Doctoral Thesis 2017

STUDY OF INTELLIGENT TRAVEL AID DEVICES FOR VISUALLY IMPAIRED PERSON

September 2017

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Introduction

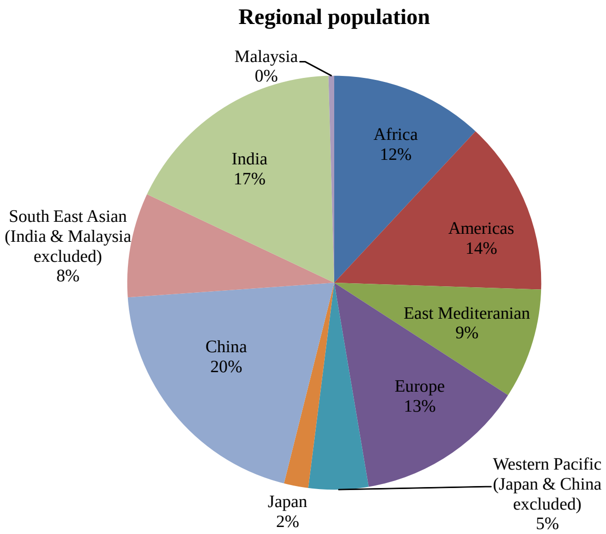
1.1 Overview

World Health Organization (WHO) has released the statistics for people with disabilities (PWDs) in the world which are 10% of the total world population and about 1 billion people in early 2011. In addition, 80% of the disabled persons are located in developing countries. The increment of these statistics is because of increased aging population, health condition and greater accessibility to facilities. In addition, there are 285 million visually impaired people in which 39 million of them are fully blind and 246 million are in the low vision person category. Malaysia has a population of about 28 million people and the number of disabled persons in Malaysia is estimated to be at 2.8 million people. However, the numbers of people with disabilities which are registered with the Social Welfare Department (JKM) are only 480,000, in which 48,000 of them are visually impaired. The disabled people in this country cannot be shown by statistics since they remain imperceptible in most of the developing countries. The real statistical data on disabled people cannot be obtained correctly. This shows a clear image of lack of connections between disability and country development which mostly occurred in developing countries. The collected data is inaccurate and shows the shortage of acceptable measurable statistics and complications faced in gathering correct data [1].

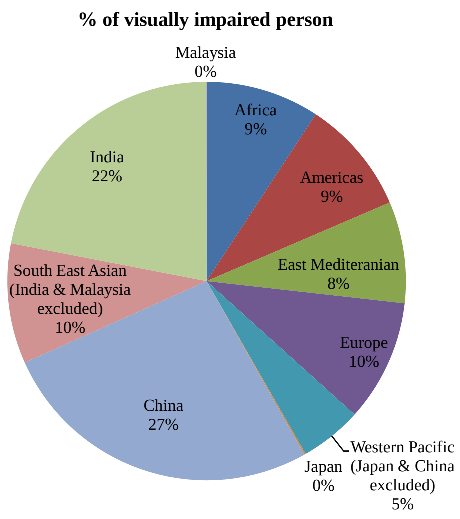
In addition, the number of visually impaired people in Japan is about 310,000 people. Meanwhile, there are about 75.5 million people who are visually impaired in China and 62.6 million in India. Figure 1.1(a) illustrates the number of visually impaired people in the world classed by region. Figure 1.1(b) and 1.1(c) show the pie chart on visu-

WHO Region	Population (million)	# visual impairment (million)
Africa	804.9	26.3
Americas	915.4	26.6
East Mediterranean	580.2	23.5
Europe	889.2	28.2
Western Pacific (Japan & China excluded)	314.5	14.39
Japan	127.8	0.31
China	1344.9	75.5
South East Asian (India & Malaysia excluded)	549.1	27.8
India	1181.4	62.6
Malaysia	30	0.048
Worldwide	6737.5	285.4

(a) Distribution of visually impaired person by region



(b) Regional population



(c) Percentage of visually impaired person

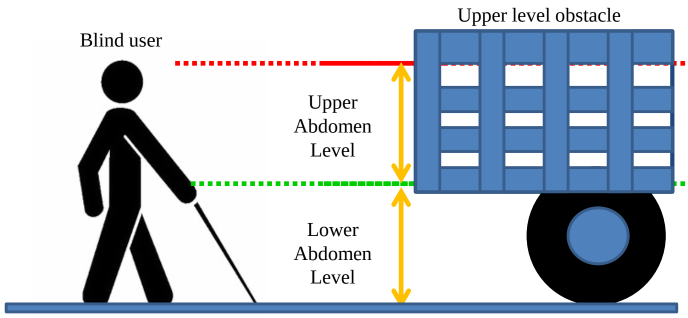
Figure 1.1: Statistics of visual impairment worldwide by World Health Organization 2011

ally impaired persons distribution by region. Based on the Convention on the Rights of Disabled Association of the United Nations, disabled people need to be prioritized and get more consideration from the local authority and government to develop a high quality of life in a country. Disabled people need to get the same chances as normal people such as accessibility, flexibility, health, education, occupation and involvement in administrative, economic and social fields [2].

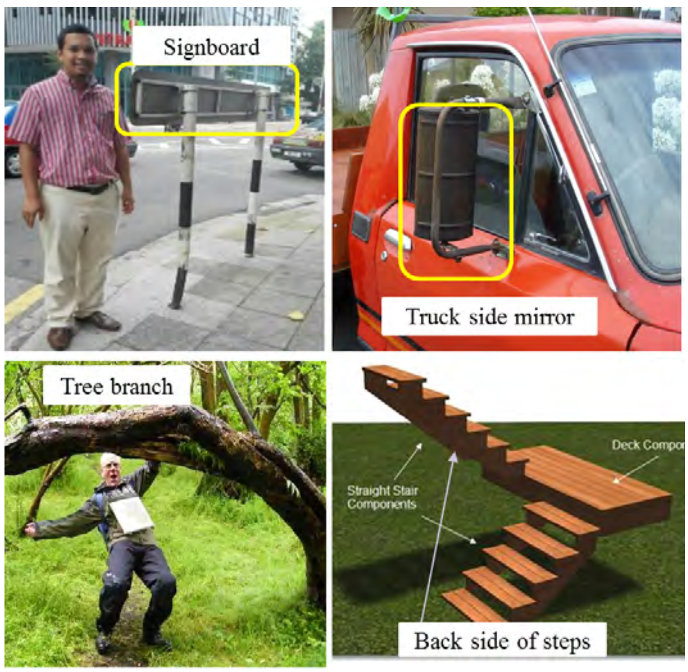
There are a few categories of disabled persons, which are hearing impaired, visually impaired, physically impaired, mental impaired and others which are recognized by the United Nations. However, amongst all of the categories of disabled people, those who are always in dangerous situations are the visually impaired as they cannot recognize their surroundings. This is because a lot of information is received visually which is about 90% for living things. All the information received by eyes will be processed by the brain and made into actions by other organs [3]. Hence, the visually impaired people could be facing great danger if they could not protect and navigate themselves well. In a study by Francois Champoux, it was shown that a visually impaired person is better in localizing sound and able to differentiate the frequencies of the sounds in the surrounding environment [4]. However, if the obstacles do not produce any sound, which are static obstacles such as walls or stairs, it is difficult for the visually impaired to recognize the location of the obstacles.

1.2 Problem statement

Conventionally, visually impaired people rely on white canes or guide dogs to assist them in order to reach their desired destination safely. It has been decades since visually impaired people used the white cane as their most common and affordable assistive tool to detect obstacles and paths surrounding them. However, conventional travel aids which are studied are normally used to help the users detect the obstacles at the lower level part of their body and have limitations. This is also supported by the statement from the Society of Blind Malaysia that there are no travel aids that can detect obstacles for the upper level of the abdomen [5]. White canes cannot protect the users from collision with obstacles at head-level, such as propped-open window, tree branch, and the opened door of a truck. Manduchi et al. have also made a survey in the United States which shows that about 300 visually impaired people who were experts in using white canes have experienced collisions with head-level obstacles. The survey shows that 39% of respondents experience a head-level accident once a year and 14% of respondents more often than once a month [6]. Figure 1.2 shows the types of obstacle which commonly exist at above the body level.



(a) Protection area for visually impaired person



(b) Type of obstacles existed at upper body level

Figure 1.2: Obstacle detection problem for visually impaired person

Moreover, the conventional white cane and guide dog are only working if the path to the destination is already familiar to the visually impaired people. It becomes difficult if the destination is new, especially at an environment that has not implemented the universal design concept, especially for visually impaired people. Difficulties still occur when using the white cane for visually impaired people as they are only able to detect paths and obstacles from the front by swinging the white cane and at the same time trying to feel the tip of the white cane that touches the ground. They do not receive enough information with only the tip of the white cane as feedback. Lack of aid signs built for visually impaired people seems to be one of the difficulties for them. They do not know where to go and cannot recognize their surroundings. It is very hard for them to travel independently from one location to another without proper navigation tools. Furthermore, the white cane could only detect obstructions through direct touch and this situation is too dangerous for them since the obstacles would be too close [7].

In addition, for visually impaired Muslim people, there is unease for them to use a guide dog to guide them everywhere to travel. The guide dog also cannot be brought inside a lot of places such as restaurants, Muslim houses and praying rooms such as a mosque. It could be hard for the visually impaired Muslim people to use a guide dog. There is quite a number of visually impaired people in Muslim countries such as Malaysia, Indonesia, and other Middle East countries. The navigation problem could be solved by a universal method and approach in order to suit the need of every visually impaired person in the world. Besides, there are about 289 million visually impaired people globally. It is nearly impossible to supply a guide dog for each visually impaired person. Since guide dogs are also living things, the life span of a guide dog is also not long enough, even though it can serve very well for the visually impaired person. It also takes a lot of time to train new guide dogs for replacement.

In order to guide and navigate visually impaired people to reach their desired destination, a reliable method and device should be investigated. There are some cases in Japan where the visually impaired people fell down from the train station platform while they used the white cane and guide dog. Even though the tactile pavement is installed at the platform, they could have the problem of searching for the tactile pavement. Hence, the probabilistic to configure their needs and problem can drive for a proposal on a reliable and feasible navigation system for them. There are also some technologies proposed which are commonly used for navigation purposes such as GPS, active RFID, mobile phone, etc. However, the usage of each technology has its limitations based on indoor or outdoor application. Based on some studies, GPS and smartphones have quite a big error margin in which they can guide a visually impaired person to walk on the road, but not the walkway side of the road since their error could be from 5 meters to 10 meters. Besides that, active RFID has also been studied [8].

However, the accuracy for active RFID is also quite big but the energy consumption with installation areas are limited. Therefore, the hypothesis of this research is to propose a new on ground detection method by using embedded RFID inside the tactile pavement which can give the visually impaired people the current location and guide the direction to be traveled when they travel alone. The shortest path algorithm will also be configured to find their destination easily when each visually impaired person could use the proposed navigation device to detect the embedded RFID inside the tactile pavement such as by using his or her NFC device included in the smartphone or mobile robot that can also give guidance and automatic driving mode for the visually impaired person. Since the usage and construction of tactile pavement on the walkway for visually impaired people in Malaysia, it has really reduced the construction cost and provided the true function of tactile pavement which is not only to inform them of the position of the walkway. This approach for the new navigation system can be used universally, both for indoor and outdoor applications.

1.3 Research objectives

The aim of this research is to provide a travel aid device that can be used by disabled people, especially the visually impaired. The research intends to investigate how the travel aid can be used effectively, so that the design requirements for the development of this travel aid device could be formulated. The proposed travel aid device could give a better quality of life for the visually impaired people in the future. After outlining the issues related to the problem faced by visually impaired people, the research has developed its objectives, and they are as follows:

1. To propose a travel aid device to reduce collision with obstructions for visually impaired people
2. To develop, fabricate and evaluate a travel aid device to reduce collision with obstructions for visually impaired people
3. To develop, fabricate and evaluate the travel aid device to navigate the visually impaired people

The following details provide the description of works to each objective in this study:-

1. To propose a travel aid device to reduce collision with obstructions for visually impaired people

   In order to enable the development of assistive travel aid for helping the visually impaired people, a literature review about the conventional and current assistive travel aids will be used for helping disabled people, especially the visually impaired. The literature review done has included the general topic for disabled people and their issues. After all the literature review is studied, the design requirement and concepts on the proposed assistive travel aid will be looked into such as mobility issue including obstacle detection, obstacle avoidance and navigation. The scope of the study will also be identified to focus on the study that will be carried out.

2. To develop, fabricate and evaluate a travel aid device to reduce collision with obstructions for visually impaired people

   Next, after the design requirements and concepts are determined, the design and development of the proposed travel aid device will be done. The appropriate software will be used to design the travel aid device before it will be developed and fabricated. The selection of all electronic components will also be done to make the travel aid with the components selected. After the proposed travel aid has been designed, it will be fabricated with a rapid prototyping machine or 3D printer to fabricate the prototype easily. Evaluation of the developed obstacle detection will also be done to confirm the functionality, feasibility and accuracy of the obstacle detection.

3. To develop, fabricate and evaluate the travel aid device to navigate the visually impaired people

   Finally, a navigation system that is useful for the visually impaired people will be developed. The novel on ground navigation device which can be used for indoor and outdoor environments will be developed and tested. Some sensors will be integrated in order to measure the parameters involved in the navigation system.

1.4 Research scope and limitations

There are many categories of disabled people which are registered based on a statistics released by the World Health Organization (WHO) such as physically impaired, visually impaired, hearing impaired, mute, cerebral palsy, etc. However, this study is only focused on visually impaired people which are commonly faced with a lot of problems since they could not receive a lot of information from their sensory feedback. Based on s study by Eric Jansen, a lot of information are received by the human eye in order to act for the next move. There are about 90% of information obtained through the human eye. Therefore, this study is focused on visually impaired people [3].

Besides that, there are many issues and problems which are also faced by the visually impaired people. For example, mobility problem, reading problem, location identification problem, employability problem, etc. However, the mobility issue is primarily focused on in this study. The mobility issue has mainly affected humans and living things to live in this world. It is also very important to make the visually impaired people independent and live without depending on other people.

The mobility issues mainly studied and explored are obstacle detection and obstacle avoidance system, since the visually impaired people could not get the information of obstacles surrounding them. This system could reduce the injuries and accidents involved by visually impaired people by detecting and avoiding the obstacles. Besides that, the navigation system is also one of the main mobility issues and it is important for them to travel independently and hence, going to work and socialize with other people. The communication with others will give them more possibilities and indirectly increase the quality of life (QOL) of visually impaired people.

1.5 Structure of the thesis

This research is focused on the mobility issues and solutions which will be proposed in order to assist disabled people, especially the visually impaired. By studying the mobility problem which has always been faced by them, the development of assistive travel aid device could reduce the accident and injuries on visually impaired people. Besides, the navigation system that could give more information to the visually impaired people that cannot be captured by their eyes would assist them to travel independently and safely. The following section summarizes the works which are performed in each chapter.

Chapter 1 presents the overview of the thesis including the introduction, problem statement, objective, scope of work and contribution of the thesis. The summary of all chapters is written in order to make the reader easy to understand the content of the thesis.

Chapter 2 elaborates the issue in mobility for visually impaired people including the current technology and research which have been conducted. There are some subjects that need to be studied such as the general issue or problem which are faced by the visually impaired people and the navigation system including the mobile phone or GPS device that are used to guide the visually impaired people, either in an indoor or outdoor environment. Besides, obstacle detection including the avoidance system will also be described. The adaptive warning system which will be included in this study is also explained.

Chapter 3 describes the proposed assistive travel aid which is developed to assist the visually impaired people. However, there are two big scopes that will be focused on which are obstacle detection and navigation system. Hence, this chapter will be focused only on obstacle detection and avoidance including the adaptive warning system. Meanwhile, navigation system will be described in the next chapter.

Chapter 4 explains the navigation system which is proposed in this thesis. The proposed navigation system which is developed will be used in indoor and outdoor environments. The study on RFID networks which is proposed to give information for the visually impaired people will also be described in this chapter, including the input method by using braille keypad and voice input. The camera input and digital compass will also be mounted to study the directional command for the visually impaired people while using the navigation cane.

Chapter 5 discloses the experimental setup for both obstacle detection and navigation system. The experimental results will be elaborated in order to evaluate the effectiveness of the developed assistive travel aid for both obstacle detection and navigation system. The experiment results will be discussed critically as well.

Chapter 6 presents the conclusions which summarize the content of this study. Besides that, future works that can be done are also given to provide continuous improvement of this study.

Chapter 2

Literature Review

2.1 Overview

Accessibility is one of the main problems which are usually associated with disabled people [9]. Physically impaired people who are using the wheelchair have difficulties of going to their desired destination when they are faced with stairs, irregular roads, etc. The physically impaired people need a flattened surface or lift/ barrier free elevator to overcome the stairs or irregular surfaces. Besides, visually impaired people have problems of accessibility if there is no tactile pavement to guide them to their desired destination. The most significant problem or barrier is lack of infrastructure and safe mobility device for guiding the visual impaired in their everyday lives [10]. Hence, there is an establishment of research to develop and construct the device and infrastructure to guide them to their desired destination safely and without any collision [11].

The implementation of technology into the life of disabled people has the tendencies to intensify their ability in order to have a more involved social life with the community around them. It could increase the quality of life and reduce the isolation problem of disabled people by increasing the independence in their lives [12] – [13]. This type of technology can be called as assistive technology. Assistive technology has various meanings and purposes. As commonly known, assistive technology is a device or tool that can be used for supporting and helping disabled or elderly people. Besides, there are some categories of assistive technologies for different purposes such as rehabilitation, assistive social, etc. Some assistive technologies that are developed to help disabled people are well documented [14] – [17]. However, there are also some ethical issues that need to be considered while designing assistive technologies which could benefit the disabled and elderly people [18] – [21].

In addition, the development of technologies that can help the visually impaired people has also emerged over the decades, which started from the Braille code typewriter to help them write and read. By using Braille, they can understand the recent information around them. Currently, the usage of Braille is not only applied for typewriters, but there are also some research that have been done for implementing the Braille code on mobile phones, etc. [22] – [24]. Thus, visually impaired people could use mobile phones as well as smart phones. Visually impaired and elderly people also need to be in line with the current technology since the fast evolution in the communication era recently. There are also many software or applications inside the smart phone that can be used to help the visually impaired people, although they cannot see them. In addition, applying ubiquitous technologies such as in smart phones can make the visually impaired people understand and 'see' their surroundings [25], [26].

Besides, there are also some assistive technologies which are traditionally used by the visually impaired people such as a white cane, screen reader, etc. The concept of wearable assistive technology has also been drastically researched since the fabrication of a small device is possible now. The development of the wearable device also meets the requirements of the design challenges for assistive technology such as real-time guidance, portability, power limitations, appropriate interface, and continuous availability, no dependence on infrastructure, low-cost solution and minimal training. Therefore, disabled people such as visually impaired people are able to wear it while traveling outside [27] – [30].

In order to start the research endeavors, some literature reviews need to be conducted. This is because the current research needs to be understood first before the direction of the research will be determined. Hence, some research studies have been reviewed, especially in assistive technology and rehabilitation study that aimed to help the visually impaired people to increase their quality of life (QOL) by leading more independent lives. The review process of current research and innovation works has been conducted through a multi-staged and systematical method of literature search by using Scopus search engine including the Web of Science. At the same time, we have also searched some publishers such as Springer, Elsevier, and IEEEXplore. The keywords that have been used on the search engine include assistive technology, visual impairment, wearable, upper body level, obstacle detection, navigation system, etc. At first, there are about 400 research publications found.

However, after reading and filtering the contents of the papers and journals, about 100 research publications have been selected to be reviewed in details. There as some categories of assistive technology that have also been researched to assist the visually impaired people. In this chapter, the research publications that have been selected will be classified into several topics such as obstacle detection and avoidance, navigation system, path finding and path planning, assistive robotics, mobile device assistive technology, etc. Therefore, more details of the study on these categories will be given in order to capture the bigger picture on the system which is researched recently. These categories are discussed in the next section.

2.2 Obstacle detection and avoidance

Conventionally, visually impaired people rely on white canes or guide dogs to assist them in order to reach their desired destination safely. However, the conventional method is beneficial only if the path to the destination is already familiar or known. It becomes difficult if the destination is new, especially where the environment is not designed for visually impaired people. They do not know where to go and cannot recognize their surroundings. It is very hard for them to travel independently without collisions with any obstacle. Additionally, the disadvantage of the white cane is that the obstacles can only be detected by contact. This problem will expose the users to dangerous situations when the visually impaired people are very close to the obstacles. Hence, a lot of research have been actively conducted in regards to supporting devices for the visually impaired people. The machines that have been researched are electric wheel chair [31], Guide-cane [32], NavBelt [33], and electronic guide canes [34], My Second Eye [35], robotic mobility aids [67] and etc.

The main requirements of the travel aid device for the visually impaired people are safety, practicability, portability and convenience. Safety is the basic requirement to judge whether an assistive device is reliable or not. The most important task for the visually impaired people is to gain information on the circumstances of the road and the location of the obstacle. By using the collected information, the deaf-blind people need to arrive at their destinations and avoid unexpected obstacles. Recently, an intelligent white cane has been developed by implementing the infrared sensor in order to detect the obstacle around the user [36] – [38]. However, the developed intelligent white cane cannot directly replace the conventional white cane because the visually impaired people need time to familiarize themselves with the intelligent white cane before replacing the conventional white cane [39], [40].

Moreover, almost all of the travel aids studied are normally used to help the user to detect the obstacles by touching the obstructions directly. Tactile pavement system is one of the many kinds of aids and assisting tools for the visually impaired people. It can be found almost anywhere; near the streets or roadside where there are heavy traffic or pedestrian areas [41]. It is used as travel aids for the visually impaired people to move from places to places, despite being highly inconvenient due to their lack of vision, and thus the presence of danger in the environment could not be sensed. Besides, there is still the need for a lot of training in order to recognize the tactile pattern and it is quite difficult for the new visually impaired people to use for navigation purpose. Based on the importance of the touch sense by visually impaired people, Amemiya et al. have developed the haptic feedback that can be used to alert the visually impaired people in order to navigate them by indicating the direction that needs to be followed [42] – [46].

The meaning of tactile detection using visual method does not mean that the visually impaired have to actually see the tactile to realize its presence. A video/image input device, which could be a camera or a webcam, is representing the visually impaired people to detect the tactile, and the output of this aiding system would be in audio, which is auditory output. This project is developed based on the needs for implementing more advanced method of detecting the tactile pavement and helping the visually impaired as much as possible. In short, the video/image input device is like " another eye " for the visually impaired which will aid them in detecting the types of tactile pavement on the road, and the auditory output system will enlighten the system user about the possible type of the tactile which depends on the detection [47] – [50].

Meanwhile, the usage of camera for obstacle detection and avoidance also has gained a lot of attention by researchers worldwide. Nagarajan et al. have carried out some researches in vision recognition combined with the fuzzy clustering method inside a developed assistive device called NAVI [51] – [52]. On the other hand, Dakopoulos et al. have also implemented the vision method in either obstacle detection or navigation purposes [53] – [56]. However, the requirement of processing speed to analyze the visual information becomes important in order for the vision method to be used in a real environment. In contrast, the usage of visual method by using camera can also be misused by some individuals who use the camera for secret photography. Hence, there are some studies conducted that used the non-visual method [57], [58].

In terms of platform of technology, there are various types of platform that have been developed by researchers to embed the intelligent system to be used by visually impaired people. The generation idea of platform type depends on feedback from the visually impaired people in terms of the availability and comfortability of the user. The platforms that have been developed can be categorized into wearable and mobile type platforms. There are wearable platforms are such as cane [59], [60], hat [61], [62], headgear [63], belt [64], waist-belt, and bracelet [65]. In addition, the mobile type platforms are wheelchair [66], mobile robot [67], portable computer [68], [69] and embedded system [70], [71].

2.3 Navigation system

In terms of navigation system, this is a common problem for visually impaired people since they could not travel by themselves. They could not visually and freely decide the direction which they need to go since the information surrounding them could not be obtained. Therefore, there are some researches and innovation works conducted to support and assist the visually impaired people to achieve self-independence when traveling at an indoor environment as well as outdoor environment. As needed in the navigation system, there are some technologies which need to be included in the system in order for the navigation system to be successfully executed. The technologies which are required include localization, path planning, error detection and correction, etc.

Meanwhile, there are some localization technologies which are focused on by some researchers. The localization technologies including infrared data association (IrDA), Radio Frequency Identification (RFID), Near Field Communication (NFC), Bluetooth, light emitting method, Wi-Fi, etc have been developed to help the visually impaired people to move while indoors with contextual information or sound navigation [8]. However, these methods have some limitations in order to use them at outdoor environments. Therefore, the usage of Global Positioning System (GPS) device can also help to guide the visually impaired people in an outdoor environment. GPS is a satellite based system that provides the location of the GPS device by indicating the longitude and the latitude of the location. Some researchers have proved that the GPS cannot function properly in an indoor space and they have presented the solution of GPS by using IrDA technology which works as a detector to guide visually impaired people in an indoor environment [72].

On the other hand, the Drishti system has been developed by Lisa et al. using combination of GPS and ultrasonic sensors can be used for outdoor and indoor navigation [73]. However, one of the problems with GPS is accuracy where the accuracy of current GPS devices is about 5 m to 10 m. The accuracy can also become worse when the measurement is done near tall buildings [74]. The measurement error is too big and very dangerous to be used by the visually impaired people since the location given by the GPS can guide them to the center of the road.

Furthermore, BLI-NAV is a navigation system designed which consists of GPS receiver and path detector for visually impaired people. Both devices are used to detect user's location and determine the shortest route to the destination. Voice command is given throughout the travel. Path algorithm is used to determine the shortest distance from the start point to end point, together with the path detector. Moreover, the user is able to avoid obstacles while traveling [75]. This system gave better results in real time performance and improved the efficiency of visually impaired travelers at an indoor environment.

On the other hand, Pocket-PC based Electronic Travel Aid (ETA) is proposed to help visually impaired people to travel at an indoor environment. Pocket-PC will alert the user when they are near the obstacles through a warning audio [76]. An ultrasonic navigation device for visually impaired people is designed. The microcontroller built in the device can guide the user in terms of which route should be taken through a speech output. Besides, the device helps to reduce navigation difficulties and has obstacles detection using ultrasounds and vibrators. Ultrasonic range sensor is used to detect surrounding obstacles and electronic compass is used for direction navigation purpose. Stereoscopic sonar system is also used to detect the nearest obstacles and it feeds back to tell the user about the current location [77].

In addition, the Blind Assistant Navigation System that can help visually impaired people navigate independently at an indoor environment has also been developed [78]. The system provides localization by using a wireless mesh network. The server will do the path planning and then communicates using the wireless network with the portable mobile unit. The visually impaired people can give commands and receive the response from the server via audio signals using a headset with a microphone [79]. A proposed RFID technology in order to design the navigation system by providing information about their surroundings has also been developed. The system uses the RFID reader that is mounted on one end of the stick to read the transponder tags that are installed on the tactile pavements [80]. At the same time, the research on RFID network can help to determine the shortest distance from the current location to the destination. Besides that, the system can help to find the way back if they lost their direction and recalculate a new path [81].

In addition, INSIGHT is an indoor navigation system to assist the visually impaired people to travel inside the buildings. The system uses RFID with Bluetooth technology to locate the user inside the buildings. Personal digital assistant (PDA) such as a mobile device is used to interact with the INSIGHT server and provide navigation information through voice commands. The zone that the user has walked on will be monitored by the system. The system will notify the user if the user travels to the wrong direction [82].

2.4 Smartphone based assistive technology

In addition, since the advancement of mobile technology, people have become more reliant on smartphones. Recently, a lot of beneficial functions and sensors are installed inside the smartphone such as GPS device, Wi-Fi, NFC, compass, accelerometer, etc. [83]. Therefore, the growth of application software or " apps " for the smartphone has also rapidly increased and become competitive. Based on the user side, the new functions or applications for the smartphone can be easily upgraded and programmed, even though sometimes, there is no need to add any hardware in order to personalize the applications. Thus, it has become the focus of some researchers and mobile phone application developers since it is the main advantage for conducting research in mobile phone applications compared to developing hardware [84].

One of the mobile applications is the Voice Maps system which is developed by Stepnowski et al. [85]. These mobile applications can be used through the smartphone for navigation purpose from one point to other point. In addition, it also can assist the visually impaired people for independent travel at various places, even in downtown areas. The input interface is by using touch screen and the output to the user can be given through text to speech (TTS). Meanwhile, Akbar et al. have also developed a software for the Android mobile phone that can help the visually impaired people to solve the daily challenges faced by them [84]. The developed software can be used for route plan following, independent shopping, collision avoidance, cross the traffic intersections as well as read letters, envelopes, medicine bottles, food containers, etc. The software only uses input interface which is the mobile phone camera that can analyze the captured image and give auditory output as by using the text-to-speech (TTS) engine.

On the other hand, the usage of public transport such as train or bus is also one of the common problems that are usually faced by visually impaired people. Baudoin et al. have developed a wearable device that can be carried by the visually impaired people when travelling using the public transport [86]. The device can be connected with Wi-Fi and communicate with other devices that have been installed at bus stops. Therefore, the visually impaired people can receive the current information of public transport from the central system. There is also another similar mobile application that has been developed by Felix et al. in order to guide the visually impaired people around the Metro bus system in Mexico [87]. The developed device is a combination of a smartphone that is included with GPS and compass and can communicate through Bluetooth. The input interface of the developed device is by using perceptible interface that helps visually impaired people to search for destinations and receive the relevant information from the Metro bus center.

Similarly, Liu et al. have also developed a mobile application by using the smartphone in order to guide the visually impaired people for independent traveling. Basically, the main part that will be used is the mobile phone camera and the output that will be given to the user by using TTS technology [88]. Besides, Behmer et al. have also designed a mobile application for the Android platform which has multimodal interfacing based on GPS application. The developed mobile phone can be used for navigation purposes and give the awareness on the surroundings condition. The visually impaired user can also explore the normally used point of interest (POI) surrounding them such as the restaurant [89]. Likewise, Song et al. have also designed the software for providing the spatial information for visually impaired people. They have done the experiment by conducting the interview and direct observation on visually impaired people on their walking behavior[90].

Furthermore, Jing Su et al. have developed the Timbremap software for enabling the visually impaired people to explore a complex indoor space [91]. The software is a mapping application that gets the input from touchscreen on the smartphone and the output will be given to the visually impaired people by using auditory feedbacks. The user's finger will be guided on the device touch interface in order to transmit the geometrical information. Besides, there is also a smartphone based application that combines the GPS technology with auditory input and output. By using this application, the visually impaired people can be guided at unknown and known environments [92]. The TTS technology is mainly used in this system in order to set the destination and also receive the information through auditory feedback about the current location and the direction and distance to the desired destination.

2.5 Assistive robotics

On the other hand, assistive robotics are also one of the potential applications of the robotics system which can be used to assist the disabled people such as visually impaired people for solving the mobility issues. Capi et al. have designed and developed a robotic system by including the obstacle detection system, space perception, etc in order to help the visually impaired people [93]. The novel robotic system is the integration of some sensors such as laser range finder (LRF), a camera which includes a notebook which is mounted on the robot. By using the integration of theses sensors and equipment, the robot could detect obstacles like stairs and steps.

Besides, Wolfgang et al. also developed the mobile robot platform which is called as CYCLOPS [94]. CYCLOPS system is remote and controllable and can be used for autonomous navigation purposes where the user can enhance the visual experience through real time image processing. The CYCLOPS can also completely connect with Wi-Fi and digital camera can be used. It can be operated by using a joystick or autonomous self-commanding. Meanwhile, Nicholas et al. proposed a robotic sensing system for partially blind people [95]. The developed robotic sensing system consists of sonars and stereo vision camera to detect the obstacle and space around them. This device can also be portable and wearable for the partially blind people. Some experiments to identify the curbs and stairs have also been conducted.

Besides, the developed robot can be used to recognize human and other objects based on the image that has been captured by camera using the image processing method and pattern recognition method. If the obstructions are detected, a voice warning will be given based on the detected object. However, the involvements of many sensors, GPS device, and rotation camera need to be applied in this system in order to be used in an outdoor environment [96]. In addition, the size of the developed device is huge because of the involvement of many equipment on the system and make the visually impaired people difficult to mobilize by using the system. The capacity of battery that needs to be used inside the system is also high, since the power consumption of the system is high as well.

Moreover, a helper to assist the elder people is necessary to monitor and give support when the elderly people cannot do the house works independently. Since there are increasing numbers of the elder people population in most advanced countries such as Japan, the United States, United Kingdom, etc., the numbers of helpers are inadequate to meet the population of elderly people. Hence, the research on mobile robots that can be applied in health care system, especially for elderly care, has also been conducted [97], [98]. This category of research can also be used as therapy for the elderly people while reducing their loneliness symptoms. Besides, it can also provide a virtual interface in order to monitor the activities of elderly people and communicate remotely through a small amount of supervisors. However, some ethical issues are concerned in terms of freedom of elderly people. The dignity and human rights of elderly people are also one of the ethical issues that have been questioned. However, ethical issues are not included in the scope of this research study.

2.6 Summary

In this chapter, some research papers based on proceedings and journals have been reviewed. The advantages and disadvantages of some developed assistive technologies have been recognized in order to develop the novel and applicable assistive travel aid for the visually impaired people based on the scope that has been set such as navigation system including path planning system, obstacle detection, and obstacle avoidance system. By designing and developing the new assistive travel device, it can expand visually impaired people's ability to join social activities independently and at the same time increase their quality of life.

