DEVELOPMENT OF OBSTACLE DETECTION SYSTEM FOR COLLISION AVOIDANCE

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DEVELOPMENT OF OBSTACLE DETECTION SYSTEM FOR COLLISION AVOIDANCE

by

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LIST OF ABBREVIATIONS

AAWC	Advanced Augmented White Cane
CCD	Charge-Coupled Device
CDR	Correct Decision Ratio
ETAs	Electronic Travel Aids
IDE	Integrated Development Environment
IMU	Inertial Measurement Unit
IR	Infrared
MATLAB	Matrix Laboratory
MIT	Massachusetts Institute of Technology
RGB-D	Red, Green and Blue-Depth
WHO	World Health Organization

PEMBANGUNAN SISTEM HALANGAN PENGESANAN UNTUK MENGELAKKAN PERLANGGARAN

ABSTRAK

Tongkat tradisional adalah alat biasa yang digunakan oleh cacat penglihatan untuk mengesan halangan di hadapan paras lutut daripada mereka. Walau bagaimanapun, masalah utama dengan menggunakan tongkat tradisional adalah ketidakupayaan untuk pengguna untuk mengesan halangan di atas paras tanah dan di luar tongkat jarak pengesanan. Banyak alat bantuan perjalanan elektronik (ETA) boleh didapati untuk membantu kesukaran mobiliti cacat penglihatan. Walaupun, sesetengah ETA mempunyai limitasi dalam halangan pengesanan untuk mengelakkan perlanggaran. Untuk mengurangkan limitasi ETA yang sedia ada dan kesukaran mobiliti cacat penglihatan, sistem halangan pengesanan perlu dibangunkan. Projek ini membentangkan pembangunan prototaip tongkat dengan sistem mengesan halangan berdasarkan perpaduan penderia. Penempatan dan orientasi penderia pada tongkat berjaya dianalisa dari segi mengesan sudut dan jarak. Selain itu, sistem kawalan sudut kecondongan dilaksanakan pada prototaip ini bergantung kepada ketinggian pengguna untuk memastikan penderia bekerja dengan berkesan dalam jarak pengesanan. Selepas beberapa ujian telah dijalankan, sistem kawalan sudut kecondongan dapat mengekalkan sudut mengesan penderia ultrasonik dalam sekitar sudut optimum iaitu 10 darjah. Akhir sekali, suara amaran aplikasi Android dibangunkan untuk membantu cacat penglihatan untuk meramalkan kedudukan halangan. Terdapat lebih daripada 85% nisbah keputusan yang betul telah diperolehi bagi tinggi halangan, tengah-tengah halangan, rendah halangan dan halangan yang tergantung.

DEVELOPMENT OF OBSTACLE DETECTION SYSTEM FOR COLLISION AVOIDANCE

ABSTRACT

The traditional walking stick is a common tool that visually impaired use to detect an obstacle in front of knee level of them. Nevertheless, the main problem with the use of the traditional walking stick is its inability for a user to detect obstacle above the ground level and beyond the stick detect range. There have many electronic travel aids (ETAs) are available for assisting mobility difficulties of the visually impaired. However, some of the ETAs exist limitation in obstacle detection for collision avoidance. To reduce the limitations of existing ETAs and mobility difficulties of visually impaired, an obstacle detection system needs to be developed. This project presents the development of a walking stick prototype with a sensor fusion based obstacle detection system. The placement and orientation of the sensor on the walking stick are successfully analysed in terms of detecting angle and range. Moreover, a tilt angle control system is implemented on the prototype depend on the height of user to ensure the sensors work effectively in the detection range. After several tests have been conducted, the tilt angle control system is able to retain the angle of the ultrasonic sensors in around the optimal angle which is 10 degrees. Lastly, a voice alert Android application is developed for assisting the visually impaired to predict the position of obstacle. There has more than 85% correct decision ratio was obtained for the high, middle, low and hanging obstacle.

CHAPTER 1

INTRODUCTION

1.1 Background

"The eyes are the windows to the soul" is an expression that is always used to describe the important of the vision to the human for seeing surrounding world. Vision not only is a mechanism that provides a seeing feedback but also plays a vital role in human sensory. According to the World Health Organization (WHO) research in 2014 [1], there were 285 million people estimated to be visually impaired globally, which are 39 million people in blindness and 246 million people have low vision. Most visually impaired prefer a white cane or a guide dog as their mobility aid in the daily-life walking activities.

White cane is a long rod device used by visually impaired to give them tactile information about the environment and to detect the obstacles on the ground, holes, uneven surface of their path. The main reasons for the visually impaired prefer to use a white cane are easily replaceable, low cost, and able folded into a small piece to bring it out. On the other hand, a guide dog is able to assist visually impaired to walk safely, guide them to avoid the obstacles such as stairs and kerbs [2]. However, there still have disadvantages for visually impaired to use white cane and guide dog. White cane has a short sensing range only and it cannot detect the obstacles above knee level such as objects are hanging at the head level. Besides that, visually impaired who use a guide dog needs spend a lot of time, cost and responsibility to take care it such as feeding, watering and training. Therefore, white cane and guide dog are difficult in assist the visually impaired to avoid all kind of obstacles when they are walking.

To further improve the weakness of traditional travel aids and reduce the risk of the visually impaired injuries while walking, electronic travel aids (ETAs) were introduced in the 1970s [3]. ETAs are using sensors to extend the obstacle detection range and inform the user through sensory feedback. By implementing the measurement technology of robotics in ETAs for visually impaired, they need to fulfil two main functions, which is obstacle detection and navigation [4]. However, this project will only focus on the obstacle detection function for collision avoidance.

