Automated Obstacle Detection System for Safe Locomotion

A THESIS

SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

D O C T O R O F P H I L O S O P H Y

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To my beloved families,

my wonderful wife Raja Roziana Raja Bidin,

and….

my lovely kids,

Nik Muhammad Danial, Nik Nurin Nazuha, Nik Muhammad Haziq,

Nik Muhammad Wazif, Nik Nurin Batrisyia, Nik Nurin Farzana,

Nik Muhammad Hazim, Nik Muhammad Arham and Muhammad Wajdi.

ABSTRACT

The dramatic growth in aging population has opened up the opportunity for engineers and scientists to develop sophisticated devices, especially in supporting the elderly for safety navigation. Mobility assistive device is a supportive tool which can assist the elderly during walking either indoor or outdoor environment. The number of fall-related diseases among the elderly could be reduced using sensor based mobility assistive devices. These machines will grow further as new supportive tools of electronic devices for daily locomotion, and become more feasible and pervasive. Sensor embedded mobility assistive devices with wireless technology compatibilities are the solution to accommodate the elderly's safety in navigation. The newly designed system must be highly reliable, efficient, hands-free, cheap and most importantly, practical for use in real life activities. These technologies are said to bring a number of significant improvements into the next generation of mobility assistive devices, including miniaturization, low power consumption, full integration of system capability and low cost of production. Miniaturization is a great advantage as it means that the devices or systems should require only small volumes of space and suitability to embed insole of shoes. With low power consumption, only small batteries might be needed as power supply or even energy scavenging can be sufficient to power them, if not a combination of these. As full system integration on a single chip is also possible, signal processing and computation can be performed on the same chip with greatly improved overall system performance. Most interestingly, the low per-unit cost is what business and consumers are looking for in every product and this has been a significant trend.

In addition, technologically, it also offers numerous tools that are not only excellent electronically for sensing and alarming, but also biologically compatible. Undoubtedly, these integrated sensor-based devices are promising tools for indoor and outdoor navigation.

Current assistive devices are not comfortable for the elderly to dress in because they are not hands-free and they need assistance before they start walking. This research analyses several distance measurement sensors such as ultrasonic, infrared, laser and sonar that may be suitable for the obstacle detection system. The study suggests that ultrasonic and infrared sensors are very suitable for this application based on the cheap cost, miniature, applicable sensing distance, sensitivity, fast processing and high resolution, thus a prototype model is proposed in this research. The work includes an investigation into obstacle materials, shapes, colours and sizes. Analysis was performed on the utilized sensor to investigate several key performances such as sensing distance, obstacle detection, and size of detected obstacle and the change of environment. To further complement the obstacle detection system, other features such as wireless data transmission and alerting modality are also taken into focus.

Investigations into the wireless system and potential alarms modality are crucial to ensure comfortability for the elderly while walking. Buzzer, vibrator and audio messages are the alerting modalities used in this prototype. The force sensing resistor is employed to act as a switch which enables the obstacle detector sensor to detect an obstacle only when the foot fully touches the ground. Experimental work clearly reveals that a high accuracy measurement of obstacle detection is achievable using the selected sensors. The sensors also demonstrated good detection for various types of obstacle materials, colours, sizes and shapes in all environments. As such, this thesis reports the requirement studies, design, prototype development, analysis and optimization of an obstacle detection system for safe navigation. Finally, a new obstacle detection system has been developed to reliably and securely detect obstacles and generate alarms to the users. The research demonstrates that the sensor-based mobility assistive devices fulfil the requirements of hands-free supporting device for the elderly in navigation.

DECLARATION OF ORIGINALITY

"I, Baharuddin Mustapha, declare that the PhD thesis entitled **Automated Obstacle Detection System for Safe Locomotion** is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work".

[redacted]

---------------------- Signature

02/12/2016

---------------------- Date

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LIST OF ABBREVIATIONS

BCI	Brain-Computer Interface
BP	Blood Pressure
CDC	Centre for Disease Control
DOF	Degree of Freedom
ETA	Electronic Travel Aids
FES	Functional Electrical Stimulation
FF	Flat Foot
FSR	Force Sensing Resistor
GPS	Global Positioning System
ICT	Information and Communication Technology
IR	Infrared Sensor
IRW	Intelligent Robotic Wheelchair
LED	Light Emitting Diode
MAD	Mobility Assistive Devices
MCU	Microcontroller Unit
MMR	Multipurpose Mobile Robot
ODS	Obstacle Detection Sensor
PAD	Portable Assistive Device
PAMM	Personal Aid for Mobility and Monitoring
PCB	Printed Circuit Board

PIC	Peripheral Interface Controller
PSD	Position Sensitive Detector
RFID	Radio Frequency Identification
SWOT	Strengths, Weaknesses, Opportunities and Threats
US	Ultrasonic Sensor
WAR	Walking Assistance Robot
WMR	Wheeled Mobile Robot

LIST OF PUBLICATIONS

1. *B. Mustapha, A. Zayegh and R.K.Begg, 2014. 'Development of a Wireless Obstacle Detection System', AMSE Journals: Modelling C, vol. 75, no. 1, pp. 79-99. ISSN 12595977.*

2. *B. Mustapha, A. Zayegh, and R.K. Begg, 2014. 'Reliable Wireless Obstacle Detection System for Elderly and Visually Impaired People with Multiple Alarm Units',in* ***Proceedings of the IEEE International Conference on Computer, Communication and Control Technology (IC4T 2014)****, 2-4 September, Langkawi Malaysia, pp. 271-276. ISBN 978-1-4799-4554-2.*

3. *B. Mustapha, A. Zayegh and R.K.Begg, 2015. 'Wireless Obstacle Detection based on Multiple Sensor', in* ***Proceedings of the Second International Conference on Innovative Trends in Science, Engineering and Management 2015 (ICITSEM 2015),*** *25-26 February, Dubai, UAE, 2015.*

4. *B. Mustapha, A. Zayegh, and R.K. Begg, 2012. 'Design and Implementation of Wireless Obstacle Detection System for Safe Locomotion', in* ***Proceedings of the IEEE 2012 Third International Conference on Intelligent Systems Modelling and Simulation****, 8-10 February, Kota Kinabalu Malaysia, pp. 718 - 722. ISBN 978-1-4673-0886-1.*

5. *B. Mustapha, A. Zayegh, and R.K. Begg, 2014. 'Wireless Obstacle Detection System for the Elderly and Visually Impaired People', in* ***Proceedings of the 2013 IEEE International Conference on Smart Instrumentation, Measurement and Applications (ICSIMA)****, 25-27 November, Kuala Lumpur Malaysia, pp. 1-5. ISBN 978-1-4799-0842-4.*

6. *B. Mustapha, A. Zayegh, and R.K. Begg, 2014. 'Ultrasonic and Infrared Sensors Performance in a Wireless Obstacle Detection System', in* ***Proceedings of the IEEE 2013 First International Conference on Artificial Intelligence, Modelling & Simulation****, 3-5 December, Kota Kinabalu Malaysia, pp. 487-492.ISBN 978-1-4799-3250-4.*

7. *B. Mustapha, A. Zayegh, and R.K. Begg, 2014. 'Microcontroller Based Wireless Obstacle Detection System for the Elderly', in* ***Proceedings of the 4th International Conference on Artificial Intelligence with Applications in Engineering and Technology (ICAIET), 2014****, 3-5 December, Kota Kinabalu Malaysia, pp. 325-329. ISBN 978-1-4799-7909-7.*

Thesis Overview

CHAPTER

1

1.0 Introduction

Obstacle detection is one of the important features which have been considered in the development of mobility assistive devices for the elderly. Modern mobility assistive devices are equipped with this function as an obstacle detector during walking either in the indoor or outdoor environment. Detection of obstacles on the pathway walking area is very important to avoid the occurrence of a collision with obstacles which can cause user to experience a fall. Falls are a serious issue in an aging population. Centre for Disease Control and Prevention (2010) stated that 1 in 3 adults aged 65 years old and older falls each year and of those who fall, 20% to 30% suffer moderate to severe injuries that make it hard for them to get around or live independently (CDC, 2010). Furthermore, about 4.5% of people aged 70 years old or older died after such a fall compared with 1.5% of nonelderly people (Spaniolas et al., 2010).

Recently, researchers have revealed that when collisions happen, elderly people are more likely to initiate falls and get between moderate to severe injuries, such as hip fractures and head traumas, and can even increase the risk of early death. In the United States of America, such fall-related injuries led to an annual cost of $20.2 billion in 1994 and are expected to reach up to $32.4 billion by the year 2020 (Rentschler et al., 2003). In Australia, the overall health costs attributable to fall injury among persons aged 65 years old and over are expected to reach $788.7 million by the year 2021 (Moller, 2003).

It is clearly stated that the highest direct medical expenses in Australia came from fall-related injuries (approximately $3 billion) relative to other types of injuries as shown in Figure 1.1.

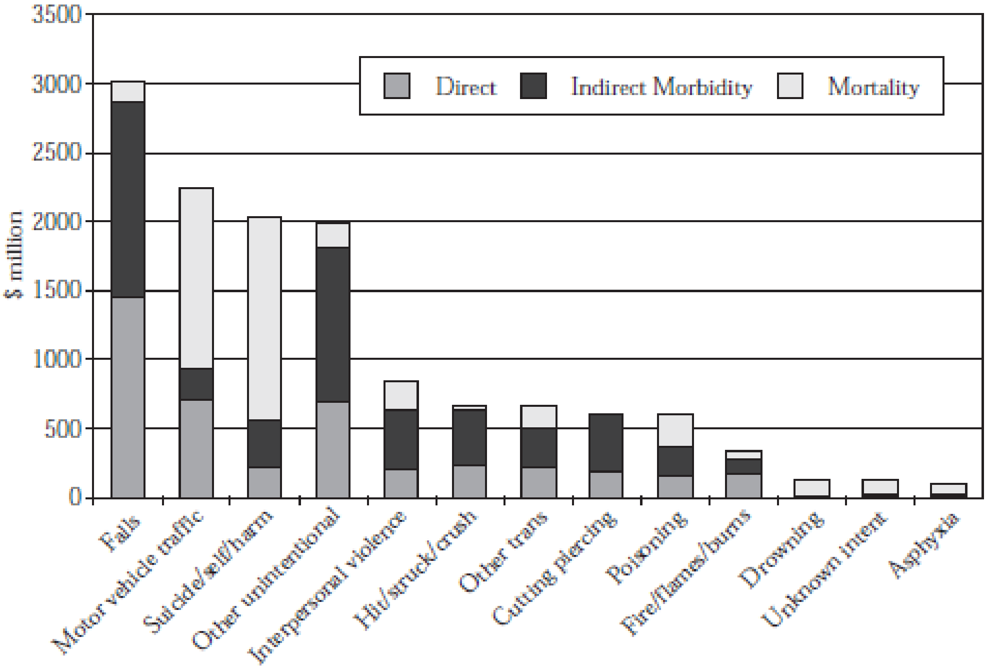


Figure 1.1: *Direct medical costs of all injuries in Australia (NHMRC, 2011).*

Dramatic increase of the elderly population in the society (Jyh-Hwa & Feng-Chun, 2009) urged for scientists and engineers to identify the best solution on how walking assistance aids could serve them better in order to avoid collision in performing their daily activities. Figure 1.2 shows the percentage of the elderly population in some of the developed countries (United States of America (USA), Japan, France, Sweden and Australia). From the graph, it is evident that the elderly will reach up to 20% of the whole population for some of these countries by 2020.