Research topics	Author/Developer	Main components			Platform	Tasks
		Input	Output	Comm. module		
Electric wheel chair	Hara, M., Yasuno, T. and Harada, H. (2008)	Ultrasonic sensor	Vibrator	Direct	Wheelchair	Obstacle detection and avoidance
Navbelt	S. Shoval, I. Ulrich, and J. Borenstein (2013)	Ultrasonic sensor	Vibrator	Direct	Belt	Obstacle detection and avoidance
My 2nd Eye	Kassim, A. M., Jamaluddin, M.H., Yaacob, M.R.,(2011)	Ultrasonic sensor	Vibrator	Direct	Cane	Obstacle detection and avoidance
Smartcane	Sung Yeon Kim and Kwangsu Cho (2013)	Ultrasonic sensor	Vibrator	Direct	Cane	Obstacle detection and avoidance
Blind guidance sys.	Amjed S. Al-Fahoum, Heba B. Al-Hmoud, et al. (2013)	Infrared sensor	Auditory	Direct	Hat	Obstacle detection and avoidance
Robotic mobility aids	C. Jacquet, Y. Bellik, Y. Bourd, et al. (2006)	Laser telemeter	Auditory	GPS,WiFi	Mobile robot	Obstacle detection and avoidance, indoor navigation system
SmartVision system	Jose J, Farrajota M, Rodrigues JMF, et al (2011)	Stereo camera	Auditory	GPS, Active RFID	Portable computer	Obstacle detection and avoidance, indoor navigation system
SoundView	Min Nie, Jie Ren, Zhengjun Li , et al. (2009)	CCD camera	Auditory	Direct	Embedded system	Obstacle detection and avoidance
NAVI	G. Sainarayanan, R. Nagarajan, and S. Yaacob, (2007)	CCD camera	Auditory	Direct	Headgear	Obstacle detection and avoidance, indoor navigation system
Walking aid system	Min, Seonghee; Jung, Yunjae; Oh, Yoosoo (2015)	Ultrasonic sensor	Haptic feedback	IoT using Zigbee	Cane	Obstacle detection and avoidance, indoor navigation system
Smart Blind	Maher M. Abd El- Aziz, Wael M. Khalifa (2015)	Ultrasonic sensor	Auditory	GPS, GSM	Hat, Mini hand stick	Obstacle detection and avoidance, indoor navigation system
Assisted guidance	Filipe, V., Faria, N., Paredes De, H., et al. (2016)	Kinect sensor, wall-mounted markers	Auditory	Direct, GIS data	Embedded system	Obstacle detection and avoidance, indoor navigation system
Air navigation	Tapu, R., Mocanu, B., Zaharia, T.(2017)	Camera	Auditory	Smart-phone	Portable computer	Indoor navigation system, Space perception
Indoor positioning	Guerrero, L.A., Vasquez, F.· Ochoa, S.F, (2012)	Infrared camera, Wiimote	Auditory	WiFi	SmartphoneCane	Indoor navigation system
Electronic bracelet	Bhatlawande, S., Sunkari, A., Mahadevappa, M.(2014)	A camera and an ultrasonic sensor	Auditory	Direct	Waist-belt and bracelet	Obstacle detection and avoidance
CrowdSensing	Hao Ji., Lei Xie, Chuyu Wang, et al. (2015)	Passive RFID tag	Auditory	Direct	Embedded system	Indoor navigation system
RoboCart	Kulyukin V, Gharpure C, Nicholson J.(2005)	RFID, Barcode, LRF, Odometer	Locomotor , Haptic	Bluetooth	Mobile robot	Independent shopping, robot assisted navigation
Shop Mobile 2	Aliasgar Kutiyanawala, Vladimir Kulyukin, (2014)	Camera	Haptic feedback	WiFi, 3G	Smartphone,	Mobile based independent shopping
PARO	National Institute of Advanced Industrial Science and Technology (AIST),Japan (2007)	Touch sensor, infrared sensor, stereoscopic vision	Actuators	Not mobile robot	Robot	Robot therapy for elderly people
Mobile manipulator	Deegan P, Grupen R, Hanson A (2008)	Camera sensors, mobile interface	Mobile robot	WiFi Remote	Robot	Robot therapy for elderly people

Figure 2.1: Summary of literature review

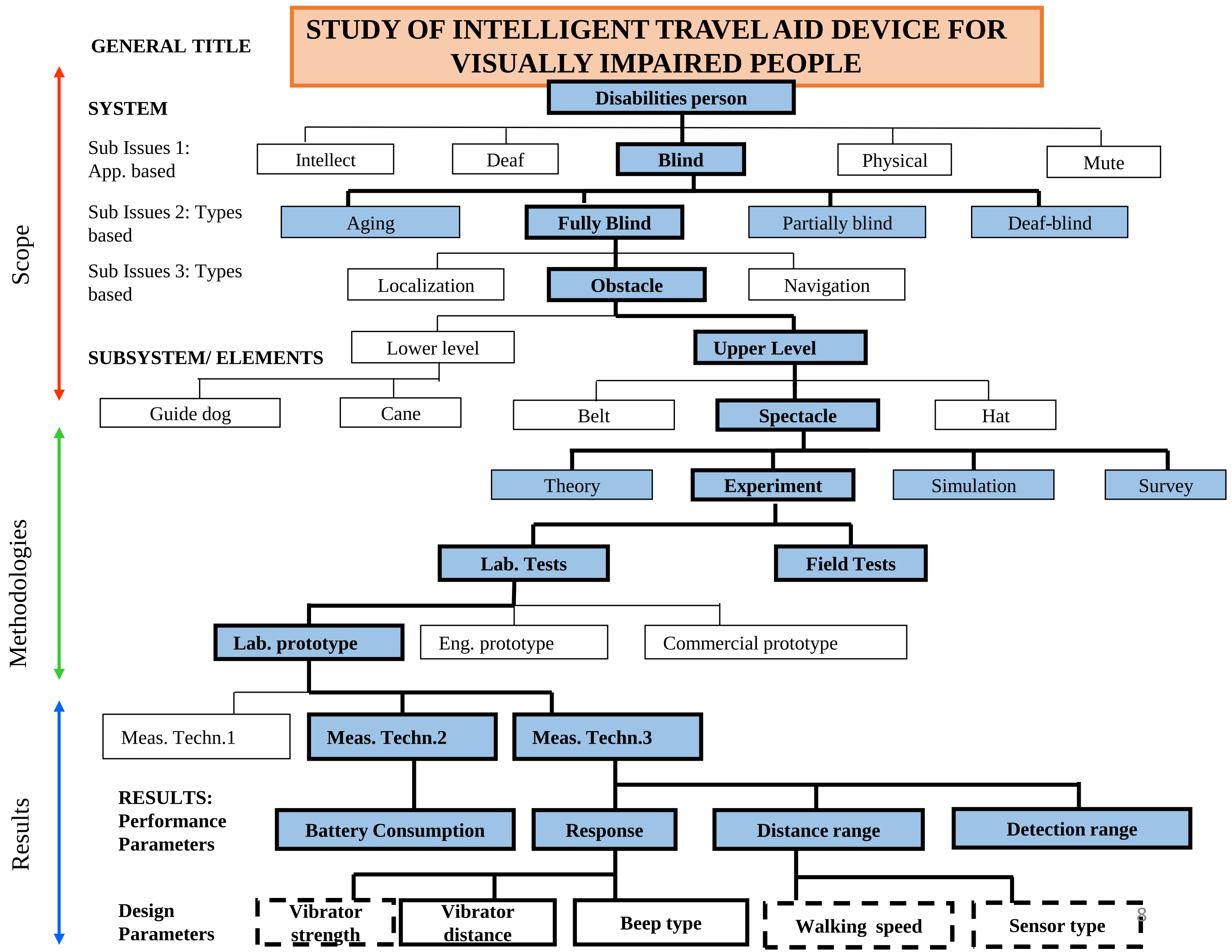


Figure 2.2: Knowledge chart for summarized travel aid device

Chapter 3

Development of Electronic Spectacle

3.1 Overview

Earlier in Chapter 2, the current research including the research problem has been discussed. In this chapter, the research methodology employed in the research such as the design and development of obstacle detection method in order to reduce the collision of obstruction at the upper body level will be discussed in detail. Since the development of a new approach of obstacle detection system for the upper body level, previous works will also be disclosed. Then, the design, development and fabrication method of the intelligent spectacles including the system configuration, sensor and component selection, detection angle, and detection range will be explained. In addition, the warning method in order to alert the user which is visually impaired people will also be designed and developed. Besides, the CAD design based on the components which have been selected also described in this chapter.

3.2 Previous works

Previously, the development of a travel aid device to assist visually impaired persons to travel alone has been conducted [35]. This study is based on statistical studies by the World Health Organization (WHO) statistics and a collaboration study with the Society of Blind Malaysia (SBM) including Malaysian Association for the Blind (MAB) regarding the major problems faced by visually impaired persons in Malaysia. From the interview session, the visually impaired people normally face difficulties when they travel alone without any guidance by helpers or guide dogs. The basic problems that are always faced are obstacle detection and avoidance in order to travel and reach a destination safely. Severe accident and injury can be caused by accidental fall and collision with obstacles.

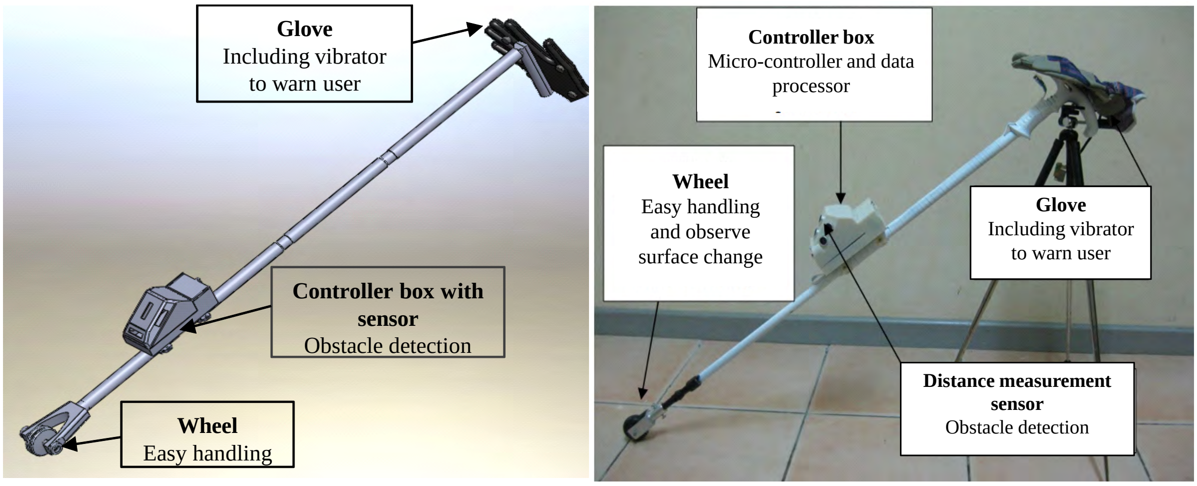
Therefore, some concepts need to be understood and fulfilled in order to design and develop the travel aid suitable for the visually impaired persons. The technology requirements that need to be fulfilled include real time guidance, portability, power limitation, appropriate interface, continuous availability, no dependence on infrastructure, low cost solution and minimal training [99]. By fulfilling these entire requirements, the visually impaired people can travel independently without depending on human or guide dogs and the accidental rate can be reduced.

In the brainstorming stage, an electronic device that can detect an obstacle existing around the user using non-contact approach is proposed. Thus, the design of an electronic device using distance measurement sensors in order to detect the obstacle is done. It is different from the conventional white cane, which needs to touch an obstacle in order to recognize the obstacle and its location. The proposed electronic white cane which is designed by using SOLIDWORKS is shown in Fig. 3.1(a), while the developed and fabricated electronic white cane is shown in Fig. 3.1(b).

After the first prototype is developed, some discussions and interviews with 30 participants who are visually impaired and partially blind from SBM and MAB are done in order to verify and obtain some feedbacks based on the perspective of visually impaired persons. Numerous feedbacks are received from the discussion. Some of the main feedbacks are classified into a SWOT analysis table. Figure 3.2 shows the customer analysis based on the SWOT analysis concept, which concludes the user's feedback. Then, the idea selection is finalized by changing the idea from electronic white cane to electronic spectacles, as there is no device or tool to detect obstacles in the upper body level for visually impaired persons after the feedbacks are concluded.

Hence, the development of a new travel aid device is conducted, which started by designing a spectacles type obstacle detection system for the upper body level. The concept of obstacle detection system using spectacles is triggered through some observations on the visually impaired, as they always wear black spectacles while traveling in order to protect their eyes from hitting an obstacle directly. By applying the distance measurement sensor inside the spectacles, they can avoid from hitting the obstacle.

The first prototype, which has been designed and developed based on the electronic spectacles concept, is elaborated in the next section.



(a) Designed electronic white cane (b) Developed electronic white cane

Figure 3.1: Designed and developed electronic white cane

<u>Strength</u> New technology using sensor application and vibrator. Non-contact approach. Easy to identify obstacle using vibrator. No need to swing cane. Low cost product.	<u>Weakness</u> Need to wear glove. Quite weight. Not easy to carry when unused. Not waterproof.
<u>Opportunity</u> White cane only cover for lower body level. No protection for upper body level. Currently not many competitors.	<u>Threat</u> Easy to copy. Niche market.

Figure 3.2: Target user feedbacks using SWOT analysis

3.3 Design concept of upper body level obstacle detection

In order to design and develop the proposed obstacle detection system for detecting the obstacles at upper body level of the visually impaired people, there are many methods which can be used as product development process. Here, the product development process which is focused on includes the method that has been proposed by Fujikawa et al., [100]. Fujikawa et al. has approached a new product development (NPD) which is illustrated in Figure 3.3.

Here, the new product development process is started from product planning including the idea generation through brainstorming process. By using this method, the needs of customer will be assumed and designed. In our product development process, we also conducted same process by brainstorming and listing assumptions of the visually impaired people's needs. At the first step of our product development process, we assumed that the visually impaired people are having problem by using white cane which needs to touch the obstacles in order to know the location of obstacles.

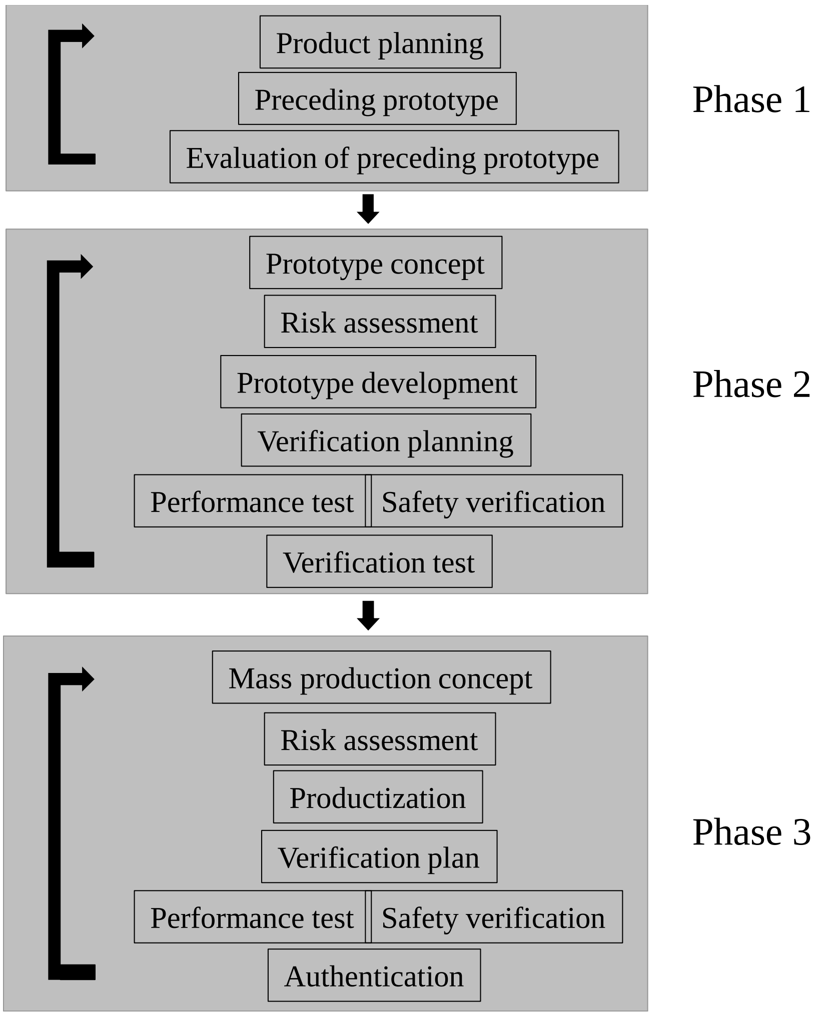


Figure 3.3: Flowchart of new product developments with safety verification

Then, the development of a preceding prototype to realize the idea is conducted based on the idea generation process. The evaluation of preceding prototype as an idea screening process by conducting discussion with the target customer which is the Society of Blind Malaysia in order to get some information and feedbacks is also conducted to confirm the needs of the target customer. The idea development and evaluation of obstacle detection system for upper body level of visually impaired people are conducted.

Then, after we have done the evaluation and observation on the visually impaired people, the information is synthesized from the observation of potential market where the visually impaired people are always faced with some big problems when they want to travel alone without any guidance by helpers or guide dogs. The basic problems which are always faced include obstacle detection and avoidance in order to travel and reach the destination safely. Almost all of the visually impaired people are using white canes and guide dogs in order to travel independently. The visually impaired people do not have any device or tool to detect the obstacle which existed at the upper body level, which is one of the conclusions made from the discussion.

After the idea of an obstacle detection system to detect upper body level obstacle received good feedback and fulfill the need of the visually impaired people, the prototype concept to design the device is decided. Some of prototype concepts such as goggles, hat, pendant, and spectacles are proposed. From the proposed concept, the design using the spectacles concept made the most sense through some observations of visually impaired people who are always wearing black spectacles while travelling in order to protect their eyes from hitting obstacles directly. By applying the distance measurement sensor inside the spectacles, they can avoid from hitting the obstacle. This approach by using non-contact approaches is different from the concept of white cane which needs to touch the obstacle in order to detect the obstacle.

Besides, the risk assessment by using the spectacles concept in the design is also conducted to check and confirm that there will be no risk by using the concept in terms of intellectual property and user safety. Once the risk and the concept are confirmed and determined, the prototype design and development will be conducted. There are some prototype design software proposed such as SOLIDWORKS, IronCAD, AutoCAD, etc. Since SOLIDWORKS software is commonly used inside our research lab, the prototype design will be conducted by using it. The designed prototype can also be easily fabricated by using a 3D printer or Rapid Prototyping Machine (RPM).

Then, the prototype which has been fabricated will be integrated with the electronic parts which have been decided. After the overall system has been constructed, the firmware or coding will be inserted into the ROM of the microcontroller. Next, the verification test which needs to be conducted will be planned such as functionality of the system. Then, if the prototype is functional, further evaluation process including device performance test and safety verification will be done such as detection range of the distance measurement sensor, effectiveness of warning signal consisting of vibration and audio warning signal, battery level indicator and user-friendliness through experiment and survey. All the experimental result will be concluded and improvement of the concept and design will be decided.

And finally, the design improvement will be conducted and implementation of design changes will be done. After the design changes have been done, the new prototype will be fabricated and tested again until the design is optimized in terms of functionality, durability, usability, effectiveness. If one of the processes is not functional as per the specification, the process will be repeated from the prototype concept. If the verification test is conducted successfully, the mass production stage will be transferred. At this stage, the knowledge transfer process will also be done in order to implement to target user which are visually impaired people.

3.4 Development of upper body level obstacle detection

3.4.1 System configuration

The proposed electronic spectacles are designed like sunglasses since visually impaired persons usually wear them when traveling outside in order to give comfort to the users. This idea has been collected by a lot of visually impaired people which are tested during prototype development by taking some considerations through previously designed intelligent canes that detect obstructions only for the lower abdomen level. The proposed electronic spectacles will protect the above abdomen body such as head level before injury due collision with obstruction. However, there are two types of designs which have been proposed and developed which are full direction spectacles and simplified spectacles. System configuration for both designs is described such as follows.

Full direction design

Figure 3.4 shows the overall system construction considered to be used in the design of electronic spectacles. All these electronic components need to be included inside the spectacles. The electronic components used are microcontroller, distance measurement sensors, voice module, rechargeable battery, headphone, vibrator and wireless module. A microcontroller functions as a head of the system that contains memory and program which is used to communicate with other hardware. In addition, there are two types of warning system which are vibration warning system and audio warning system included inside the overall system since the visually impaired people are very sensitive through tactile and hearing senses. Four pieces of vibrators and a single headphone are used. The warning signal strength is generated by using Pulse Width Modulation (PWM) which is given to the user based on distance of obstacle to the device which is measured by a distance measurement sensor.

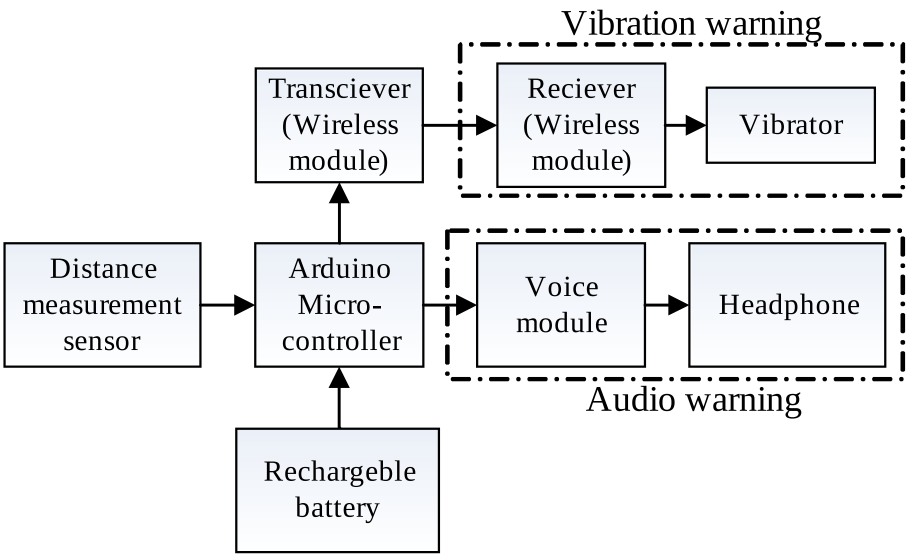


Figure 3.4: System overview of developed electronic spectacle

Furthermore, four pieces of distance measurement sensors which need to be used inside the electronic spectacles to detect obstacle for the directions of forward, right, and left and down side are applied. Each direction responds to each vibrator that has been installed. The data from the distance measurement sensor measured will be transmitted and processed inside the microcontroller. If the measured data for each distance measurement sensor is more than the threshold that has been set, the vibrator and single headphone will not be activated. If the captured data is fewer or equal to the threshold that has been set, the vibrator and single headphone will be activated through the microcontroller and generate the vibration. Meanwhile, the power source of electronic spectacles is supplied by using a rechargeable battery that is easily rechargeable and replaceable while traveling to an outside environment.

Simplified design

Figure 3.5 shows the overall system configuration of the developed electronic spectacles. There are some electronic components selected and needed to be used inside the system such as AVR microcontroller chip as the main processing unit, ultrasonic sensors as distance measurement input, Li-Ion battery inside the power bank as rechargeable battery, single headphone, vibrator and some LEDs as warning devices. These electronic components are selected based on the component features and specifications by comparing different types of components by using a pair wise comparison table and the weightage of the features [39].

All these electronic components will be included inside the frame of electronic spectacles except for the power bank since it will be mounted separately from the electronic spectacles. This is because the developed electronic spectacles will be too heavy if the power bank is included in the frame of the electronic spectacles. In addition, the power bank can also be easily recharged and changed if the battery capacity has become zero. After the determination of electronic parts and detection range and angle which will be adapted inside the electronic spectacles, the process of sketching and development of the proposed electronic spectacles type device for visually impaired people are conducted.

Each part that has been selected will be designed by using the SOLIDWORKS software. The designed parts are based on actual size of the components in order to fabricate and assemble the designed part easily inside the developed electronic spectacles. If each selected part is designed completely, all mechanical parts which need to

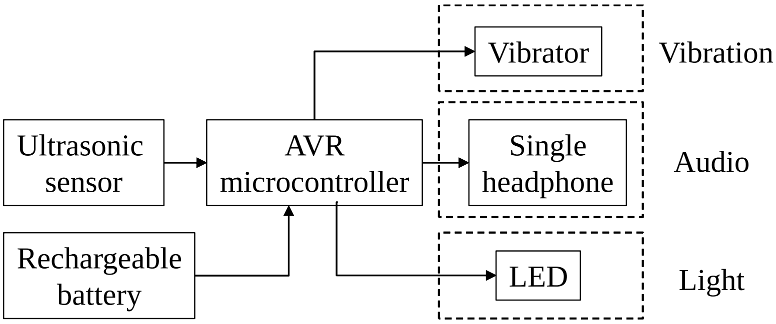


Figure 3.5: System configuration of new developed electronic spectacle

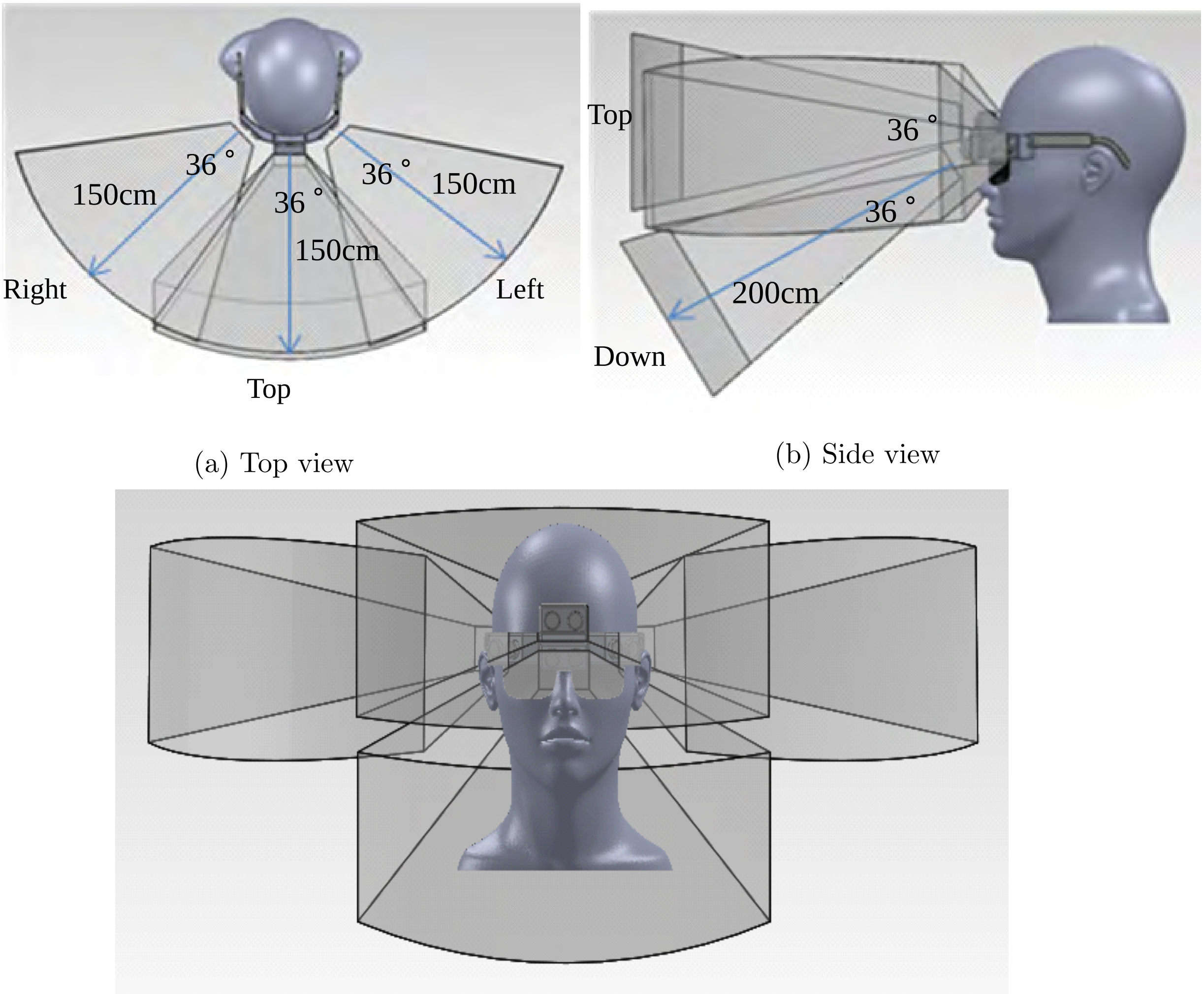
be fabricated such as spectacles cover, handle, etc. will be developed by using a 3D printer or Rapid Prototyping Machine (RPM). Then, firmware will be inserted into the microcontroller and basic testing will be conducted such as functionality of the system. If the prototype is functional, further evaluation process will be done such as detection range and effectiveness of the warning signal, especially the vibration warning signal.

3.4.2 Detection range and system flowchart

Full-direction design

The proposed directional angle and areas for mounting the distance measurement sensor inside the spectacles are illustrated in Figs. 3.6(a) and 3.6(c). The safety zone threshold for each distance measurement sensor is decided based on human walking speed, which is 4 km/h $\approx$ 1 m/s. Thus, the threshold or limit is 1.5 m in order to ensure safety for the visually impaired while using the electronic spectacles. In addition, the threshold or limit needs to be more than 1 m based on previous results and surveys [40]. Hence, the alert system is used to warn the user when the distance between the user and the object is 1.5 m.

Furthermore, the usage of left and right sensors can also be optimized by the visually impaired such as a wall following robot where the visually impaired people can follow the wall at the right or left side of the user to reach the desired destination. From Fig. 3.6(c), the down sensor is designed to deviate downward 30 deg. from the spectacle horizontal line. The down sensor angle is set for detecting obstacles above the abdomen. The obstacle range that can be sensed by the front sensor is at 1.5 m away. Obstacles



(a) Top view

(b) Side view

(c) Front view

Figure 3.6: Detection range and angle for full direction

in the range of 0.85 m below the head level until the abdomen level can be detected, while obstacles below 0.85 m from the head level are detected using the white cane. This is assumed for visually impaired people with an average height of 1.7 m. The trigonometrical method which is applied for detection angle calculation is shown in Eq. (3.1).

$$\theta = \tan^{-1}\frac{\text{Opposite}}{\text{Adjacent}} = \tan^{-1}\frac{\text{Height of head to abdomen level}}{\text{Distance of obstacle to front sensor}} \tag{3.1}$$

$$\theta = \tan^{-1}\frac{85}{150} = 29.5^\circ \approx 30^\circ \tag{3.2}$$

The system flowchart of the warning mechanism is shown in Fig. 3.7, whereby each warning device will be activated when the distance between the obstacle and the user is less than the threshold. The threshold of each distance measurement sensor is set at 1.5 m for the top, right and left directions.

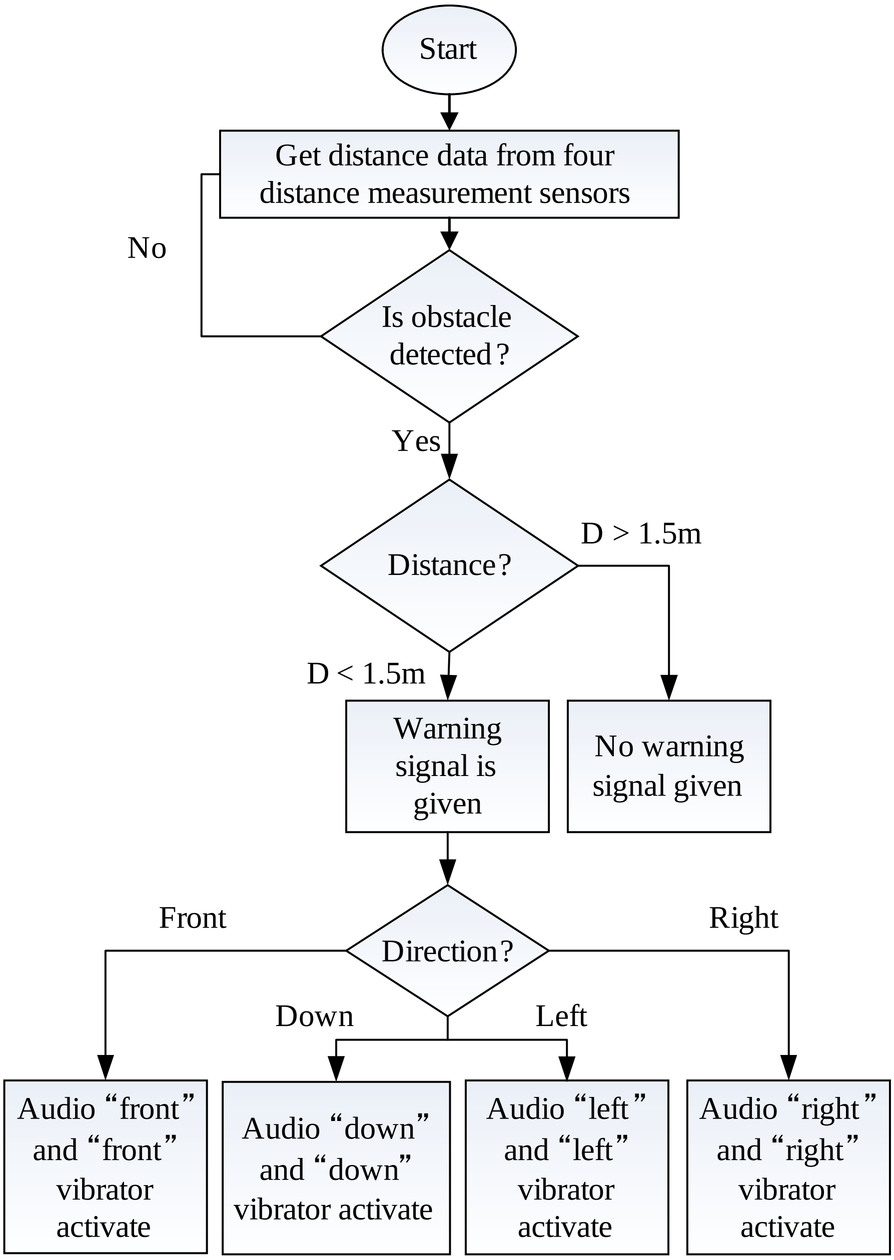


Figure 3.7: System flowchart for full-direction design

Meanwhile, the threshold of the distance measurement sensor for the down direction is set at 2.0 m based on the calculation using the trigonometric function. At the same time, the type of obstacles can be recognized using the collaboration between the top and down sensors. For example, an obstacle such as a wall or a big obstacle will be identified by both the top and down sensors at the same time. An obstacle is perhaps identified as a floating object, such as tree branches or the rear of a truck, only if the top sensor observes the obstacle. Moreover, an obstacle is identified possibly as a small object on the ground, such as rock or table, only if the down sensor spots the obstacle.

Simplified design

Meanwhile, in order to improve the disadvantages of electronic spectacles for a full direction design, the calculation of effective detection angle and range for simplified electronic spectacles only consist of two pieces ultrasonic sensor. The range determination of the proposed simplified design of electronic spectacles is illustrated in Fig. 3.8. The threshold of safety zone of each distance measurement sensor is decided based on the calculation of human walking speed which is approximately 1 m/s. Thus, the threshold or limitation decided is 1.5 m in order to give safety zone to the visually impaired people while using the electronic spectacles. Hence, the alert system will be used to warn the users of the distance between them and the object at 1.5 m for each sensor.