With the rapid development of sensor and robot technology, obstacle detection system is widely used in many fields. For example, it had played crucial roles in the autonomous robot, automobile and manufacturing. In the autonomous robot, obstacle detection system is most of the data input part for path mapping and routeing [5] and the system is used to scan obstacles surrounding the vehicle in the automobile. Besides, a lot of research have been done by using different measurement technology in ETAs and mobile robot platforms to measure the range of obstacles. Common measurement technologies that are used for the obstacle detection system consist of laser sensor [6], infrared (IR) sensor [7], ultrasonic sensor [8], and Red, Green and Blue-Depth (RGB-D) sensor [9].

In this project, an obstacle detection system will be developed on a walking stick to assist the users detect the obstacle above ground level of them, along with ground surface detection. Sensor fusion of IR sensor and three ultrasonic sensors will be developed in this system for obstacle detection function. Two ultrasonic sensors will be used to detect the obstacle in knee level of the users while another one used to detect the obstacle in the head level of them. Furthermore, IR sensor will be used for the uneven ground surface detection such as holes and descending stairs. Moreover, a tilt angle control system will be developed depending on the height of user to ensure the sensors work effectively in the detection range. Besides that, an Arduino device which installed voice alert Android application is connected to the system through Bluetooth communication for assisting the visually impaired to predict the position of obstacle. Finally, analysis of the obstacle detection system will be done in this project.

1.2 Problem Statement

The traditional walking stick is a common tool that visually impaired use to independently detect an obstacle in front of knee level of them. Nevertheless, the main problem with the use of the traditional walking stick is its inability for a user to detect obstacle above the ground level and beyond the stick detect range. According to a survey by R. Manduchi and S. Kurniawan [10], 13% out of 307 visually impaired who participate the survey interview was experienced head-level injuries at least once per month and 7% was experienced falls while walking at least once per month. This survey was strongly proved that use a traditional walking stick unable provides a better protection against head-level to the visually impaired.

In order to reduce the limitations of the traditional walking stick, many ETAs have been available for assisting mobility difficulties of the visually impaired. The rapid development of technology has contributed several ETAs with their independent advantages in terms of cost, function, size and carry method. However, some of the ETAs exist limitation to detect obstacle for collision avoidance. For example, double IR rangefinders [7] can be influenced by natural light, so conditions for using this system were limited in a room or indoor and it has a low performance to detect mirror obstacles. Besides that, virtual blind cane system [6] are using a line laser-based vision system to help a blind person recognise an obstacle and find the distance to the obstacle. This system is easily affected by strong illumination, so its maximum detect range is limited about 1.8 m from the user.

Apart from the mono sensor ETAs, sensor fusion based ETAs were also developed by some of the researchers. One of the existing sensor fusion based ETAs is Advanced Augmented White Cane (AAWC) [3]. It is a sensor fusion of ultrasonic sensor and IR sensor based white cane for obstacle detection and it can detect obstacles at four vertical levels as well as provides multi-sensory feedback. However, the AAWC might occur error detection in a narrow corridor because the ultrasonic sensor could detect the walls due to its wide field. Besides that, the tilt angle can affect the distance measurement between sensor and ground.

To reduce the limitations of existing ETAs and mobility difficulties of visually impaired, an obstacle detection system that can detect the obstacles need to be developed. The obstacle detection system should also be mounted on a walking stick to facilitate the visually impaired use in the daily walking activities. In addition, a tilt angle control system must be developed in order to avoid false distance measurement. Besides that, the obstacle detection system should improve the movement performance of the visually impaired and minimise the impact by detecting the obstacles.

1.3 Objectives

The objectives of this project are as below:

1) To develop a walking stick prototype with a sensor fusion based obstacle detection system.

2) To implement a tilt angle control system on the prototype to ensure the sensors work effectively in the detection range.

3) To develop a suitable voice alert Android application for assisting the user in obstacles position prediction.

1.4 Project Scope

The scope of this project covers the development, implementation and analysis of the obstacle detection system. The work of this project is divided into software development and hardware implementation. Hardware implementation consists of two parts which are hardware design and prototype design. Firstly, the circuit of the system is constructed by using Arduino Nano microcontroller, three ultrasonic sensors, an IR sensor, a Bluetooth module, an accelerometer, a vibration motor and a servo motor. After that, several obstacle detection tests will be conducted to determine the optimal sensor arrangement and detecting angle to detect an obstacle in various height levels.

For the software part, there will be three software involved in this project. The software used to program the microcontroller is Arduino IDE 1.6.1. The microcontroller software part includes the programming of the sensor, Bluetooth module, and motor. Besides, MIT Inventor App 2 also will be used to develop an Android application for smartphones that can inform the visually impaired effectively through Bluetooth module. Furthermore, MATLAB will be used to plot a graph to analyse the detect range and accuracy of the obstacle detection system on a walking stick.

1.5 Report Outline

Overall, this progress report consists of five main chapters that describe the full details from the introduction to the conclusion of this project. The first chapter starts with a brief introduction of the project. This chapter describes the background of the project, the problem statement, objectives, and the project scope.

The second chapter is a literature review of the previous works done related to the field of this project. Summary of the past studies on different techniques and methodology for obstacle detection are presented in this chapter. Besides that, the process of choosing appropriate obstacle detection technology is elaborated in this chapter.

In chapter 3, methodology for the hardware and software development of this project is explained in detail. It includes the hardware and prototype design of the system, obstacle detection algorithm, tilt angle control system, voice alert Arduino application and performance evaluation.

Chapter 4 describes the result and discussion for this project. This chapter shows the analysis of detection distance, detection angle and drop-off detection of the system. Besides that, the optimal sensor arrangement and detecting angle for the prototype walking stick will be determined in this chapter. Besides that, the performance analysis of tilt angle control system is also explained in detail. Moreover, the performance of obstacle position prediction is analysed and the result of voice alert correct decision ratio for the position of obstacle detected is shown.