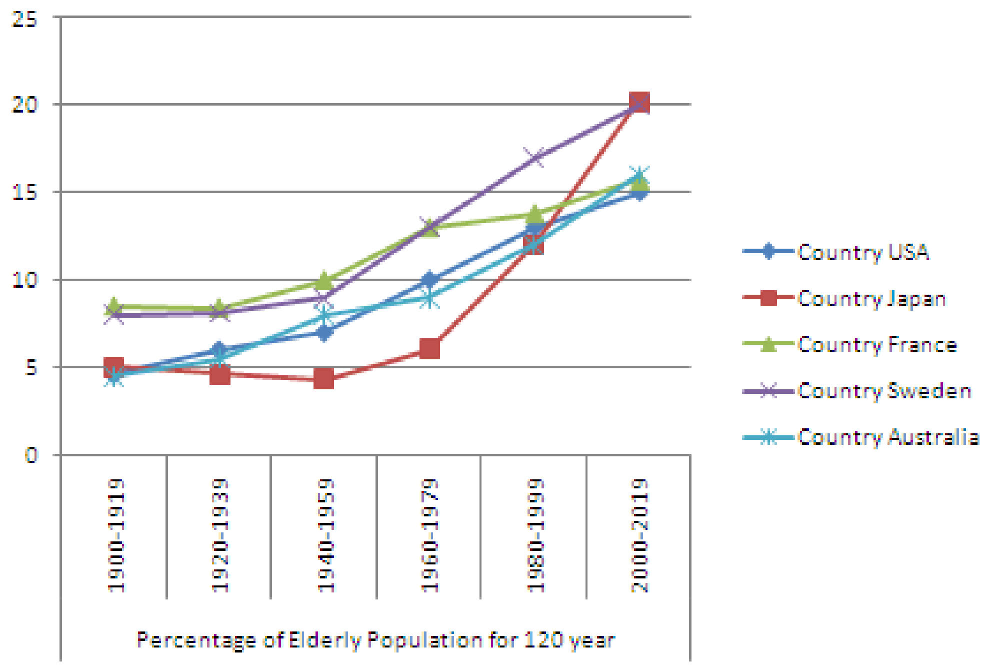


Figure 1.2: *Population in several developed countries, observed and projected (Weston et al., 2001; Fujie et al, 1994).*

The need for effective and user-friendly mobility assistive devices (MAD) is required in order to improve people's (e.g. elderly and patient with low ability) locomotion and help them maintain balance as well as minimizing falling. The amazing development of advance technology such as robotics, biomedical instrumentation, bioengineering and sport science has made it possible to build sophisticated system that is capable of supporting the elderly from falling due to the loss of balance and control. The development of the sophisticated MAD such as Personal Aid for Mobility and Monitoring (PAMM) have helped the elderly and provided comprehensive data for researchers to identify risk factors which cause falls during walking (Dubosky, 2000). Additionally, it will also help doctors and caregivers to respond quickly when patients or the elderly sustain a fall or are in need of assistance.

Other types of smart MAD that have been utilized in the elderly navigation either indoor or outdoor are powered wheelchairs (Murakami et al., 2009), smart canes

(Kajathepan, 2009) and smart walkers (Spenko et al., 2006). In conclusion, biomechanical support, obstacle avoidance capability and navigational assistance are the features that should be considered while designing an effective MAD device for the elderly and visually impaired people. The integration of these functions would reduce the need for supervision, cost of care and increase the independence and well-being of the elderly. Figure 1.3 shows some examples of these devices that have such functionalities as needed for assisting the elderly and visually impaired people in navigation. However, these devices still need further improvement in terms of handling, pricing and being comfortable to wear. In several cases, these devices are abandoned due to discomfort when they are being used.

(i) (ii) (iii)

Figure 1.3: *Mobility Assistive Devices:(i) ETA (Jameson & Manduchi, 2010) ; (ii) Shoe-mounted inertial navigation system (Castaneda & Lamy-Perbal, 2010); (iii) Robotic Wheelchair (Chung Hsien & Chen, 2006).*

1.1 Motivation

As roughly mentioned in the previous section, the current status of the development of wearable assistive devices for the elderly and visually impaired people is still lacking behind the reality of technology achievement. In this subsection, the motivation for this research is described specifically with respect to hands-free devices for obstacle detection while walking as the current devices are not fully optimized in many aspects, such as:

- Unsuitable for real world or outdoor application
- Not cost effective
- Not enabling efficient signal processing
- Not fully integrative for better reliability and long lasting use
- Not considering the required gait specifications for multi-user application
- Not supporting efficient alarming system

Most interestingly, despite the proven track records, there is no reported innovation that the hand-free obstacle detection system is attached to the shoe for assisting the elderly in navigation either for indoor or outdoor environment.

1.2 Research Methodology

This section elaborates on the steps and tools used throughout the research duration to accomplish the research target. In general, the use of PIC development board as an integrated tool for sensors and microcontrollers interface testing is involved. In addition, software programming tools, namely the MP Lab IDE version 8.76 and Hi-Tech C Compiler are also employed regularly. As the aims of the project involve two outputs, which are sensing the obstacles within 2-meter distance and alerting the user, this subsection is divided into two parts for easy elaboration. The first part, which in 1.2.1 is devoted to the obstacle detection sensor at the transmitter section while 1.2.2 caters for the alarming units at the receiver end of the entire system.

1.2.1 Obstacle Detection Sensor

The steps involved in this part of research are enlisted below:

1.2.1.1 Investigate different types of obstacles detection sensors (ODS)

This step involves searching and digesting the knowledge presented in relation to publications. An extensive review into the different types of ODS will be carried out appropriately. This study will address all aspects of different sensors, their configuration through detection schemes and algorithm, and characteristics of the sensors. Different types of sensors such as optical sensors, i.e., photoelectric sensor, infrared sensor, fibre optic sensor, proximity sensor and photodetector will also be tested. The characteristics of each sensor will be analysed and evaluated specifically for their suitability for detection, range, angle, resolution, sensitivity and sensing mode.

1.2.1.2 Study and specify target objects and limitations

This step requires the study to conduct an analysis of various types of obstacles (e.g., colour, material, shape and sizes) and distance of the obstacle to be detected. In this research, we propose that the distance of obstacles to be detected by the sensors should be up to 2 meters which is recommended in many literatures. The types of obstacles to be considered will include small objects (e.g. toy, bottles and etc.), large objects (e.g. chair, desk, square box and etc.), stairs, wall and uneven surfaces such as bumps on the walkway. Properties such as signal reflection and signal absorption will also be further investigated.

1.2.1.3 Development of a smart algorithm for obstacle detection

The main functions of the algorithm are to read the sensors output continuously and process these data to determine the existence of obstacle(s) and then, generate the necessary warning signal (i.e., sound, vibration and audio messages). Several scenarios should be considered depending on obstacles such as distance and nature.

1.2.1.4 System Testing and Analysis

The entire system will be assembled, the program will be loaded and the system will be tested and tuned for optimal performance. Figure 1.4 illustrates the block diagram of the system's main components.

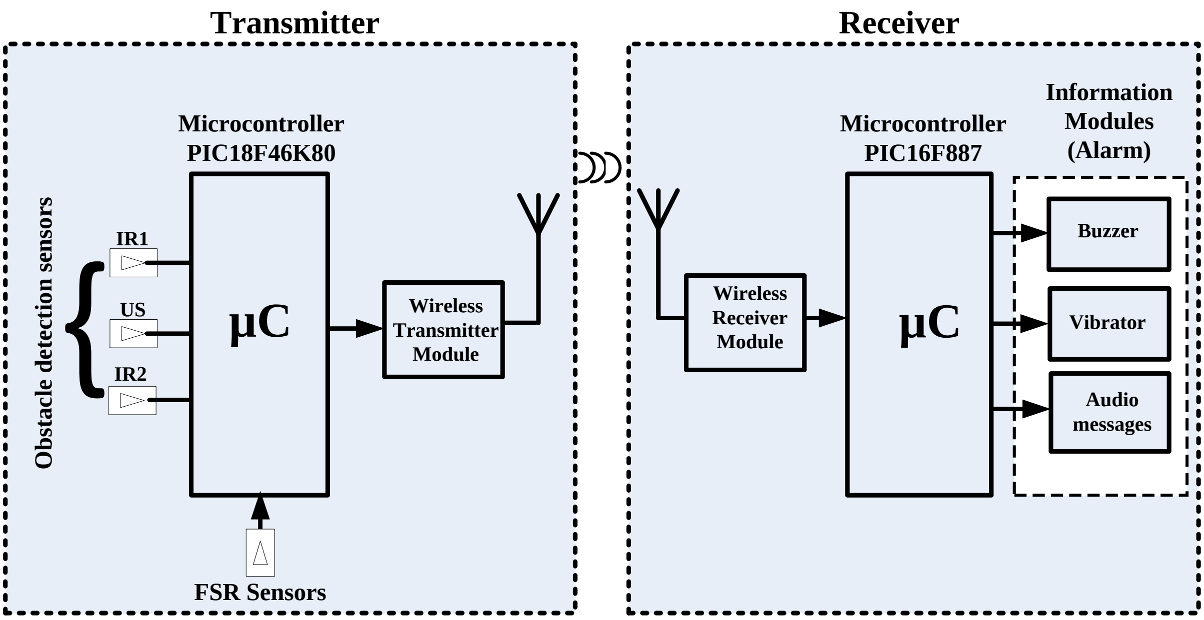


Figure 1.4: *Block diagram of the proposed system.*

1.2.2 Alarming units

The steps involved in the research for this device's design and analysis are:

1.2.2.1 Study of the suitable feedback modalities to alert the user

Literature review on the above subject is carried out to understand the type of modality that is suitable for human. The common feedback modality is then compared with the actual needs to identify the gap.