In addition, the angle determination for both ultrasonic sensors is also important to ensure the effectiveness of detection for upper body level obstruction. Figure 3.9 shows the angle determination for the proposed simplified electronic spectacles through the top view. Besides, some calculations which are involved are based on Eqs. (3.3) and (3.4),

$$\theta_1 + \theta_2 + \theta_3 = 180 \text{ deg.} \tag{3.3}$$

$$\tan\theta_1 = \frac{B}{A/2} \tag{3.4}$$

which θ_1 indicates the degree of combination of both sensor's beam which could be calculated from Eq. (3.4). A indicates distance between both sensors. B indicates the blind spot distance. Besides that, θ_2 indicates the half of sensor beam angle which is

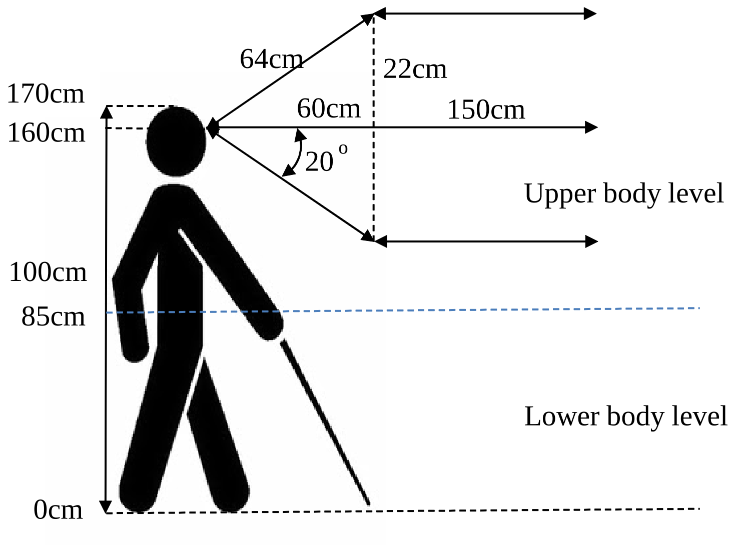


Figure 3.8: Range determination

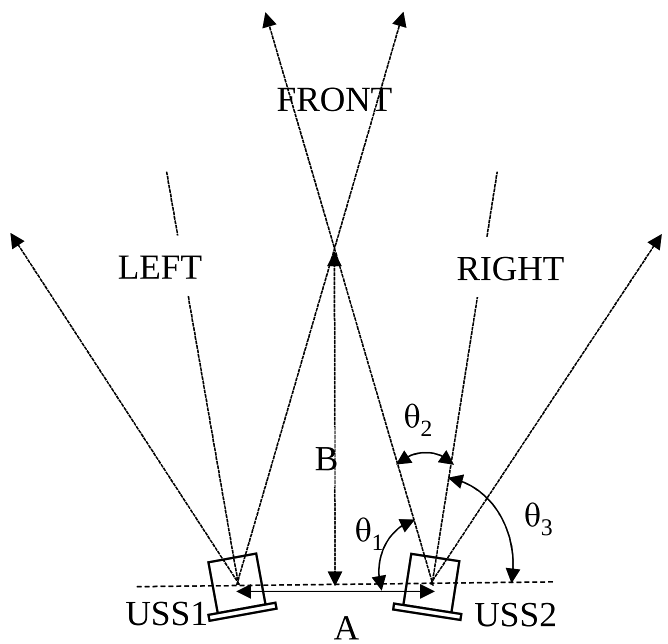
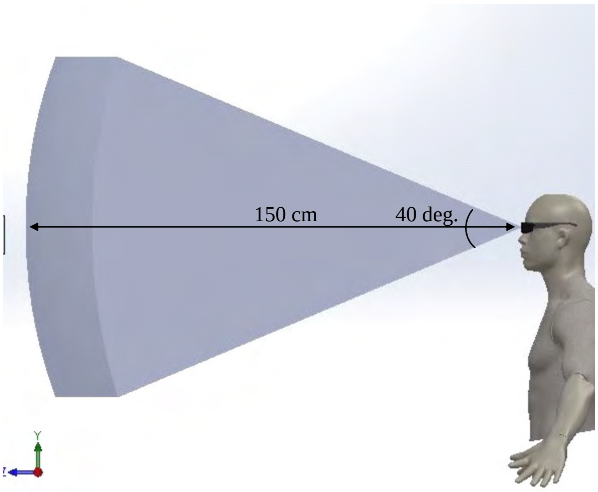
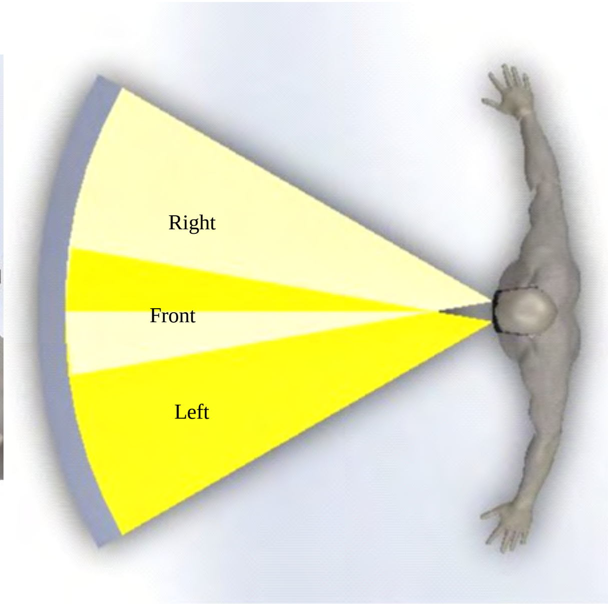


Figure 3.9: Angle determination



(a) Side view



(b) Top view

Figure 3.10: Detection range and angle for simplified design

20 deg, while θ_3 indicates the inclination angle of sensor from the front line that could be determined and implemented in the SOLIDWORKS design.

Some design simulations will be conducted through SOLIDWORKS to determine the optimized values of A, B and θ_3. Furthermore, Figs. 3.10(a) and 3.10(b) show the coverage of installed sensor at the side and top views. From the calculation, the sensor beam range could cover from head to chest. Both right and left ultrasonic sensors will detect for the front side. Meanwhile, the coverage for travel safety width can also be calculated since the average adult shoulder size is around 0.46 m. Since a down sensor is not provided, the down area could be protected by using a white cane which needs to be used along with the proposed electronic spectacles based on this proposed detected angle and range.

3.4.3 Sensor and electronic component selection

Distance measurement sensor

All of the electronic components need to be selected wisely in order to develop a user-friendly, reliable and mobile travel aid device for the visually impaired. First, the selection of the distance measurement sensor, which is a key technology used in the system, is done. Regarding the types of distance measurement sensor, three types of sensor are compared in order to select the best sensor for the system. Some studies have also been done to evaluate the performance of different distance measurement sensors in order to detect objects of different materials [101]. The selection of sensor depended on its features such as measurement range, accuracy, cost, weight, size and energy consumption. The distance measurement sensors which are compared include ultrasonic sensor, infrared sensor and laser range finder.

The ultrasonic sensor is commonly applied in many applications since it functions by transmitting an ultrasonic sound through a transmitter and measures the required time for the sound to return to the receiver. One of the applications is the car parking sensor system, where the ultrasonic sensor is mounted on each edge of a car bumper to protect the body of the car from colliding with obstacles [102]. The infrared sensor is a combination of signal processor, location sensitive gauge and laser emitting diode. The laser is transmitted and reflected when it hits an obstacle. In case of no object, the light will not be reflected. The usage of infrared sensor is quite limited since it is easily affected by other light sources. Few studies on object reflectivity have related the color of the object and the adoption of the triangulation method [103].

On the other hand, the laser range finder is a type of optical distance sensor by using light (laser). The laser range finder scanned the surrounding to measure the distance for object detection in two-dimensions. All types of distance measurement sensors with their specifications are listed in Table 3.1. From Table 3.1, a comparison is made and the weightage for each sensor specification is shown in a pair-wise comparison table in Table 3.2. By using the pair-wise comparison table, the weightage of each feature is determined using Eq. (4.5).

$$\mathrm{Weightage(w)} = \frac{\mathrm{Votes(v)}}{\mathrm{Total\ votes(T_v)}} \tag{3.5}$$

For the distance measurement sensor, accuracy (A) and range (B) had the highest weightage, while cost (E) had the lowest weightage to determine the best sensor to be used. Based on the weightage of each feature, the specification of each sensor is compared and the point is given, as shown in the weighted objective table in Table 3.2. If the specification of the sensor was the best, three points are given, while if the specification of the sensor was the lowest, one point is given. After comparing all features, the total scores are calculated in order to select the best distance measurement

Table 3.1: Comparison of sensors and specifications

Sensor type.		Ultrasonic sensor	Infrared sensor	Laser range finder
Model no.		MB1003	GP2Y0A21YK	URG-04LX
Figure				
Manufacturer		MAXBOTIX	SHARP	HOKUYO
Supply voltage	VDC	2.5 to 5.5	4.5 to 5.5	5
Range	cm	15 to 645	10 to 80	2 - 400
Supply current	mA	2	33	500
Weight	g	4.3	5	160
Size (L x W x H)	mm	20 x 22 x 15	29.5 x 13 x 13.5	50 x 50 x 70
Volume	mm^3	6,600	5,177.3	175,000
Price	USD	20 to 40	15 to 30	1000 to 1500

Table 3.2: Pair wise comparison table

Features		A	B	C	D	E	F	Votes (v)	Weightage (w)
Accuracy	A	-	B	A	A	A	A	4	0.267
Range	B	-	-	B	B	B	F	4	0.267
Size	C	-	-	-	D	C	C	2	0.133
Weight	D	-	-	-	-	D	F	2	0.133
Cost	E	-	-	-	-	-	E	1	0.067
Energy consumption	F	-	-	-	-	-	-	2	0.133
Total votes (T_v)								15	1.000

sensor based on the algorithm in Eq. (4.6). Finally, the best distance measurement sensor is chosen by referring to the highest total score based on the weighted objective table, as shown in Table 3.3. For this project, the ultrasonic sensor is chosen because it acquired the highest point compared to other shortlisted sensors and is used in this application.

Table 3.3: Weighted objective table

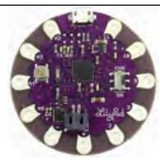
Features		Weightage (w)	Ultrasonic sensor score (s)	Infrared sensor score (s)	Laser range finder score (s)
Accuracy	A	0.267	2	1	3
Range	B	0.267	3	1	2
Size	C	0.133	3	2	1
Weight	D	0.133	3	2	1
Cost	E	0.067	2	2	1
Energy consumption	F	0.133	3	2	1
Total score (T_s)			2.666	1.466	1.801

$$\text{Total score}(T_s) = \sum \text{Score}(s) \cdot \text{Weightage}(w) \tag{3.6}$$

Microcontroller

The selection of microcontroller is important and is based on having a compact size, light in weight, fast processing time and sufficient input/output (I/O) ports to develop the obstacle detection and warning device. Few microcontrollers are considered for the system such as AVR microcontroller and PIC microcontroller, which are easy to be programmed. In recent years, the Arduino platform, which uses AVR microcontroller, is broadly used in the embedded system. The Arduino platform with its specification is shortlisted for selection as shown in Table 3.4. From the shortlisted boards, Arduino Pro mini is selected because of its small size based on the volume calculation as shown in Table 3.4. In addition, Arduino Pro mini is also light in weight and has enough I/O pin for the application, which uses four pieces of ultrasonic sensor to be mounted on the analog input. Besides, since the clock speed and memory are the same for all boards, they are not considered for the selection.

Table 3.4: Arduino board comparison and specifications

Model		GEMMA	Promini	LilyPad
Figure				
Microcontroller		ATtiny85	ATmega32u4	ATmega328
Operating voltage	VDC	3.3	3.3	3.3
Digital I/O pin	num	3	14	9
Analog input	num	1	6	4
DC current / pin	mA	20	40	40
Clock speed	MHz	8	8	8
Flash memory	kB	8	32	32
Weight	g	2	2	5
Size	mm	28 x 6.5 (D x H)	33 x 18 x 2 (L x W x H)	36 x 6.5 (D x H)
Price	USD	10	10	25

Power supply/ battery

In addition, the type of battery including battery capacity, light-weight and compact size are considered for power supply. In this project, three types of battery are considered, namely Lithium-ion (Li-ion) battery, Lithium Polymer (Li- Po) and Li- ion battery which is inside an external battery package. All batteries are selected based on the same capacity, which is about 2200 mAh. Table 3.5 shows a comparison and the specification of the rechargeable battery that would be selected. If the battery capacity increases, the battery size also increases and longer lifetime can be provided. On the other hand, the volume of each rechargeable battery is also considered in order to select the best rechargeable battery for the system. In terms of battery weight, the Lithium-ion battery was the lowest, but it did not include the recharging circuit compared to the Li-ion battery in an external battery package.

Therefore, since the Lithium-ion (Li-ion) battery and Lithium Polymer (Li-Po) battery were without chargers and had incompatible input voltage with the microcontroller and ultrasonic sensor, Li-ion or external battery would be the best rechargeable battery for the system. If the battery is depleted of power, it can be easily recharged using a USB-connected charge system such as from a personal computer or any USB

Table 3.5: Rechargeable battery comparison and specifications

Figure				
Manufacturer		TRUSTFIRE	TURNIGY	OEM
Charging mode		Li-Ion Charger	Li-Po Charger	USB charger
Output current	A	5.2	44	0.8
Capacity	mAh	2600	2200	2600
Input voltage	VDC	3.7	11.1	5
Output voltage	VDC	4.2	5.3	5.3
Weight	g	46.5	185	57
Size	mm	18.6 × 65.2 (D x H)	103 x 33 x 24	97 x 25 x 22
Price	USD	10	22	6

connector. Furthermore, it can also be replaced easily with other external battery if the battery capacity decreased and the cost of unit is low with stable performance.

Miscellaneous/ Other peripherals

On the other hand, other peripherals such as switch, small electronic parts, volume adjuster (potentiometer), headphone, etc. will also be selected. However, since these components are small and easy to mount inside the frame of spectacles, they will not be described in details.

3.4.4 Obstacle warning system

The obstacle warning system is an important function that needs to be included inside the electronic spectacles in order to alert the visually impaired people. This is because the visually impaired people need an effective method to alert them since they cannot see and sense well. Hence, there are some effective methods to alert them which are proposed inside the overall system which will be described. Since the visually impaired people are excellent on the hearing and touch senses, the warning methods which are proposed will be consisted of both sensing methods such as audio warning, beep warning, and vibration warning. Besides, the light warning such as LED to assist and guide the partially blind or low vision people can also be applied. The details of these warning systems will be explained in this subsection.

1. Audio warning system

   The first warning system which is proposed is the audio warning system. Some recorded voices such as FRONT, DOWN, LEFT and RIGHT will be saved inside a micro SD card which will be inserted inside the voice module, WTV-020. The recorded voice will be used to give the direction of obstacle when detected by the ultrasonic sensor. These recorded voices will be played and given to the user directly through a single headphone. Therefore, the user or visually impaired people can easily know the obstacle and recognize the surrounding. They can avoid the obstacle easily and not collide with the obstacle. Figure 3.11 shows the voice module which is manufactured by Guangzhou Waytronic Technology. The features of the voice module are as follows:-

Figure 3.11: Voice module(WTV-020)

   - Support 1GB SD card max. or SPI flash 64MB max.
   - Working voltage: DC2.7～3.5V
   - Quiescent current: 3uA
   - 16 Bit DAC / PWM audio output.
   - Sampling rate from 6kHZ to 36KHZ for AD4 voice format.
   - Sampling rate from 6KHz～16KHz for WAV voice format

2. Beep warning system

   In addition, the audio warning signal has also been included in the wireless warning device. The beep sound will be given to the users in order to inform them about the danger surrounding them before they collide with the obstruction after it is detected. The beep signal is generated at the same time when the vibration warning is generated. The audio warning signal is applied as an optional method in order to ease the users to differentiate the location of the obstruction. The users will distinguish the location of the obstruction, either at front or to the right or left side of them. The beep frequencies which have been set are 1200 Hz for the front, 700 Hz for the right side and 300 Hz for the left side. The microcontroller is used to generate different tones such as DO, RE, MI and FA tone signals by using the setting of frequency in the program. The tone signals generated are applied in order to differentiate the direction of obstruction for front, down, left and right. It makes the user easy to access and know that the obstructions are located. For visually impaired people, the tone signal will be given through the right earphone. The other ear will be used for other purposes such recognizing the surrounding places.

However, the users do not know whether the obstructions are already near or still far. Therefore, the warning beep tone signal is given and the intensity of it will increase if the obstructions become closer to the users and they will be able to avoid them effectively. The beep strength can also be adjusted by using an adjustable resistor. In order to indicate the battery level which is very important to the users before using the developed electronic spectacles, the battery level indicator will be given to the users at three stages which are 100% , 70% , and 30% . It is used for them to prepare a new battery or recharge the battery before they used it. The battery level indicator will be given directly after the device is switched ON by using a beep signal such as 100% : 3 beeps, 70% : 2 beeps, 30% : 1 beep and 0% : no beep.

3. Vibration warning system

For the proposed warning system, the vibration type and sound type system is the best solution as a warning system for visually impaired people or even for deaf-blind people because it applies the touch sense of a human and the hearing sense as a medium of communication between device and human when the system is run. The human's sense of touch and hear is very suitable for blind people

(a) Vibrator

(a) Specification

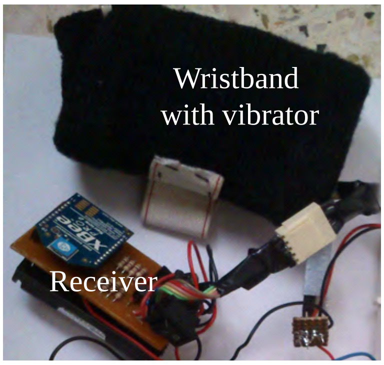
Item	Specification
Rated speed	12000 rpm
Rated current	100 mA
Rated voltage	2.7 – 3.3 V
Vibration amplitude	0.4 G
Weight	0.7 g
Dimension	8.0 mm

Figure 3.12: DC motor

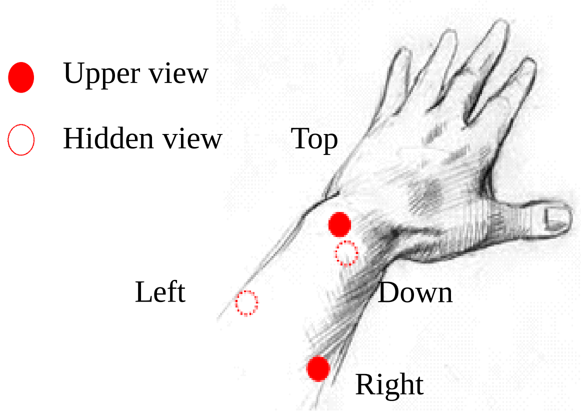
and even for the deaf-blind people to know the circumstances around them. By using the vibration method, the users can receive a direct warning to the skin when the ultrasonic sensors sense the obstruction without a direct contact to the obstruction.

The type of vibrator which is used in the proposed warning system is a coreless vibrator that can be illustrated in Fig. 3.12(a). From Table 3.12(b), the operating voltage range of the vibrator is 2.7V $\sim$ 3.3V. Hence, the speed of vibrator can be controlled by using Pulse Width Modulation (PWM) from the microcontroller for generating various types of vibration patterns. The various vibration patterns can also be applied in order to differentiate the direction of the obstruction or to indicate the distance of the obstruction from the user.

If the obstruction started to be detected by the ultrasonic sensor, the strength of the vibration is set starting from the PWM with a value of 10% . The strength of vibration can be increased proportionally inversed to the distance of the obstruction to the ultrasonic sensor. If the obstruction becomes nearer to the sensor or user, the vibration strength will be become increased until the PWM value is 100%. Practically, four pieces of vibrator are mounted into the wristband at different locations and have quite some distances between each vibrator. If the location between each vibrator is near, there is a probability where the users cannot identify the location for which vibrator has vibrated. Because of this, each vibrator at each location has its own function which shows the input of the ultrasonic sensor from different directions such as front, left, right and down



(a) Vibration warning wristband



(b) Vibrator location

Figure 3.13: Fabricated travel aid device for upper body level

which can be illustrated in Fig. 3.13.

Here, six configurations of the vibrators location are proposed in order to optimize the most comfort and less identification mistakes from the user. The clear red points indicate the location of the vibrator in the wristband which has to been worn by users and can be seen directly. Meanwhile, the locations of vibrators which are hidden and cannot be seen directly and are indicated as points with red line only. An experiment by using the switching method is conducted in order to give the command input to the vibrator when the obstruction is detected by ultrasonic sensors.

Besides, the vibration warning device for simplified electronic spectacles will also be applied. The power consumption of the developed full direction electronic spectacles which is evaluated in Subsection 5.2.4. The vibration warning method could be useful for the deaf-blind people since they could not hear the beep warning signal and see with the LED blinking method. The strength is also changed depending on obstacle distance. The vibration strength is generated by using PWM which is given to the user based on the distance of obstacle to the device which is measured by an ultrasonic sensor.

In addition, the application of both beep and vibration warning devices can be changed to rely on user preferences and environments. For instance, users are advised to switch from using the sound warning device to vibration warning device only when they are going to crowded places such as department store, train station, and etc.. This is because they are advised to use their ears to hear the environment sound around them. Figure 3.14 shows the proposed multi-modal warning device which is developed inside the electronic spectacles.

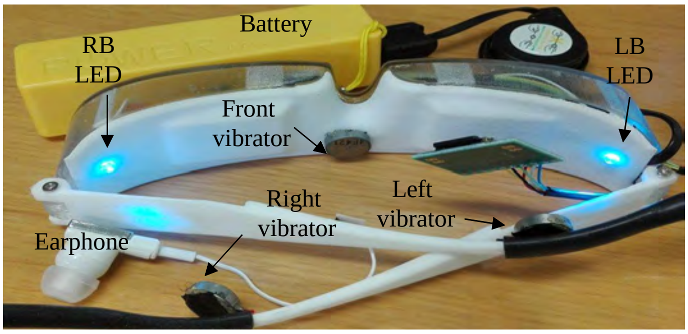


Figure 3.14: Developed vibration warning device on simplified electronic spectacle

4. Light warning system

   On the other hand, although fully visually impaired people could not see light, as the light warning type is mainly applied for the partially blind people or low vision people to identify the existence of obstacle around them. There are four pieces of LEDs which are used and mounted inside the developed electronic spectacles. In order to warn the partially blind people, two pieces of LEDs are mounted at the back side of the electronic spectacles. Besides, there are also two pieces of LEDs which are mounted at the front of the spectacles to inform other people of the existence of the users, especially at night and dark places. Moreover, the LEDs will also blink if the obstruction is detected, either to the left or right side based on the detection side. In contrast, all LEDs will blink if the obstruction is detected in front of the user. The speed of blinking also relies on obstruction distance where the speed will be increased if the obstruction becomes near to the user. Figure 3.15 shows the proposed multi-modal warning device which is developed inside the electronic spectacles.

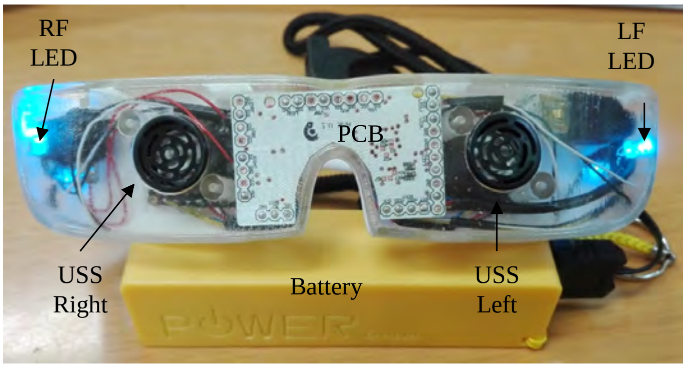


Figure 3.15: Developed light warning system on simplified electronic spectacle

3.5 CAD design and fabrication

3.5.1 Electronic parts

As stated in the previous section, some electronics components such as ultrasonic sensor, rechargeable battery and microcontroller have been selected through the pair wise comparison method. In order to make all the components connected to each other and function as per the concept designed, the CAD design of printed circuit board (PCB) for electronic spectacles is conducted. There are some software that can be used to design the printed circuit board (PCB). For example, Proteus, CR5000, Eagle, Daisylab, AutoCAD, etc. The free version of Eagle software can be used to design the PCB for up to 80 mm x 100 mm (L x W) of PCB. Since the design concept of electronic spectacles is small and compact, the Eagle software is chosen to design the PCB. Some other PCB design software need a license to operate the software.

In order to design the PCB by using the Eagle software, there are two big steps that need to be followed. First, the schematic diagram of full system which needs to be included in the electronic spectacles will be sketched. All components such as ultrasonic sensor, microcontroller, battery, and other electronic peripherals need to be inserted in the sketch. After the schematic diagram is designed completely, the schematic diagram can be converted to board diagram to sketch the PCB board layout. The size of each component which is inserted in the schematic diagram will be reflected to the board diagram based on the components library. However, if the components are not inserted, they will not appear in the board diagram. In the Eagle software, the schematic drawing will be saved as .SCH file. Meanwhile, the board diagram will be saved as .BRD file. The guideline of Eagle software can be referred to the Eagle manual [104]. Figure 3.17shows the fabricated PCB board for simplified electronic spectacles with all electronic components. The size of the fabricated PCB is about 43 mm (L) x 27 mm (W) in order to fit inside the designed spectacle frame.

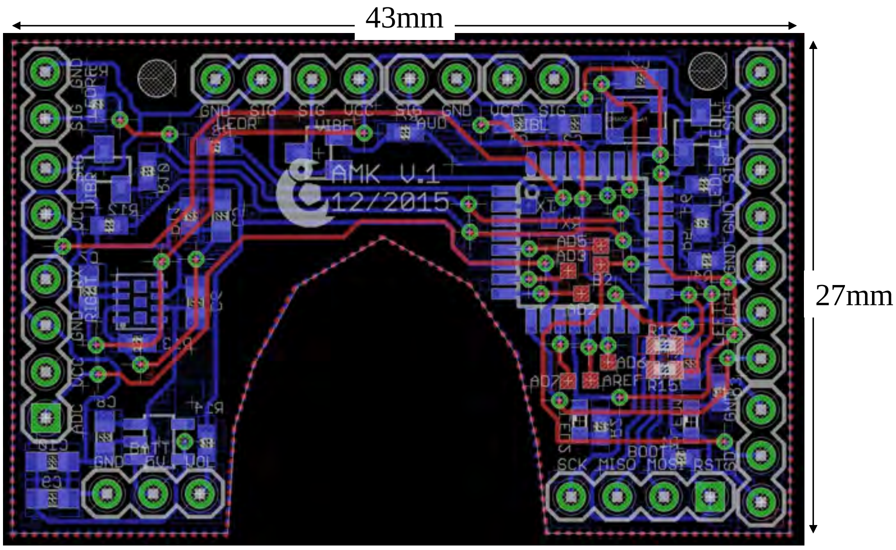


Figure 3.16: Board layout

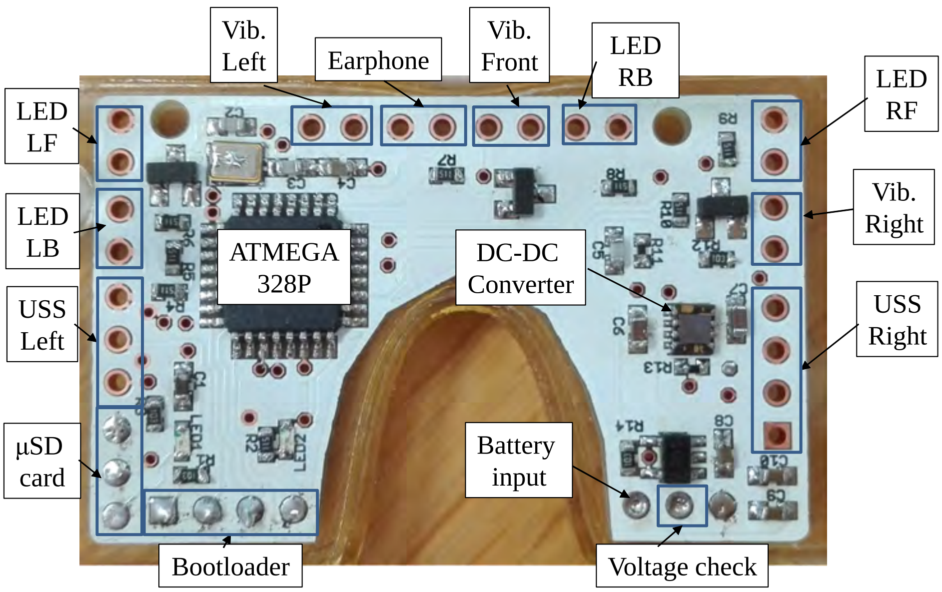


Figure 3.17: After solder

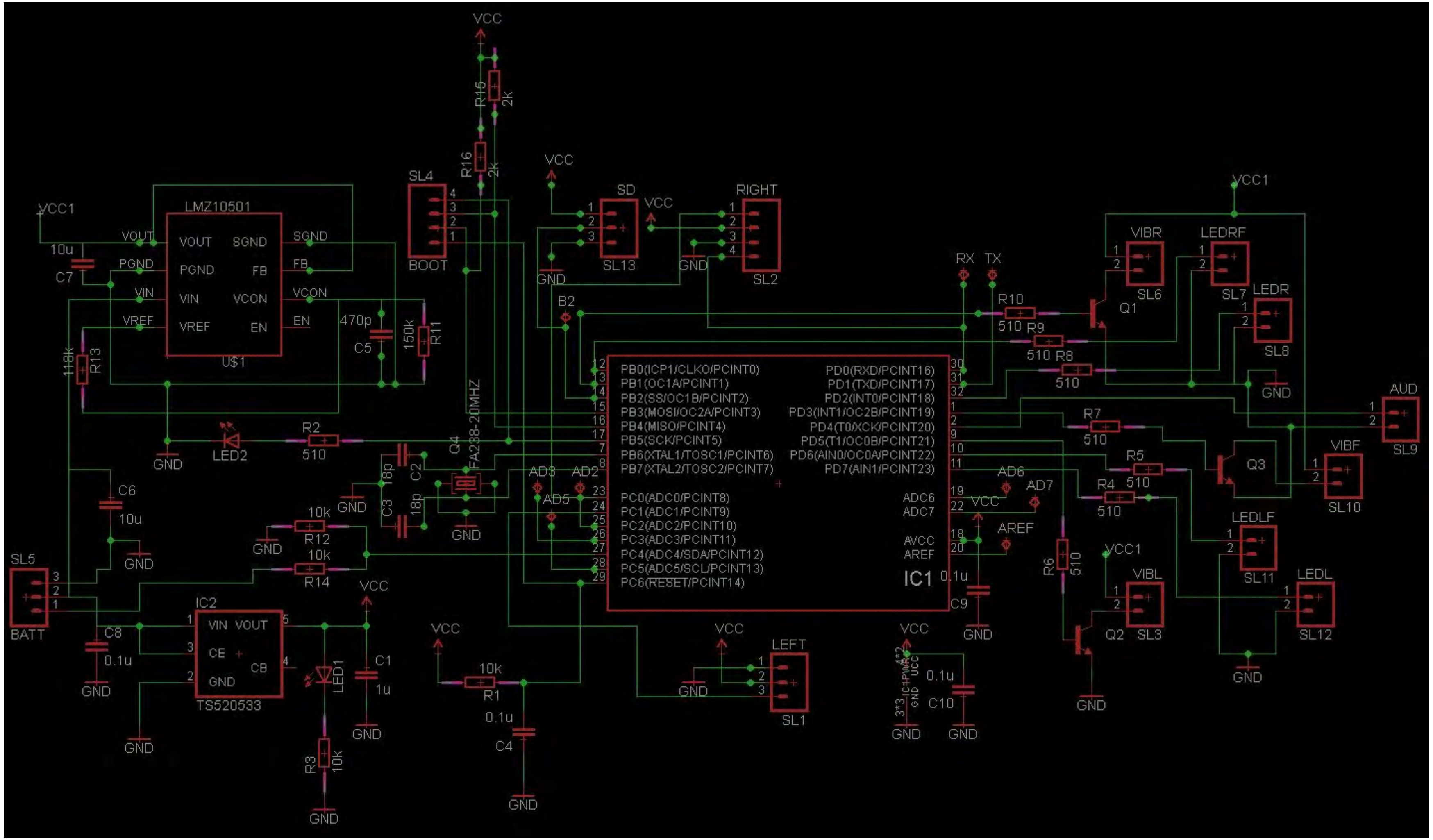


Figure 3.18: Schematic diagram of new electronic spectacle

Figure 3.18 shows the schematic diagram of the new electronic spectacles which has been designed. In this design, the power circuit, micro-controller circuit and warning system circuit include the vibrator, LED and speaker. Then, the conversion of schematic diagram to build the board layout has been executed. Figure 3.19 shows the designed PCB board layout. This PCB board layout has been designed for two layers of PCB board. After the design of board layout is completely finished, the fabrication of PCB board will be conducted first in the laboratory before the finalized PCB board can be fabricated through a PCB board manufacturer.

(a) PCB prototype

(b) PCB CNC machine

Figure 3.19: In-house PCB fabrication

3.5.2 Mechanical parts

After the selection of electronic components and detection range, the design and development of the spectacles type device for visually impaired persons are conducted. In addition, Figure 3.20 shows an exploded view of the designed electronic spectacles by using SOLIDWORKS software for each part involved inside the electronic spectacles. Each part of the electronic spectacles such as distance measurement sensor, USB mini connector, single earphone, Arduino microcontroller and wireless module will be drawn earlier before the spectacles part is designed. All the parts are drawn exactly as the actual size since it will be fabricated with actual sized parts. However, the connection to the rechargeable battery is not shown in Fig. 3.20 because the external battery is connected to the electronic spectacles and placed inside the user's shirt pocket. If the rechargeable battery is designed to be located inside the electronic spectacles, the size of the electronic spectacles will be bulky and heavy.

Therefore, the Theory of Inventive Problem Solving (TRIZ) concept is applied when two contradictions exist in the system. Figure 3.21 hows the matrix table for the TRIZ method that will be applied in the mechanical design. For example, the weight of spectacles worsens if all operations are included in the electronic spectacles. Here, the worsening feature is weight of stationery (2) and improving feature is ease of operation (33). The solutions recommended through the TRIZ matrix are segmentation (1), universality (6), the other way around (13) or self-service (26) [105]. In this case, segmentation is selected and the electronic spectacles are divided into independent parts, which are the spectacles part and the rechargeable battery part. Meanwhile, the spectacles part can be divided into some parts such as:-

1. Spectacle main frame
2. Main frame cover
3. Frame handle right
4. Frame handle left

In addition, the rechargeable battery is connected through a mini USB which is mounted at the end of the left side handle. The spectacles handle can be adjustable for different users. Also, the rechargeable battery using Li-Ion battery including the rechargeable function can be directly recharged using a USB connector through a USB adapter or a notebook. A single earphone is mounted on the right side handle in order to give the beeping sound alert to the visually impaired people. The reason for using a single earphone in this system is because the visually impaired usually use their hearing sense in order to know the environment.

If a stereo earphone is applied, the person cannot sense the environment while using these electronic spectacles. The placement of the ultrasonic sensors in this prototype refers to the angle range that the device should detect. Meanwhile, the left and right ultrasonic sensors are set to 45 deg. from the spectacles center point in order to detect obstacles within the shoulder and arm of user. Therefore, collision between obstacle and both left and right shoulders can be avoided. After the selection of electronic components and detection range, the design and development of the spectacles type device for visually impaired persons are conducted. Figures 3.22(a) to 3.22(f) illustrate the designed electronic spectacles by using SOLIDWORKS software for each direction.