Finally, Chapter 5 presents the conclusion of the project. Summary on the project implementation is covered. This chapter includes the limitation of obstacle detection system and future works to improve it.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

To reduce the limitations of the traditional walking stick and mobility difficulties of the visually impaired, many types of researches which are related to the obstacle detection has been done. Sensor technology is one of the important factors for good performance in obstacle detection. When considering sensor technologies for the obstacle detection system, the operation environment and the type of obstacles must be considered. The obstacle detection walking stick is intended to operate in the indoor and outdoor. The obstacle encountered will primarily be either furniture, people, vehicle, and features of the building. The type of obstacle can be classified as dynamic and static object.

In this chapter, the previous studies done using these measurement technologies will be discussed in the following section. Besides that, five sensor technologies will be analysed that is IR sensor, laser rangefinder, ultrasonic sensor, RGB-D sensor as well as sensor fusion. Finally, one of the sensor technologies which is suitably used in this project will be chosen.

2.2 Sensors Analysis for Obstacle Detection

Common measurement technologies that are used for the obstacle detection system consist of laser sensor, IR sensor, ultrasonic sensor, and RGB-D sensor. These sensors are some of the efficient measurement technologies that were being developed to detect the different kinds of obstacles and to distinguish dynamic and static obstacles. Sensor selection is a challenging task for the obstacle detection system design, as it extremely affects the system performance, cost and its power consumption. In the following section, the characteristic and performance of four various sensors will be analysed that is IR sensor, laser rangefinder, ultrasonic sensor and RGB-D sensor.

2.2.1 IR Sensor

IR sensor is an electronic device which is used to determine the distance to an object by emitting and detecting IR light. These sensors use a small linear charge-coupled device (CCD) array and triangulation to calculate the distance between the sensor and the objects in the field of view [11]. A pulse of IR light is emitted by the sensor and pass through a condenser lens so that the light intensity is focused on a certain point. If an obstacle is presented in their view, the light will hit the surface of obstacle and refraction will occur. Part of the refracted light will be sent back to another lens and then passed onto the CCD array. This will create a triangle between the transmit LED, the CCD array and the obstacle as shown in Figure 2.1. The position of light falls on the CCD array can be used to calculate the distance between the sensor and the obstacle by using the formula as shown in Eq. (2.1).

$$L = \frac{F \times A}{X} \tag{2.1}$$

Where L is the distance between transmitter and obstacle, A is the distance between the centre of two condenser lenses, F is the distance between the condenser lens and CCD array and X is the distance between the centre of condenser lens and position of light falls in CCD array.

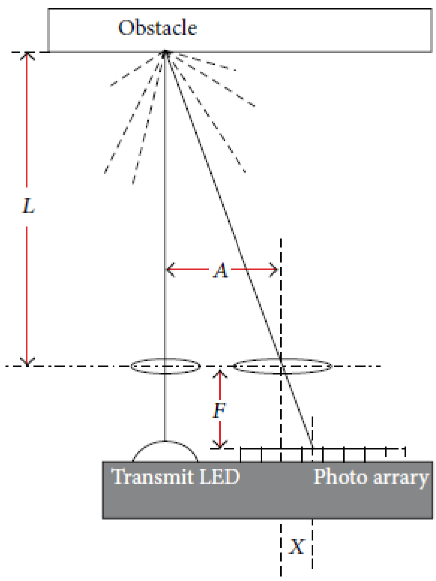

Figure 2.1: Distance measurement of the IR sensor [11]

One of the advantages of the IR sensor is faster response times compared to ultrasonic sensors. The results of research [11] show that response time of the IR sensor is 39 milliseconds, a lot faster compared with 100-200 milliseconds for ultrasonic sensors. Besides that, B. Mustapha, A. Zayegh, and R. K. Begg [12] also found that IR sensors can detect an obstacle at the distances within their usable range, especially for small distance measurement because of their high resolution and narrow range. However, these sensors have non-linear characteristic and they depend on the reflectivity of the object surfaces and colour of the object. The experiment results of this research show that reflectivity of the IR sensors is very low on the black colour compared to another colour. Besides that, the error percentage of IR sensors is higher in mirror obstacles compared to other materials of obstacles. Therefore, it can be concluded that the IR sensor has a low performance to detect mirror obstacles and its reading is different for different materials and colours. Another interesting fact about the IR sensor is it sensitive to the sunlight, and its reading can vary if the luminance in the environment changes [3].

2.2.2 Laser Rangefinder

Laser rangefinders are using a laser beam to measure the distance to a reflected object. These sensors are widely used for displacement measurement and industrial detection because of their non-contact and high-precision properties [13]. The method for distance measurement used by these sensors can be divided into several types such as time of flight, triangulation, frequency modulation, continuous-wave phase measurement, phase shift, interferometry method and others [14].

However, the laser light can be dangerous because it is harmful to the eyes [6]. Since the majority of the laser rangefinders for consumers are class 1 or class 2 and therefore extra precautions are required when using it [15]. Although the laser range finders are better than IR sensors, it will be exceeding the project's budget if a laser finder is purchased because laser sensor has a higher cost than the IR sensor and the ultrasonic sensor. Moreover, the sensor would be used by the virtually impaired and therefore if the user using the laser cane without extra precautions, it can cause a great danger not only to the user but also to other people who surrounding the user.