1.2.2.2 Analysis of the suitable location of the device on human body

Various locations are considered by analysing their strengths and weaknesses towards sensitivity for human. It is found that the head, wrist, lower arm, waist and upper arm are common places for putting the alerting device on human body, with each places having their own judgement which associate with sensitivity.

1.2.2.3 Study of possible distances to activate the alarms

The distance that is proven to give more reliable attraction is then analysed for activating the alarms. Several regions of distance are considered based on the user's style of walking. The activation of the alarms depends on the desired distances at the setting region of interest.

1.2.2.4 Alarm setup and Design

Once a suitable distance of interest is identified, the alarm setup and design are performed. The swot analysis is used to optimize and characterize the user requirement.

1.2.2.5 Assembly and Testing

The designed alarming devices are packaged, wired on Printed Circuit Board (PCB) and attached to a specially determined location of the body.

1.3 Summary of Contributions

This research will contribute to the knowledge of obstacle detection for safe locomotion for the elderly as it addresses major issues in realization of efficient, reliable and practical devices. The research is one of the pioneering attempts in introducing, designing, finalizing, realizing and characterizing the sensors for hand-free, low cost, easy to use; obstacle detection. This research will contribute to knowledge in the following specific areas:

1.3.1 Optimal sensor requirement for the obstacle detection system

Optimal sensor for gaining the optimum detection of the obstacle that satisfies the system requirement is identified. Following this, a list of analogue distance sensor specification is proposed.

1.3.2 Comparative Study of Obstacle Detection Techniques

A proper comparative study of techniques of obstacle detection is performed analytically. The analysis results are evaluated in terms of key capabilities such as detectable range, reliability of detection and suitability for all types of obstacle materials, and thus a suitable technique for obstacle detection is identified and reported.

1.3.3 Development and Characterization of Alarming Modality

An effective auditory and tactile modality is implemented for realizing wearable obstacle detection device which is capable of alerting users about the existence of obstacle in walking pathway either indoor or outdoor.

1.3.4 The Prototype Development of the Wearable Wireless Obstacle Detection

By utilizing the wireless technology applications, the transceiver wireless module is identified and a list of available wireless module and specifications is proposed.

1.3.5 Testing and Tuning of the Wireless Obstacle Detection

The performance of the prototype wireless obstacle detection system is tested according to the user requirement based on the design specifications in both environments (indoor or outdoor). The alarm is tuned for the users' comfort and suitability.

1.4 Thesis Organization

The literature review for mobility assistive devices and sensor technology are explained in Chapter 2. The gait parameters, specification, space consideration and physical ability of the user are mentioned in Chapter 3. The following chapter, Chapter 4 is devoted to the components used in the wearable obstacle detection system and implementation of the wireless application. Chapter 5 elaborates on the prototype and design of the obstacle detection device which include the hardware for transmitter and receiver. In addition, Chapter 5 provides the empirical results of the hardware, analysis, testing and also technical discussions on the said matter. Chapter 6 discusses the system performance and accuracy which include software development and implementation, system algorithm and process, testing, system performance and measurement results. Discussion, conclusion and further research recommendations are provided in Chapters 7.

Literature Review

CHAPTER

2

2.0 Chapter Overview

This chapter elaborates on the current trends of mobility assistive devices (MAD) and the most practical and economical sensors used for obstacle detection as available in the literature and the market. It also highlights the surging need for new generation of such sensors. As such, the chapter is divided into five main sections. The first section is devoted to a short overview of the trends of MAD for the elderly. Next is the section for a review of the Portable Assistive Devices (PAD). Then, a section for a review of the Wearable Assistive Devices follows. A section dedicated for sensors technology for obstacle detection and its potential comes next. Lastly, the chapter summary highlights the need for new generation MAD based on the more adaptive and economical system that enables hands-free interaction and miniature devices.

2.1 Trends in Mobility Assistive Devices for the Elderly

The need for effective and user-friendly mobility assistive devices (MAD) is required in order to improve people's (e.g. elderly and patient visually impaired) locomotion and help them maintain balance and minimize falling. The MAD should be able to provide both support and navigational assistance while reducing the need for supervision that could also reduce the cost of care and increase the independence and well-being of thousands of old people. The MAD can be classified by two categories, which are portable and wearable devices as shown in Figure 2.1. The use of leading-edge technology in the development of a new MAD rapidly flourishes; hence, it will help the elderly live safely without assistance from other people.

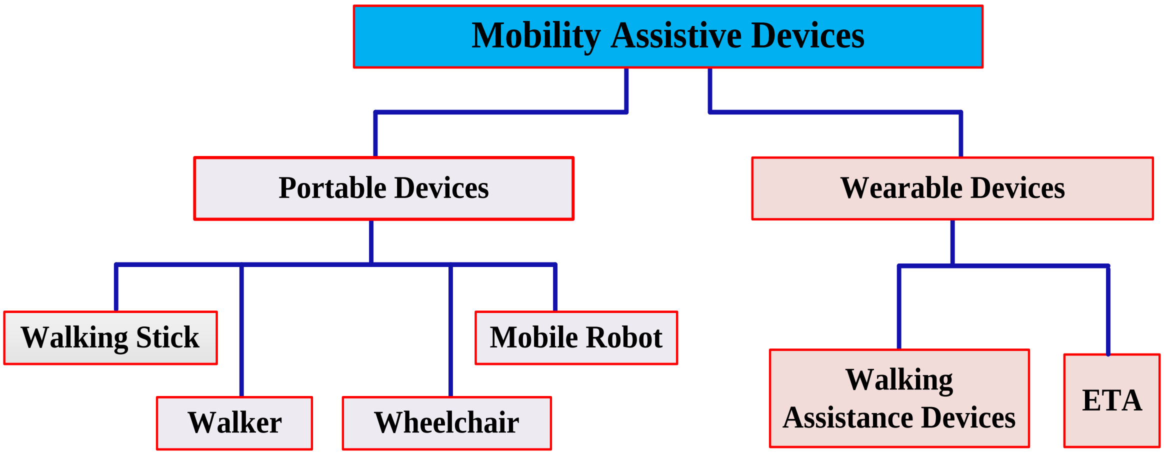


Figure 2.1: *Classification of mobility assistive devices.*

2.2 Portable Assistive Devices

Portable assistive device (PAD) is a device that is specifically designed in light weight; therefore, it can be carried, moved, conveyed, transferred or transported from place to place easily. Basically, PAD have been used as supporting mechanism during walking, the service provider for independent living and rehabilitation purposes. PAD also support and aid the elderly for better health. Modern PAD offers a variety of functions when compared to conventional portable assistive devices. Table 2.1 describes the main user of the portable mobility assistive devices and its functionality.

TABLE 2.1: PORTABLE MOBILITY ASSISTIVE DEVICES, USERS AND MAIN TASKS

Device Name	Main User	Purpose/task
Walking Stick	Elderly and visually impaired people	Body support, navigation, emergency call out, obstacle avoidance
Smart Walker	Elderly and patient	Body support, navigation, obstacle avoidance, rehabilitation
Smart Wheelchair	Elderly, disabled person and patient	Transportation, navigation, obstacle avoidance
Mobile Robot	Elderly and patient with low muscle strength	Transportation, navigation, obstacle avoidance, socially interactive, service provider, rehabilitation

2.2.1 Walking Stick

Walking stick is one of the popular travel aids to help the elderly and blind people in locomotion. This travel aid can be categorized by two versions, which are traditional cane and modern cane. Basically, the traditional white cane (H. Bateni and B. Maki, 2005) offers physical support as well as supplementary sensing feedback to the user. However, these conventional aids also revealed serious adverse effects that contribute to falling. In terms of obstacle detection, the cane should have contact with the obstacle before the user can decide on the next move. The modern cane is an improved version of a white cane, which is equipped with the sensory system to detect obstacles. For example, GuideCane (J. Borenstein and I. Ulrich, 1997) is one of the earlier generations of modern canes, which can steer blind people around obstacles. This device is equipped with a set of electronic and mechanical components such as ultrasonic sensors, mini joystick, servomotor, wheels and built-in computer. However, the GuideCane is much heavier than the ordinary white cane, and it is very hard to keep because it cannot be folded. An extended version of the modern cane is known as the Electronic Cane (S. Y. Kim and K. Cho, 2012). The Electronic Cane is lighter than the GuideCane, but it is still heavier than the conventional white cane. The Folded Cane is used for easy storage and the vibrotactile actuator generates alerts on the handle when detecting obstacles within a range of 2 meters and above the knee-level. Figure 2.2 illustrates the prototypes of the traditional white cane and modern canes.

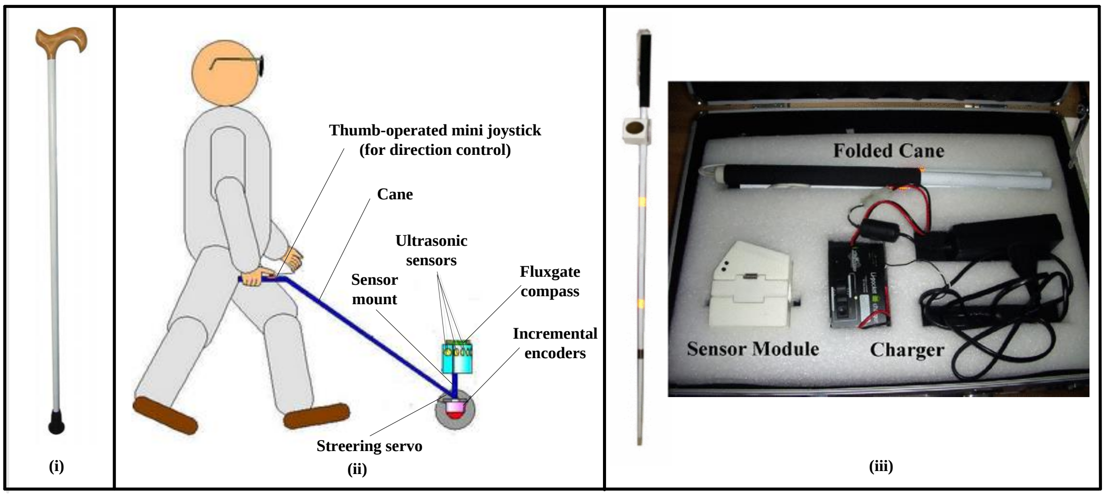


Figure 2.2: *Common types of walking sticks:(i) White Cane (H. Bateni and B. Maki,2005); (ii) GuideCane (J. Borenstein and I. Ulrich, 1997); (iii) Electronic Cane (S. Y. Kim and K. Cho, 2012).*

The development of the electronic cane never ends. Researchers have developed a new version of electronic cane named the SmartCane. The pioneer development of a smart cane is designed by a group of students from the Central Michigan University (M.H.A. Wahab et al., 2011). The SmartCane prototype consists of a sensors system, advanced materials, embedded computing, GPS and wireless networking technology to provide capabilities for remote monitoring, local signal processing and real-time feedback on the cane usage. Smart features and dynamical design of a recent SmartCane as shown in Figure 2.3 will be beneficial to the elderly to navigate safely in both the indoor and outdoor environments.