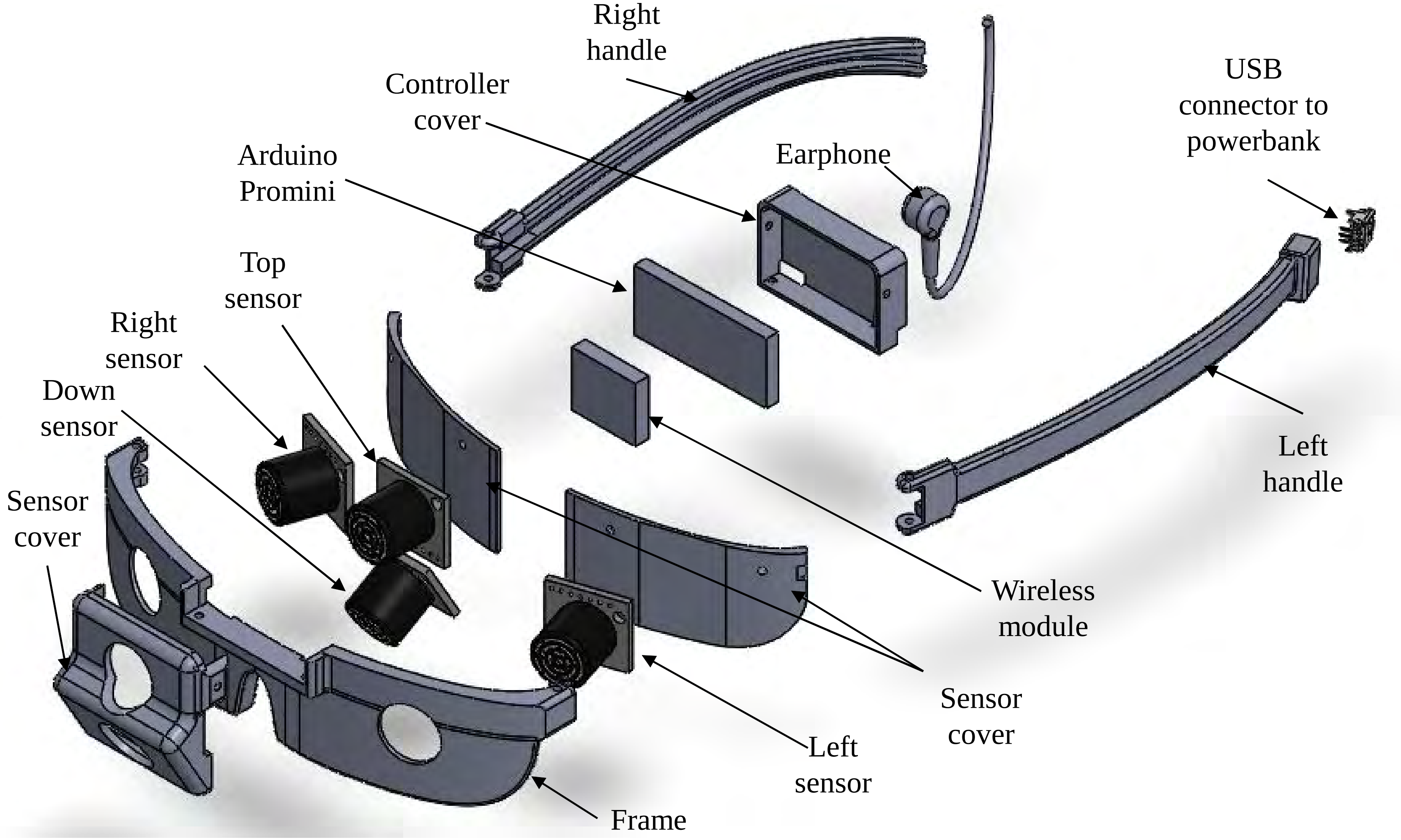


Figure 3.20: Explode view of electronic spectacle

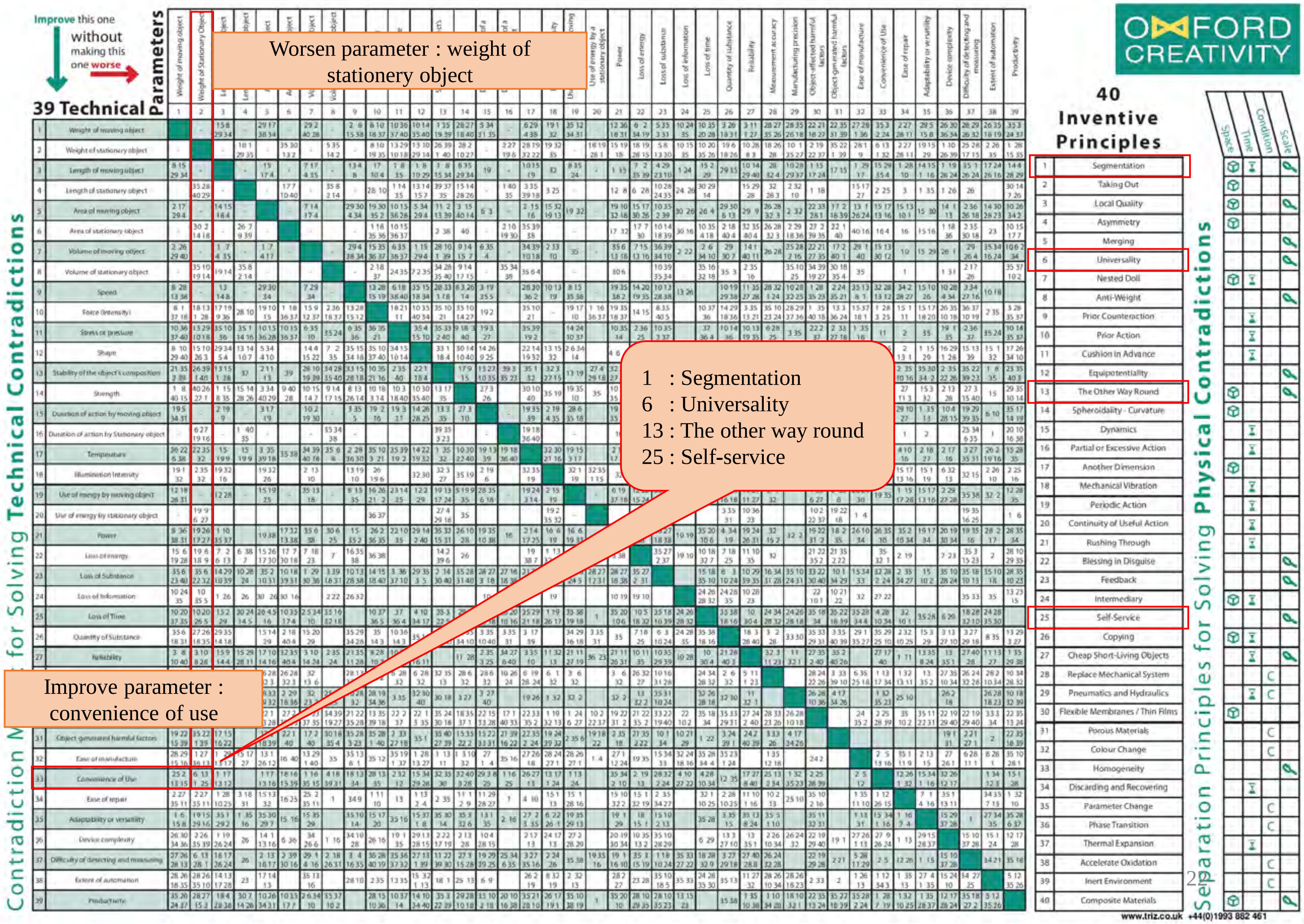
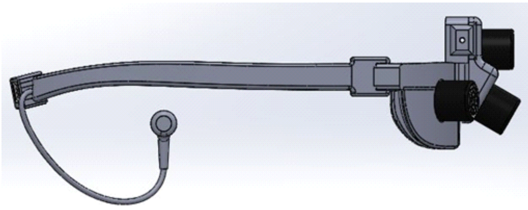


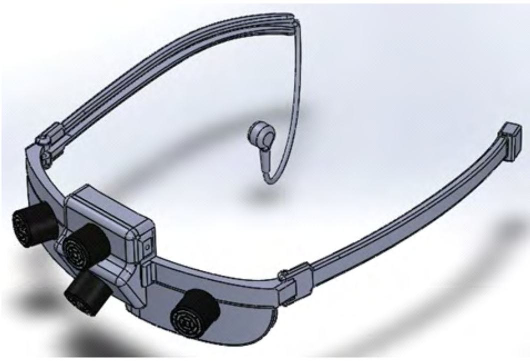
Figure 3.21: Matrix table for TRIZ method

In order to fabricate the electronic spectacles which have been designed, some apparatus such as 3D printer and Rapid Prototyping Machine (RPM) will be used. In this situation, we have decided to use a 3D printer since it is available in our research laboratory. Figure 3.23 (a) shows the illustration of the 3D printer which will be used to fabricate all parts. The 3D printer can build the parts of electronic spectacles up to a maximum size of 29.5 x 19.5 x 16.5 (L x W x H) cm. Besides, the material which will be used to fabricate the electronic spectacles is Polylactic acid (PLA) filament which is easy to obtain and low in cost. Therefore, all parts of the electronic spectacles can be produced in house and the assemble process can easily be done. In order to fabricate each part of the electronic spectacles, the total of PLA material which needs to be used is approximately 150 cm^3.

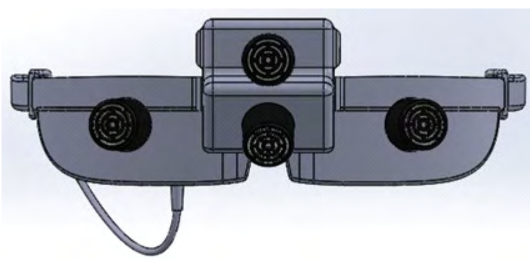
Furthermore, the fabrication time to produce all parts of the electronic spectacles is approximately 6 hours. Since the space inside the 3D printer is quite big, a total of three pieces of electronic spectacles can be produced at the same time. In order to fabricate by using the 3D printer, the designed electronic spectacles need to be saved in .STL file and inserted into the 3D printer by using USB flash memory. The position of each part needs to be determined inside the 3D printer platform based on the strength of layer to be constructed and the quantity of part that can be occupied inside the platform. If all location parts are already confirmed, the resolution and strength of the parts can be chosen before the fabrication is started. If all the settings are determined, the start button will be pressed and wait for the all the parts ready to be assembled. After all the parts are ready, the assembly process for each mechanical part and electronic part will be done. Figure 3.23 (b) shows the fabricated electronic spectacles which have been assembled.



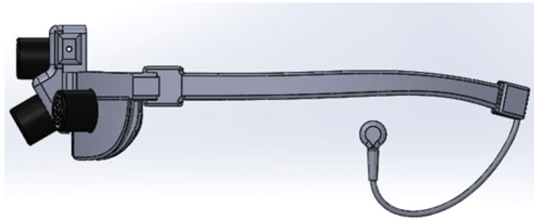
(a) Right side view



(b) Isometric view (Right)



(c) Front view



(d) Left side view

(e) Isometric view (Left)

(f) Top view

Figure 3.22: Designed electronic spectacle using SOLIDWORKS

(a) 3D printer by Makerbot (b) Fabricated electronic spectacle

Figure 3.23: Fabrication process through 3D printer

3.6 Summary

Since 2011 until now, some improvements and modifications have been done in order to make the development of wearable travel aids such as intelligent spectacles to be successfully conducted. There are six versions of intelligent spectacles that have been developed. All the intelligent spectacles are developed based on the feedbacks which have been received after the evaluation process by the Society of Blind Malaysia (SBM) and Malaysia Association for the Blind (MAB). All developed electronic spectacles are illustrated in Table 3.24. The specifications and features of the developed intelligent spectacles are shown in the table.

The first developed intelligent spectacles which we called as SMART EYE is developed in 2011. The design and development of the first prototype started after receiving the feedback about the development of intelligent white cane for visually impaired people in 2010 from the SBM Durian Daun Malacca. From the feedback and survey which have been done, the visually impaired people need a device to protect their upper body level, mainly on the head level. Therefore, SMART EYE has been developed to assist the visually impaired people community. As the first prototype, we have combined the system features of intelligent white cane inside the spectacles. As a result, the developed SMART EYE device is too bulky and heavy. Although SMART EYE functioned well, the user friendliness needs to be improved in order to be implemented by the visually impaired people. The developed electronic spectacles have also been tested with the community SBM and other visually impaired people and the same feedbacks have been obtained.

Hence, new approaches need to be adapted inside the developed first prototype. Therefore, the main problem of the SMART EYE which is bulky and heavy is resolved by using infrared sensor and separation of power bank from the spectacles frame. Previously, the usage of double type ultrasonic sensor which has the weight of 9 g and volume of 16192 mm^3 is replaced by infrared sensor which has the weight of 3.5 g and volume of 5177 mm^3. As a result, the second developed SMART EYE weight is less than 110 g for the spectacles only. However, by using infrared sensor, accuracy of distance measurement was low and not reliable to use at outdoor environment since the concept of infrared sensor is light and affected by other light sources from the sunlight. Besides, the distance measurement range is too small where it could measure only 0.1 m to 0.8 m.

Then, the third version of the SMART EYE with new ultrasonic sensors with only a single transducer is proposed. This ultrasonic sensor which is manufactured by MAXBOTIX can measure from 0.1 m to 6 m. This ultrasonic sensor has better accuracy and light in weight which is only 4 g in weight and has a volume of 6800 mm^3. However, the four ultrasonic sensors which are used to detect four directions make the visually impaired people confused. This is because the warning signal which has been given consists of four different directions. Each warning signal is given in audio type such as FRONT, DOWN, LEFT and RIGHT. The audio word is quite long and if there are many obstacles surrounding them, it is difficult to determine the direction of the obstacles.

On the other hand, the fourth developed SMART EYE has also adapted the same warning system and detection range. The fourth version is invented just to solve the problem from the feedback of visually impaired people who preferred the ultrasonic sensor to be covered by the spectacles casing. This is because the ultrasonic sensor which is mounted on the spectacles looks weird and not the same as normal spectacles. Consequently, it makes the size of spectacles bulky and heavy after we made the modification. Therefore, we also proposed two types of spectacles handles which are headband and normal handle. By using normal handle, it cannot support the spectacles to stay at the human eye since they are quite heavy. Besides, we also proposed the usage of the SMART EYE at the human forehead in order for partially blind people to use it too. However, some of the visually impaired people did not prefer it because it felt weird.

As a result, the fifth version is developed based on the feedback that the audio warning signal is quite confusing. Therefore, two pieces of ultrasonic sensors are used to reduce the number of warning signal while changing from audio warning signal to beeping warning signal. The direction which could be detected is front, right and left while the down direction could be detected by using the white cane. Besides, the fifth developed SMART EYE is tested and received good feedbacks from visually impaired people as it is simpler and easier to determine the obstacles. The size and weight of the spectacles is reduced to 70 g and easy to handle.

The sixth version that has been developed is to assist various categories of visually impaired people such as fully-blind people, partially-blind or low-vision people and multi-disabled people such as the deaf-blind. The developed intelligent spectacles type with obstacle detection system uses only a pair of ultrasonic sensors to detect the obstacle at the front, left and right. The usage of light, beep and vibration methods as a multi-modal warning system is proposed where LED, single headphone and vibrator are mounted inside the spectacles. The effectiveness of various types of warning system given by the developed intelligent spectacles to reduce collision at the upper body level is evaluated respectively. The experimental results of the performance evaluation of the developed electronic spectacles are described in Chapter 5.

Detail	Ver. 1	Ver. 2	Ver. 3	Ver. 4	Ver. 5
Developed year	May 2012	August 2013	November 2013	March 2014	June 2014
Image					
No. of distance sensors	4	4	4	4	2
Type of distance sensor	Double type ultrasonic sensor	Infrared sensor	Single type ultrasonic sensor	Single type ultrasonic sensor	Single type ultrasonic sensor
Direction detected	4 directions (Front, Down, Left, Right)	4 directions (Front, Down, Left, Right)	4 directions (Front, Down, Left, Right)	4 directions (Front, Down, Left, Right)	3 directions Front, Left, Right
Warning type	Vibrator & Audio (Front, Down, Left, Right)	Audio only (Front, Down, Left, Right)	Audio only (Front, Down, Left, Right)	Audio only (Front, Down, Left, Right)	Audio only 3 type of beeps
Size (L x W x H) (mm)	170 x 150 x 90	150 x 70 x 60	150 x 70 x 50	150 x 60 x 50	150 x 30 x 30
Spectacle weight (g)	450	110	120	180	70
Power source	PV panel & 9V battery	9V battery	2600mAH Power bank	2600mAH Power bank	2600mAH Power bank
Other features	Not waterproof	Battery separated from main frame Not waterproof	Not waterproof	Sensors covered by casing Not waterproof	Sensors covered by casing Not waterproof
Feedback Blind person	Advantages Functionality Disadvantages Bulky Heavy Not user-friendly	Advantages Functionality Usefulness Light weight Disadvantages Distance inaccurate Short detection range Battery short life	Advantages Functionality Usefulness Light weight Disadvantages Confuse warning audio Less aesthetic value Not suitable for partially blind person	Advantages Functionality Usefulness Disadvantages Spectacle bulky Quite heavy Less aesthetic value Confuse warning audio	Advantages Functionality Easy to use Light weight Disadvantages Not suitable for partially blind person and deaf- blind person

Figure 3.24: Product development and evolution

Chapter 4

Development of Electronic Cane

4.1 Overview

In Chapter 3, the development of electronic spectacles mainly for obstacle detection system for the upper body level has been done. In contrast, the development of electronic white cane which can mainly be used for navigation purpose will be described in this chapter. As mentioned earlier, white cane has been used since decades ago by visually impaired people as their most common and affordable travel aid device to detect obstacles and path surrounding them. It becomes troublesome once the destination is newly constructed and has not implemented the universal design. They do not receive enough information with only the tip of the white cane as feedback. Therefore, the proposed new approach for the navigation system that can be used universally for indoor and at the same time for outdoor application is needed.

Hence, the exploratory study of navigation tools inside the electronic white cane that can be used for visually impaired people is done partially in this thesis where some new studies will be introduced. For example, the proposed method to embed the RFID antenna inside the tactile pavement on the walkway could give a more precise navigation. It could be an on ground guide for them to know their location and direction to be traveled. The shortest path algorithm will also be configured to find their destination easily. In addition, the tactile pavement detection by using the vision method will also be slightly introduced in this chapter to show the technology that can be used for assisting visually impaired people.

4.2 Navigation system

4.2.1 System construction and configuration

In order to develop the navigation system which will benefit the visually impaired people, a total system that includes a path planning system, RFID detection system, and obstacle detection system is needed. However, in this thesis, the developed navigation system is only one part of the total navigation system which does not include obstacle avoidance system, localization system, etc. Here, the developed system is focused on the path planning system including the destination input system such as voice input system and Braille input method. Moreover, implementation of digital compass is used to guide the right way for visually impaired people when travel. Figure 4.1 illustrates the system configuration of the developed navigation system. In the developed navigation system, some components are used, such as RFID reader/writer module, microcontroller, voice module, Braille keypad, digital compass, earphone, voice recognition module, etc.

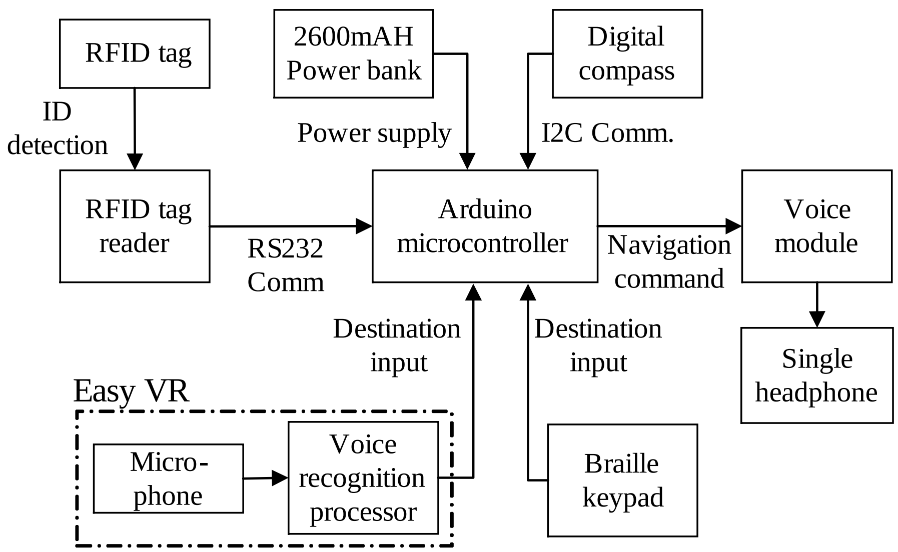
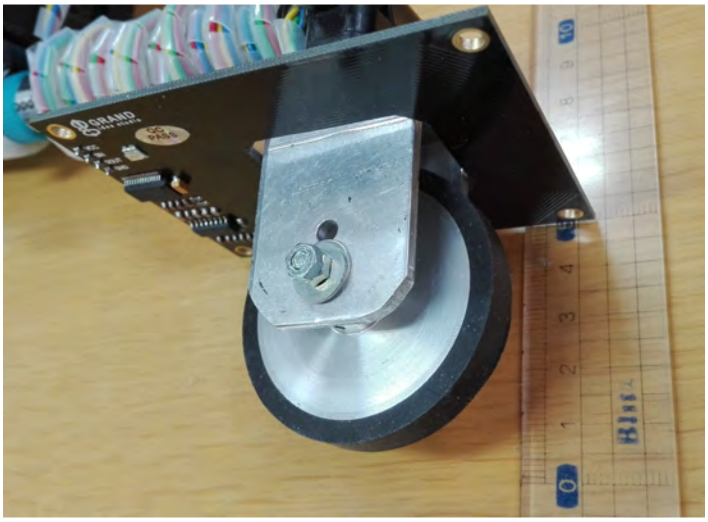


Figure 4.1: System overview of developed navigation device for visually impaired person

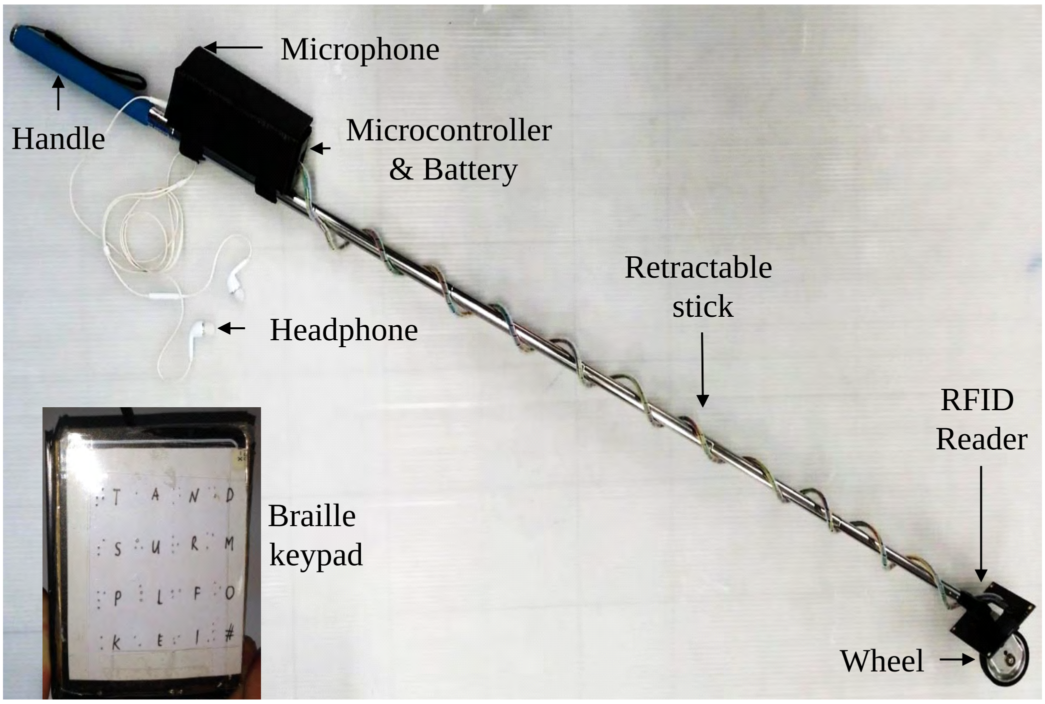
As the main part in the developed navigation system, a microcontroller which consists memory and program in order to communicate with other peripherals is installed. The microcontroller type which is selected to be implemented in this project is an Arduino Promini. The reason is because the Arduino Promini has been developed in a small size package, is light in weight and has adequate I/O port in order to construct the navigation device. In addition, the digital compass (HMC6352) is used because it can provide a high degree of heading resolution and accuracy in determining the direction. If the user travels away from the path, the navigation system will determine the direction heading and gives alert to the user based on the digital compass measurement. Once the direction is correct, the user could continue to travel by the aid of audio guidance from the voice module to the provided earphone. On the other hand, the RFID reader/writer module manufactured by Parallax also plays an important part in the developed navigation system. The RFID reader/writer module is installed at the bottom of a retractable cane for easy detection of passive RFID tags installed on tactile paving. The RFID reader/writer module could detect the RFID transponder tags at 125 kHz up to 3 inches of distance.

Figure 4.2(a) shows the RFID detection system that consists of the RFID reader/writer module. The RFID reader/writer module is directly connected to Arduino microcontroller which can be activated when the Arduino microcontroller is powered by the power supply/battery. It is also installed at the bottom of the electronic cane in order to detect the RFID tag easily which is installed on the tactile paving that can read the code of the tags and the code encryption will be done by the program inside the Arduino microcontroller. The information of the places which the RFID tags have been mounted will be prepared as a library inside the microcontroller. Each RFID tag contains pre-stored information such as the location and the surrounding environment including obstacles, place names, and building names in the library of the microcontroller with the micro SD card which has been installed with the voice module. The voice module (WTV020) is used in order to play the voice commands and inform the users on which direction that they should take and turn when there is a corner. It also plays the voice command that is followed by the measured value from the digital compass.

Figure 4.2(b) shows the illustration of the electronic cane which is developed in this research. A conventional white cane is transformed into an electronic cane in order to attach all the developed systems. At the bottom of the cane, a wheel is mounted so that the RFID reader/writer module can be easily detected by the RFID tags. The wheel size is about 4 cm and the RFID reader/writer module is mounted at 6 cm from the floor. Thus, the RFID tags can be detected respectively. At the same time, a



(a) RFID reader/writer module



(b) Developed navigation device

Figure 4.2: Developed electronic cane for navigation

wheel means the user does not have to raise and swing the cane while traveling which can tire the user. If the user swings the retractable cane, the RFID tag could not be detected by the RFID reader/writer module. In addition, the retractable stick is used as the replacement of conventional white cane which is commonly used by the visually impaired people for navigation purpose. The retractable stick can be shortened to 25 cm in order to carry and mobilize the developed navigation device when unused. Besides, the retractable stick can be extended up to a maximum of 120 cm which is similar to the conventional white cane. Hence, the retractable stick can be adjusted, depending on the height and comfortability of the users.

Figure 4.3 illustrates the ZigBee wireless networks of the communication between the server/laptop and the developed navigation device. We developed the ZigBee network in order to connect and monitor the developed navigation device when the experiment is conducted. The ZigBee network acts as the center of data transferring between the navigation device and the server/ laptop. The movement of user will be shown to the map processing system on the server/laptop respectively. Hence, the user's current position to the desired position will be displayed on the map based on a generated route. The map system then identifies the address of the target. Concurrently, the RFID reader/writer module will read the RFID tags on the tactile paving or floor. The data of the RFID tags of the current position and the address is sent for map processing.

Next, voice guidance commands will also be given based on the route which has been generated to the user through an earphone. The earphone connection is based on a Bluetooth connection. The server/laptop will send the voice guidance and user position will also be updated at the same time. Path recalculation will also be done again and voice guidance is produced if the user takes the wrong path from the recommended path. The benefit of the system is when user needs to take the corner turning, the digital compass will compare the angle and ensure the user to take the corner effectively without hitting the nearby obstacles. The server receives data from ZigBee network and suggests mounting at fixed locations inside the buildings. The server must be updated and the information of the destinations and objects need to be stored inside the database with respect to the map system.

In order to optimize the functionality of the developed navigation device for guiding the visually impaired people in the correct direction throughout the travel path, the experimental setup to evaluate the accuracy of the digital compass is set. The orientation or direction is attained by using a digital compass mounted on the developed electronic cane. Figure 4.4 shows the digital compass setup and the reference compass, respectively. The digital compass is connected to the Arduino microcontroller to obtain the analog signal and convert it back to the digital signal by using the on-board analog digital converter (ADC). The digital signal will be displayed on the serial monitor of the Arduino microcontroller and the digital compass can be tuned accurately. The digital compass is fixed at the certain point where the RFID tag has been mounted to ensure the digital compass is always pointing to the North. The digital compass which is equipped inside the iPhone is used as the reference compass to make comparison when calibrating the digital compass.

Figure 4.3: System configuration of developed navigation system including server/laptop

Figure 4.5 shows the experimental field including tactile paving which is used for the

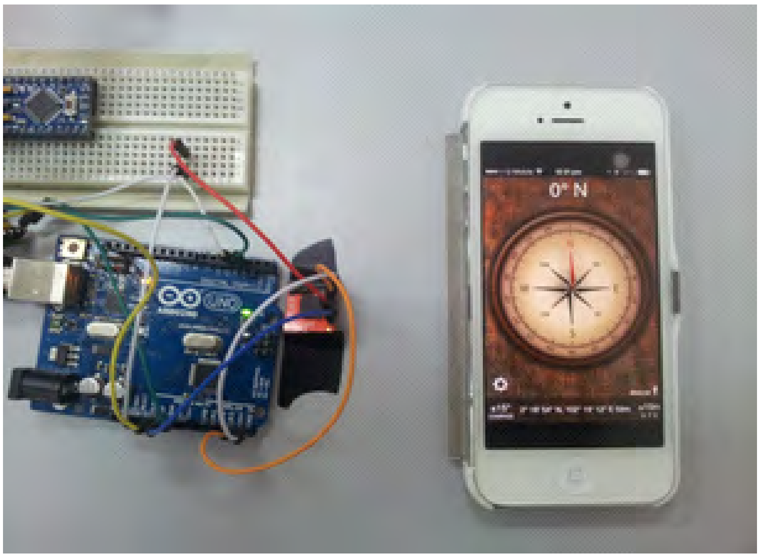


Figure 4.4: Digital compass setup and the reference compass

experiment. Tactile paving is numbered with 00, 01, 02, 03, 04, 05, 06 and 07 as the point paths while blue objects represent the obstacles which cannot be passed through. Voice module (WTV020) has been saved with five types of sound which are forward, turn left, turn right, stop and warning. At this stage, only five directions of sound are used as navigation after the shortest path is generated to follow the direction from start to the target node. There are two destinations which can be set in this experiment which are the ATM and toilet. There are some influence factors that need to be considered during the navigation evaluation test such as systematic error and human error.

Systematic error where there is bias in measurement leads to the path completion time. The error occurred for the time response of the system where there is some time delay for the ZigBee during data transmission and when sending voice commands. Human error is another error that is not intended and cannot be avoided. For this case, the human error is response of the participants when they started to walk as they received the voice commands. There were some delays at the starting point and cornering. This will give different results for the path completion time. However, the time that is needed to complete the path does not put too much emphasis on how fast the person reaches the destination.

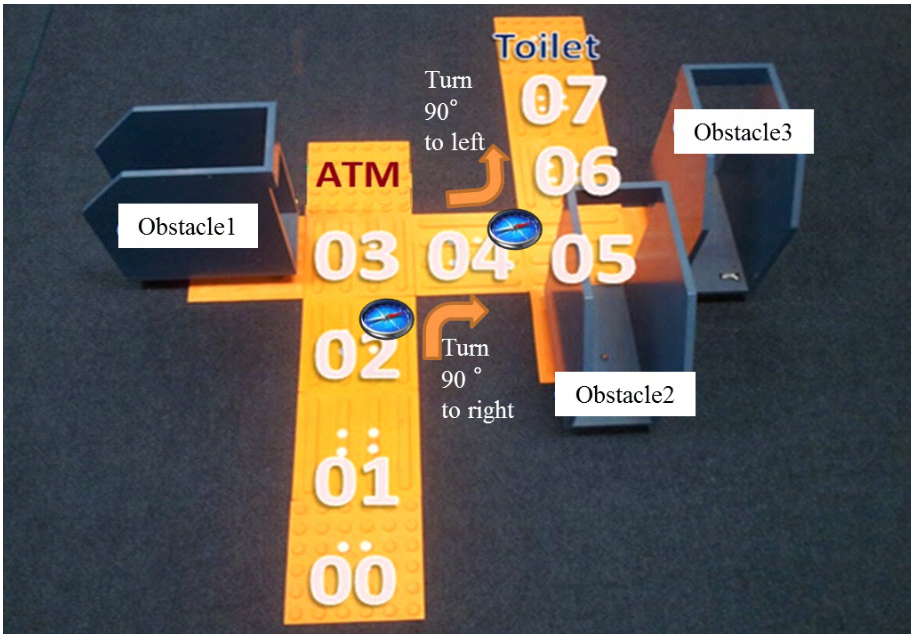


Figure 4.5: Field setup which include RFID tags on tactile paving with some obstacles

4.2.2 Control flow chart for navigation system

Figure 4.6 shows the process flowchart of the designed and developed navigation device. In order to use the developed navigation device, the RFID reader/writer module needs to be initialized respectively. The user could set the desired destination at the start point after detecting the nearest RFID tag which has been mounted on tactile paving or on the floor around them. In order to navigate to the desired location, the RFID reader/writer module is activated and will read the transponder tags. If the RFID reader/writer module has failed to read the tag, even though the RFID tag is already in the detection range, the device will return to the tag reader activation process by initializing the RFID reader/writer module first. On the other hand, if the next RFID tags are successfully detected, the Arduino microcontroller will carry out the encryption of the tag identity which has been programm in the library of the system. Each RFID tag has its own identification code and the code is transferred to Arduino microcontroller through RS 232 for identification code encryption. After that, the controller system proceeds to the navigation processing. The information extracted will be then reprocessing and converted into voice commands. Then, the users will receive the commands on how to travel their path and the information about their surrounding environment.

After the identity encryption process has succeeded, the device process to path localization will lead to the user's desired destination guided by voice commands which will be given through headphone. In case the user travels at the wrong path, especially when the user turns at the junction, the process will proceed to route a processing subroutine. In the route processing subroutine, the digital compass is activated by initializing the serial communication from the Arduino main board. The magneto sensor inside the digital compass will measure the angle deviation and recalculate the correct heading direction. If there is no more angle deviation, the user can continue his or her travel through voice commands until reaching the destination and vice-versa.

4.2.3 Desired destination input method

In order to set the desired destination, there are two types of methods for inputting the target destination as proposed inside the developed navigation system which will be described in this subsection. Two types of methods proposed are the voice input system and Braille input system. The proposed destination input system is an option for the visually impaired people to set the target destination to which they want to go. If the visually impaired users are not familiar with the Braille character, they can use the voice input system.

Voice input

In the configuration of the voice input system inside the developed navigation system, a microphone acts as the input device in the voice recognition system. A received voice sample is sent to the EasyVR module in order to recognize the voice sample and match it with a prerecorded voice command. The program for the voice recognition system was designed using the Arduino programming language. If the voice command of the user matches a prerecorded voice command, EasyVR will permit the electronic cane to guide the blind person to the destination that has been set. Through the detection of the RFID tag containing information stored electronically, a recorded output voice command will lead the blind person by giving exact directions to reach the destination.

Figure 4.7 shows a flowchart of the proposed voice input navigation system. Firstly, the RFID reader is initialized. The RFID reader determines the starting point by

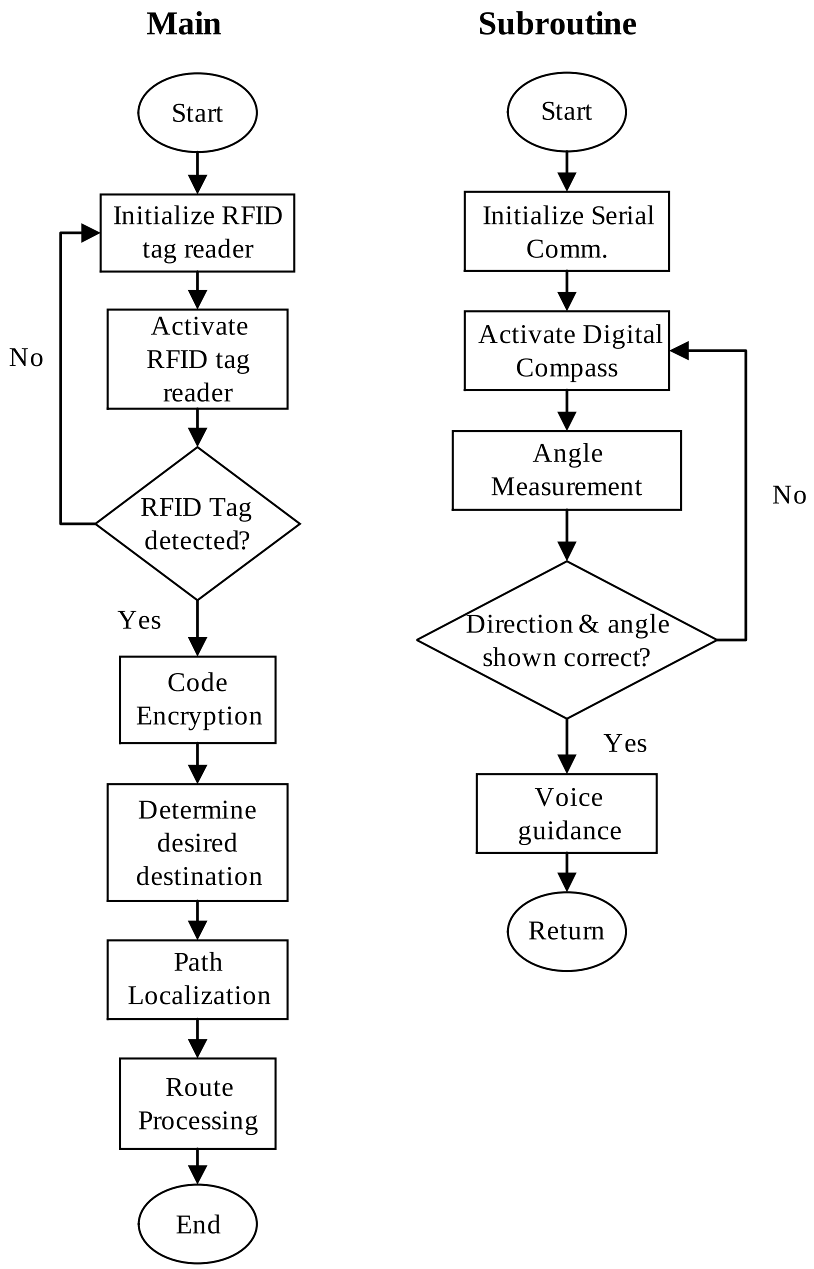


Figure 4.6: Process flowchart based on digital compass for RFID navigation system

touching the nearest RFID tag. If the RFID reader fails to read the tag, even if it is already in the detection range, the RFID reader is initialized again. In contrast, if the RFID tag is successfully detected, the Arduino microcontroller encrypts the tag identity. Then, the user can determine the desired destination by inputting the location through the microphone. All the destinations have been pre-stored in the microcontroller library. After the voice is detected by the template matching method, the path localization process leads the user to the desired destination via the voice guidance system, which gives instructions through the earphone.