2.2.3 Ultrasonic Sensor

Ultrasonic sensor is one of the sensor frequently used in obstacle detection systems and distance measurements. It is a device that used to measure the distance between the sensor and the object. The sensor works by generating high-frequency sound waves and evaluates the echo which is received back by the sensor [12]. By using the speed of sound and the time interval between sending the signal and receiving the echo, the distance between the sensor and the object can be calculated. The distance can be calculated with the formula as shown in Eq. (2.2).

$$d = \frac{t \times s}{2} \tag{2.2}$$

Where d is the distance between the object and the sensor, t is the time interval between sending the signal and receiving the echo and s is the speed of sound.

A work about the performance comparison of ultrasonic and IR sensors for various materials of obstacles has been done by S Adarsh et al. [16]. The correlation analysis of the measured distance with actual distance was performed in this work based on the data obtain from the sensors. The materials selected for the analysis were rubber, cardboard, paper, sponge, wood, tile and plastic. S Adarsh et al. [16] found that the ultrasonic sensor has a good performance for almost all of materials whereas the IR sensor only has a good performance for a specific type of material. Another research was done by B. Mustapha, A. Zayegh, and R. K. Begg [12] show the ultrasonic sensor has a linear output characteristic and it has a higher percentage of accuracy detection for all colours and difference materials of obstacles compared to the IR sensor. However, it has slightly lower resolution than that of the IR sensor, especially for small distance measurement within their usable ranges.

2.2.4 RGB-D Camera

RGB-D cameras are novel sensing systems that can capture colour images and per-pixel depth information as shown in [17]. One of the products developed by using the RGB-D camera is Kinect. Kinect was investigated by Microsoft Company in 2009 and it able to acquire colour image, depth image, human movement, and stereoscopic sound [18]. Depth image is a 3D representation of the environment in grey scale format. Based on the distortion in the IR pattern, Kinect sensor can calculate the depth of an object from the camera.

T. Wang and L. Bu [18] also have proposed an obstacle detection system based on the Kinect depth image and the Kinect camera was used in this work. The results showed that the camera can detect obstacle areas out accurately in complex scenes and therefore it is robust to illumination. Besides that, the RGB-D camera is much more accurate and detailed than ultrasonic sensor [17]. However, most of the product like Kinect sensor are designed for indoor gaming applications, thus their range is not that great and this sensor requires more processing power compared to other sensors [4]. Due to they are novel sensing system, so they are costly. Besides that, this sensor has optical limitations because it can be blinded by direct sunlight. Therefore, it is not suitable to work under outdoor lighting conditions. Moreover, the Kinect sensor is inefficient to detect the transparent glass wall and featureless objects, such as big plain colour walls.

2.3 Review of previous work related with obstacle detection

There are various types of obstacle detection system has been developed with different approaches. Each obstacle detection system has its own advantages and disadvantages. In this section, five researches with using various types of approaches and sensor technologies will be discussed.

2.3.1 Obstacles Detection System using Double IR Rangefinders

An approach for obstacles detection by using double IR rangefinders was proposed by S. Kumpakeaw [7]. This approach was used to detect obstacles and build environment maps in the indoor environment. Due to the measurement of IR sensor can be influenced by natural light, so conditions for testing these sensors were limited in a room or indoor. The twin sensors were placed on a servo motor which can turn 180 degrees. One of the IR sensors was used to detect short range between 20 cm and 150 cm whereas another one was used to detect long range between 100 cm and 500 cm.

From the experiment results of this work, they found there were some distance measuring errors due to parallax detections from both IR sensors with different measuring angles and this cause a blur zone in overlapping ranges. Besides that, the result also shows the short-range IR sensor can detect obstacles in circumstance under 100 cm, but the long-range IR sensor cannot detect the obstacles due to its limited measuring capacity.

2.3.2 Laser-based Vision System

S. V. F. Barreto, R. E. Sant'Anna, and M. A. F. Feitosa [19] have proposed an obstacle detection system based on laser distance triangulation and image processing. In this work, the laser triangulation distance measurement is applied through a camera and a laser sensor and the system is implemented on a white cane. The laser and camera are working together to detect the obstacles that in front of the user. The distance calculation is based on the laser's position on the image captured by the camera. The results show that the system has a good performance in the indoor environment and it is easily identified the laser on the image captured by the camera including several types of surfaces. Nevertheless, the system has a limited performance for glass and mirror surfaces. Besides that, the accuracy of distance measurement is depending on the laser reflection, the system may inform a wrong distance or it is unable to detect the laser. For the outdoor environment, the camera is harder to find the laser spot due to the excess of light and then cause the system is difficult to detect the laser spot for the distance longer than 1 meter.

Some of the laser rangefinders are use a line laser and camera to scan a particular area for detecting an obstacle. For example, a virtual blind cane system proposed by Q. K. Dang et al. [6] using a line laser-based vision system and an inertial measurement unit (IMU) to help a blind person recognise an obstacle and find the distance between the obstacle and him/her as shown in Figure 2.2. The type of obstacles is classified by investigating the height of the laser point distribution, while the distance between the obstacle and the user is calculated by combining the swing movement analysis with the 3D laser point coordinates. The results showed that the obstacles can be classified accurately and the distance between the obstacle and the user has a small error. The advantages of the system are its simplicity and accuracy. However, the system is easily affected by strong illumination, so its maximum detect range is limited about 1.8 m from the user. This cause some significant errors in the measuring the distance to the obstacles, because some laser light points are out of effective detect range when the system is swinging.