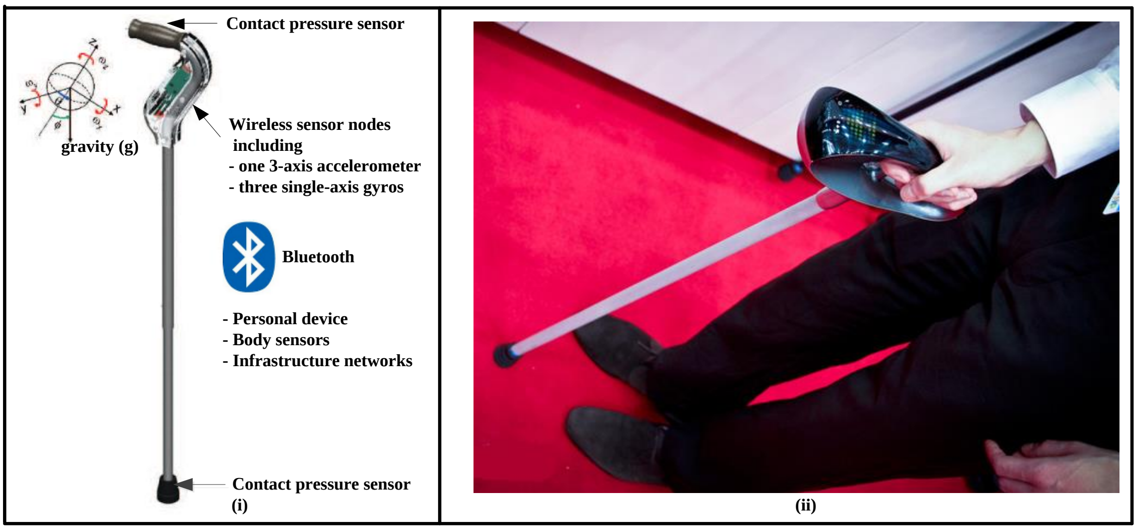


Figure 2.3: *Recent Attractive SmartCane: (i) SmartCane for Geriatrics (M. Lan et al., 2009) ; (ii) Fujitsu GPS Walking Stick (R. Henderson, 2013).*

2.2.2 Walker

The walker is another walking aid for people who have difficulty walking unassisted, such as the elderly, disabled person and patients. The main objective of a walker is to provide additional support to maintain balance or stability while walking. However, traditional walkers as shown in Figure 2.4 create some problems for some of the elderly. The standard walker requires the user to lift and move the device forward to walk.

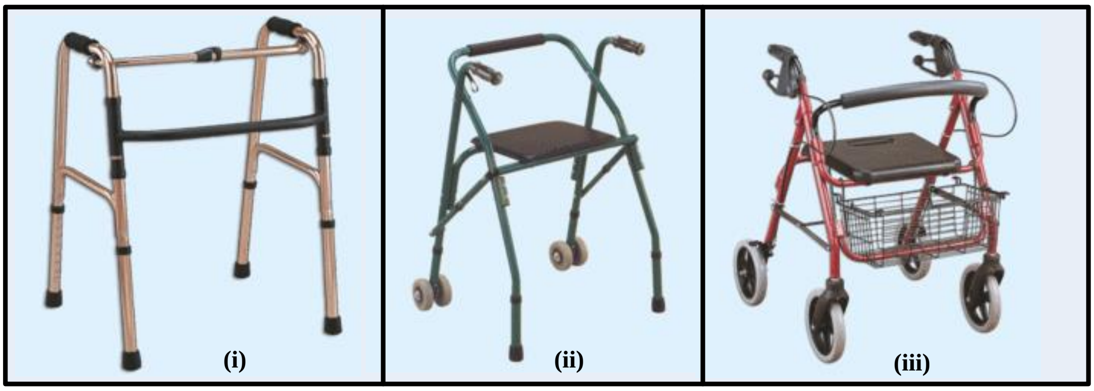


Figure 2.4: *Types of traditional walker (Drive Medical Design and Manufacturing, 2014): (i) Standard Walker ; (ii) Comfort Walker ; (iii) Aluminium Rollator.*

Although front-wheeled walker equipped with brakes could solve this problem, but it may not be suitable for uneven areas such as slopes, hills and stairs. The Rollator is better in terms of rolling and pivoting smoothly compared to other conventional walkers, but it provides the least stability, which may increase the risk of falling by a variety of mechanisms (W.C. Mann et al., 1995). The I-Walker (R. Annicchiarico et al., 2008) as shown in Figure 2.5 has been developed to address the stability problem when facing inclined surfaces. The objective of this device is to control the velocity of the walker, especially while climbing.

Figure 2.5: *The prototype of the I-Walker (R. Annicchiarico et al., 2008).*

Recently, the development of this walking aid has become more sophisticated with extra features added. One of the attractive features include a new model of walker which has the capability to detect an obstacle for safe journey. The newly designed walker as shown in Figure 2.6 applies the human-machine interface approach which allows the device to extract the user's movement intentions. This user-walker interface is based on a joystick and is intended to be user-friendly, simple, efficient, low-cost and with little electronics.

Figure 2.6: *Prototype of the human-machine interface smart walker (NeoASAS) (M. M. Martins et al., 2012).*

The idea of smart walkers is to provide traditional rolling walkers with sensors in order to assist users, caregivers and clinicians. The integral part of the Smart Walkers is an autonomous agent which monitors the activity of the user, assesses his physical conditions, and detects potential risks of falls. A remarkable feature of the smart walker brought an idea to extend its application for rehabilitation purposes. The feature-based classification of a rehabilitation walker (UFES Walker) as shown in Figure 2.7 can be divided by four categories as follows:

(i) Physical stability and motion support: This type of walker classification must provide related functions such as propelling power, motor task assistance and movement intent detection. It offers three features, which are passive, active and hybrid systems; waking and multitask assistance; handle force sensors.

(ii) Navigation and localization components: It provides intelligent navigation coupled with localization assistance. Some features must be added to the system (e.g. installed map, obstacle avoidance, environment and interactions) for smart execution. The localization assistance can be delivered through embedded Global Positioning System (GPS), visual and voice feedback; automatic return to selected location.

(iii) Biomechanical and bioelectrical monitoring: It refers to the functional and physiological monitoring including gait or specific motor task parameters and bio-signals.

(iv) Safety measures: In order to prevent fall, several tools must be added to the system such as braking, involuntary movement detection, user-device distance and gravity compensation.

The conceptual design of the UFES walker is shown in Figure 2.7.

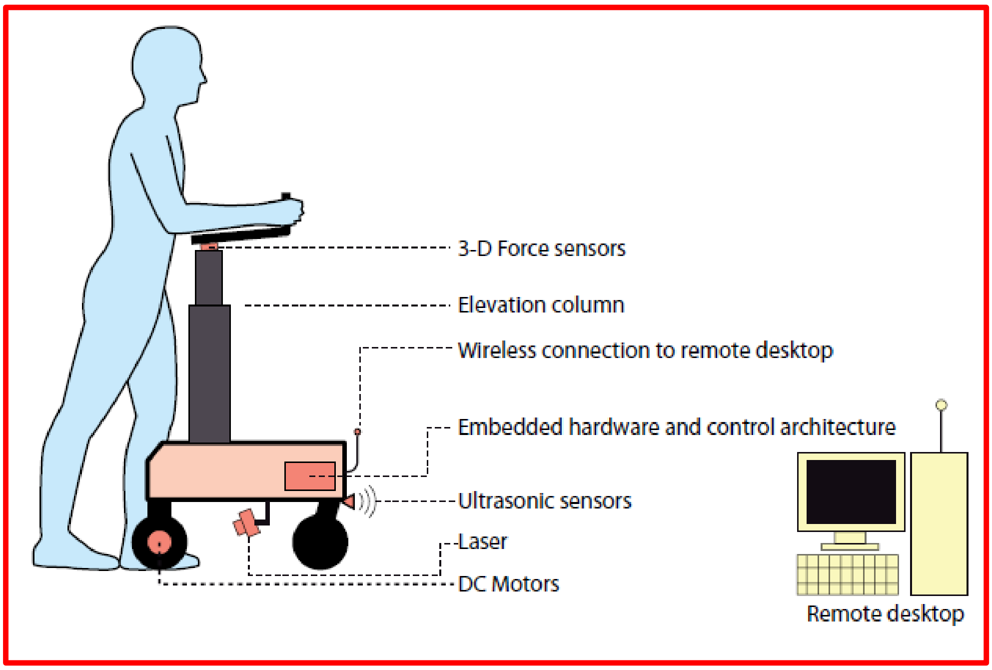


Figure 2.7: *UFES walker conceptual design (A. Elias et al., 2012).*

2.2.3 Wheelchair

Most of the time, the wheelchair is widely used as a patient vehicle in the hospital, medical centre, aged care centre, nursing home and clinic for moving around. Handicapped or disabled patient can utilize this device whenever needed. In some cases, the elderly who suffered from leg fracture and lost the ability to walk can also use the wheelchair in their daily activities. However, traditional wheelchairs do not provide much functionality for safe navigation compared to smart wheelchairs. Some of the smart wheelchairs are specially designed coupled with obstacle avoidance function for safe journey either in the indoor or outdoor environment. The Xeno (T. Rofer et al., 2009), Rolland (C. Mandel et al., 2009) and Smarter Wheelchair (J. Kong et al., 2012) as shown in Figure 2.8 are the recent wheelchairs that employed the distance sensors (e.g. Laser Range Finder and Ultrasonic sensor) to detect an obstacle along the working area or pathway.