Commonly used voice recognition methods are template matching and feature analysis. In this developed navigation system, a simple location or destination is spoken by the user through a microphone, which is transformed into electrical signals by using an analog to digital converter. Hence, the template matching method is chosen since the template matching method is the simplest technique and has the highest accuracy. However, since the voice of each person varies, the program must be trained with a new user's voice input, as shown in Fig. 4.8(a). In the training phase, the user needs to speak a word several times to the microphone and the system extracts the features of the voice and stores a template in the memory using the feature extraction method. Furthermore, during the detection phase, features matching is applied by comparing the database of samples and the input voice, as illustrated in Fig. 4.8(b). Both feature extraction and feature matching modules are equipped inside the EasyVR module [106].

On the other hand, the amplitude is the property focused on when analyzing the results obtained from an oscilloscope. This is because the higher the amplitude of the voltage, the higher the volume of the sound. Therefore, a difference in amplitude in a sound waveform is caused by the input of sounds with different loudness. The amplitude or peak value is indicated as a voltage. To find the average voltage, V_{ave} of a non-sinusoidal waveform, the area underneath the waveform needs to be calculated. Equation 4.1 shows the calculation method for the average voltage, V_{ave} using the mid-ordinate rule, where n is the number of mid-ordinates used and V_i is the peak voltage for each sample time.

$$V_{ave} = \frac{\sum_{i=1}^{n} V_i}{n} \tag{4.1}$$

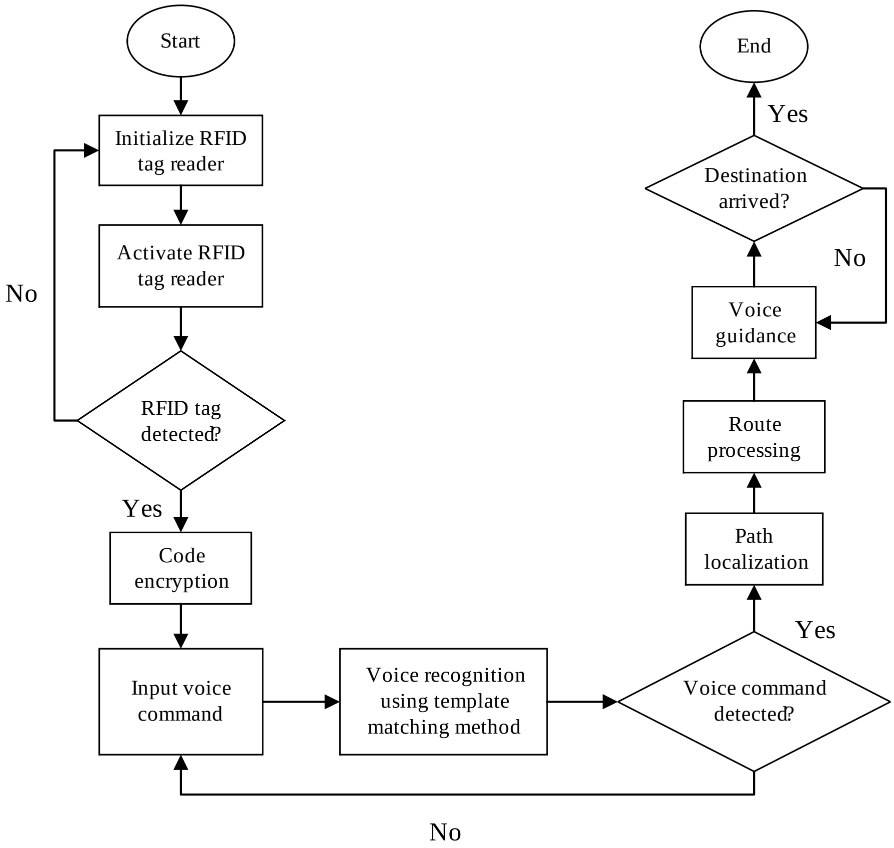
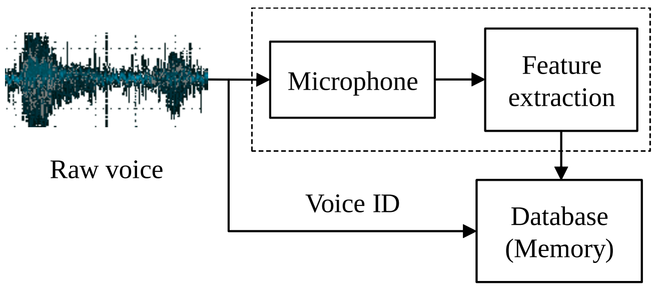
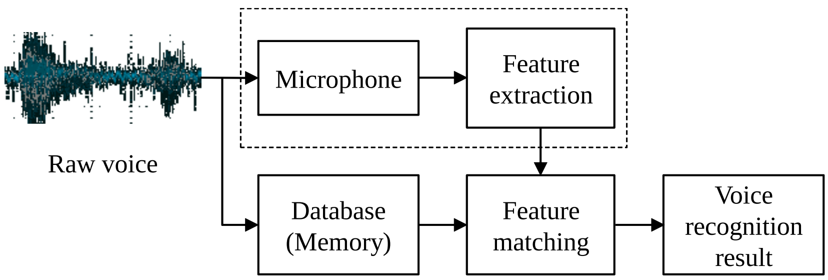


Figure 4.7: Navigation flow using voice recognition system



(a) Training phase



(b) Detection phase

Figure 4.8: Voice training method

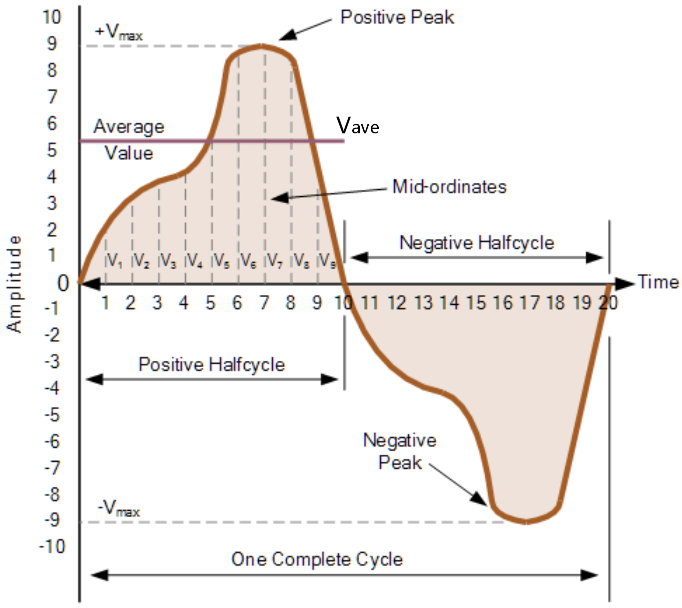


Figure 4.9: Average value of non-sinusoidal waveform

Braille input

Figure 4.10 shows the developed keypad by implementing the Braille code to be used as destination input method by visually impaired users. The Braille input system is attached and connected on the top of the 4 x 4 numeric keypad. It is specially modified for the Braille key in the destination with the combination alphabet such as T, A, N, D, S, U, R, M, P, L, F, O, I, E, L, # " which can be inputted as the desired destination such as TOILET, ATM, ROOM, RESTAURANT, STORE, PLATFORM, etc. The reason why we have selected these alphabets in our prototype is because we only need to develop a simple map which includes all the destinations that have been mentioned earlier. The entire desired destination has been pre-programmed in the library of the microcontroller. The users need to input the desired destination on the modified Braille keypad with the Braille code. After inputting the desired destination, the # character needs to be inputted in order to indicate the end of the word. Afterwards, the device will start to give the audio guidance to the visually impaired people through an earphone.

(a) Keypad 4x4

(b) Braille keypad

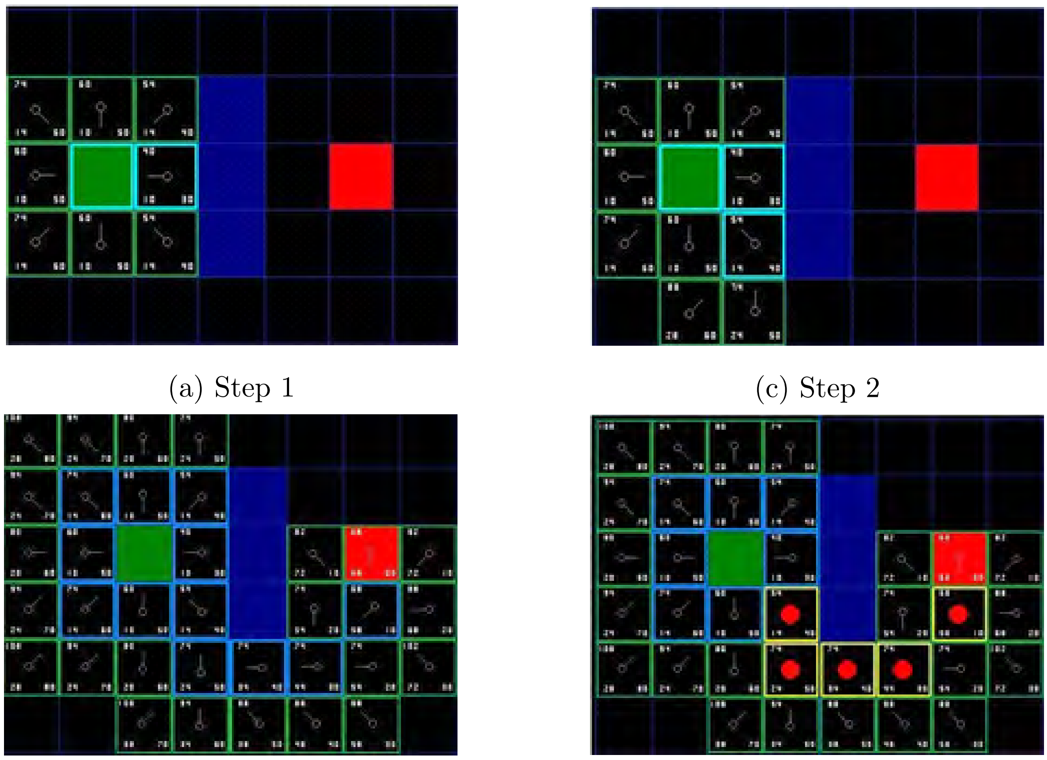
Figure 4.10: The modified keypad using Braille code

4.2.4 Path planning system

In order to calculate the shortest path from the initial node to the goal node, the shortest path A* search algorithm is implemented because its accuracy performance is known among researchers. Figure 4.11 shows the steps which are involved in the shortest path algorithm. A* search algorithm tends to find the shortest path from the given initial node to the goal node. The distance between adjacent nodes and the initial node will be compared in order to determine the shortest distance taken to get to the second node. If the second node has been set to be the node taken among other adjacent nodes, then the initial node will be set to be the parent node of the second node. This means that the initial node has now become a closed node that will not be used to search for the third node.

Meanwhile, the second node is now used as the reference node to determine the third node. The shortest distance from node to node will be compared until the shortest distance to reach the goal node is determined. A* search algorithm implements heuristics (usually denoted as $h(n)$ for a given node n) which is the estimated cost from the current node to the goal node and past path function (usually denoted as $g(n)$ for a given node n) which is the known distance from the starting node to the current node to calculate the evaluation function of node $f(n)$ for a given node n. Thus, the complete equation to determine the next node from the current node is shown in Eq. 4.2.

The heuristics $h(n)$ should not overestimate the distance from the current node to the goal because the path generated will not be the smallest possible distance if overestimation occurs. Taxicab distance is used in this project to estimate the distance from the starting node to the goal node of heuristics $h(n)$. Taxicab distance is the sum of absolute differences between two points in a Cartesian coordinates. The taxicab distance between node n and node m in a Cartesian coordinate is determined with the sum of absolute differences between $|n_x - m_x|$ on x - axis and absolute differences between $|n_y - m_y|$ on the y - axis. The complete equation to determine the taxicab distance, $d_{Taxicab}$ between node n and node m is shown in Eq. 4.3.



(a) Step 1 (c) Step 2

(b) Step 3 (d) Step 4

Figure 4.11: Shortest path planning algorithm

$$f(n) = g(n) + h(n) \tag{4.2}$$

$$\mathrm{d_{Taxicab}} = |n_x - m_x| + |n_y - m_y| \tag{4.3}$$

Thus, heuristics $h(n)$ of node n and node m can be estimated as shown in Eq. 4.4,

$$\mathrm{h(x)} = |n_x - m_x| + |n_y - m_y| \tag{4.4}$$

The pseudo code created for the A* algorithm in the path planning method is shown as Fig. 4.12. A* search algorithm first searches the route that it is most likely to lead to the goal node from the initial node. It maintains a priority queue of nodes to be searched.

```
function astar(start,goal)   // initialize A* algorithm function from start node to goal node
  map[ ][ ] = {array of empty map}   // Array map of navigated nodes
  closedset[ ][ ] = {evaluated nodes}   // Array map of evaluated (already visited) nodes
  openset[ ][ ] = {start}   // Array map of nodes to be evaluated (unvisited) nodes

  g[start] = 0   // cost of distance from starting node to current node
  h(start , goal) = abs(start1- goal1) + abs(start2 - goal2)   // heuristic estimate distance from current to goal
  f[start] = g[start] + h(start , goal)   // estimated total cost from start to goal f = g + h

  while (openset[ ][ ] != empty)   //while openset not in empty state
    current = node in openset[ ][ ] that has the lowest f[ ] value   // current node that contains lowest f value
    if current = goal   // if goal node found to be same node as current node
      return path_found   // path to goal has been found

    remove current from openset[ ][ ]   // current node that becomes parent node is eliminated from open set map
    add current to closedset[ ][ ]   // current node that has become parent node is added to close set map
    for each adjacent_nodes in adjacent_nodes(current)   // Neighboring nodes of current node
      uncertain_g = g[current] + dist_between(current,adjacent_nodes)   // calculated g value from current node
      // heuristics estimate distance from adjacent node to goal node
      h(adjacent_nodes , goal) = abs(adjacent_nodes1- goal1) + abs(adjacent_nodes - goal2)
      uncertain _f = uncertain _g + h(adjacent_nodes , goal)   // calculate f value from current node
      if adjacent_nodes in closedset and uncertain _f >= f [adjacent_nodes] // whenever f value is not the lowest
value
          continue   // continue searching

      if adjacent_nodes not in openset or uncertain _f < f[adjacent_nodes]   // if lowest value of f is found
        map[adjacent_nodes] = current   // the adjacent node found with lowest f value is updated in map
        g[adjacent_nodes] = uncertain _g   // the g value of the adjacent node is updated
        f[adjacent_nodes] = uncertain _f   // the f value of the adjacent node is updated
        if adjacent_nodes not in openset   // check adjacent avaibility in open set map
        add adjacent_nodes to openset   // if not in open set map add adjacent node to open set map

  return path_not_found   // return if path cannot be calculated
```

Figure 4.12: Coding of A* algorithm for the shortest path searching algorithm

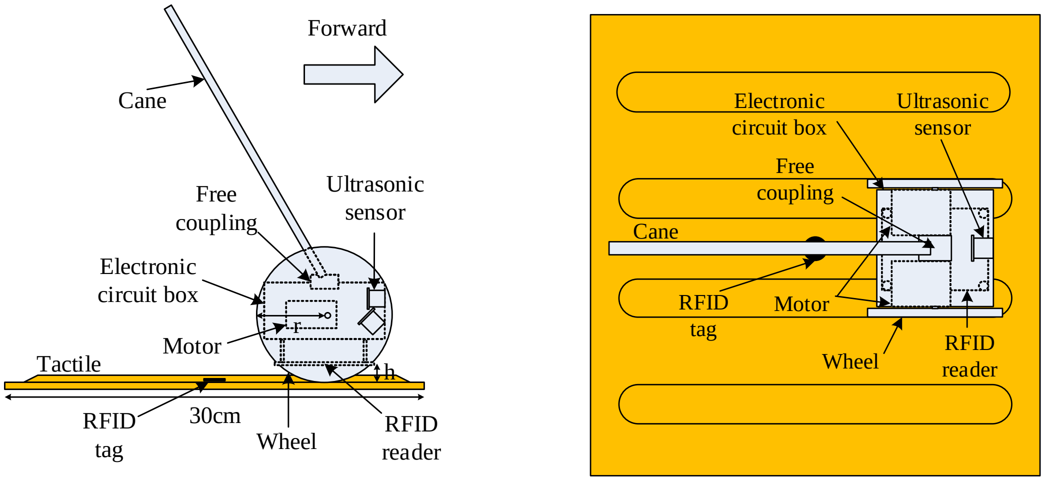
This priority queue is known as open set because the lower evaluation function of $f(n)$ for a given node n gives a higher priority. Node with the lowest $f(n)$ is removed from a priority queue at each step of the algorithm. Neighbor nodes of a removed node within a priority queue will be updated with the latest value of $f(n)$ and $g(n)$. The algorithm continues to search for lower $f(n)$ along the route value until goal node is reached and the queue is empty. The $f(n)$ value of goal node is the final distance of the shortest path from the initial node to the goal node.

Whenever the start and goal points are known, the algorithm will calculate the shortest path between the two points based on $f = g + h$. Pseudo code above is implemented in Java programming language with Processing 2.0 as its compiler. The start and goal points are selected with the left mouse button while the route is generated when any key on the keyboard is pressed. Processing 2.0 is chosen as the compiler for its capability to interact with Arduino microcontroller conveniently compared to other types of compilers.

4.2.5 Auto-navigation system

Based on the previously developed navigation system for visually impaired people, the auto-navigation system is proposed in order to change the previous concept of applying human as the decision maker. The previous navigation system uses a manual method where humans will control the white cane to turn or go forward when hearing the voice navigation from the previous system. Hence, by applying the auto-navigation system which includes DC servo motor to guide the visually impaired people automatically, the burden of the user will be reduced. At the same time, each information from the sensor units such as digital compass, encoder, accelerometer, color sensor, GPS unit and ultrasonic sensor will be measured and collected to ensure the safety of the user. Figure 4.13 illustrates the design of the auto-navigation system for the visually impaired people on the tactile pavement.

Furthermore, the addition of other environmental sensors instead of digital compass such as encoder will assist the visually impaired people on the distance that has been traveled. Hence, the user would know the distance's information directly from the navigation system. Besides, the usage of inertial measurement unit (IMU) / accelerometer sensor unit will also help the user on tracking when the user is strayed from the tactile pavement path. This condition sometimes happens when big obstacles such as car, bike or bicycle are parked on the tactile pavement. The visually impaired people need to avoid the obstacle and find the tactile pavement again in order to reach the destination safely. Moreover, a color sensor can also be applied inside the auto-navigation system



(a) Side view (b) Top view

Figure 4.13: Illustration of proposed auto navigation system with tactile pavement

to ensure the path that the visually impaired people use to travel is yellow in color which is normally used in Japan. Figure 4.14 illustrates the total system overview of the proposed auto-navigation system for the visually impaired people in order to navigate either at an indoor or outdoor environment.

In addition, two pieces of ultrasonic sensor which are mounted in front of the auto-navigation system will also assist the visually impaired people to detect the obstructions that exist around them. The usage of two pieces of ultrasonic sensor is due to detection for the front and down direction of the auto-navigation system. If there are any obstructions such as holes or stairs, the change of the distance measured by the ultrasonic sensor will be monitored and the alert by using voice and vibration will be given. At the same time, the DC motor will also be activated to turn to the safe direction. Here, the proposed control system which will be applied is a fuzzy control system to identify the safe distance from the obstruction and calculate the turning degree of the DC motor. Besides, the GPS unit is also mounted on the auto-navigation system just to log the place which has been traveled by the visually impaired people in order to track them if they are lost. Therefore, the relatives of the visually impaired people could find them easily.

Moreover, the moving speed of the auto-navigation system is designed to be similar to the human walking speed, v_h. Thus, the calculation of rotational speed for the designed auto-navigation system is based on the circumference, C of a wheel as shown

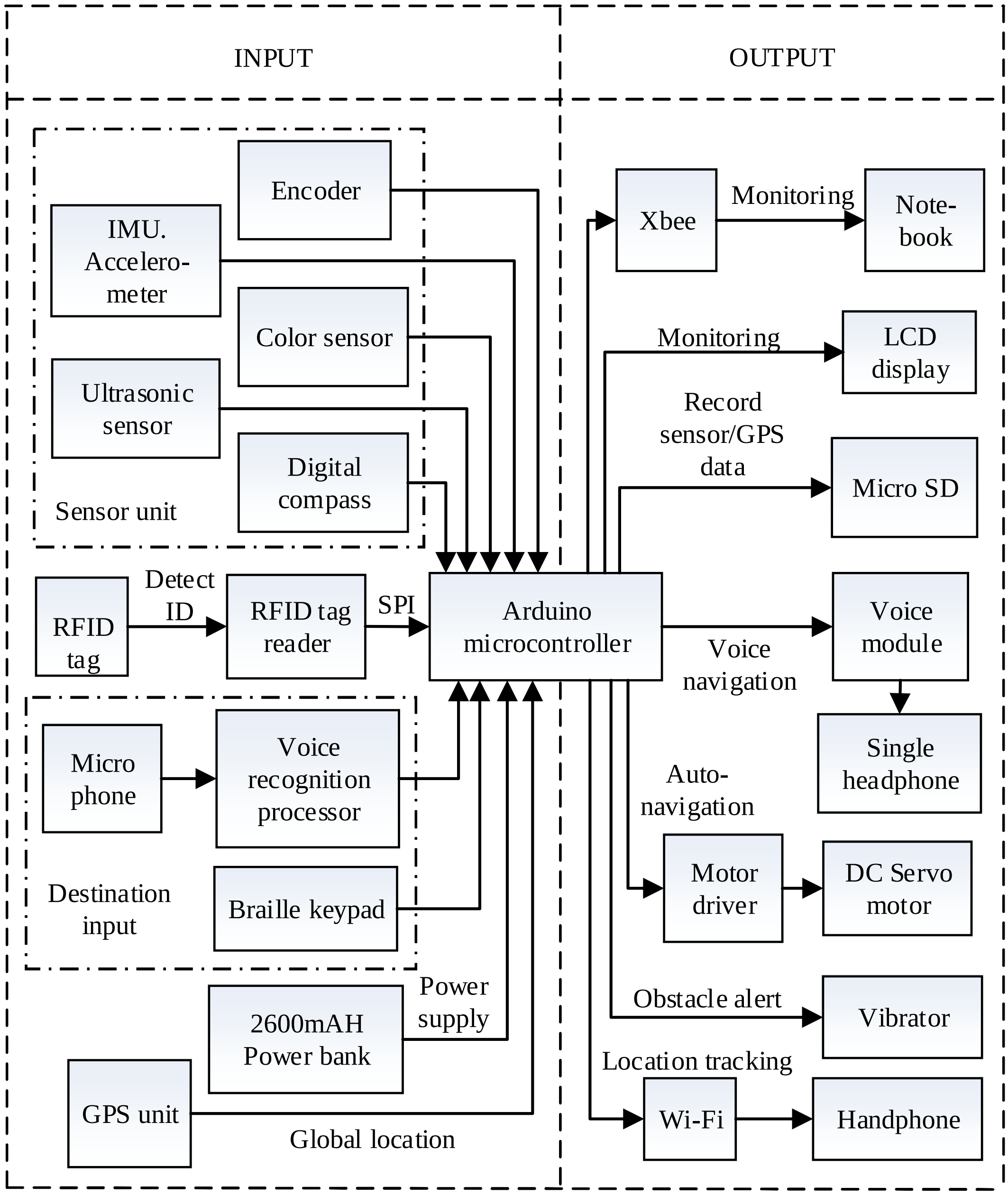


Figure 4.14: Overall system overview of proposed auto-navigation system

in Eq. (4.5).

$$C = 2\pi r[\text{m}] = 2(3.14)(0.05) = 0.314[\text{m}] \tag{4.5}$$

where tire diameter, d which will be used is 0.1 m. The wheel circumference, C which is calculated based on Eq. (4.5) is 0.314 m. Hence, the required DC motors rotational speed, ω is determined by using Eq. (4.6).

$$C = \frac{v_h}{\omega} \tag{4.6}$$

$$\omega = \frac{v_h}{C} = \frac{66.67}{0.314} = 212[\text{min}^{-1}] \tag{4.7}$$

where the average human walking speed, v_h is 4 km/h $\approx$ 66.67 m/min. Thus, the required DC motor rotational speed is about 212 min^{-1} and the recommended supply voltage for DC motor is about 3 V to 5 V due to the core power supply which provides about 5 V from the 2600 mAH power bank.

4.3 Tactile pavement detection system using vision

Figure 4.15 shows the system configuration between personal computer with MATLAB, web camera, Arduino microcontroller board, XBee transceiver, voice module WTS 020 and speaker in order to give auditory warning to visually impaired people after the implementation of vision based tactile detection method. After a coding has been inserted into the Arduino microcontroller, it will be ready to receive signals from MATLAB, and then send commands to the voice module to play selected audio files. In order to produce auditory output, a voice module will be used to play the required audio file when commands are executed. Figure 4.16 shows the actual hardware which has been developed in order to validate the performances of the proposed vision based tactile pavement detection system.

From the illustration which is shown in Fig. 4.16, a web camera is mounted on the center of the electronic cane. A distance between the web camera to the tactile paving is about 50 cm. The web camera is connected to the personal computer which

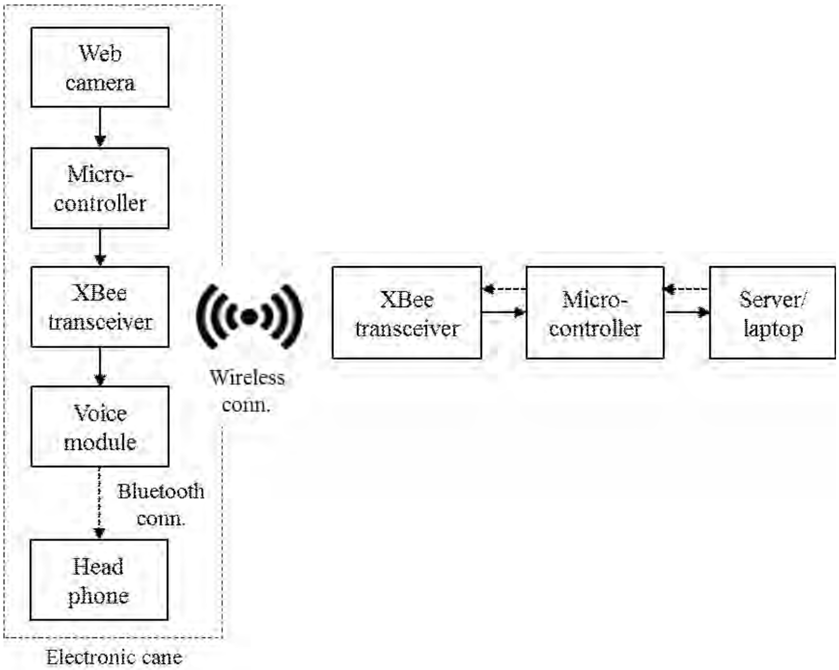


Figure 4.15: System configurations

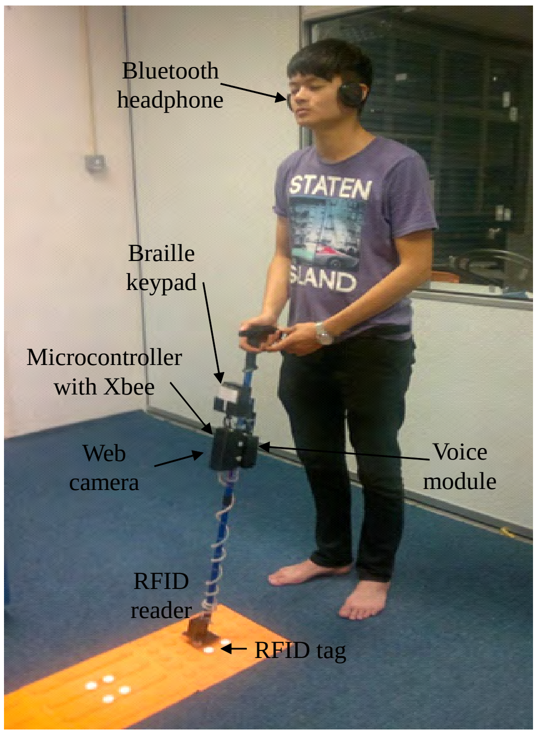


Figure 4.16: Actual hardware

has been installed with the MATLAB software through XBee wireless communication. The personal computer will process the image which has been captured through the web camera by using the proposed tactile pavement detection system. After the shape of the tactile pavement has been successfully determined by the proposed tactile pavement detection system, two types of voice guide will be given which are WARNING and DIRECTION through speakers worn at the head of the user. The result of the detection will be sent through XBee transceiver to the guide the cane's transceiver in order to activate the voice module. The voice guidance will be given through Bluetooth wireless communication.

This vision based system consists of five main phases. The first part is to input the image containing the tactile pavement with the warning tactile and directional tactile. The second part is the pre-processing of the input images, which includes the filtering of the noises for the tactile detection in the image. The third part is to extract and determine the area and perimeter of the connected components detected in the image. The fourth part is to determine the metric for the connected components by using the area calculation algorithm of the detected components. The last part is to produce the accurate audio output to the visually impaired people. A process flowchart regarding the overall process of this system is shown in Fig. 4.17.

Input Image

A webcam/camera will be used to capture the image that contains the pattern of tactile pavement. It will be loaded into MATLAB for further pre-processing to successfully detect any possible tactile shapes. Figures 4.18 (a) and 4.18 (b) show the images of tactile paving which are warning tactile and directional tactile.

Pre-processing

This phase of the whole process is to filter the image of what is actually required to be detected in MATLAB. There are several steps that are shown in Figure 4.17 in pre-processing which are important to achieve the goal of the vision based system.

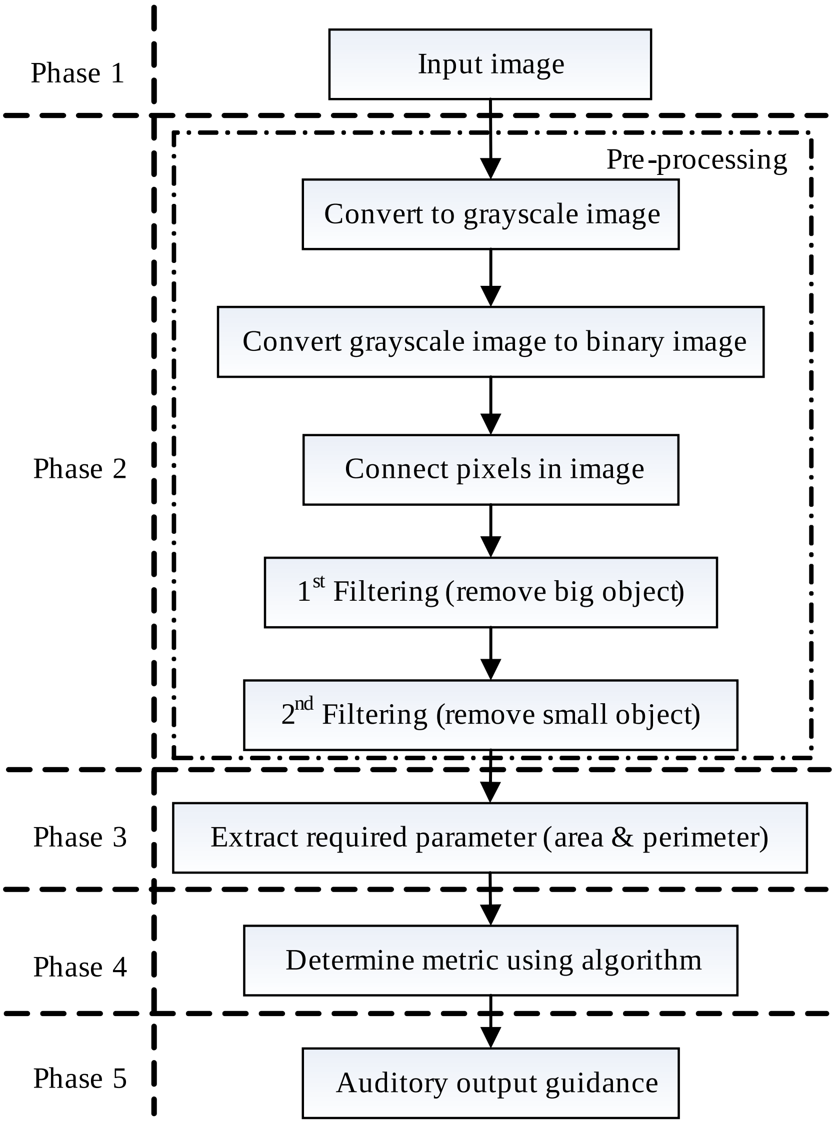
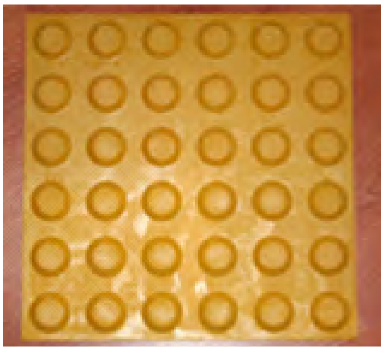
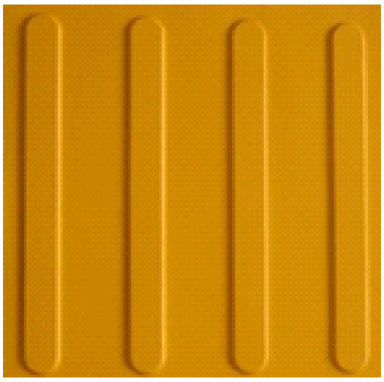


Figure 4.17: Overall process flowchart of vision based blind guide system



(a) Warning tactile



(b) Direction tactile

Figure 4.18: Input tactile image

Color image to grayscale image

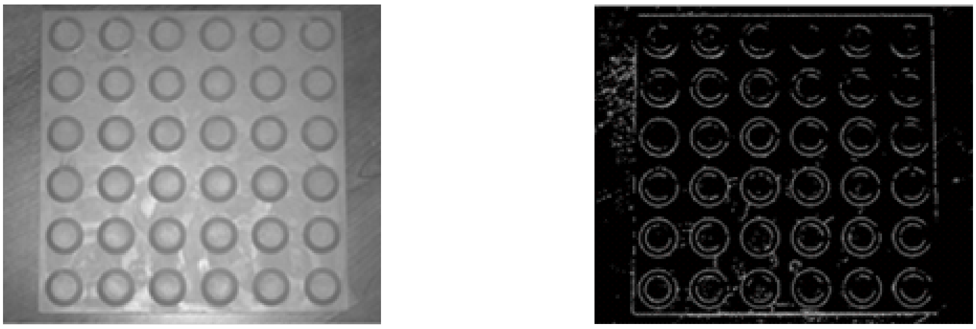
The previous image is an RGB image, which is a colored image. The brightness levels of the red (R), green (G) and blue (B) components are each represented as a number from decimal 0 to 255. Therefore, the RGB image has to be converted to black and white image for the ease of processing. The lightness of the grey is directly proportional to the number representing the brightness levels of the primary colors. Black is represented by value for each R, G, B is 0 while white is represented by value of each R, G, and B is 1. The converted grayscale image is shown in Fig. 4.19 .