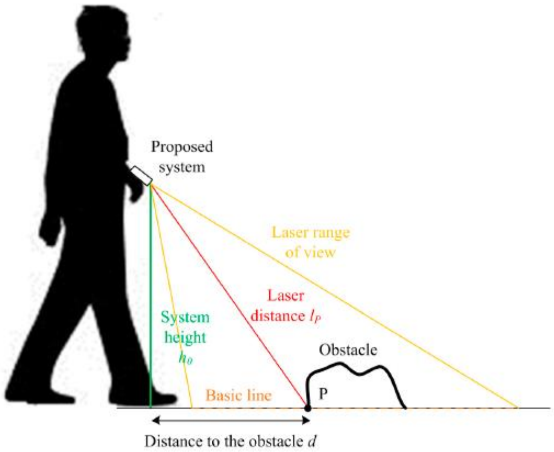

Figure 2.2: Obstacle detection with line laser-based vision system [6]

2.3.3 Sound and Touch based Smart Cane

The work proposed by R. K. Megalingam et al., which is Sound and Touch based Smart Cane [8] was used to detect the static obstacles and the moving obstacles. The Smart Cane consist of a Bluetooth enabled obstacle detection module, a temperature detection module and a haptics module. Ultrasonic sensors are used in the Smart Cane to detect an obstacle in front of the user. The distance between the static obstacle and the user is sent to an Android device via Bluetooth. After that, the user can get voice feedback about the distance through an earphone. The haptics module is used to inform the user about the moving obstacles. An algorithm has been proposed in the work for moving obstacle detection. The distance received from the ultrasonic sensor is measured 5 times and the difference between the previous reading and present reading is taken. If the measured value is within 55 cm which is equal to the average footstep of the user means that the obstacles are static and zero vibration motor is given. If the difference more than 55 cm, it means that the obstacle is moving and the vibration motor will be vibrating. The intensity of vibration in motor depends on the speed of the moving obstacles.

2.3.4 Obstacle Detection System using RGB-D sensor

A new algorithm for obstacle detection by using a RGB-D sensor was proposed by G. Yang et al. [9]. This algorithm not only can detect the obstacles but also can distinguish between dynamic obstacles and static obstacles based on the information of Kinect depth image. The RGB-D sensor was implemented on a mobile robotic platform and the new algorithm was tested on it. The depth image data from the RGB-D sensor was converted into the 3D point cloud and the points belong to the dynamic obstacle can be detected as shown in Figure 2.3. A grid map was created to show the obstacle segmentation for moving obstacles and static obstacles as shown in Figure 2.4. The static obstacle was detected out accurately on the grid map as blue area and the moving obstacle was segmented as red area. The result clearly shows that the robot by using the RGB-D sensor can discriminate the dynamic and static obstacles.

(a) (b)

Figure 2.3: Moving object segmentation: (a) Depth image with obstacles; (b) Image of moving object segmentation [9]

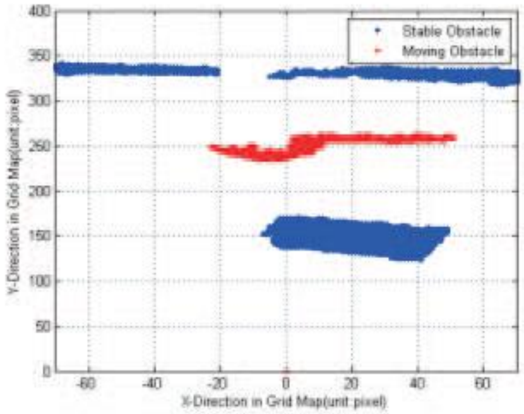

Figure 2.4: The corresponding grid map of obstacle segmentation for moving obstacles and static obstacles [9]

2.4 Sensor Fusion for Obstacle Detection

The advent of sensor technology has contributed several sensors with their independent advantages in terms of range, size, shape, environment, power consumption and cost for obstacle detection. However, these sensors have different limitations in obstacle detection. Therefore, the combination of sensors has been successfully used for obstacle detection. For example, a combination of ultrasonic sensor and IR sensor for obstacle detection has been proposed by S. Chaurasia and K. V. N. Kavitha [20]. In this work, two ultrasonic sensors are mounted on the stick that have ranged from 20 cm to 350 cm and two IR sensors are also implemented on the lower side of the stick for avoiding small obstacles ranging from 2 cm to 10 cm. The results showed that with the help of this electronic walking stick, the virtually impaired can improve more than 15-20% travel speed, reduce minor collision, do not lose their way, and increase safety compared to unaided equipment. However, they observe that the major drawback of IR sensors is their non-linear characteristic because a big change in output voltage does not change the range of IR sensors.

R. Pyun et al. [3] have also proposed a sensor fusion of ultrasonic sensor and IR sensor based white cane for obstacle detection that is Advanced Augmented White Cane (AAWC), which detects obstacles at four vertical levels and provides multi-sensory feedback. The AAWC is developed with three ultrasonic sensors to detect the obstacles at different height levels that are head, trunk and leg-level, as well as an IR sensor to detect drop-offs. The angles of the ultrasonic sensors are designed as 38 degrees for leg-level, 58 degrees for trunk-level, 85 degrees for head-level with respect to the white cane, and the angle for the IR sensor is fixed at 27 degrees as shown in Figure 2.5. The head, trunk, and leg-level detection have tested with different types of the obstacles. The result shows that the measured distance values corresponded to the expected distance value.