The Xeno wheelchair uses the joystick to steer the direction either to turn right or turn left. If any obstacle is detected, the user controls the joystick to avoid the obstacles. This smart wheelchair mainly depends on the arm of the user to drive the joystick for optimum performance. Users who have difficulty in moving their arms would not be able to leverage on the benefit of this function. To address this issue, researchers put on effort to design a smart wheelchair called Rolland, which comprises of a Brain-Computer Interface (BCI) system coupled with a sensorial system, an Light Emitting Diode (LED) panel, an EEG cap and a processing laptop. The BCI system analyses specific patterns in the user's brain activity and translates them into commands to control the software or hardware devices for further action. Thus, without any joystick assistance, the user can still travel using the wheelchair safely.

Figure 2.8: *Smart Wheelchairs: (i) Xeno (T. Rofer et al., 2009); (ii) Rolland (C. Mandel et al., 2009); (iii) Smarter Wheelchair (J. Kong et al., 2012).*

According to a group of researchers (J. Kong et al., 2012), most of the existing smart wheelchairs have limitations on the extensibility and flexibility of building new functionality because they only consider other wheelchairs and surrounding things as replica objects. To extend the flexibility and interactivity of the smart wheelchair, they developed a smarter wheelchair, which integrates of ultrasonic sensor, pressure sensor, accelerometer, gyroscope, touch switch, light sensor and temperature sensor coupled with the Radio Frequency Identification (RFID) reader and minicomputer. The RFID reader is used for indoor localization and the laptop computer enhances the human-chair interaction. Smarter wheelchairs can interact with other smart objects in surrounding area such as light; if the room is dark, then the wheelchair asks the light to be switched on or increase the brightness.

The Intelligent Robotic Wheelchair (IRW) (P. E. Hsu et al., 2012) as presented in Figure 2.9 is another mobility device intended to assist senior citizens to walk in crowded environment.

Figure 2.9: *Prototype of the Intelligent Robotic Wheelchair (IRW) (P. E. Hsu et al., 2012).*

Technically, the IRW is composed of a moving vehicle, a multiple degree-of-freedom (DOF) seat adjustment mechanism, an information and communication technology (ICT) module, blood pressure (BP) and glucose meter. The IRW could facilitate physical interaction and changing environment, and control over the environment as well as information exchange and interpersonal communication with the outside world. The multiple DOF seat adjustment of the IRW is achieved by a four-axis Stewart Platform, which is capable of adjusting the height, pitch, and sway to provide transfer assistance, sit-stand assistance, and comfortable sitting. For example, when continuous and concentrated pressure is detected, the seat will be automatically adjusted to comfort zone. The ICT module installed with the Application mode on a tablet PC provides several functions such as display messages, photos, timely reminder and communication channel for the users. The tablet PC also serves as a platform for tele-healthcare management.

2.2.4 Mobile Robot

The use of a mobile robot in the living home is purposely designed either to assist the elderly in daily activities or for taking care of the elderly at home (M. Vincze, 2013; F. Broz et al., 2012; P. Dario, 2013). Recently, several robotic-based MADs have been developed for helping the elderly during navigation such as the Wheeled Mobile Robot (WMR) (A. A. New et al., 2008), Robot of Living Aid (Rola) (S. Kai-Tai et al., 2008), Walking Assistance Robot (WAR) (S. Hyeon-Min et al., 2005), Robotic Wheelchair (S.R.S. Krishnan, 2009) and Multipurpose Mobile Robot (MMR) (D. Lowet and H.Frank, 2012; D. Lowet et al., 2012). Most of these devices provide some physical supports, obstacles monitoring, obstacle avoidance, visual tracking, navigation, body pose recognition and emergency call out.

Figure 2.10 depicts some of the latest service robots that have been used in smart living home as a robot helper for the elderly. These mobile robots provide social interaction, personal care, health services support, sensible family friend, and video conferencing with family members or professional caregivers.

(i) (ii) (iii) (iv)

Figure 2.10: *Interactive Mobile Robots:(i) Hobitt (K. Papoutsakis et al., 2013); (ii) Care-O Bot3 (U. Reiser et al., 2013; T. Jacobs and B. Graf, 2012); (iii) GiraffPlus (S. Coradeschi et al., 2013); (iv) Mobiserve (H. V. D. Heuvel et al., 2012).*

Hobbit (K. Papoutsakis et al., 2013) presents a new concept called the “Mutual Care," which is based on the user centred approach. The mutual care concept is defined as building relationship between the user and the robot in which both take care of each other. User and the machine share, care and assist each other like a friend. The Hobbit robots offer services such as picking up and bringing objects, calling friend and taking incoming call, playing games, initiating dialogue, reminder, emergency detection and handling, energy management, ambient assisted living (AAL) alarms, etc. Close cooperation from both parties creates friendly environment for better living. The Care-O-Bot3 (U. Reiser et al., 2013; T. Jacobs and B. Graf, 2012) is another service mobile robot, which actively supports the elderly in domestic environments. The robot can perform basic tasks within the household such as fetching and bringing objects, which is similar to the Hobbit robot. In addition, a camera system will help the robot to localize and grab objects. It also has a serving tray which is used for user interaction such as providing drink, water, playing music, playing memory and mind training for the user.

The GiraffPlus (S. Coradeschi et al., 2013) robot is developed by considering of the needs from the both resources, which are primary (e.g. elderly living in their apartment) and secondary (e.g. health-care professional or family members and friends) users. The system consists of a network of home sensors that can measure health status of the user such as blood pressure or temperature. The system can also detect the situation of the surrounding working area such as whether somebody occupies a chair, falls down or moves inside a room. By capturing and interpreting all the data from the sensors, the robot can justify the health status of the user such as well-being, sleeping, tiredness and well-rested. These activities can then trigger alarms or reminders to the users or their caregivers, or be analysed over time by a health professional. The GiraffPus is an effective mobile communication platform, which is equipped with video camera, monitor, microphone and speakers for telepresence purposes. Tele-presence will help the users keep in touch with their friend for social interaction. The novelty of the GiraffPlus system from a research perspective is the development of a system combining sensors and a tele-operated robot with high level reasoning that includes context recognition, configuration planning and personalization and interaction services.

The Mobiserve robot (H. V. D. Heuvel et al., 2012) develops a personal intelligent platform consisting of various middleware and devices plus a primary set of functionalities. The physical elements are a robotic platform equipped with cameras and wireless communication devices, smart home automation infrastructure (e.g. Wi-Fi, sensors, central home control server, etc.) and intelligent textiles embedding sensors.

2.3 Wearable Assistive Devices

Wearable technology is achieved by devices that are actually worn on the body. In contrast to portable devices, wearable devices enable minimum hands-free interaction. As wearable technology advances and spreads, the information technology is becoming even more ubiquitous, with complex implications for the elderly who used assistive devices in their daily navigation either indoor or outdoor. The applicable areas of the body where these wearable assistive devices are promptly attached such as fingers, hands, wrist, abdomen, chest, feet, tongue and ears as demonstrated in Figure 2.11. The fixation of these devices on the body is achieved by head-mounted devices, wristbands, vests, belts, shoes and etc.

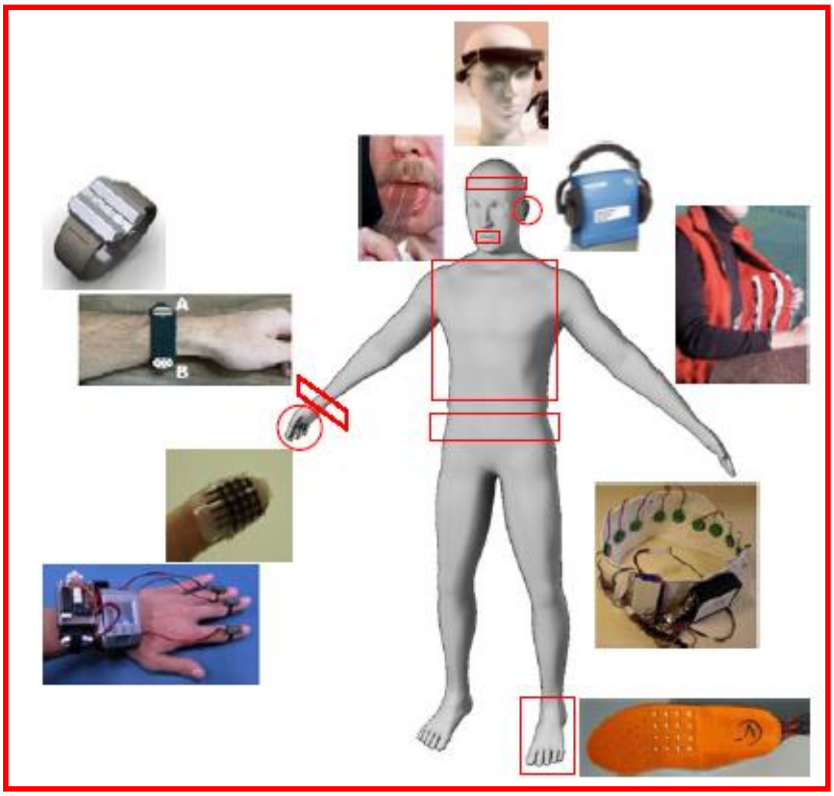


Figure 2.11: *Overview of the body areas involved in wearable assistive devices (R. Velázquez, 2012).*

2.3.1 Walking Assistance Device

This device provides a closed-fitting-type walking assistance device (T. Ikehara et al., 2011) for legs with self-contained control systems. The use of self-contained control systems in the device has allowed its users to walk about on ground level whether indoors or outdoors. The functionality of this device is to provide assistance with simple construction of flexion and extension of knee joints, and dorsal and plantar flexion of ankle joints for elderly people who can walk independently, but have some anxiety about how they walk and for patients who suffer from mild hemiplegic strokes. The detachable integrated frames with hip orthosis are used to cover the full length of legs, from the soles to femoral regions as shown in Figure 2.12.

Figure 2.12: *Illustration of the body areas involved in Walking Assistance Device (T. Ikehara et al., 2011).*

This device uses pressure sensors which are attached at the thenars and heels of the foot to find out walking phases based on the variations in voltage. This system is unable to detect the existence of obstacle in pathway, but only capable of detecting the walking phases of the elderly whose muscle strength has reduced significantly. Figure 2.13 illustrates the sole pressure sensor embedded to the foot.