Grayscale image to binary image

This process will change the grayscale image to a binary image, which is an image with only black and white pixels in it. Figure 4.19 (a) shows the grayscale image after the conversion process. The pixel value that exists in this format of image is only 0, which is black in color, and 1, which is white in color. Figure 4.19 (b) shows the resulting image of the binary image after it has been through the thresholding method when the threshold has been set to the value of 0.5.

Connecting pixels in image

In this phase, pre-processing is used to identify the connected components inside the binary image. Figure 4.20 shows the connected components algorithm which is applied



(a) Grayscale image (b) Binary image

Figure 4.19: Image conversion process

in order to identify the connected components by using a group of binary symbols. After the connected components have been identified, the next process is to fill the " holes " inside any connected pixels in the image automatically using MATLAB, in an attempt to make the connected pixels look more obvious. Therefore, further detecting process for the tactile shapes could be performed easier. The processed image in which the " holes " have been filled with white color is shown in Fig. 4.21.

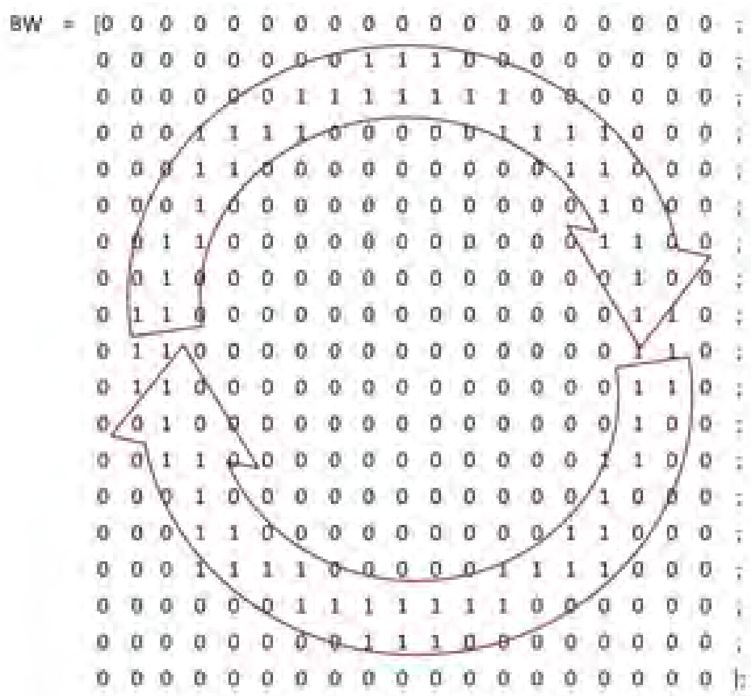


Figure 4.20: Connected components algorithm

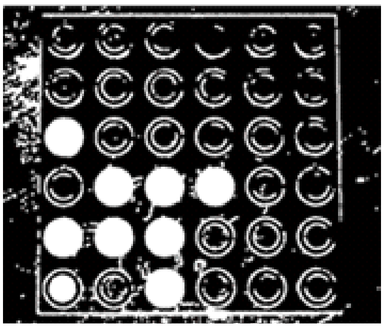


Figure 4.21: Image with filled holes inside connected components

First round image filtering

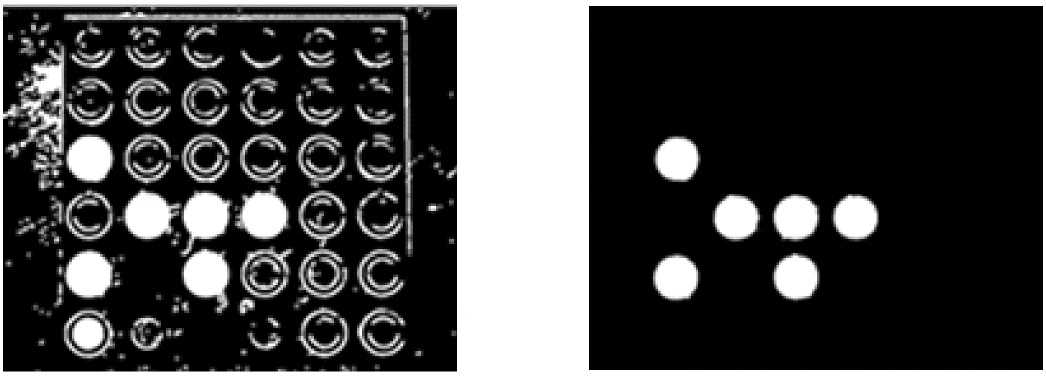
This process has been implemented to remove all objects that are connected to the edge, in which these noises could cause problems for tactile detection in the image. Furthermore, pixels that are connected to the edge are more than likely be useless in gaining any information that is required, therefore removing them would work as filtering. Figure 4.22 (b) shows the image with a cleared border.

Second round image filtering

As it shown in Fig. 4.22 (a), there are still far too many noises present in the image, even after the first round of image filtering. Therefore, another method has been implemented to filter the image of the noises even more. This method is to set a threshold value for the pixel size, and anything that has a pixel value below the threshold value will be removed. Figure 4.22 (b) shows the image after it has removed all components that have a pixel value of less than 1000 $pixel^2$.

Extract required parameters from connected components

In this phase, after the image is filtered by the pre-processing process, some parameters are required from the connected pixels/components that are left. The parameters required by the tactile detection algorithm are area and perimeter of the left image. A function in MATLAB will be used to determine these required parameters. Figure 4.23 shows the pieces of area which is recognized and each of the parameters found by the function on the connected pixels is shown in Tables 4.1a to 4.1f.



(a) First round filtered image (b) Second round filtered image

Figure 4.22: Filtering process

Figure 4.23: Parameters (area, perimeter, centroid) of the connected pixels

Determining the metric

This phase will be the main part that will decided whether the connected components/ pixels in the image are the potential image containing tactile or not. The metric is determined by using Eq. 4.8.

$$m = \frac{4\pi A}{p^2} \tag{4.8}$$

where m indicates metric, A indicates area and p indicates perimeter. Therefore, it is important to obtain the required parameters, which are the area and perimeter of the connected pixels before this phase. MATLAB will calculate the metric from the

Table 4.1: Metric table

(a) Parameter for no.1

Area	1919
Centroid	[146.1730,176.4815]
Perimeter	163.7317

(b) Parameter for no.2

Area	1980
Centroid	[213.070,242.8086]
Perimeter	173.8234

(c) Parameter for no.3

Area	1988
Centroid	[280.6459,242.7938]
Perimeter	177.6812

(d) Parameter for no.4

Area	1951
Centroid	[348.2952,242.4567]
Perimeter	165.6812

(e) Parameter for no.5

Area	1984
Centroid	[144.9057,311.9995]
Perimeter	170.6102

(f) Parameter for no.6

Area	1993
Centroid	[280.9910,310.4752]
Perimeter	173.0955

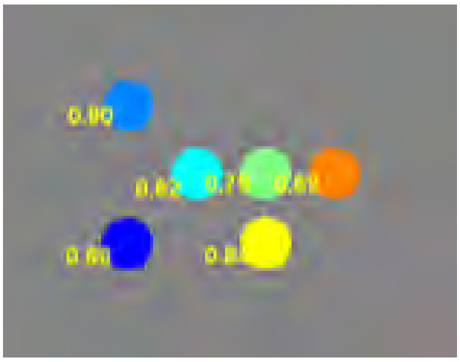
parameters obtained earlier using Eq. 4.8. Table 4.2 shows the result of the metrics of the connected components/pixels.

Table 4.2: Calculation results of metric for each area

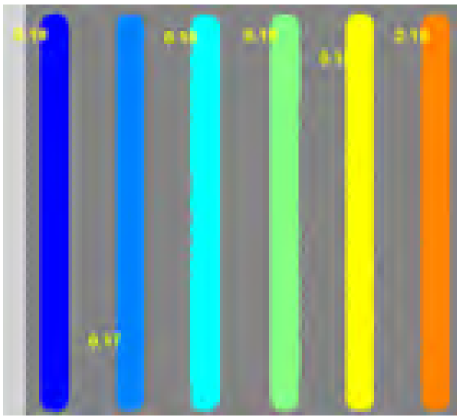
Area	1	2	3	4	5	6
Metric	0.899	0.823	0.791	0.893	0.857	0.836

Producing auditory output based on metric

After the metric for each connected component/pixels has been calculated, the " shape " for each will be determined. In the results, it is proven that the connected pixels which have metric values in the range of 0.85 to 1.0 will most likely be a circle, representing the warning tactile. In contrast, the connected pixels that have metric values in the range of 0.15 to 0.30 will most likely be a bar, which represents the directional tactile. Figures 4.24 (a) and 4.24 (b) show the results of the metric for warning and directional tactile images. After the results of metric values have been



(a) Warning tactile



(b) Direction tactile

Figure 4.24: Final image results

calculated, the system will then send a signal to the auditory output system, and notify the visually impaired people about what have been detected.

Figure 4.25 shows the overall system hardware process flow for the auditory output. In this case, when the warning tactile has been detected (metric value in range from 0.85 to 1.0) in MATLAB, MATLAB will send a signal to the voice module to have an auditory output saying WARNING via Arduino microcontroller, and if the directional tactile has been detected (metric value in range from 0.15 to 0.30), the auditory output would be DIRECTION. Prior to sending signal to the voice module from MATLAB via Arduino microcontroller, a serial communication between MATLAB and Arduino must first be made. After the serial communication has been established, only then will Arduino microcontroller be able to receive any signals from MATLAB when the command is being given.

After the metric has been determined, a certain signal will be send to the Arduino microcontroller, where coding is already uploaded to the Arduino microcontroller board beforehand through the Arduino I/O interface. There are three cases where the metric values are of range 0.15 to 0.30, 0.85 to 1.0 and all the other metric range out of the two before. For example, when the metric values of range 0.15 to 0.30 are found, MATLAB will send a signal to indicate DIRECTION, and Arduino microcontroller will receive it, and execute the next command. It is the same for two other cases, where b will be sent if metric values of range 0.85 to 1.0 indicates WARNING are found and will be sent if none of these two metric ranges are determined.

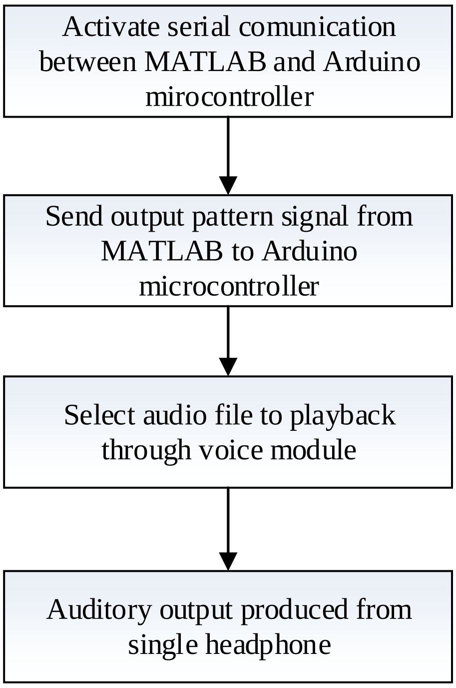


Figure 4.25: System hardware control flowchart

4.4 Summary

In this chapter, the explanations about the navigation system that can be an option for the visually impaired people are described. The navigation system that has been developed consists of RFID detection system, destination input system including voice input and Braille input, path planning system and tactile pavement detection system. These developed systems can be attached inside the electronic white cane and separated from the developed electronic spectacles. Therefore, some experiments will be done and will be explained in details in Chapter 5.

Chapter 5

Experimental Results and Discussions

5.1 Overview

In order to ensure that the designed and developed travel aid device proposed are safe to be used and applied for the visually impaired people, some simulation and experiments are systematically conducted. Some experiments that will be conducted including both developed electronic spectacles and navigation system will be used to assist the visually impaired people mainly on obstacle detection and navigation purposes. Since both topics are related to different kinds of technologies and techniques, this section will be divided into two subsections in which each subsection will discuss on the performance evaluation of developed electronic spectacles and developed navigation system. For the first subsection which is for the developed electronic spectacles, some experiments are done as follows:

1. Blind spot evaluation
2. Simulation study on different design using SOLIDWORKS
3. Respond time of warning system
4. Power consumption evaluation
5. Field test

On the other hand, some experiments which will be conducted for the developed navigation system for visually impaired people can be arranged as follows:

1. RFID detection range
2. Vision base tactile paving
3. Voice recognition
4. Digital compass
5. Shortest path search algorithm
6. Performance of developed navigation system in field test

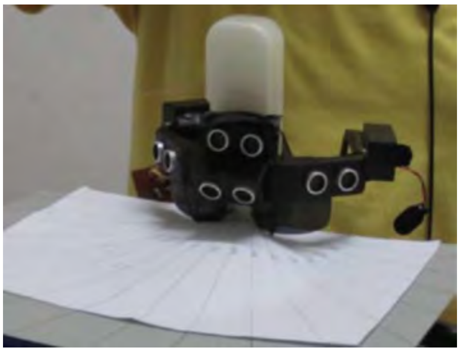
5.2 Performance evaluation of electronic spectacle

5.2.1 Blind spot evaluation

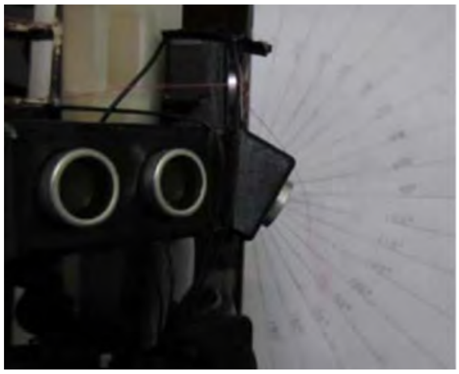
Firstly, the evaluation of blind spot for the developed electronic spectacles is required in order to ensure the safety zone that can be used to protect and guide the user when using the electronic spectacles. There are two types of electronic spectacles that have been developed which are full direction type and simplified type. The developed full direction type electronic spectacles are evaluated based on the detection range and angle that can be covered through the experiment. However, the evaluation of blind spot for the simplified type of electronic spectacles will be conducted through simulation by using SOLIDWORKS software. The details of the evaluation for the simplified type will be described in subsection 5.2.2.

Figure 5.1 shows the experimental setup for evaluation of the blind spot of the developed full direction of electronic spectacles. The apparatus used are tripod, developed electronic spectacles and measuring tape. The developed electronic spectacles device is installed on a tripod. A cardboard with an angle is placed below the electronic spectacles with the center of the angle is the same with the center of the electronic spectacles. The developed electronic spectacles will be activated and obstacle will be moved in front of the device horizontally from 0 deg. until 180 deg. slowly from left to right. The same method is also applied for the experiment for the front and down sensors. The obstacle will be moved from up to down vertically from 0 deg. until 180 deg.

Figure 5.2(a) is a detection range that shows the results of the blind spot from the top view for front, left and right sensors for the developed full direction type electronic spectacles. At this time, the threshold of 0.5 cm is set to ease the measurement. The

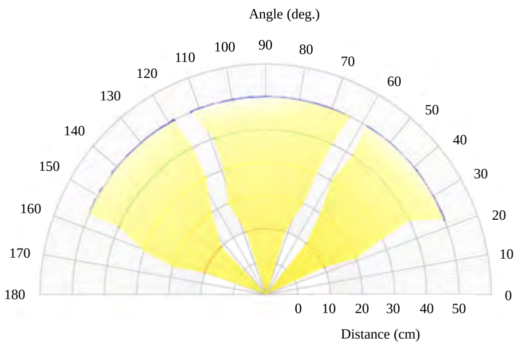


(a) View of front, right and left sensor

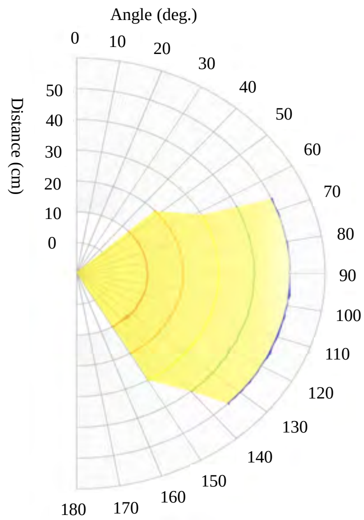


(b) View of front and down sensor

Figure 5.1: Blind spot experimental setup



(a) View of front, right and left sensor



(b) View of front and down sensor

Figure 5.2: Blind spot experimental result

results showed that the range of detection angle is increased proportionally to the distance of the device and the obstacle. At the same time, the results also showed that there were two blind spots for the designed full direction type device. For the left sensor, the beam line was not smooth and the distortion occurred at the distance between 0.1 m and 0.2 m. The distortion also occurred for the right sensor at a distance of 0.4 m. In addition, Figure 5.2(b) shows the radar chart of detection range from the side view for the front and down sensors. The radar chart in Fig. 5.2(b) shows that the detection range is inversed proportionally decreased to the distance. In addition, two distortions occurred between the distance of 0.2 m and 0.3 m. The blind spot occurred because the strength of the sonar signal is concentrated at the center of the beam and with some lobes beside it.

5.2.2 Simulation for simplified design by using SOLIDWORKS

On the other hand, the evaluation of the new design for electronic spectacles is also important in order to design and develop the user-friendly and highly effective travel aids before further development of the simplified type of electronic spectacles can be done. This is because the previously developed full direction type electronic spectacles was heavy and had low user-friendliness. Hence, some simulation studies are done by using the SOLIDWORKS software to search the optimum detection angle and detection range which can be covered by the proposed simplified electronic spectacles. The parameter which is involved for mounting both ultrasonic sensors are the distance between each ultrasonic sensors indicated as A, the angle of mounting for both ultrasonic sensors indicated as θ_3, the blind spot distance indicated as B, and the coverage length indicated as L. Figure 5.3 shows the parameter involved in the simulation.

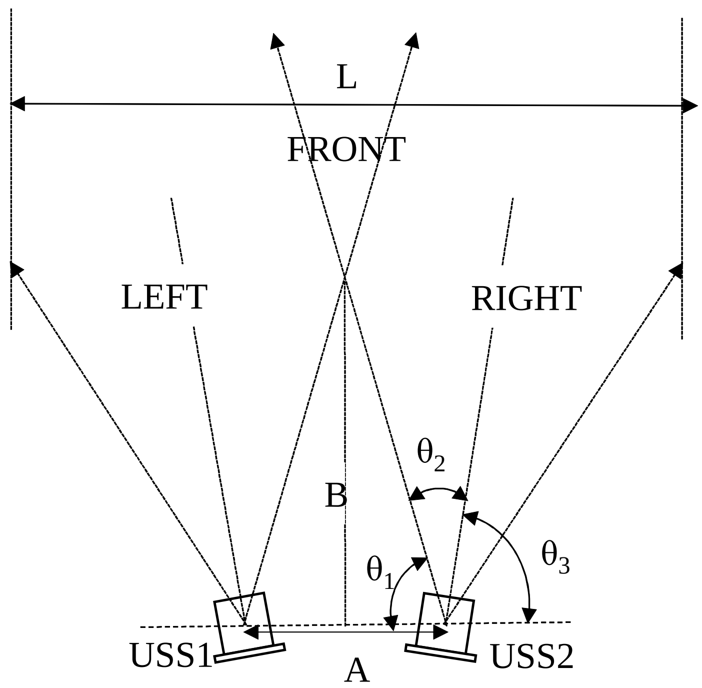


Figure 5.3: Parameter involved in simulation

Therefore, some values of distance, A and the mounting angle, θ_3 inside the proposed design are simulated. The value of distance, A which is selected to be simulated from 8 cm until 13 cm because the distance between both human eyes is 8cm and the length of human forehead is about 13 cm. Meanwhile, the mounting angle, θ_3 which will be simulated stated from 60 deg. until 85 deg. where the inclination of surface to mount the ultrasonic sensor is inside the spectacles frame. Table 5.1 shows the overall simulation for all parameters which need to be determined.

Table 5.1: Simulation result for simplified design

Mounting angle, θ_3 (deg.)	USS distance,A (mm)	Blind spot, B (mm)	Coverage length, L (mm)
60	82	∞	680
70	80	343	584
75	80	188	500
80	80	128	420
85	80	96	360
80	130	199	477

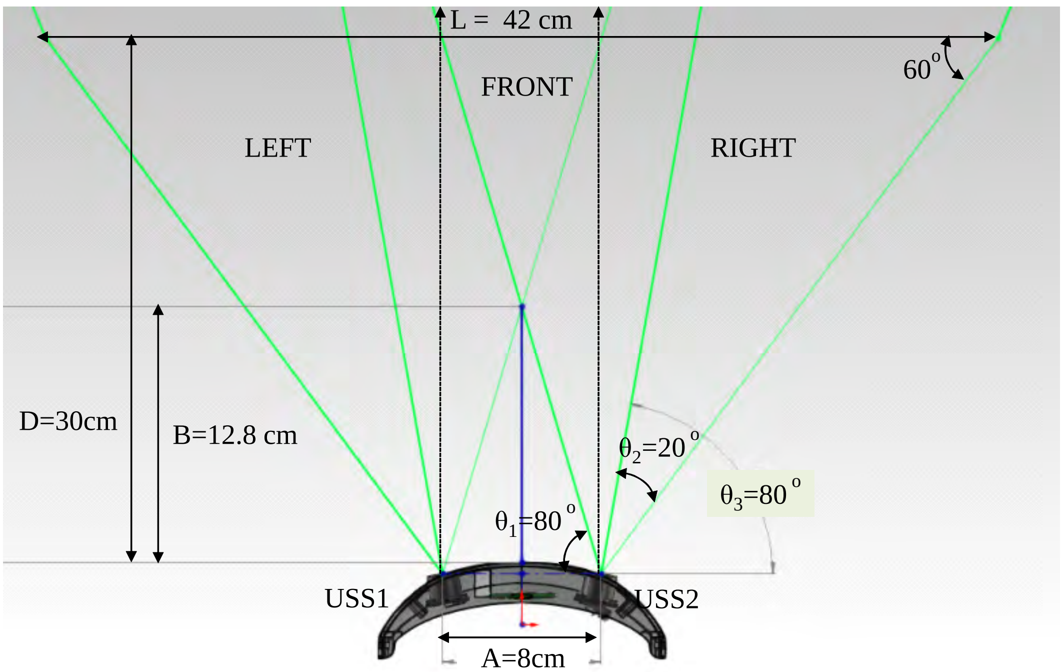
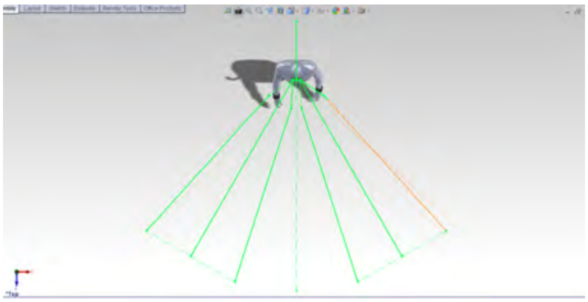


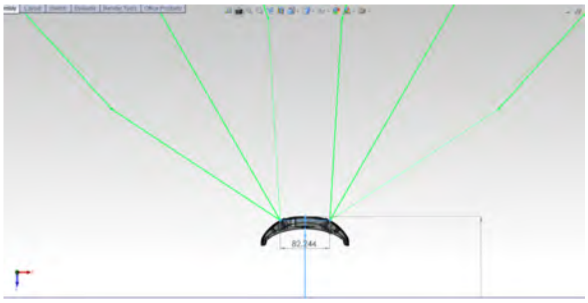
Figure 5.4: Example of calculation for simplified electronic spectacle

Figure 5.4 shows the calculation result for the optimum design where the parameter of A is 8 cm, θ_3 is 80 deg.. However, the blind spot, B that has been detected is about 19.9 cm and not too safe to be used for visually impaired people. Therefore, the simplified design that has been selected to be developed as a mounting angle is 80 deg. and sensor distance is 8 cm because the result of the blind spot is at 12.8 cm. Besides, the result of coverage length, L is also important where the maximum range that can be covered is at 30 cm. The optimum range which needs to be provided is more than 42 cm when the minimum avoidance distance is at 30 cm. The coverage length for travel safety width is calculated based on the average adult shoulder size of around 42 cm.

Figure 5.5 to Fig. 5.10 show the illustration of the simulation result for each parameter that has been simulated. For Fig. 5.5, the blind spot exists for whole front area because the range between both right and left ultrasonic sensors is not integrated. Therefore, the mounting angle, θ_3 is increased. As the result, the blind sport, B area is decreased to 34.3 cm and so on. The distance between each ultrasonic sensor is also simulated at 13 cm in order to ensure the blind spot, B by using different design.

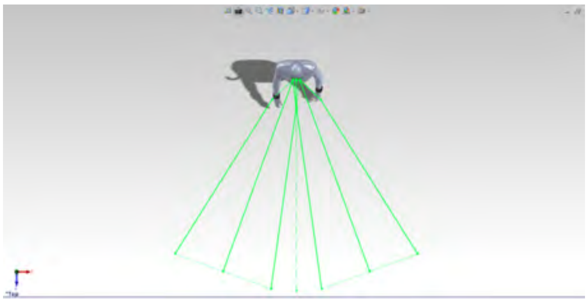


(a) Whole view

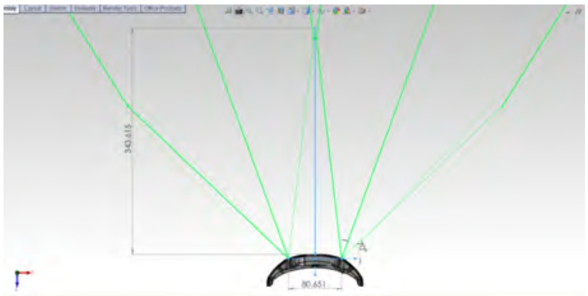


(b) Spot view

Figure 5.5: Mounting angle = 60 deg. and Distance = 8.2cm

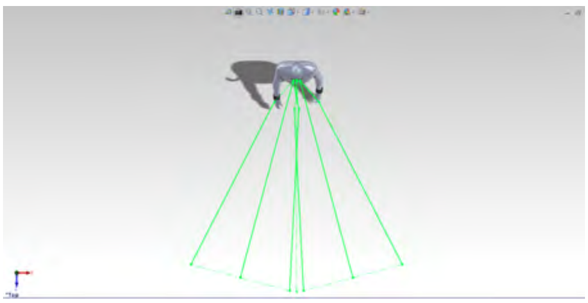


(a) Whole view

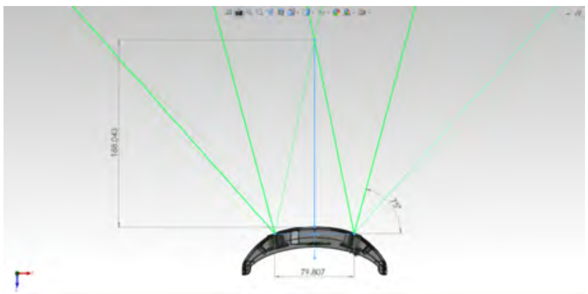


(b) Spot view

Figure 5.6: Mounting angle = 70 deg. and Distance = 8cm

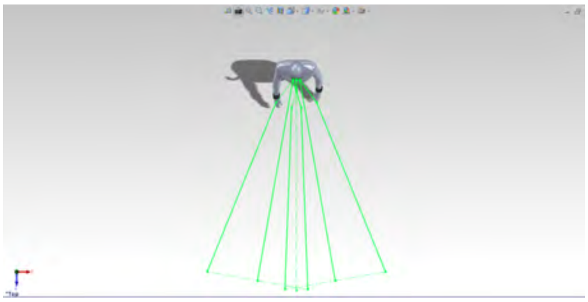


(a) Whole view

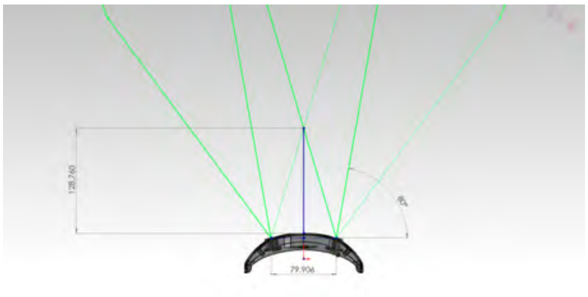


(b) Spot view

Figure 5.7: Mounting angle = 75 deg. and Distance = 8cm

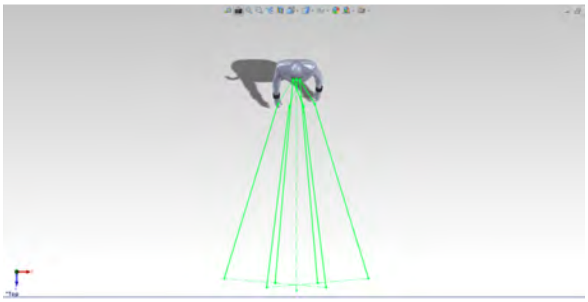


(a) Whole view

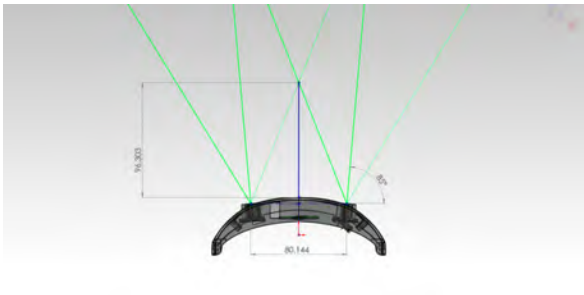


(b) Spot view

Figure 5.8: Mounting angle = 80 deg. and Distance = 8cm

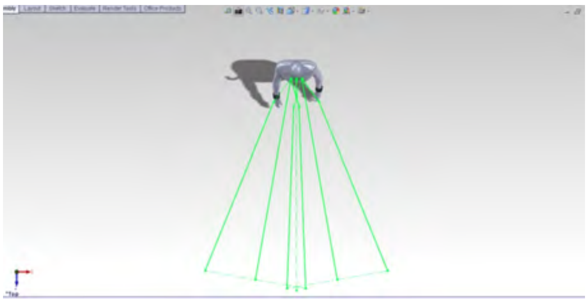


(a) Whole view

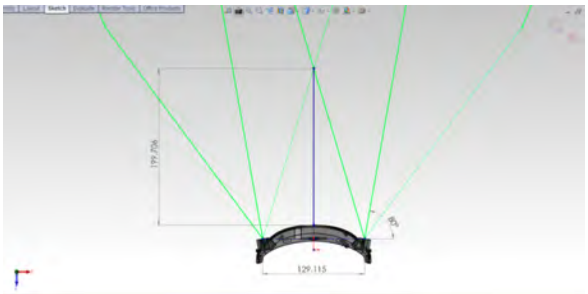


(b) Spot view

Figure 5.9: Mounting angle = 85 deg. and Distance = 8cm



(a) Whole view

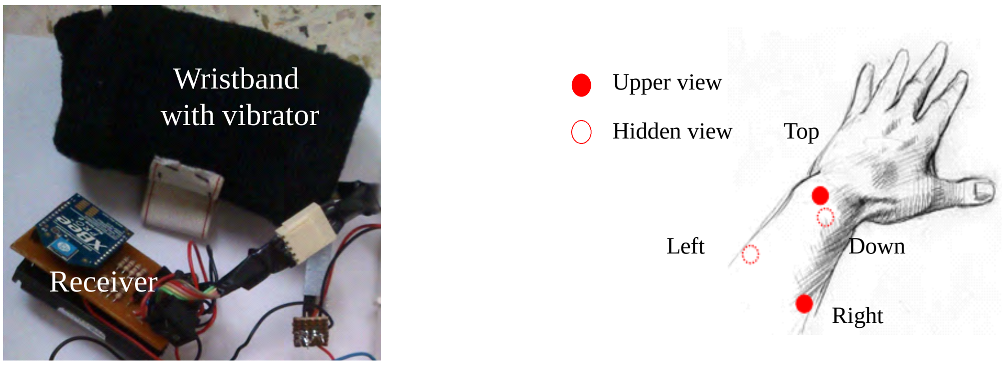


(b) Spot view

Figure 5.10: Mounting angle = 80 deg. and Distance = 13cm

5.2.3 Respond time of warning system

In order to evaluate the effectiveness of the designed and developed electronic spectacles, the implementation of electronic spectacles for visually impaired people has been conducted. There are 20 respondents who participated in this experiment. In this experiment, the respond time by the users to differentiate the direction of the obstacle when the vibration warning device is activated accurately and quickly is evaluated. This aspect is one of the main features needed to be verified in order to evaluate the safety zone by the decision of threshold from obstacle and users. As part of the evaluation method, the explanation will be given to the participated respondents earlier about the operating manual and the direction of each distance measurement sensor including the vibration motor that will be tested in this experiment.



(a) Vibration warning wristband (b) Vibrator location

Figure 5.11: Vibration warning device

Figure 5.11 shows the developed vibration warning device that will be tested. At first, one vibrator will be selected and activated and the respondent is required to differentiate the location of vibrator and the direction of obstacle. Then, when the respondent could answer the location of the vibrator precisely, the respond time will be recorded and the vibrator will be deactivated. This step will be repeated to other respondents to verify the time taken for all respondents. At the end of the experiment, the result is compiled and the graph of experimental result is drawn and illustrated in Fig. 5.12. The x-axis indicates the time taken by the respondent to differentiate the location of obstacle and y-axis indicates the number of respondents. Almost all respondents took around 1.5 s to localize the vibrators mounted in the wristband

and recognize the direction of the obstacle correctly. Nevertheless, the time taken for respondents to localize the vibrator is about 1.8 s in average. As a conclusion, the users need around 1 s to 2 s in order to recognize the location of the obstacle and this result needs to be considered in order to implement better alert system, directional angle and warning distance based on visually impaired people's walking speed.