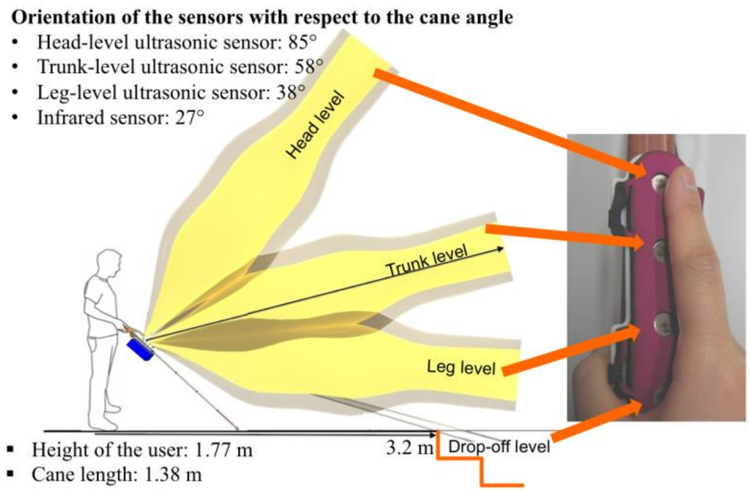

Figure 2.5: Optimal sensor arrangement of AAWC based on a reconstruction of the beam shape of the ultrasonic sensors with respect to a human user [3]

The AAWC has also tested at ascending stairs and descending stairs. For the ascending stairs, the distance between the IR sensor and the ground is unchanged, so it is unable to distinguish ascending stairs from tall obstacles. When the user walking on a flat surface towards the descending stairs, the distance is changed. Thus, the AAWC able to inform the user before the drop-off. However, the distance between the drop-off and the cane tip could be influenced by the user’s height, the tilt angle, the stride, walking speed, sweeping range, and the reaction time. Besides that, the AAWC might occur error detection in a narrow corridor because the ultrasonic sensor could detect the walls due to its wide field, and then cause the wrong vibrotactile feedback sent to the user constantly. Moreover, the slight change of the tilt angle could result in the significant change of distance between IR sensor and ground, and false alerts might occur.

2.5 Summary

Based on the literature review above, it can be seen that many types of research on the obstacle detection based on the different sensor technologies have been conducted. For laser sensor, it has noncontact and high-precision properties but it is harmful to the eyes and can be dangerous to other people who surrounding the user because of its high-power light. Besides that, it much more expensive compared to ultrasonic and IR sensor. With all these considerations, the laser rangefinder is neglected from the sensor selection in this project. For the RGB-D sensor, it can detect and distinguish between dynamic and static obstacles, but due to the RGB-D sensor has a large size and relative costly, so the RGB-D sensor is also neglected from the sensor selection.

For IR sensor, it can be used in obstacle detection because of its high resolution, low cost and faster response time. However, it has some disadvantages such as non-linear characteristic, sensitive to sunlight and depends on reflectance properties of the object surfaces. For the ultrasonic sensor, it is also suitable for obstacle detection because it has a higher percentage of accuracy detection for all colours and difference materials of obstacles and not affected by outdoor lighting condition. However, it has several limitations which are its wide beam-width and low resolution. Although the IR and ultrasonic sensors have different limitations in obstacle detection, the system can be utilised by using sensor fusion of IR sensor and ultrasonic sensor in an unknown environment and different type of obstacles. Finally, sensor fusion of IR sensor and ultrasonic sensor is chosen to implement in this system.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will focus on the discussion of the proposed system and the method that used to achieve the objectives of the project. In this project, a walking stick prototype with a sensor fusion based obstacle detection system will be developed to assist the user in detecting the obstacles. The ultrasonic and IR sensors are used for the obstacle detection and the controller platform used in this project is Arduino Nano Board. After that, a tilt angle control system will be implemented on the prototype to ensure the sensors work effectively in the detection range. Lastly, a suitable voice alert Android application will be developed for assisting the user in predicting the position of obstacles. The platform used to develop the Android application is MIT Inventor App 2.

In this chapter, the project implementation flow is explained in Section 3.2. This project comprises of two main parts, which are hardware implementation and software development of the obstacle detection system. Section 3.3 list out the software and hardware of the project requirement used in the system. Section 3.4 describes the hardware implementation of the system which includes the hardware design and prototype design. In section 3.5, the software development consists of obstacle detection algorithm, tilt angle control algorithm and voice alert Arduino application are presented. Section 3.6 shows several performance evaluations on the functionality of the system which is obstacle detection, tilt angle control and obstacle position prediction. Finally, a summary of this chapter is presented in Section 3.7.

3.2 Project Implementation Flow

The main project implementation flow is shown in Figure 3.1. This project consists of two main parts, which is hardware implementation and software development. Hardware implementation consists of two parts which are hardware design and prototype design. Firstly, the circuit of the system is constructed by using Arduino Nano and various of sensors and motors. Next, the overall system is implemented on the prototype walking stick. Besides that, obstacle detection sensors are mounted on the optimal position of the walking stick and the optimal angles for the sensors with respect to the walking stick are determined.

For the software development, there is three software involved in this project. The algorithm of obstacle detection system is developed by using Arduino IDE 1.6.1. Then the sensors tilt angle control system is also developed by using this software. After that, Android application is developed by using MIT Inventor App 2 to provide voice feedback to the user through Bluetooth module and Android phones. Then, the functionality of the system is tested and analysed. Fine tuning will be performed so that a better performance of the obstacle detection system can be obtained.