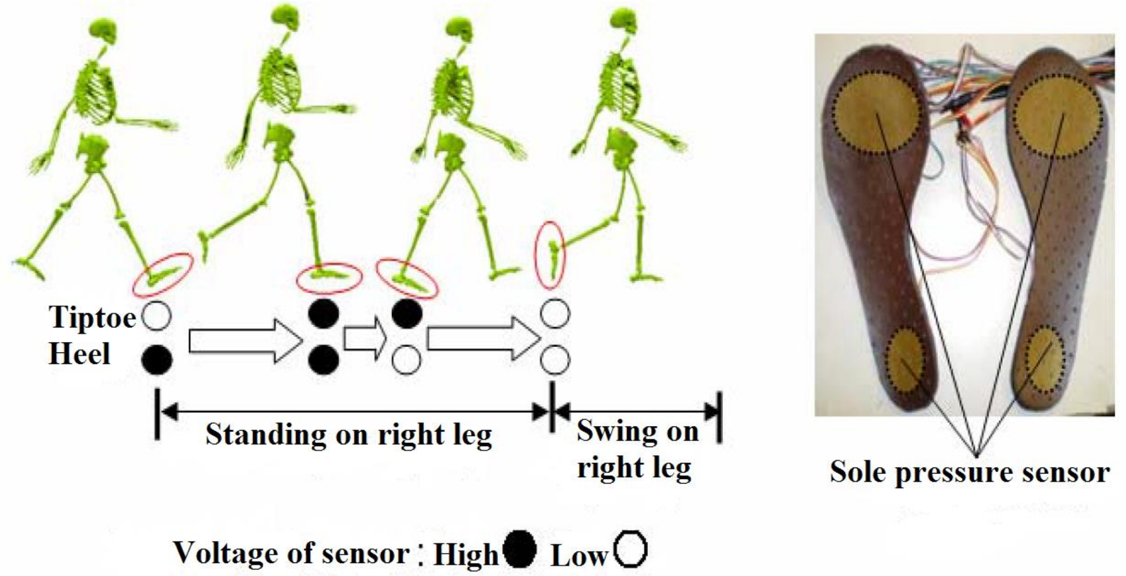


Figure 2.13: *Illustration of the sole pressure sensor embedded to the foot.*

The paper concludes that the walking assistance device provides good support for joint muscle to keep users walking independently without any helpers. The use of self-contained control system in the device has allowed its users to walk about on ground level for both indoor and outdoor environment activities. The device could reproduce the power of kicking motions at ankle joints when controlled by the hybrid system.

2.3.2 Electronic Travel Aids (ETA)

An Electronic Travel Aid (ETA) is one of the popular wearable assistive devices that are specially designed for blind people to navigate either in the indoor or outdoor environment. The development of the ETA has rapidly increased in the last four decades, but the user acceptance of these devices is quite low, and it is rarely used (R. Velazquez et al., 2009).

2.3.2.1 Minimalistic

This paper discussed a safety concept during ambulation for the blind people when they are possibly to hit an obstacle at head level and to avoid collision. This system provides warning signal in the form of sound (acoustic) or vibration (tactile) when a hazard is detected. Two ultrasonic sensors are installed in the shirt pocket for obstacle detection purposes. Special care is devoted to optimizing the devices' performance in terms of the range of accuracy and detection or false alarm rate and to minimize the form factor and power consumption. The proposed ETA as shown in Figure 2.14 is comprised of ultrasonic sensors associated with a package of pre-amplifier, switch and band-pass filters. The synthesis of the transmit signal is accomplished using the DSP's onboard PWM (Pulse Width Modulation). A number of serial communication protocols will allow the device to interface with a laboratory PC or another embedded system (such as a robot), and to be re-programmed or re-purposed.

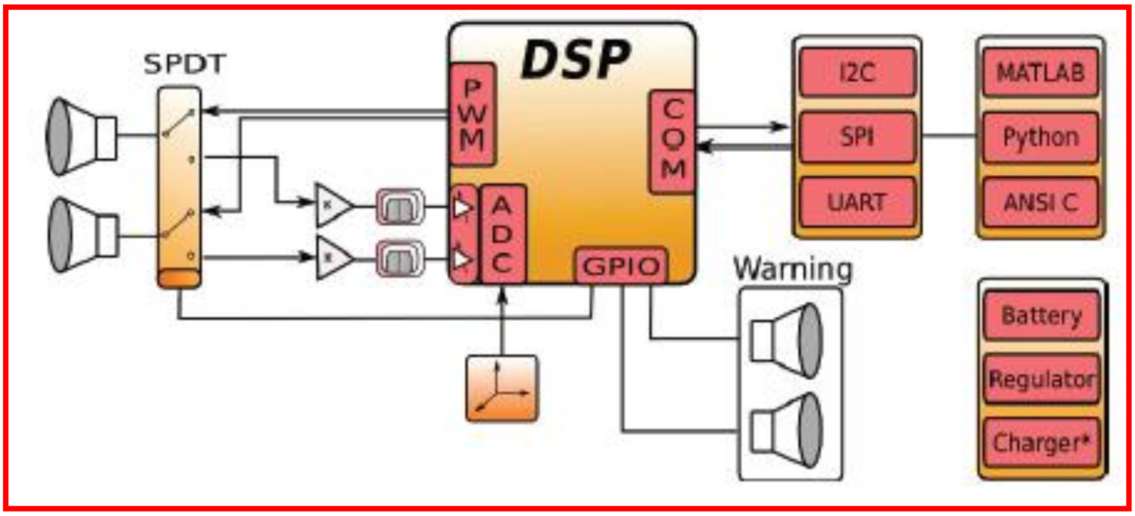


Figure 2.14: *The block diagram of the ETA system (B. Jameson and R. Manduchi, 2010).*

From this paper, the sensors used are small and compatible to clothes so that they do not affect the wearer's activity.

2.3.3 Le Chal

This article describes a new haptic shoe for the blind people called the Le Chal (A. Sharma, 2010) as shown in the Figure 2.15. This system consists of proximity sensor, vibrators, microcontroller unit and smart phone (e.g. HTC, Sony Ericson Xperia and Samsung Galaxy) with the Global Positioning System (GPS). The smart phone is bundled with the Android operating system (OS) which allows the user to use the Google Maps application software package. The user begins by entering their destination on Google Maps on the smart phone before starting a journey. The Bluetooth communication technology is capable of communicating with a microcontroller (LilyPad Arduino), located in the heel of the shoe. The users will listen to the turn-by-turn directions from Google, along with locational data from its own GPS unit; the phone gets the microcontroller to activate each of the four vibrators in the shoe as needed. Figure 2.16 presents the layout of the shoe.

Figure 2.15: *Overview of Le Chai (A. Sharma, 2010).*

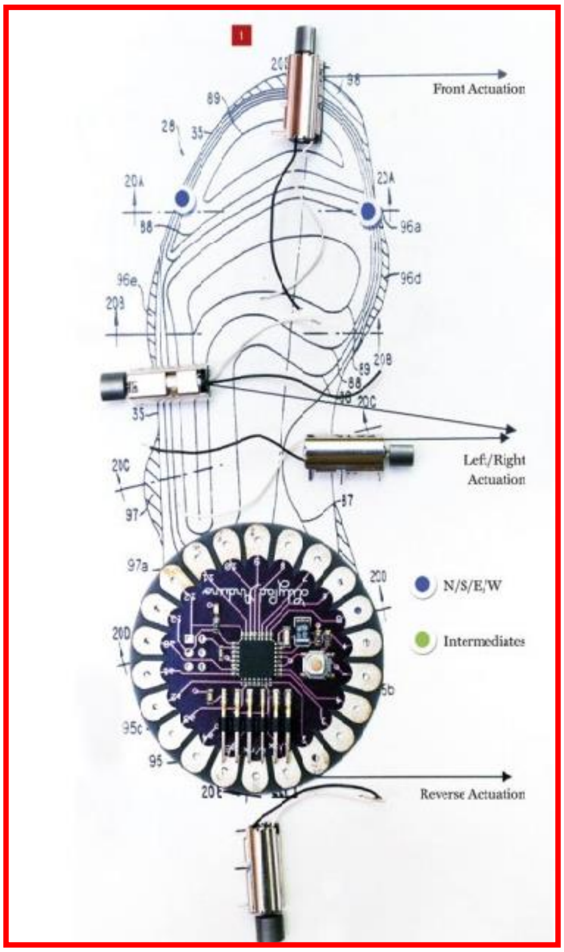


Figure 2.16: *The layout of Le Chal, with its LilyPad Arduino circuit board and four Vibrators (A. Sharma, 2010).*

The GPS technology on the smartphone is capable of getting real-time location and the exact position of the user. When the turning point is approached, a mild vibrational feedback activated in the shoe informs the user which direction they should go. The strength of the vibration depends upon the overall proximity from the destination, that is, vibration is weak in the beginning and is incrementally stronger at the end of the navigation task. The built-in proximity sensor of the shoe can detect up to 3 meters, informing the user of the surroundings and allowing him or her to make decisions and plan the next move.

2.4 Sensors Technology for the Obstacle Detection

Sensors are the heart of the obstacle detection systems. Typically, there are many types of sensors used in the Obstacle Detection System (ODS), i.e., ultrasonic sensors, infrared sensors, laser sensors, sonar sensors, radar sensors, vision sensors, proximity sensors, etc. These sensors provide electrical signal output (either voltage or current) that is proportional to the sensing distance. The applications of the sensors are widely implemented in automotive industries; product based industrial, robotics and healthcare systems. Ultrasonic sensors are commonly used to measure distance and detect obstacles. Therefore, it has provided a reliable source of obstacle detections. Hence, the ultrasonic sensors are not affected by poor lighting and transparent objects. However, due to their wide beam-width, the azimuth information is poor and affected by specular surfaces (D. Bank, 2002), and the inability to detect objects within 0.5 metres (T. Dutta and G. R. Fernie, 2005).