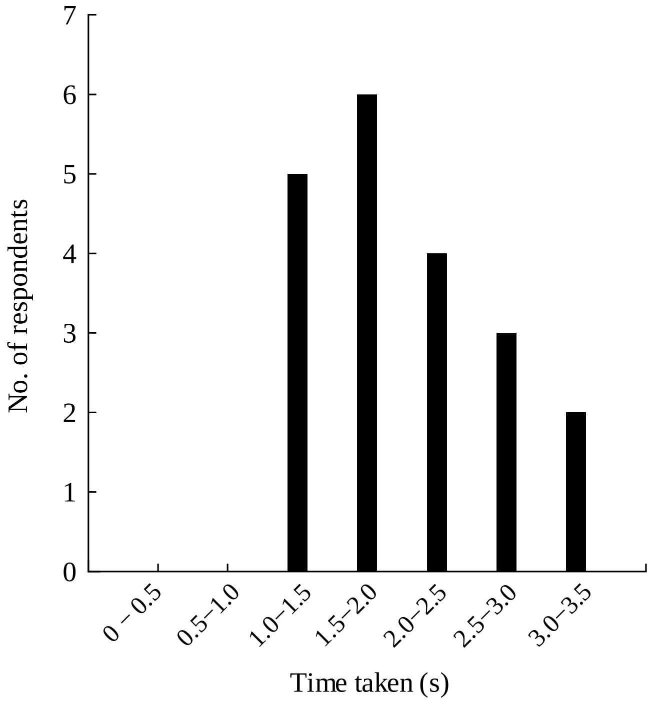
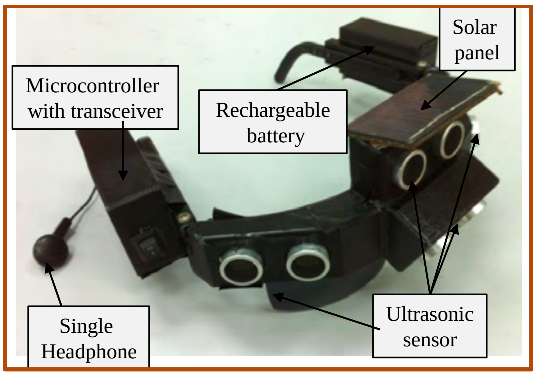


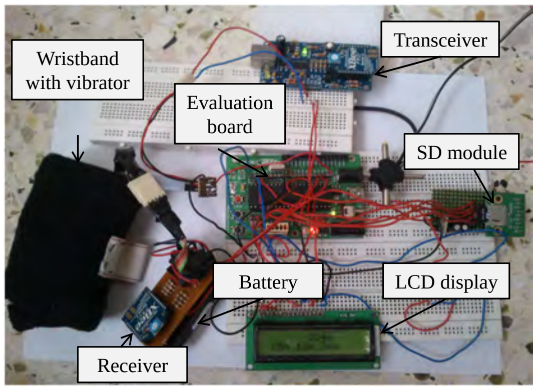
Figure 5.12: Time response by respondent for vibration warning system

5.2.4 Power consumption evaluation

Figure 5.13(a) shows the developed electronic spectacles to detect the obstacles which exist at the upper body level. The developed electronic spectacles consist of the ultrasonic sensor, microcontroller, rechargeable battery, and an earphone. The ultrasonic sensor is used for applying non-contact approach to detect the obstructions at above abdomen level which are floating and difficult to sense by using the white cane. Besides, the wristband type wireless vibration warning device consists of the vibrator, XBee module and 2 pieces of AAA batteries at a total voltage of 3 V which is shown in Fig. 5.13(b). The vibrator inside the wristband is connected to the micro-controller



(a) Electronic spectacle



(b) Vibration device

Figure 5.13: Obstacle detection device for full direction type

through XBee module. LCD display is used to display the measured time and voltages.

In order to evaluate the power consumption for the developed full direction electronic spectacles, two types of experiments are conducted in which the first is always in the ON mode and the second has a switching mode for four vibrators. For the always ON mode experiment, all vibrators are set to ON status until the batteries are finished. Meanwhile, in the switching mode experiment, all vibrators are switched to ON and OFF status every 30 sec. The microcontroller is used to log the supply voltage and XBee output voltage and time elapsed every 30 sec into an SD card.

Figure 5.14 shows the supply voltage which started at 3075 mV and drastically decreased to 2800 mV in 5 minutes. The overall progression of the supply voltage is decreased from 3075 mV to 1950 mV in 630 minutes. This is also similar to XBee output voltage which is decreased from 1875 mV to 1450 mV. Therefore, the overall power consumption is 1.26 W. Besides, the switching mode in Fig. 5.15 shows the supply voltage oscillated in range 200 mV while XBee output voltage oscillated in range 1850 mV. In the overall progression, supply voltage took 937 minutes to drop from 3200 mV to 2200 mV. The XBee output voltage also oscillated between 50 mV and 1850 mV. The overall power consumption is 0.47 W. The evaluation of power consumption for developed wireless vibration warning system has succeeded. The switching mode proved that the wireless vibration warning device could activate for about 15.5 hours.

On the other hand, an experiment has been conducted in which an obstacle is placed in front of the device in order to evaluate the power consumption of the simplified design of electronic spectacles. In this case, a power bank is placed as an obstacle

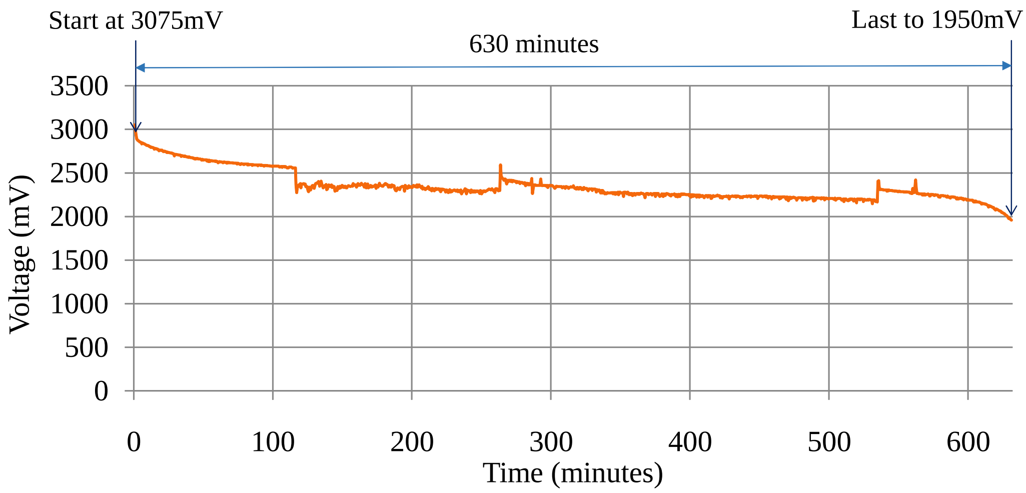


Figure 5.14: Power consumption result for always ON mode

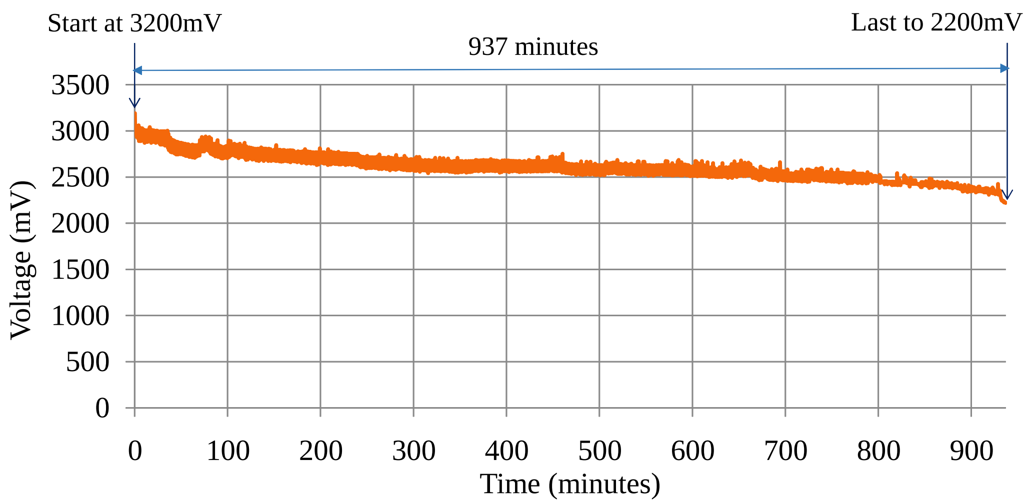


Figure 5.15: Power consumption result for switching mode

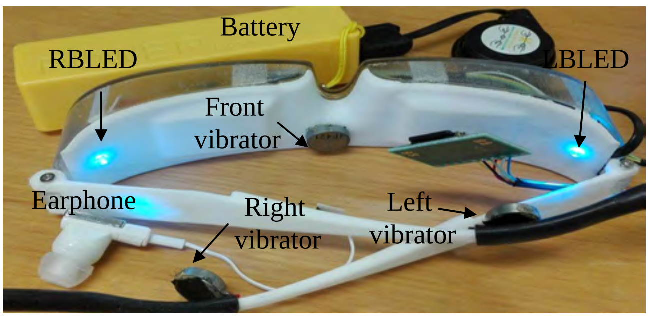


Figure 5.16: Power consumption experimental setup for simplified type

which is illustrated in Fig. 5.16. The power bank used is 3.7 V 2600 mAH Li-on battery. All warning systems including vibration, LED and beep warning device will be activated continuously until the warning device stops, even when the obstacle still exists. The raw battery voltage including time will be recorded at a sampling time of 1 sec each.

As the result, Fig. 5.17 shows the experimental result for the newly developed electronic spectacles. From the figure, the fully charged raw supply voltage starts from 3.68 V. The supply voltage is decreased gradually until the vibration warning device is stopped at 3.4 V. At the same time, the LED and beep warning are still activated. All warning devices are stopped at 3.1 V around 140,000 seconds which are about 38 hours after the experiment started.

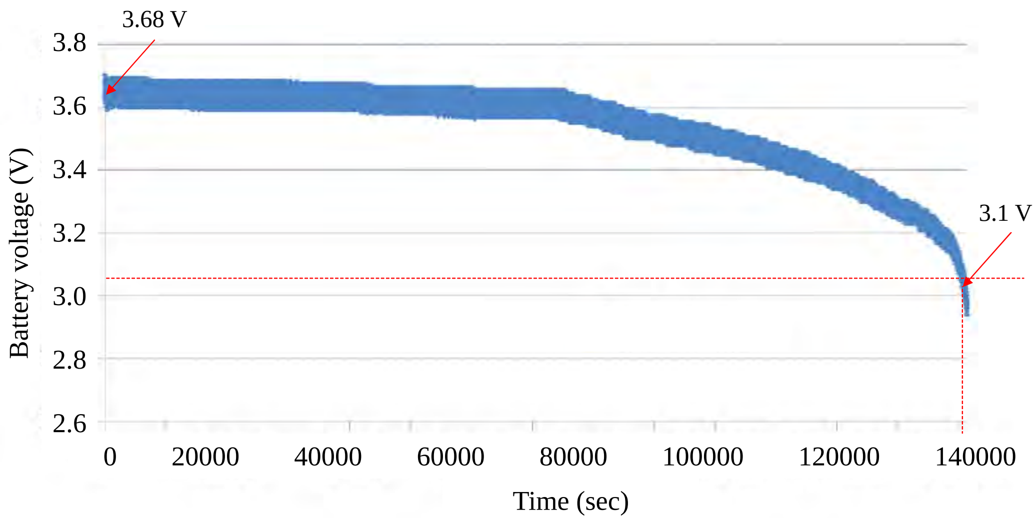


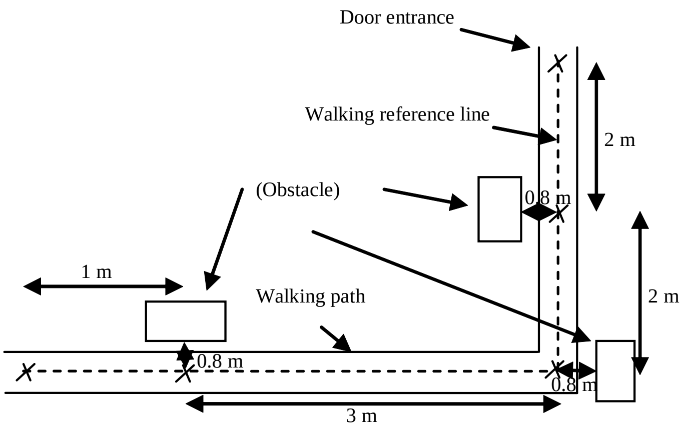
Figure 5.17: Power consumption result for simplified type

5.2.5 Field test

Full direction type electronic spectacle

In addition, the experiment to evaluate the performance of the device while walking has also been conducted. Figure 5.18(a) shows the performances test for the developed full direction electronic spectacles. The apparatus used are measuring tape, developed full direction electronic spectacles, SD card circuit, and obstacles such as a ping-pong table and a tripod with two wheels installed at a stand. The developed full direction electronic spectacles are mounted on the tripod. Four obstacles are placed along a track. The distance from the obstacle to the track is set to 80 cm each and the point is marked down as a reference point for each obstacle which is illustrated in Fig. 5.18(b). The distance between the starting point to the obstacle, the obstacle to the next obstacle and obstacle to the end point will be recorded.

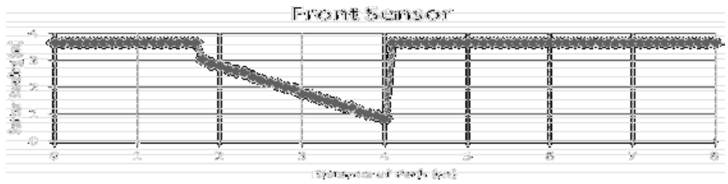
(a) Performance test while walking motion



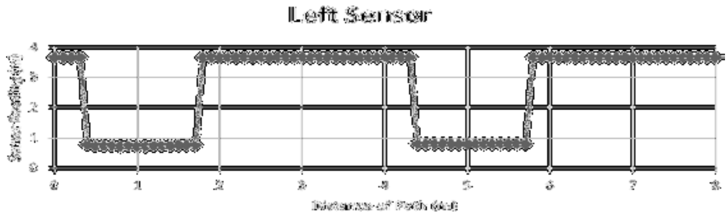
(b) Time response by respondent for vibration warning system

Figure 5.18: Field test setup

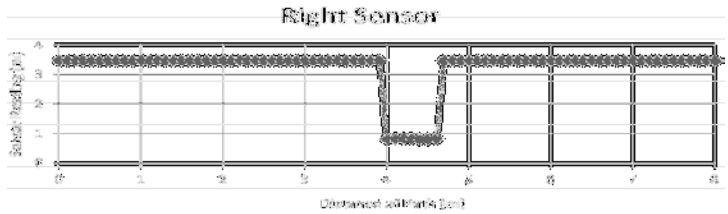
Figure 5.19 shows the experimental results for the walking motion. From the figure, the graphs for 0.4 m until 1.7 m and 4.4 m until 5.7 m show approximately 0.8 m. This is because there are obstacles placed beside the way of the path. For the front and down sensors, the graph is similar because the obstacle which has been set for the path is the same for the front and down sensors. The reading started to drop from 1.8 m until 4 m. This happens because in the experiment, the device is pushing closer to the



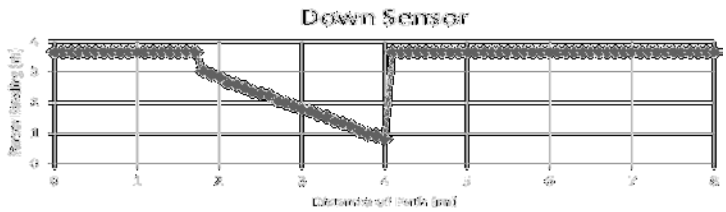
(a) Distance detected for front sensor



(b) Distance detected for left sensor



(c) Distance detected for right sensor



(d) Distance detected for down sensor

Figure 5.19: Experimental result while walking in field setup

obstacle. For the right sensor, there is approximately 0.8 m shown on the ultrasonic sensor data for the path from 4 m until 4.6 m. This is because the obstacle is placed at the path to ensure the effectiveness of the right sensor. For the walking experiment, the average accuracy for four of the sensors in the experiment is 97.95%. This is because of the angle of reflect. The ping-pong table is placed beside the path and perpendicular to it. During the experiment, the side sensors sensed the table with the angle that is not perpendicular to it, and accuracy cannot be obtained at 100% because of this.

Simplified type electronic spectacle

On the other hand, the performance evaluation of the developed simplified electronic spectacles also needs to be done. The evaluation includes the proposed multi-modal warning device on electronic spectacles which can be used to detect the upper abdomen level obstacles. The effectiveness of the warning device that will be given to the subject to avoid the obstacles which have been set in the experimental setup will be evaluated. Figure 5.20 shows the field setup which is set to conduct the experiment. This field is set at the corridor with a size of about 8.0 (L) x 2.6 (W) x 2.6 (H) m. In this experiment, three pieces of obstacle are used and mounted at different positions which are illustrated in Fig. 5.21. Sizes of these obstacles are about 0.6 (L) x 0.3 (W) x 0.2 (H) m each. These obstacles are hung up at 1 m from ceiling by using ropes. At the center of the path, some tactile pavement blocks are also mounted to guide the subject after avoiding the obstacle to walk at the center again. The experiment started from the warning tactile until the next warning tactile which is about 6 m long.

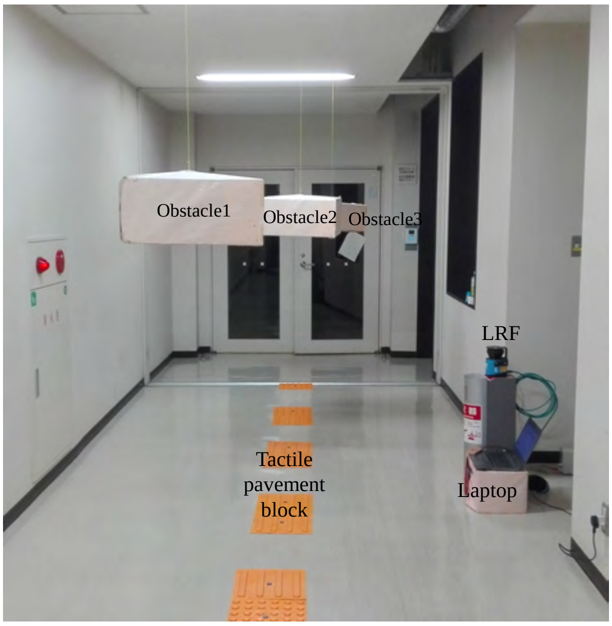


Figure 5.20: Experimental setup for simplified type

In this experiment, the subjects involved are normal people. There are five subjects who have cooperated in conducting the field experiment. Average age of subject is about 25 years old. The subjects will wear the developed electronic spectacles including

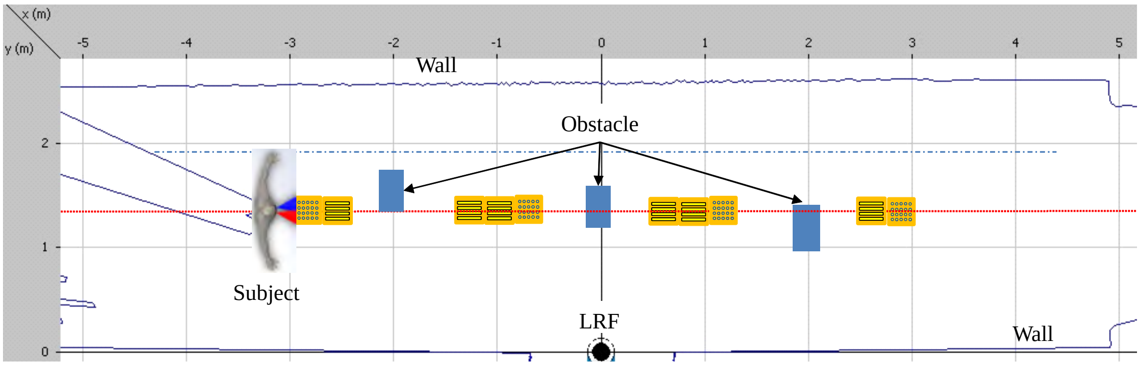


Figure 5.21: Field setup illustrated by using LRF

the multi-modal warning device in front of their eyes. Since the spectacles are black in color, they can be act as a blindfold where the subjects cannot see anything around them. The subjects will only use the warning signal which is given from the warning device such as the beep sound, vibration and light from LED in order to avoid the obstacles around them. At the same time, a laser range finder (LRF) is mounted at the center of the floor as an external observer of the experimental setup. The movement of the subject will be traced and the path will be recorded by using LRF.

In addition, the field experiment can be analyzed successfully by using some sensors which have been mounted on the subject's head such as gyro sensor and ultrasonic sensor in order to analyze the movement of the subject's head while detecting the obstacle and the detected obstacle distance. The subject will also wear a helmet that has been installed with a gyro sensor is shown in Fig. 5.22. Here, Fig. 5.23 to Fig. 5.26 show the experimental result for one of the subjects that has been selected. The overall route is divided into seven steps to confirm the action of the subject. Fig. 5.23 shows the experimental result that has been measured by using LRF to trace the position of subject while walking through the field. From the result, the subject's path is shown each second when the subject walked and avoided the obstacles.

The average time that the subject took to finish the experiment is about 1 min 10 sec. However, the result of the subject which is shown in Fig. 5.24 took about 1 min 37 sec where the measurement by the ultrasonic sensor inside the developed electronic spectacles is shown which is subject C. Table 5.2 shows the time consumed by each subject who participated in the field experiment including their ages. For subject C, it is confirmed that the distance between subject and obstacle is decreased when the

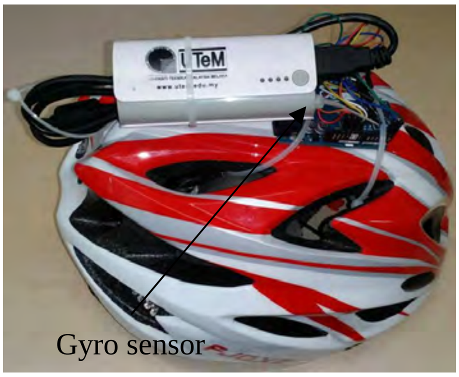


Figure 5.22: Installation of gyro sensor on the helmet

subject is nearing the obstacle. Hence, the subject walked and made the decision carefully. From the result, the subject avoided the obstacles successfully, although the subject took 5 s to 8 s to identify the location of the obstacles for avoiding the obstacles. Then, while avoiding the obstacle, the subjects confirmed the location of the obstacle by turning their head to ensure either the obstacle is already passed or not. This can be confirmed by the measurement of the gyro sensor at X, Y and Z-axis since the sensor platform is mounted 45 deg. on the subject's head which is shown in Fig. 5.25. Here, X-axis is mainly analyzed in this experiment.

Table 5.2: Average age and time consumed by each participant

Subject	Age (years old)	Time consumption (sec)
Subject A	25	60
Subject B	22	55
Subject C	21	97
Subject D	23	70
Subject E	34	65
Average	25.4	70

For the first obstacle, the subject took a right turn action when the multi-modal warning device such as LED warning blinked at the left side only where the obstacle existed. After avoiding the obstacle, the subject turned left to return back to the center of the path by sensing the tactile pavement that has been set by using a white cane. Next, for the second obstacle, the subject took several times to identify the obstacle carefully when multi-modal warning device such as both left and right LEDs blinked. The subject turned his head right and left repeatedly to confirm the location of the obstacle. Then, the subject took an avoidance route at the right side while confirming the location of the obstacle. For the final obstacle, the subject received an LED blink signal at the right side only and took the turn right action for avoiding the obstacle. From the result, it has also shown some small objects which are observed separately from the subject's body. This object was a white cane to guide the subject to the tactile pavement captured by LRF that has been mounted at 0.8 m from the floor.

The strength of warning signal given to the subject also varied. This is related to the distance measured by each ultrasonic sensor and the duty cycle which is shown in Fig. 5.26. The duty cycle value is increased when the distance between obstacle and spectacles decreased for each direction of ultrasonic sensor. In addition, the left warning device is activated when the obstacle is detected at the left side. Meanwhile, when the obstacle is detected by both left and right ultrasonic sensors, the duty cycle of the front warning device is increased and activated successfully. The same effect is also confirmed when only the right side ultrasonic sensor detected the obstacle. The time respond to activate the warning device also is not delayed and effective enough to give a direct warning signal to the visually impaired people.

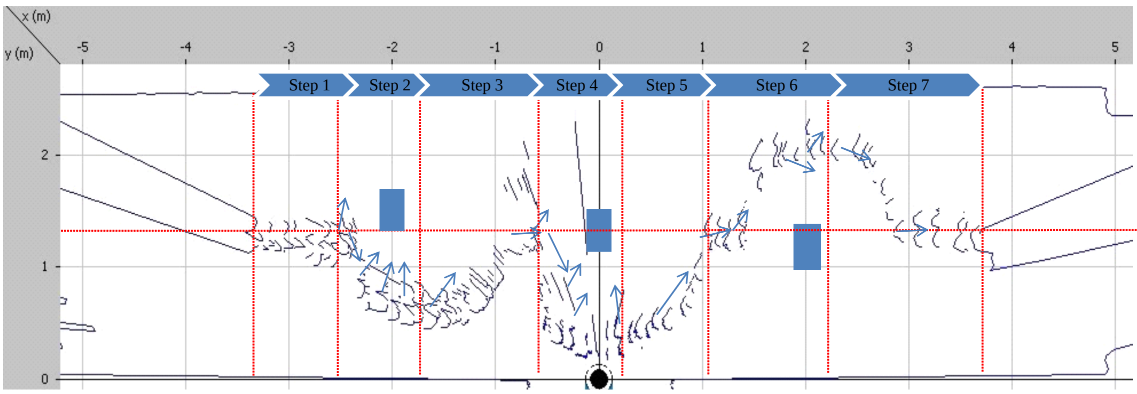


Figure 5.23: Avoidance result

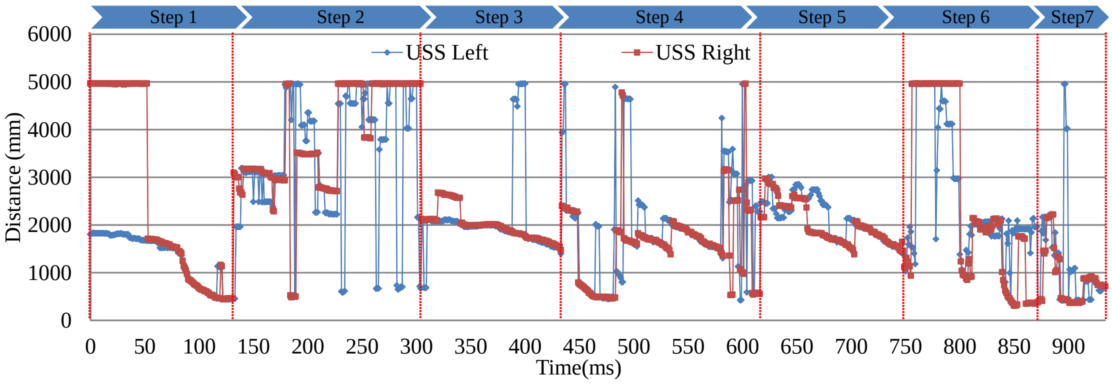


Figure 5.24: Obstacle distance measurement

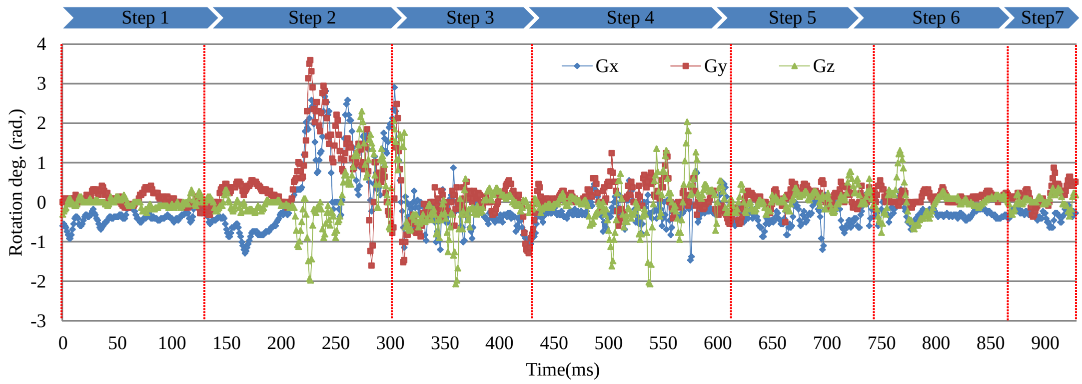


Figure 5.25: Head movement

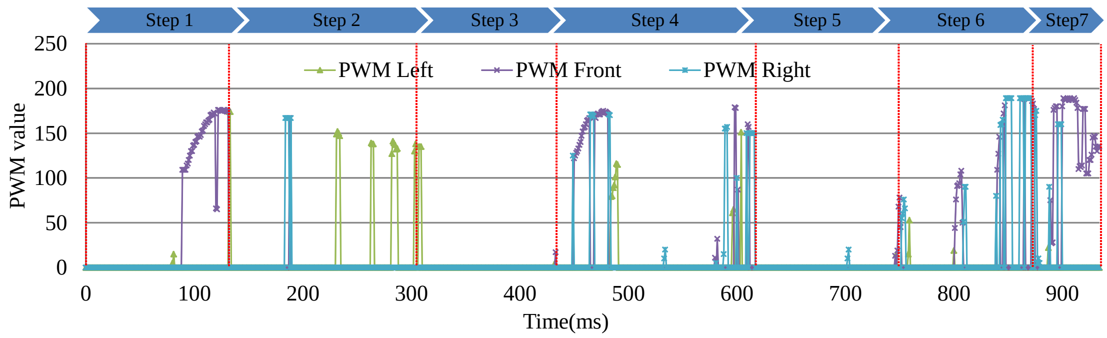


Figure 5.26: PWM value

5.3 Performance evaluation of navigation system

5.3.1 RFID detection range

Relation between antenna size with maximum detection range

In order to validate the maximum detection range of the RFID reader/writer, some experiments have been conducted. The experiment which has been done is the maximum detection range of the RFID reader/writer when the height of the RFID reader/ writer is changed. The purpose of this experiment is to determine the optimum height of the RFID reader/writer which will be used in the proposed auto-navigation system for outdoor environment to assist the visually impaired people. Besides, the size of the RFID tag that will be set on the tactile pavement will also be determined based on the result of the maximum detection range. The experimental apparatus are set up as illustrated in Fig. 5.27. The height of the RFID reader/writer is set from 0 cm up to the maximum detection height for each RFID tag type such as 20 mm chip type and 30 mm chip type. However, the card type of RFID tag with a size of about 54 mm x 86 mm will not be conducted in this experiment because it will not be used on the tactile pavement due to the tag size which is too big.

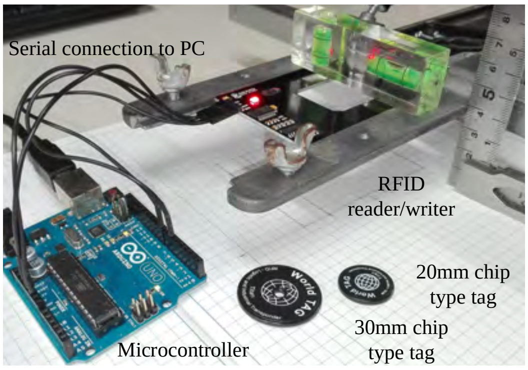
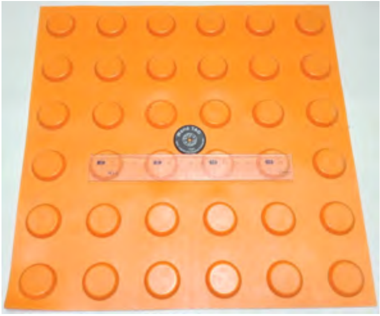


Figure 5.27: Experimental setup of detection range for passive RFID tag

In addition, the second experiment is conducted on the relation of maximum detection range of RFID reader/ writer with the different types of objects which covered the RFID tag during the detection process. Some objects have been selected in order to evaluate based on the possibility of the object to be appeared on the tag location. The selected objects are plastic, steel, paper, rock, rubber, fabric, wood, leaf and glass.



(a) Warning tactile with 30 mm chip tag

(b) Direction tactile with 20 mm chip tag

Figure 5.28: Illustration of passive RFID tag mounted on tactile paving including warning and directional tactile

This is because the selected objects which will be evaluated in this experiment normally can cover the RFID tag and disturb the detection process. The objects will be mounted directly on the RFID tag and the maximum detection range will be measured by changing the distance of RFID reader/writer from the selected objects. The measurement of maximum detection range for selected objects is done on three types of tag which are the 20 mm chip type, 30 mm chip type and card type. Figure 5.28(a) and 5.28(b) show the condition of 20 mm and 30 mm chip type RFID tags mounted on the tactile pavements which are the warning tactile and directional tactile.

Initially, the experiment is done for 20 mm chip type RFID tag based on the experimental setup for maximum detection range for the 60 mm x 60 mm sized 125 kHz RFID reader. Figure 5.29 shows the detection range of 20 mm chip type passive RFID tag relative to measurement height. From this result, the maximum coverage which can be covered by the RFID reader in order to detect 20 mm chip type RFID tag is about 6.5 cm in radius when the height of RFID reader is the same to the chip type RFID tag which is 0 cm. However, the detection coverage is decreased when the height of the RFID reader is increased to 1 cm and above. Hence, the maximum height of the RFID reader which can detect the 20 mm chip type RFID tag is 7 cm. On the other hand, the size of the RFID reader which is used in the experiment is also included in Fig. 5.29 to illustrate the electromagnetic wave produced by the RFID reader.

Moreover, the experiment is repeated by using 30 mm chip type RFID tag with the same 60 mm x 60 mm sized 125 kHz RFID reader. The experiment started from the same height of the RFID reader to the 30 mm chip type RFID tag which is 0 cm. In

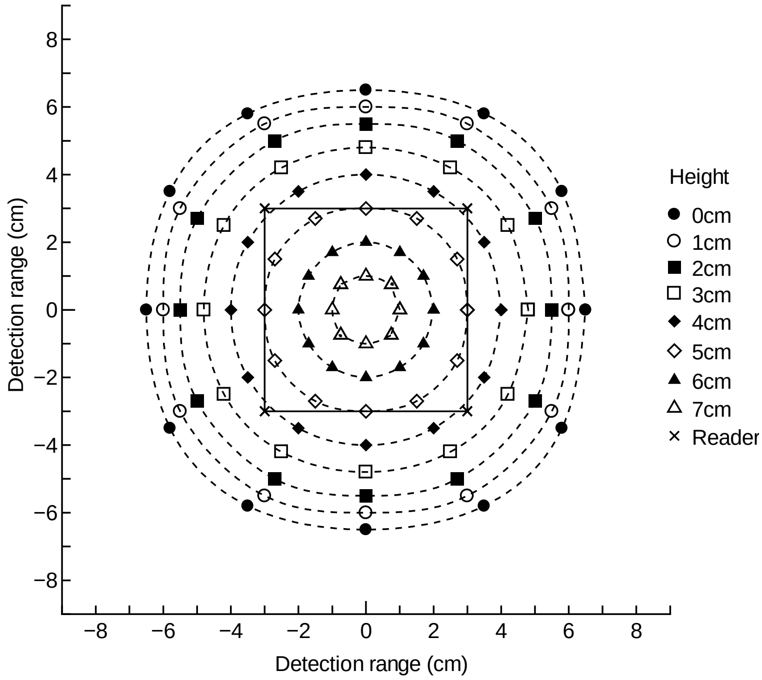


Figure 5.29: Detection range of 20 mm chip type passive RFID tag relative to measurement height

this experiment, the maximum detection range of the RFID reader in order to detect the 30 mm chip type RFID tag is about 8 cm in radius which is shown in Fig. 5.30. Similarly to the 20 mm chip type RFID tag, the detection range of the RFID reader for the 30 mm chip type RFID tag is decreased when the height of the RFID reader is increased from 0 cm to the maximum detection height. Hence, the maximum detection height that can detect the 30 mm chip type RFID tag is about 9.5 cm when the RFID tag is located perpendicularly at the center of the RFID reader. Similar to the 20 mm chip type RFID tag, the size of RFID reader which is used in the experiment is also included in Fig. 5.30.