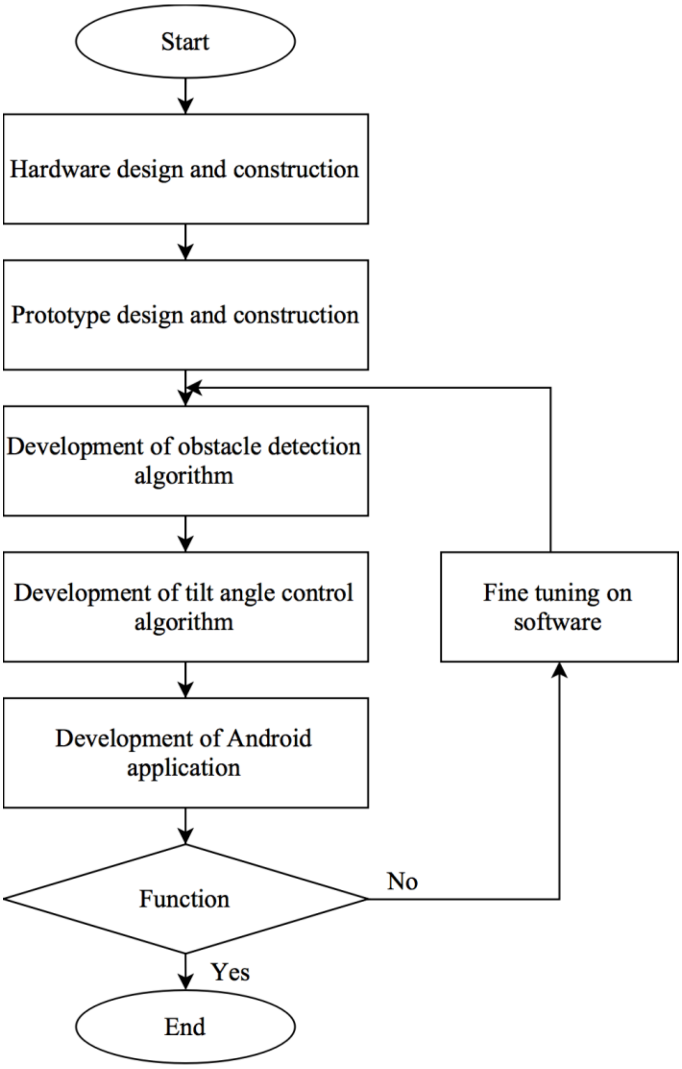

Figure 3.1: Flow chart of the project development

3.3 Project Requirement

In this project, there are several requirements being employed to build an obstacle detection system on a walking stick. The requirements for this project consist of two parts, which is hardware and software.

3.3.1 Hardware

The components used to develop the walking stick prototype with an obstacle detection system are listed in Table 3.1.

Table 3.1: List of hardware components

No.	Hardware	Quantity
1	Arduino Nano ATmega328 Board	1
2	Ultrasonic Sensor HC-SR04	3
3	IR Sensor Sharp GP2Y0A21YK0F	1
4	Bluetooth Module HC-06	1
5	Accelerometer MMA7361	1
6	Micro Servo Motor SG90	1
7	0834 Coin Vibration Motor	1

a) Arduino Nano ATmega328 Board

The Arduino Nano is a small and complete microcontroller board based on the ATmega328 as shown in Figure 3.2. This microcontroller has 5V operating voltage and it can be powered via the Mini-B USB connection. Besides that, it has 14 digital pins that can be used as input or output function. In addition, the Nano board also has 8 analog pins that can provide 10 bits of resolution from ground (0) to 5V (1024). All analog pins can be used as digital pins except analog pins 6 and 7. The Nano board can be programmed by a computer through the Arduino software to receive input from a variety of sensors and transmit output for controlling lights, motors and actuators. Datasheet for the Arduino Nano board is shown in Appendix A (Section A.1).

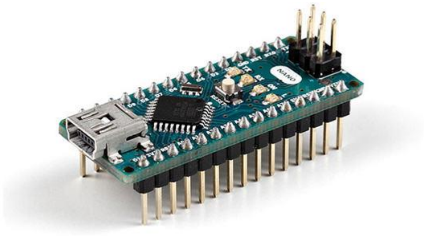

Figure 3.2: Arduino Nano ATmega328

b) Ultrasonic Sensor HC-SR04

Figure 3.3 shows the ultrasonic sensor HC-SR04 that is used to detect the obstacles at the head and middle levels of the user in this project. It able provides 2 cm to 400 cm detect range and has 15 degrees measuring angle. The module includes an ultrasonic transmitter, an ultrasonic receiver and a control circuit. Besides that, the operating frequency of the modules send the signal is 40kHz and its operating voltage is 5V DC. Datasheet for this module is shown in Appendix A (Section A.2).

Figure 3.3: Ultrasonic sensor HC-SR 04

c) IR Sensor Sharp GP2Y0A21YK0F

Figure 3.4 shows the IR Sensor Sharp GP2Y0A21YK0F that is used to detect the obstacles at the ground level of the user in this project. It is an analog output distance measuring sensor unit and its distance measuring range is 10cm to 80cm. The sensor consists of an integrated combination of position sensitive detector, IR emitting diode and signal processing circuit. The operating voltage of the sensor is 4.5V to 5.5V and its output voltage is corresponding to the detection distance, so it can be used as a proximity sensor. Datasheet for this sensor is shown in Appendix A (Section A.3).

Figure 3.4: IR Sensor Sharp GP2Y0A21YK0F

d) Bluetooth Module HC-06

Bluetooth serial module is a wireless technology for exchanging data over a short distance from serial port to Bluetooth devices as shown in Figure 3.5. The module has a 2.4GHz digital wireless transceiver, its operating range is approximately 10 meters and its operating voltage is 3.1V to 4.2V. Besides that, the module has two modes of operation which is Command Mode and Data Mode. Command Mode is used to send AT commands to it whereas Data Mode is used to transmits and receives data to other Bluetooth devices. Datasheet for this Bluetooth module is shown in Appendix A (Section A.4).

Figure 3.5: Bluetooth module HC-06

e) Accelerometer MMA7361

The MMA7361 is a sensor that has low power and low frequency capacitive micromachined accelerometer as shown in Figure 3.6. Its operating voltage is 2.2V to 3.6V and it has three analog output for x, y and z axis. It can be used to measure static or dynamic acceleration in all three axes (x, y and z). Besides that, it also can be used to measure the tilt of a platform with respect to earth axis. In this project, the accelerometer is used for tilt measuring of a walking stick. Datasheet for this accelerometer is shown in Appendix A (Section A.5).