Recent researchers used ultrasonic sensors in their obstacle's detection system to detect shorter range objects and indoor walls in homes, assisted-living facilities and hospitals (K. Chung-Hsien and H. H.W.Chen, 2006; T. Jyh-Hwa and C. Feng-Chun, 2009). Many researchers used an ultrasonic sensor in their system because of its low cost, easy to use and compatibility with other components, especially for data transmission. The major disadvantages when using ultrasonic sensors in the obstacle's avoidance system (OAS) are the fact that these sensors cause mutual interference and might not operate properly in rooms with wall to wall carpeting and thick drapery. The utilization of ultrasonic sensors in many MADs is due to its wide angle sensing detection obstacle and effective sensing distance for indoor application. The Electric Powered Wheelchair (H. Murakami and H. Seki, 2009) have used 4 ultrasonic sensors to detect an obstacle up to 6.45 metres in home navigation. In real noisy environment, the Robust Voice Recognition Robot (N. Huu-Cong et al., 2009) is equipped with 16 ultrasonic sensors for detecting the obstacles in indoor locomotion. The Walking Guide Device (S. Byung-Seop et al., 2007) detects the front obstacles during walking by using 6 ultrasonic sensors for both indoor and outdoor applications. The infrared (IR) sensors are another option, which could be used for distance measurements. In mobile robot navigation, the IR sensors are extensively used for obstacle avoidance tasking. Cheaper in cost and faster in response time make the IR sensors more attractive compared to ultrasonic sensors and other types of optical sensors. However, the intensity of the light detected depends on several factors, including the surface reflectance properties, the distance to the surface and relative orientation of the emitter, detector, and surface.

The laser and ultrasonic range (sonar) sensors are expensive compared to the ultrasonic sensors and IR sensors. Therefore, they are not suitable for the healthcare system. Furthermore, laser can damage either the user or other persons in the surrounding area. Table 2.2 shows the summary of several mobility assistive devices, which use a variety of sensor technologies such as optical and ultrasonic sensors to detect obstacles.

TABLE 2.2: VARIETIES OF SENSORS USED IN MOBILITY ASSISTIVE DEVICES

Model Name	**Sensor Technology**	**Number of** Sensor	**Effective Sensing Distance**	**Environment**
Walbot (J. Sin-Yi et al., 2011)	Laser	9	0.41m	Indoor
Tom Pouce & Minitact (J. Villanueva and R. Farcy, 2012)	IR	1	4m	Indoor & Outdoor
Johnnie (Y. Kuan-Ting et al., 2010)	Sonar	1	5m	Indoor

Electric Power Wheelchair (H. Murakami and H. Seki, 2009)	Ultrasonic	4	6.45m	Indoor
Robust Voice Recognition Robot (N. Huu-Cong et al., 2009)	Ultrasonic	16	NA	Indoor
GIMOS (H. Jinpyo et al., 2007)	IR	16	0.8m	Indoor
Walking Guide Device (S. Byung-Seop et al., 2007)	Ultrasonic	6	3m	Indoor & Outdoor

2.5 Chapter Summary

Following the trend in modern assistive devices, its actual requirement and the current status of technology achievement, undoubtedly, integrated sensor technology coupled with fast computing technology is the best option to be adopted for the next generation of mobility assistive devices for helping the elderly in path navigation. Considering the global phenomena of surging aging and diabetes mellitus affected citizens, the need for navigation assistance devices that can effectively detect the obstacles and give the alarms feedback during walking activities of daily living is becoming very obvious. After a long literature review about the state-of-the-art of such assistive devices, it is obvious that there is a need for better mobility assistance device to satisfy the requirement of obstacle detection and varieties of alarming systems. For that reasons, a promising integrated assistive device with high technology will be explored to design and possibly materialize better devices in order to resolve the weaknesses of existing aids.

Human Physiology and Gait Analysis

CHAPTER

3

3.0 List of Peer Reviewed Publication Produced

1. *B, Mustapha, A. Zayegh and R.K.Begg, 2014. 'Development of a Wireless Obstacle Detection System',* ***AMSE Journals: Modelling C****, vol. 75, no. 1, pp. 79-99. ISSN 12595977.*

2. *B. Mustapha, A. Zayegh, and R.K. Begg, 2014. 'Reliable Wireless Obstacle Detection System for Elderly and Visually Impaired People with Multiple Alarm Units',in* ***Proceedings of the IEEE International Conference on Computer, Communication and Control Technology (IC4T 2014)****, 2-4 September, Langkawi Malaysia, pp. 271-276. ISBN 978-1-4799-4554-2.*

3.1 Chapter Overview

This chapter provides a review on human physiology and its gait analysis that relates to the elderly locomotion. The gait parameters of the elderly during walking are discussed in the first section of this chapter. The specification and space consideration of the pathway navigation that give maximum detection of the obstacle are elaborated in Sections two and three. A section that consists of a review of physical ability of the elderly comes next. Lastly, the chapter summary highlights the need of such information for designing an effective obstacle detection system device for the elderly.

3.2 Gait Parameters of the Elderly

Gait is an important functional activity that elderly individuals use to stay active and be able to execute their daily living tasks. In biomechanics research, the gait (style of walking) is one of the imperative criteria for assessing balance during locomotion. The most frequent basic gait parameters used include velocity, stride length, step length, and step frequency. The gait cycle can be divided into two (2) main phases, which are stance phase (60%) and swing phase (40%). The stance phase is defined as the interval in which the foot is on the ground. Meanwhile, the interval in which the foot is not in contact with the ground is referred to as swing phase. A stance phase is comprised of five relevant events (e.g., initial contact, loading response, mid stance, terminal stance, and pre-swing) and the swing phase contains three other events (e.g., initial swing, mid-swing and terminal swing) as shown in Figure 3.1.

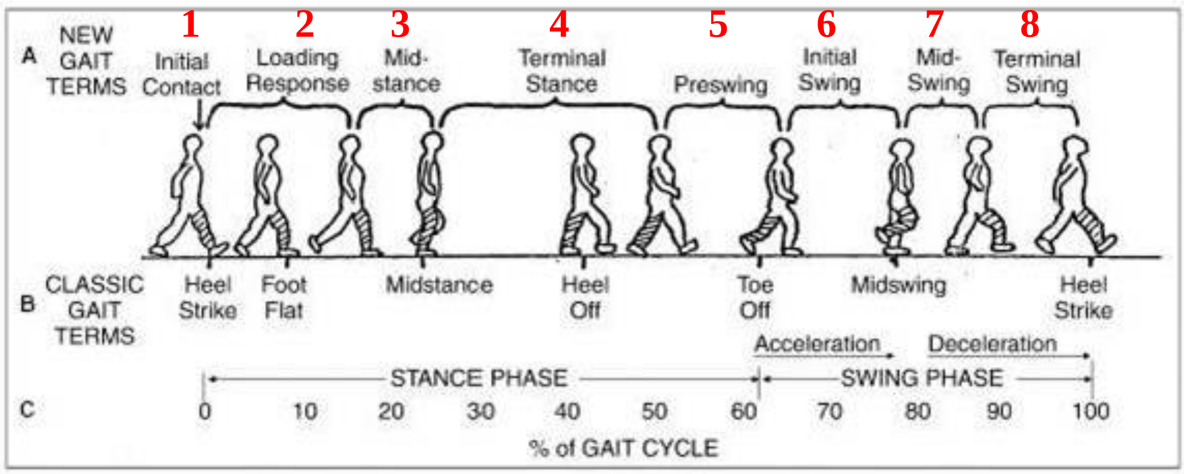


Figure 3.1: *Human gait cycle (C. Sara, 2004).*

The initial contact is an instantaneous point only in time and occurs at the instant of the foot of the leading lower limb touches the ground. The loading response phase occupies about 10 percent of the gait cycle and constitutes the period of initial double-limb support. During loading response, the foot comes in full contact with the floor, and the body weight is fully transferred onto the stance limb. The initial double-support stance period is occasionally referred to as the initial stance. The elderly tend to walk with slower velocity, shorter step length, wider step width and a relatively increased portion of time spent in the double-support phase (R. Paroczai and R. Kiss, 2006). The flat foot (FF) support is the point in time when the foot completely touches the ground. The FF posture occurs for approximately 20% of the gait cycle (J. Perry and J. M. Burnfield, 2010). The mid-stance represents the first half of single support, which occurs from the 10 to 30 percent during the period of the gait cycle. It begins when the contra-lateral foot leaves the ground and continues as the body weight travels along the length of the foot until it is aligned with the forefoot. Terminal stance constitutes the second half of single-limb support. It begins with heel rise and ends when the contra-lateral foot contacts the ground. Terminal stance occurs from the 30 to 50 percent during the period of the gait cycle. Pre-swing is the terminal double-limb support period and occupies at least 12% of the stance phase, from 50% to 62%. It begins when the contra-lateral foot contacts the ground and ends with the ipsilateral toe off.

The gait analysis is most frequently used to determine the walking pattern disorder of older people. The incidence of gait irregularities in older adults has been estimated at over 15% over the age of 64 years old, to more than 35% in those over the age of 70 and more than 40% above the age of 85 years old (J. Verghese et al., 2009). Changes in the kinetics and kinematics values influence the balancing of a person and consequently link to falls. It is not surprising that over 50% of falls among older people are caused by the loss of balance during walking (R.A. Kenny et al., 2011). An assessment of gait parameters could prevent falls and subsequent injury risks in elderly populations (M. Williams, 2008; N. Shiozawa et al., 2011). Comprehensive research in gait analysis also brings relevant significance to the development of an obstacle detection system for collision avoidance. The elderly tends to fall after hitting the obstacle in the pathway due to lack of concentration while walking either in close or open area environment. Therefore, a good knowledge of temporal characteristics of the gait cycle is very important to develop an obstacle detection system. The initial double limb stance, single limb stance and terminal double limb stance are segments in the stance phase that represent the temporal characteristics in one gait cycle.

These temporal characteristics are performed by either both or one feet when in flat contact with ground. Figure 3.2 illustrates the segments where one of the feet lands completely on the ground, thus giving an optimum detection for the obstacle detection system.