Although the card type of RFID tag cannot be mounted on the tactile pavement for the system setup, the maximum height that can be detected by the RFID reader is measured to be about 12.5 cm. The maximum detection height for each tag type which is used is compiled in Table 5.3. As a result, the maximum coverage of the 60 mm x 60 mm size 125 kHz RFID reader when using the 30 mm chip type RFID tag is the optimum tag size can be covered up to 16 cm in diameter which is more than 50% of a piece of tactile pavement area. Therefore, one piece of 30 mm chip type

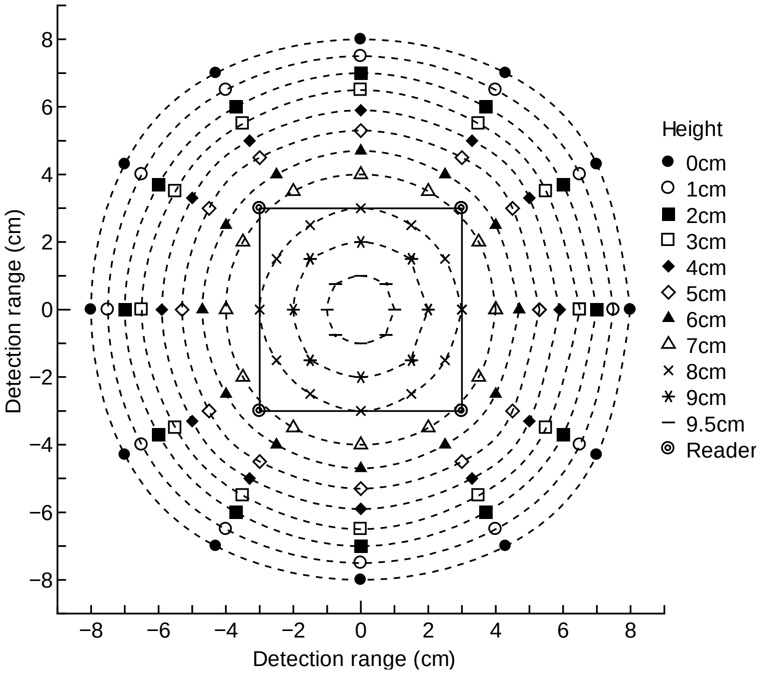


Figure 5.30: Detection range of 30 mm chip type passive RFID tag relative to measurement height

RFID tag can be used in order to be mounted on the tactile pavement. Meanwhile, the construction of the 60 mm x 60 mm size 125 kHz RFID reader needs to be mounted as low as possible to the RFID tag at the bottom of the proposed auto navigation system for visually impaired people. At this point, the recommended height is about 1 cm from the RFID tag which can detect up to 15 cm in diameter due to consideration of tactile pavement height about 5 mm.

Table 5.3: Detection range of passive RFID tag

Tag type	Chip	Chip	Card
Size	20 mm	30 mm	54 mm x 86 mm
Maximum range	70 mm	95 mm	125 mm

Type of materials

The effect of RFID detection range when the RFID tag is covered by selected objects and materials also conducted. Firstly, the 20 mm chip type RFID tag is located on the tactile pavement and the maximum detection height based on Table 5.3 is set. When the experimental setup is already set, the selected objects are set on top of RFID tag started from plastic type object. If the RFID reader cannot detect the RFID tag, distance of RFID reader to the RFID tag will be reduced until the RFID reader can detect the RFID tag.

From the experiment, the distance between RFID reader and RFID tag is recorded for each object. Figure 5.31 shows the measured detection distance for each tag type when examined by using all selected objects. From the results, almost of the selected objects that used to covered the RFID tags can still be detected except the steel type material such as aluminum. From the result, an aluminum material either solid or holes can also block the electromagnetic waves from the RFID reader and RFID tag is known.

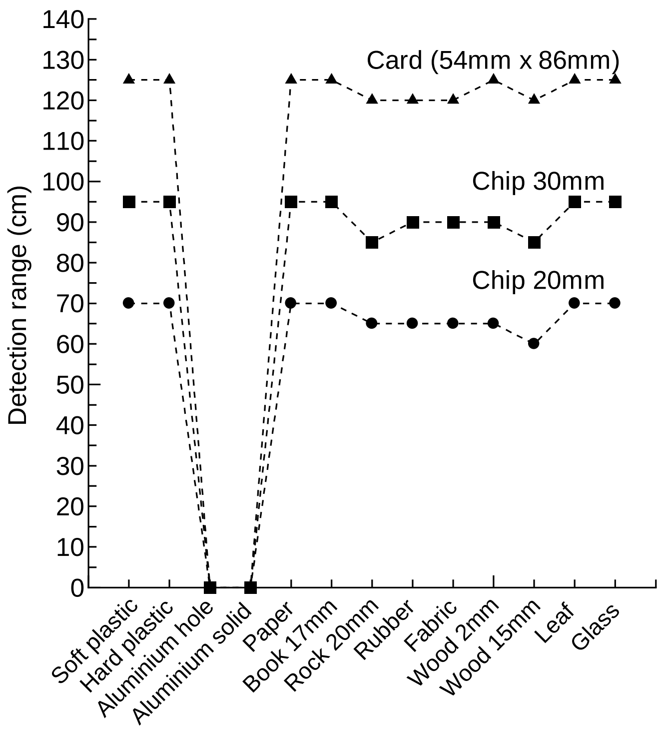


Figure 5.31: Detection range using different tag type and materials

5.3.2 Vision based tactile paving

In order to validate the effectiveness of developed vision based tactile detection method, an experiment is conducted to recognize variety of shape by using the proposed detection algorithm. This experiment is conducted to proof the proposed detection algorithm can compare different shape such as circle, bar, eclipse, square, triangle and diamond shapes. Some shapes have been captured through web camera and also downloaded from internet. A metric, will be used to detect the shapes. The metric in the coding works by calculating any connected components area and perimeter in a binary image after pre-processing, and then compute it using Eq. 5.1. After the metric has worked on the connected components, it will give a certain range of values for different shapes detected.

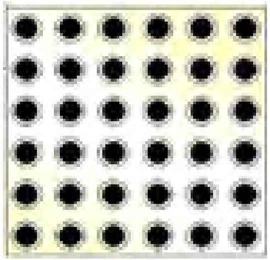
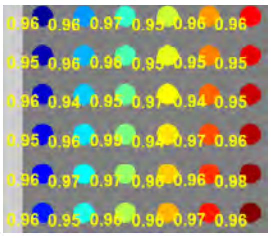
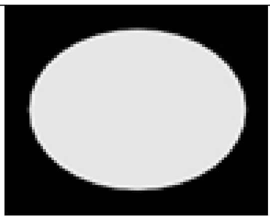
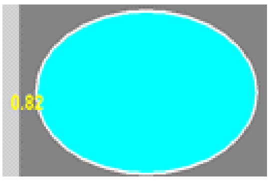
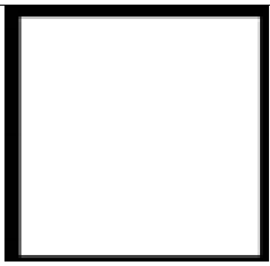
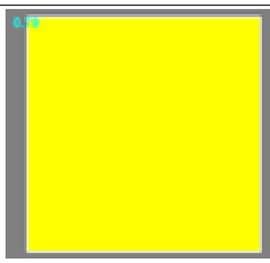
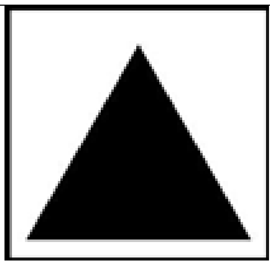
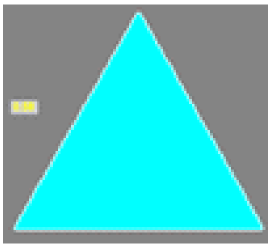
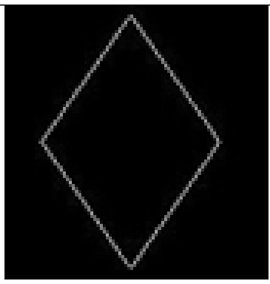
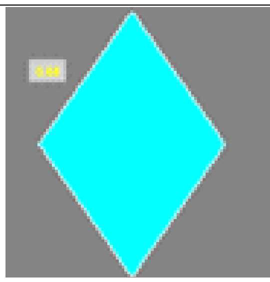
$$m = \frac{4\pi A}{p^2} \tag{5.1}$$

Table 5.4 shows the detection result of a variety of shapes by using the proposed tactile detection algorithm. From Table 5.4 results, the range of the metric value for each shape is confirmed by using the vision based tactile detection algorithm. These metric values will be the benchmark value for each shape in order to differentiate the image shape. However, there are some shapes which are having similar metric values such as circle, eclipse and square. These analysis results will be used to improvise the current detection algorithm, making the system better and more robust to different types of detection environment of the tactile paving.

5.3.3 Voice recognition

Figure 5.32 illustrates the result of the first experiment for the original voice of “ Toilet ” recorded in the EasyVR module, which is compared with the voice samples of eight different words. The average voltage, V_{ave} is calculated using the mid-ordinate rule at each sampling time of 40 ms and plotted in Fig. 5.32. Table 5.5 shows the result of the voice sample detected for “ Toilet ” by the proposed method. From the results, the highest amplitude obtained in the entire graph is 6.8 mV, while the lowest is 1.2 mV, which are acquired from the original voice and the eight samples, respectively.

Table 5.4: Detection results of variety of shapes

Tactile image	Detection metric	Detected shape
		Circle (0.9-1.0)
		Bar (0.15-0.3)
		Eclipse (0.82)
		Square (0.79)
		Triangle (0.58)
		Diamond (0.68)

The result for the fifth sample, which is the word " Toilet " is detected because of its similarity with the original graph in the memory in terms of the graph flow, in which the maximum voltage rises and drops rapidly.

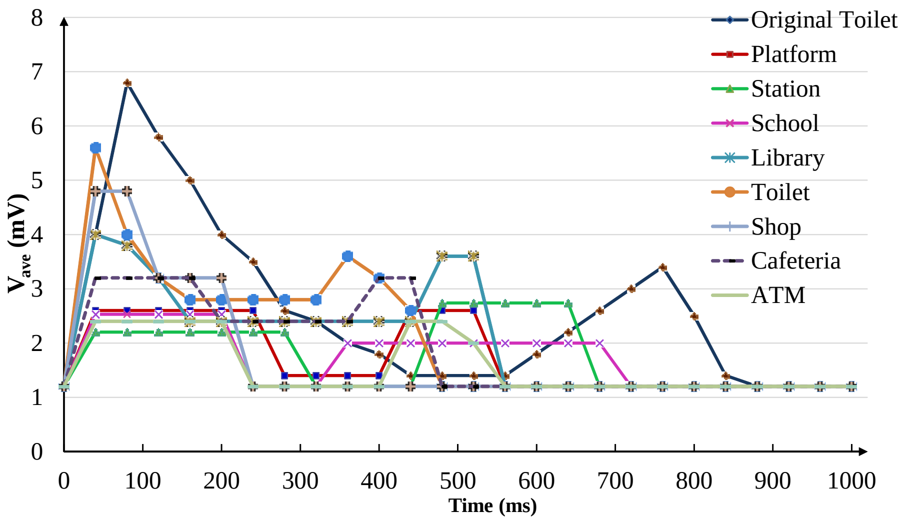


Figure 5.32: Comparison of peak average voltage of samples for Toilet

Table 5.5: Voice detection result for toilet

Word	1	2	3	4	5	6	7	8
Detection	No	No	No	No	Yes	No	No	No

On the other hand, Fig. 5.33 shows the average voltage versus time graph for "ATM". The original voice recorded in the EasyVR module is compared with the eight voice samples obtained from the different words. Table 5.6 shows the result of the voice sample obtained for " ATM " that is detected by the proposed system. The highest point in the graph is reached by sample 5 and the lowest point is reached by sample 2, with peak voltages of 6.8 mV and 1.2 mV, respectively. The graphs of the original sample and eighth sample, corresponding to the word "ATM" have similarities in their shapes: the voltage rises and drops back to the original voltage after a short period and then rises again to the same amplitude as reached before. Figures 5.34 and 5.35 show the raw data obtained by the oscilloscope during the experiments when the original words were "Toilet" and "ATM", together with the sample voices of "Toilet" and "ATM".

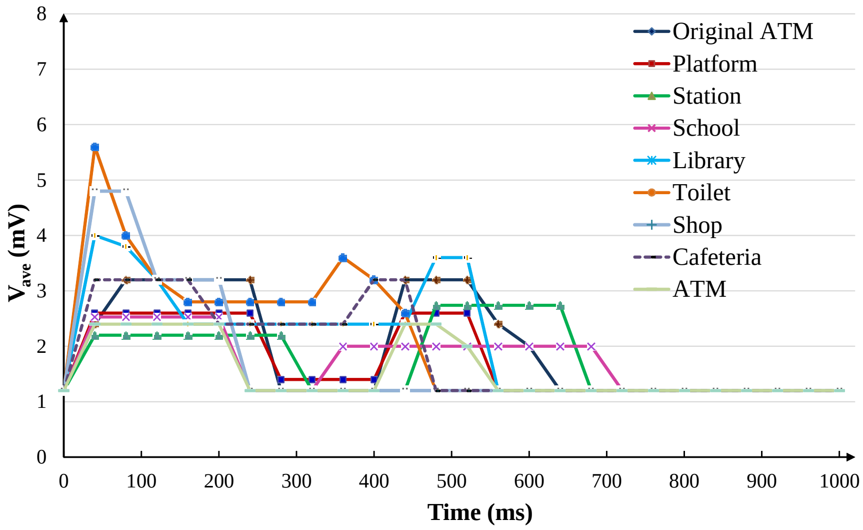
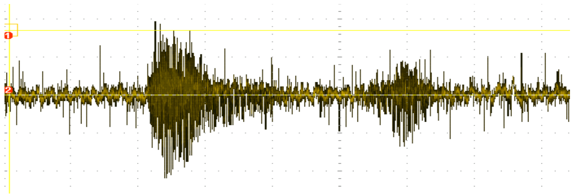


Figure 5.33: Comparison of peak average voltage of samples for ATM

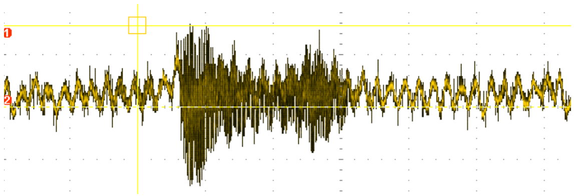
Table 5.6: Voice detection result for ATM

Word	1	2	3	4	5	6	7	8
Detection	No	No	No	No	No	No	No	Yes

Table 5.7 shows the result obtained for the third experiment carried out to evaluate the performance of the proposed method at locations with different sound intensity levels. As shown in the table, it is found that the number of successful detections decreased when the sound intensity level is increased. When the sound intensity level was 50 dB to 59 dB, the accuracy was 100% i.e., the developed voice recognition system detected all 30 utterances of "Toilet". However, the performance accuracy dropped to 73.3% when the sound intensity increased to 60 dB to 69 dB, at which only 22 out of 30 utterances are correctly detected.

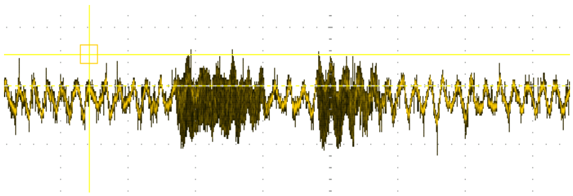


(a) Original Toilet

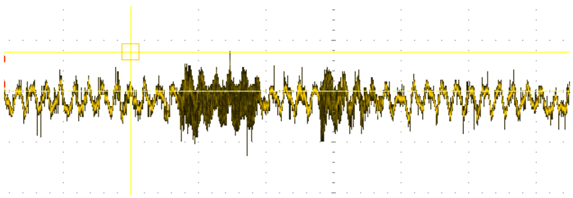


(b) Word 5 (Toilet)

Figure 5.34: Comparison of voice waveforms for toilet



(a) Original ATM



(b) Word 8 (ATM

Figure 5.35: Comparison of voice waveforms for ATM

Table 5.7: Performance at locations with different sound intensity levels

Range of sound intensity level (dB)	50 - 59	60 - 69
Number of successful detections	30	22
Number of failed detections	0	8
Total number of data	30	30

5.3.4 Digital compass

Table 5.8 shows the compass accuracy test results when the digital compass is pointed to North. From the table, the compass reading clearly shows that the resolution of the digital compass is high and able to produce the compass reading in two significant values. The repeatability test is carried out about 20 times to prove that the results are valid to be used in the navigation device. Besides, the accuracy test for the digital compass has been done 20 times at different places and different time. In the result also shows that the relative error is getting smaller and close to the desired North degree because of the digital compass output is getting stable. This implies that the digital compass is suitable to use for navigation to provide accurate heading direction.

Table 5.8: Compass accuracy test

Times	Pointing to North	Degrees (deg,)	Relative Error	Percent Relative Error
1	Yes	356.30	3.70	1.0278
2	Yes	356.40	3.60	1.0000
3	Yes	356.30	3.70	1.0278
4	Yes	355.70	4.30	1.1944
5	Yes	358.20	1.80	0.5000
6	Yes	357.80	2.20	0.6111
7	Yes	357.70	2.30	0.6389
8	Yes	357.80	2.20	0.6111
9	Yes	358.20	1.80	0.5000
10	Yes	357.90	2.10	0.5833
11	Yes	359.20	0.80	0.2222
12	Yes	359.30	0.70	0.1944
13	Yes	359.20	0.80	0.2222
14	Yes	359.30	0.70	0.1944
15	Yes	359.30	0.70	0.1944
16	Yes	359.20	0.80	0.2222
17	Yes	359.20	0.80	0.2222
18	Yes	359.60	0.40	0.1111
19	Yes	359.40	0.60	0.1666
20	Yes	359.40	0.60	0.1666

Note : North(N) direction point to 0 deg. or 360 deg.

Mean of 20 times repeatability = 358.27 deg.

Mean of percent relative error = 0.4805%

Figure 5.36 shows the percent relative error of the readings obtained from the digital compass when it is pointing to the North. The maximum peak of the percent relative error is 1.1944% . The average percent relative error is 0.4805% . The graph shows the percent relative error is decreasing gradually towards the end and becomes nearly constant between the 11 and 17 times of trials. This implies that the relative error is getting smaller and the readings are very close to the 360 deg. when the digital compass points to the North. The data obtained is said to have high reliability. Besides, the digital compass has very high sensitivity and able produce significant value at tenth decimal places.

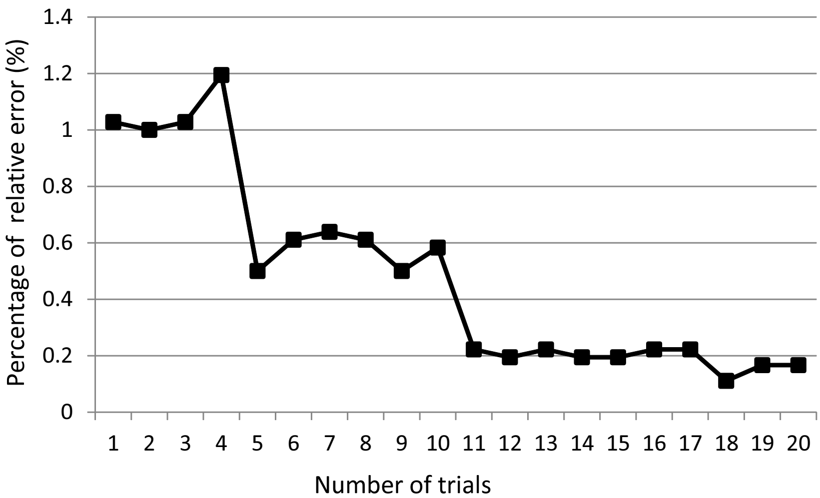
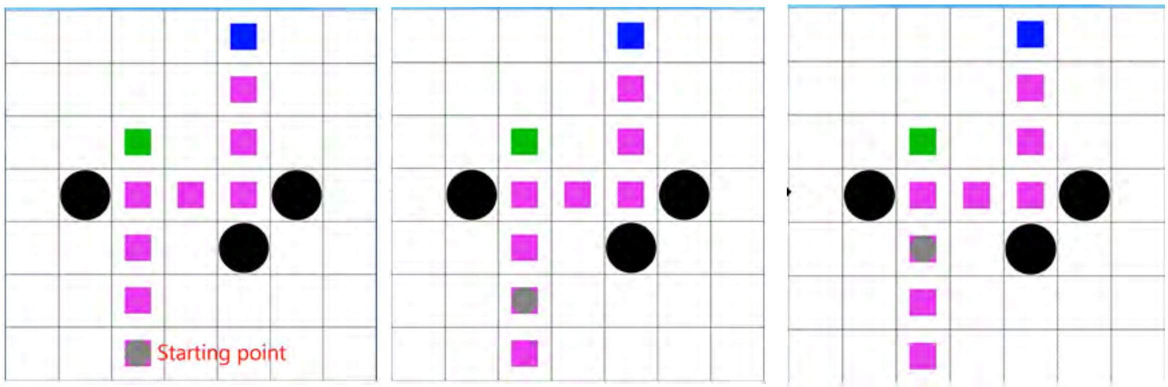


Figure 5.36: Percent relative error of digital compass pointing to North

5.3.5 Performance of shortest path planning algorithm

Figures 5.37(a) to 5.37(c) show the navigation map created by using the Processing 2.0 software. The navigation map is designed to be the same as the arrangement of the floor plan which is illustrated in Fig. 5.38. The purple square represents the tactile paving, the green square is the destination " ATM " and the blue square is the



(a) 0x00 (b) 0x01 (c) 0x02

Figure 5.37: RFID detection on navigation map by using Processing 2.0

destination "Toilet". There are three large dark circles which are the static obstacles that users cannot pass through. Figure 5.37 shows the changing of the position when RFID tag detected by RFID reader and displayed on the navigation map. Once the RFID reader reads the tags, a grey circle will be shown on the map system automatically because the RFID detection system had already connected to the laptop through ZigBEE network wirelessly which is illustrated in Fig. 5.37(a). For example, tag numbered 0x00 is the starting point, whereas tags 0x01 is the next tag to be scanned and the rest respectively illustrated Figs. 5.37(b) and 5.37(c).

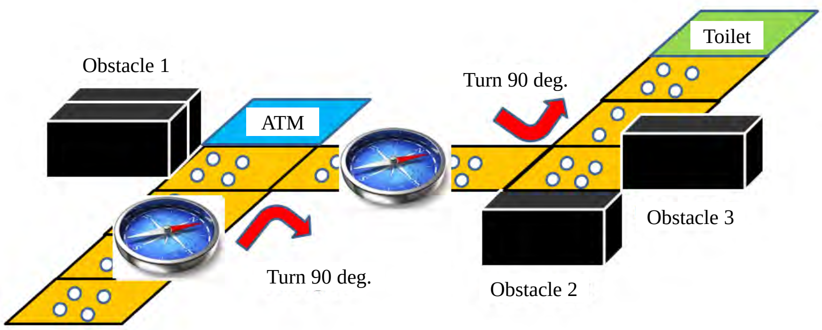
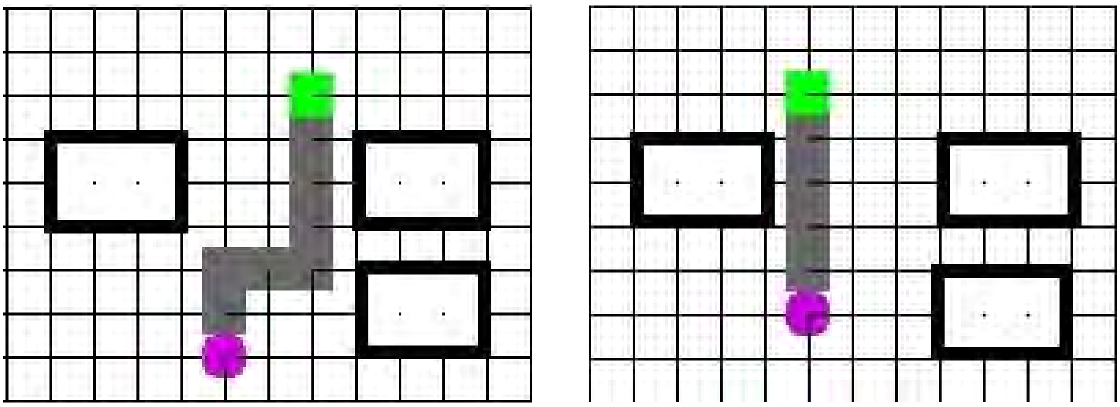


Figure 5.38: Field setup which include RFID tags on tactile paving with some obstacles

The navigation map shown in 5.37 is to provide the shortest path and how the visually impaired people could travel through this path. This algorithm is used to find



(a) Toilet (b) ATM

Figure 5.39: Shortest path planning algorithm

path from start node to the end node using graph and chose the suitable shortest path. For the Fig. 5.39(a), when the tag reader scans the RFID tags where the user at the origin, the initial starting point (purple circle) will be shown on the map. After the user has keyed in the destination such as "Toilet", the destination point will pop up at the map (green rectangle). The processing will show the shortest path automatically which is the grey paths; it shows that there are only seven steps between the starting and ending points. On the other hand, the destination for "ATM" which is illustrated in Fig. 5.39(b) also takes only four steps to reach the destination.

5.3.6 Performance of developed navigation system in field test

From Table 5.8 which shows the validity of the digital compass which can be used inside the developed navigation system, the developed navigation system is evaluated for its performance at the real field by using the RFID tags that have been installed on tactile paving. The navigation device built with the digital compass for direction guidance and voice module is able to inform user about the direction. The digital compass will be able to detect the error if the user travels out of the direction and the misdirection lead to the wrong path. Thus, the voice module will inform the user, WARNING! repeatedly and alert user from taking the wrong path. The navigation proceeds until the user turn over and travel on the right direction. Figure 5.40 shows the illustration of the developed navigation device which is conducted on different subjects such as human and mobile robot.

(a) Human

(b) Mobile robot

Figure 5.40: Experiment conducted for comparing the performance of navigation device based on different subjects such as human and mobile robot

Here, the traveling time which is consumed to finish the route is measured. The travel distance which is needed to be done is 240 cm in which each tactile paving is about 30 cm in length. There are two subjects which have been tested at the field which are human subject and a mobile robot. The RFID reader/writer module is attached at the bottom of the mobile robot in order to easily detect the RFID tag. Then, the RFID reader/writer module reads the tags first and at the same time the Arduino microcontroller will synchronize with the digital compass for route processing. For the experiment by using a mobile robot, the command is given to the DC motor in order to go straight or turn. However, for the human subject, the voice module will inform the user how to turn at the corner, e.g. 90 deg. turn left or 90 deg. turn right. Through this experiment, there is a high accuracy for the digital compass to give fast and precise directions.

Table 5.9 shows the average traveling time which is recorded for fast and precise mobile robot at 25 s while for humans, it is 33 s. From these results, the difference which can be related is the size of the subject. The mobile robot which is used is a wheeled robot sized 20 cm in diameter. However, the human subjects which are tested in this experiment are 170 cm in height and the position of humans is 40 cm behind the end of the electronic cane. Therefore, the human subjects experienced difficulty to turn when the voice command is given. Meanwhile, the mobile robot can easily turn because the mobile robot can turn at the same axis when the command is given to the DC motor, respectively.

Figure 5.41 shows the picture from the video for human subject when the experiment is conducted. These pictures are taken at every second for all time elapsed which took 54 s to complete the course that has been set. In order to set the desired destination which is " Toilet " by using the developed Braille keypad, the human subjects took about 21 s from the starting point. Then, the human subjects took about 33 s to travel from the starting point to the desired destination. The human subject traveled by using voice guidance from the developed navigation device such as forward, turn right, turn left, and etc.

Table 5.9: Performance comparison of different subjects

Subject	Human with electronic cane	Mobile robot
Size	170cm (Height)	20cm (Diameter)
Average travelled time	33s	25s

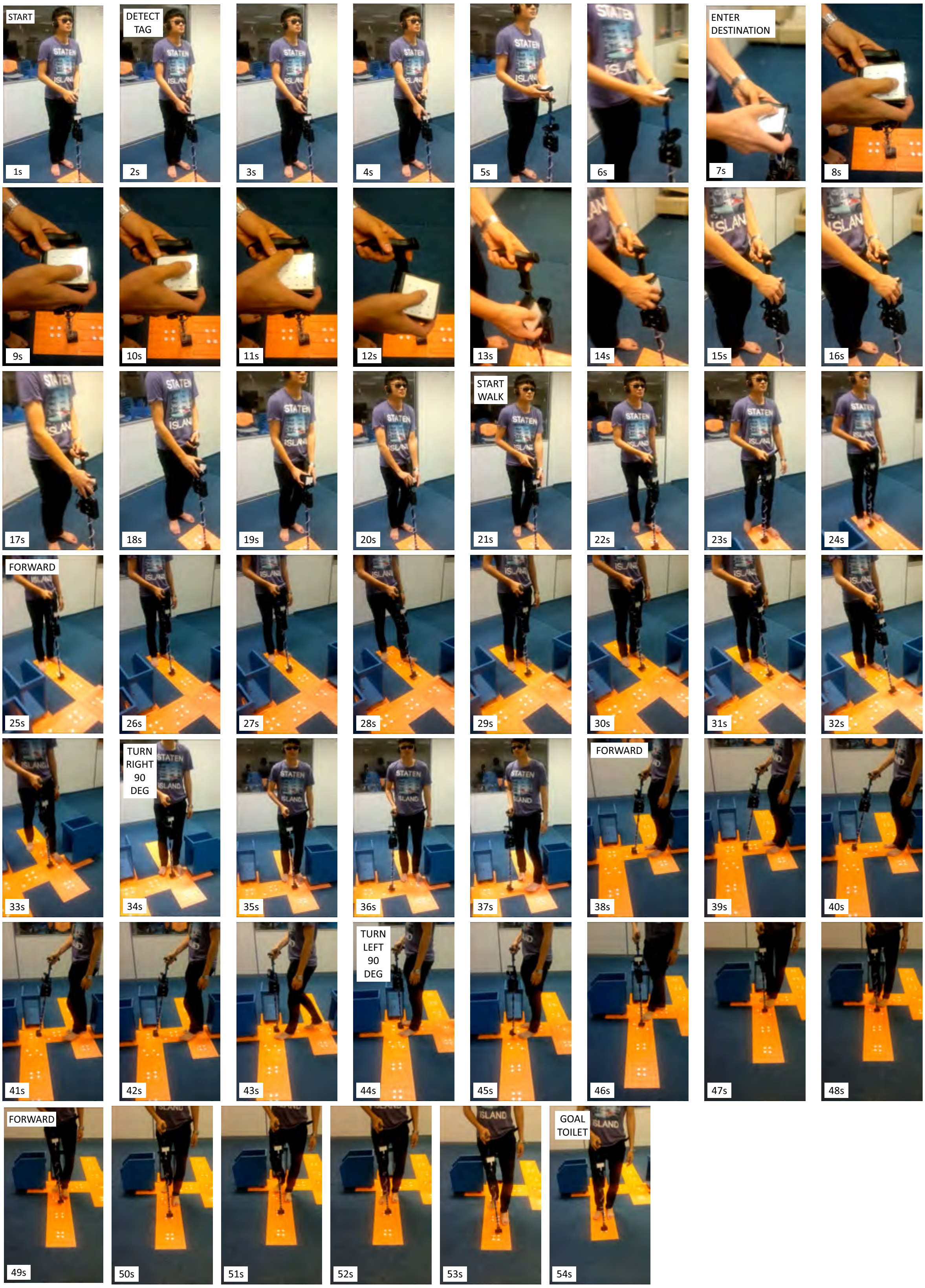


Figure 5.41: Movement for each sec by human subject when walk using developed navigation device

Chapter 6

Conclusions and Future Tasks

6.1 Conclusions

In this study, a design concept and implementation of an electronic spectacles for the visually impaired to detect the obstacles at the upper body level are described. The electronic cane is proposed at first. However, since the electronic device for the upper body level does not exist, it needs to be designed and developed through discussion with the visually impaired persons from some communities of visually impaired people such as the Society of Blind Malaysia (SBM) and Malaysian Association for Blind (MAB).

Therefore, the overall system configuration for new electronic spectacles that can be used for protecting and guiding the visually impaired people is constructed. Some electronic components such as microcontroller, distance measurement sensor, vibrator, single headphone, etc. have been selected through a systematical method. Suitable distance measurement sensors, which are the main component, are compared and selected by using a pair-wise comparison table and weightage method, and the ultrasonic sensor is selected. Then, the designed electronic spectacles are fabricated successfully with a weight of about 70 g without battery and the vibration warning system. After all the designed and fabrication of the proposed electronic spectacles are done, some evaluation processes have been successfully conducted initially such as blind spots and the effectiveness of the proposed warning system such as vibration warning, beep warning and LED warning device. All of these proposed warning systems are developed inside the electronic spectacles in order to give a direct warning signal to the user for avoiding obstacles effectively.

Furthermore, the evaluation of power consumption has also been done successfully for both types of electronic spectacles in order to ensure the usability of the device. From the result, the simplified type of electronic spectacles can be used up to 38 hours continuously when the condition of obstacles exists at all directions. Therefore, the visually impaired user can use it safely and easily. Lastly, before the experiment is conducted, the experimental method has been submitted to the Ethics Committee of Tokushima University for evaluation and the evaluation has been passed successfully. Then, the performance evaluations have been done for both types of electronic spectacles inside the experimental field by multiple subjects that volunteered to participate in the study. Analyses from some sensors that have been mounted such as ultrasonic sensor, gyro sensor and acceleration sensor have also been done successfully and correctly. These sensors are used to capture the real condition of the proposed electronic spectacles and the user's condition such as user's movement, user's decision, etc..

On the other hand, the navigation device has been successfully developed in order for it to be an option for the visually impaired user when traveling indoors and outdoors. The proposed navigation device consists of the RFID detection system, vision-based tactile detection system, the destination input system including voice recognition system and Braille (tactile) keypad and a digital compass. Besides, some options that could be used by the visually impaired are researched such as the path planning algorithm in order to search the shortest path to go to the desired destination. Some simulations and experiments have also been conducted to evaluate the proposed navigation device. Basically, the designed navigation device is proposed to be attached at the white cane that is usually used by a visually impaired user.

The RFID detection system is beneficial to the visually impaired people since it can provide the feedback information regarding the current location, distance and the direction that need to be traveled to get to the desired destination. At the same time, the digital compass and the shortest path planning algorithm by using A* search algorithm are applied and have successfully guided the user by providing accurate distance and direction through the experiment done. It could assist and guide the visually impaired to travel independently, without needing any help from others. Lastly, the effectiveness of developed navigation device in order to navigate the visually impaired user has been confirmed. The performance comparison for the human subject and robot has also been successfully done. From the result, it is shown that the robot was faster than the human subject since it decided precisely while the human subject was doubtful while making his decision.

6.2 Future Task

In the future, we would like to integrate the developed electronic spectacles with the developed navigation device which is constructed on the white cane into one compact device that could be usable and beneficial to the visually impaired people. It has been shown that there is a need of an auto-navigation system in order to assist and guide the visually impaired people including obstacle detection, obstacle avoidance, navigation system, localization, etc. The design of the auto-navigation system has been done. However, the development and the fabrication processes will be done in the near future to realize the needs of visually impaired people. Besides, the auto-navigation system can be communicated through Wi-Fi to the internet in order to update the information while traveling at an unknown path. The usage of other types of GPS device such as GLONASS, Galileo, Navic or Beidou will also be studied in order to reduce the accuracy of GPS and the user can safely travel to the desired location.

◇ ◇ ◇ ◇ References ◇ ◇ ◇ ◇

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1. “Conceptual design and implementation of electronic spectacle based obstacle detection for visually impaired persons” Anuar MOHAMED KASSIM, Takashi YASUNO, Hiroshi SUZUKI, Mohd SHAHRIEEL MOHD ARAS, Hazriq IZZUAN JAAFAR, Fairul AZNI JAFAR, Sivarao SUBRAMONIAN, Journal of Advanced Mechanical Design, Systems, and Manufacturing (JAMDSM), Vol. 10, No. 7, pp. 1-12, JAMDSM0094, Oct. 2016, Published
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【Patent】

1. PI2012003042A system for alerting of a motion of a person

【Industrial Design】

1. SPECTACLE ID :13 - 01600 - 0101 (Class 16-06)