around them. The evaluation session aims to study the performance of the obstacle detector prototype in providing audio cues when an obstacle is detected. Your participation in this evaluation helps us in testing the performance of the prototype in detecting obstacles.

Procedure

You will be invited to complete the following tasks using the obstacle detector prototype: (1) attaching a phone on the wrist for recording the audio cues (2) attaching the prototype on one of the fingers (3) wearing a no-vision or low-vision simulator (4) walking through the selected paths. The entire activity is expected to take about 15 minutes, depending on your walking speed. The data collected from the evaluation session will be used to determine the effectiveness of the obstacle detector prototype.

Participation

Your participation is completely voluntary. You have the rights to participate or to withdraw from the research at any time. If you choose to participate, you must be 18 years of age or older. Any feedbacks or recommendation for the prototype can be given during or after the experiments.

Risk

This evaluation will be conducted during your free time to avoid any interruptions to your schedule. The activity will take place in the campus walkways and vacant classroom after office hours and during weekends. This is to minimize the risk of getting injured or interrupted.

Confidentiality

Your participation in this research is confidential and it is for educational purposes. Your personal information will not be included in any publication of this research. Audio recording of the sound of alerts will be deleted after the data is analysed. If you have any further enquiry regrading this evaluation session, please do not hesitate to contact the co-researcher: Lau Bee Theng , Tel: 082-260686, e-mail: blau@swinburne.edu.my.

Consent

A copy of this Participant Information Statement and verbal explanation is given to you. If you agree to participate in this project, you will be guided to complete the evaluation. By participating and completing the evaluation of the prototype, your informed consent is implied and indicates that you understand the above conditions of participation in this project and that you have had the opportunity to have your questions answered by the researchers.