Figure 3.6: Accelerometer MMA7361

f) Micro Servo Motor SG90

The SG90 is a tiny and lightweight (9 g) with high output power servo motor as shown in Figure 3.7. The servo motor can be rotated approximately 180 degrees and its rotate direction can be controlled via Arduino servo code. The operating voltage of this servo motor is 4.8V to 5V and its operating speed is 0.1 s/60 degrees. The servo motor is controlled by sending a pulse width modulation through a control wire. The rotate direction is based on the pulse duration sent via the control wire for every 20 milliseconds (ms). The servo motor will rotate in position “0” for 1.5 ms pulse, position “90” for 2 ms pulse and position “-90” for 1 ms pulse as shown in Figure 3.8.

Figure 3.7: Servo motor SG90

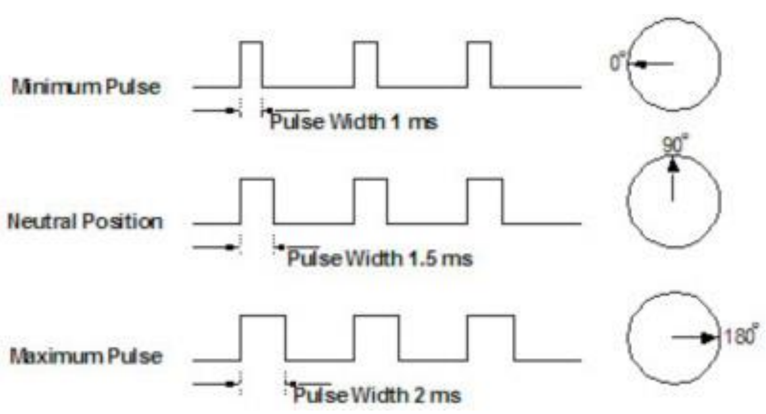

Figure 3.8: Variable pulse width modulation control servo position

g) 0834 Coin Vibration Motor

Figure 3.9 shows the coin vibration motor that is used in a wide range of product, like tools, mobile phones, medical instruments, GPS and control sticks. In this project, the main actuator of the motor is providing haptic feedback to the user. Its operating voltage is 2.7V to 3.3V DC and it can be fixed in any place with only 8mm diameter and 3.4 mm thick.

Figure 3.9: 0834 Coin Vibration Motor

3.3.2 Software

The software used to develop the obstacle detection algorithm and analyse the performance of the system are listed in Table 3.2.

Table 3.2: List of software

No.	Software
1	Arduino IDE 1.6.1
2	MIT Inventor App 2
3	MATLAB

3.4 Hardware Implementation

Hardware implementation consists of two parts which are hardware design and prototype design. For hardware design part, the block diagram and schematic diagram is showed and the circuit construction is elaborated. For prototype design part, the concept for system operation and sensors arrangement is explained.

3.4.1 Hardware Design

The block diagram of the overall system is shown in Figure 3.10. To reduce the limitation of the mono sensor obstacle detection system, a sensor fusion obstacle detection system is used in this project. This system consists of three ultrasonic sensors and an IR sensor. An ultrasonic sensor (S_h) is designed to detect the obstacles in head-level, another two ultrasonic sensors (S_m: S_{mr} for the right side and S_{ml} for the left side) for middle-level whereas IR sensor (S_g) is used in ground level for uneven ground surface detection such as holes and descending stairs. Then the detected distance from the sensors is transferred to Arduino Nano. After that, Arduino Nano is programmed to provide tactile and voice feedback to the actuators based on the data received. The vibration motor is used to provide tactile feedback to the user when an obstacle is detected. Besides that, an Arduino device which installed voice alert Android application is connected to the system through Bluetooth communication to assist the user in predicting the position of obstacle. The accelerometer is used for tilt measurement of the walking stick and prevent error detect range of sensors. In addition, tilt measurement of the walking stick is also used to retain the angle of the sensors in a constant angular position. If the tilt angle of walking stick is changed, then the sensors will be adjusted back to the position using servo motor.

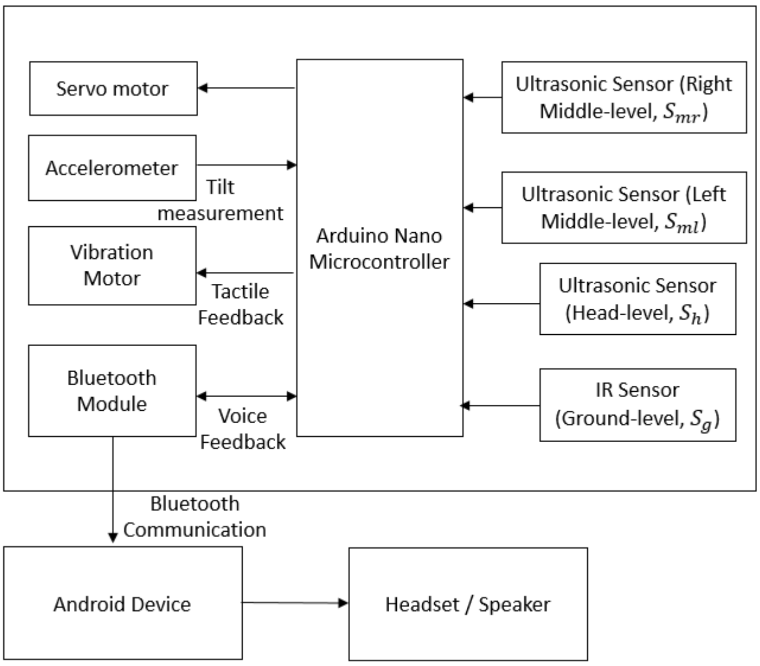

Figure 3.10: Block diagram of the overall system