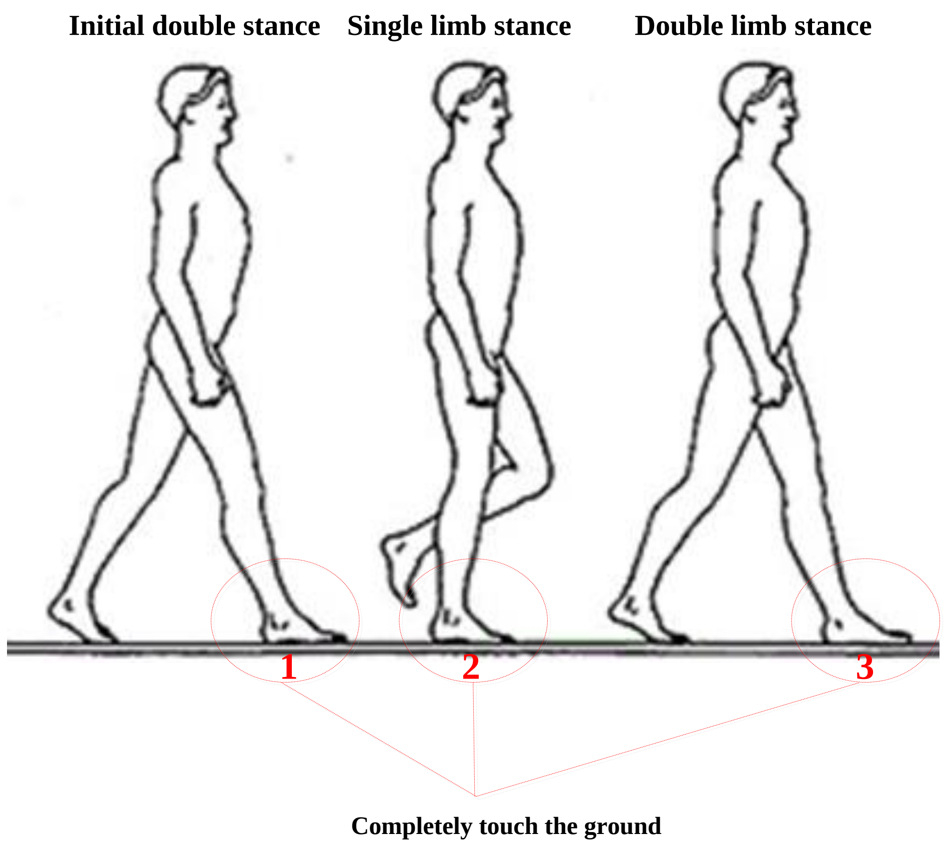


Figure 3.2: *The segments in stance phase where one foot touches the ground completely (E. Ayyappa, 2011).*

Subsequently, one foot having flat contact with ground also occurs in the early swing and mid-swing phases as shown in Figure 3.3.

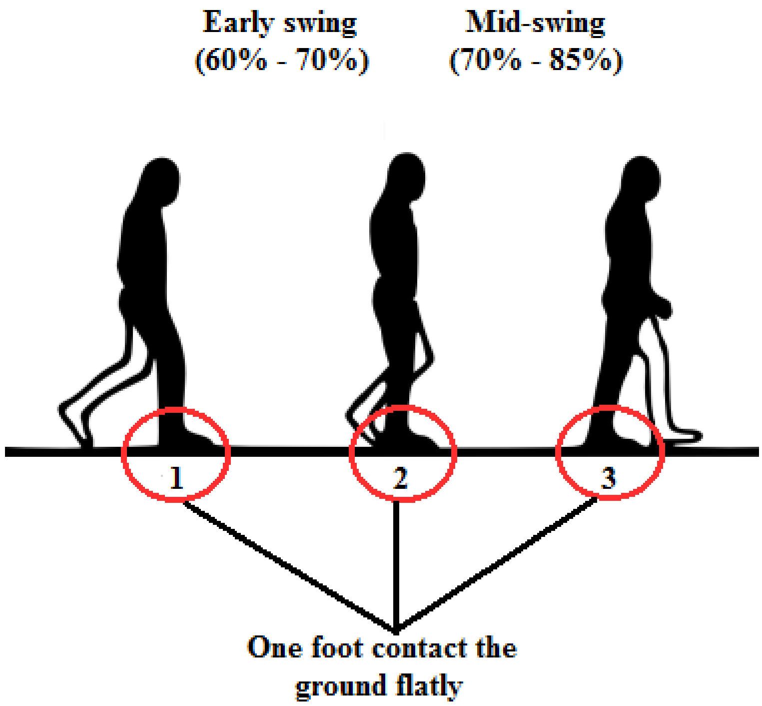


Figure 3.3: *One foot completely touches with the ground in the early swing and mid-swing phases (R. Baker, 2013).*

All these illustrations are evidences that all phases in the gait cycle contribute at least one time (single support); the foot completely touches the ground as shown in Figure 3.4.

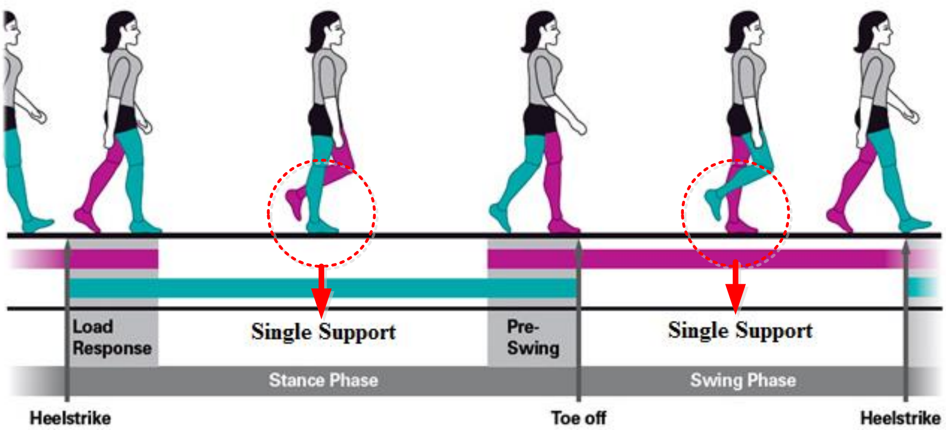


Figure 3.4: *Phase in the gait cycle where one foot (single support) touches the ground (OptoGait, 2012).*

Single limb support represents 40% of the stance phase period (J. Perry and J. M. Burnfield, 2010) and approximately 40% of the swing phase for one gait cycle (B. R. Umberger, 2010).

The actual duration of these gait cycle intervals depends on the walking velocity of the age and health status of a person. The normal walking speed for a healthy elderly is approximately 1.12 m/s (S. Studenski et al., 2011). Figure 3.5 depicts the timing diagram for temporal characteristics which describe the situation either the foot having contact or no contact with the ground in all phases in a gait cycle.

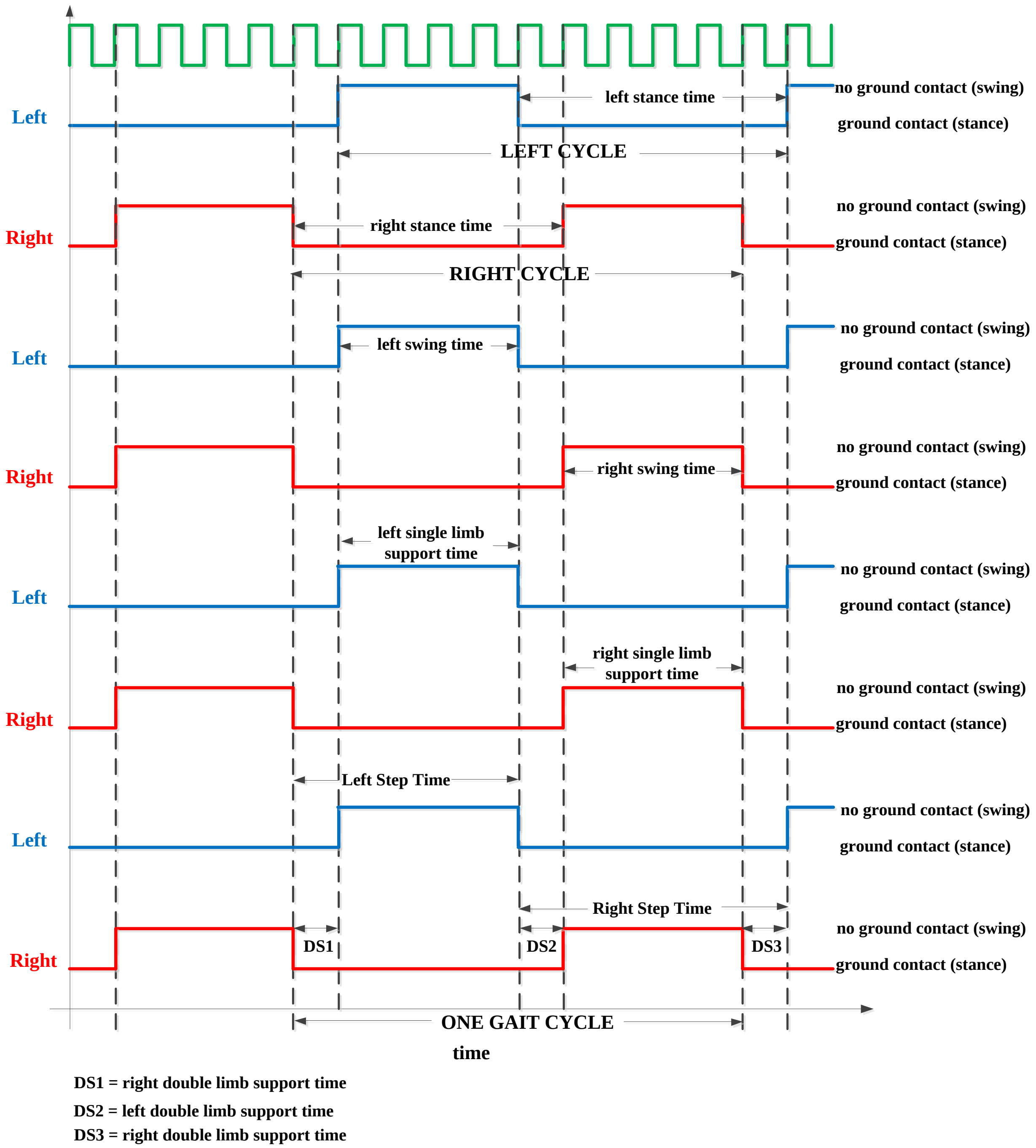


Figure 3.5: *Timing diagram in which right and left foot touch the ground in one gait cycle.*

In the timing diagram above, one clock cycle is equivalent to 10% of the gait cycle. At normal walking rate, single support limb and double support limb periods represent 40% and 20% (DS1 and DS2) of the gait cycle, respectively, while the second double limb interval (DS3) corresponds with the beginning of the next gait cycle. Total ground contact for both feet in one gait cycle is 60%, which is equivalent during the stance phase period. The single limb support time is equal to the swing time as they occur at the same time (see Fig. 3.5). In addition, the information of spatial characteristics of the gait cycle is pretty important as parameters need to be considered as a cut-off value in the process of designing an obstacle detection system. The step width and step length are the two examples of spatial characteristics in stride length that are equivalent to one gait cycle. One gait cycle is comprised of two steps as shown in Figure 3.6.

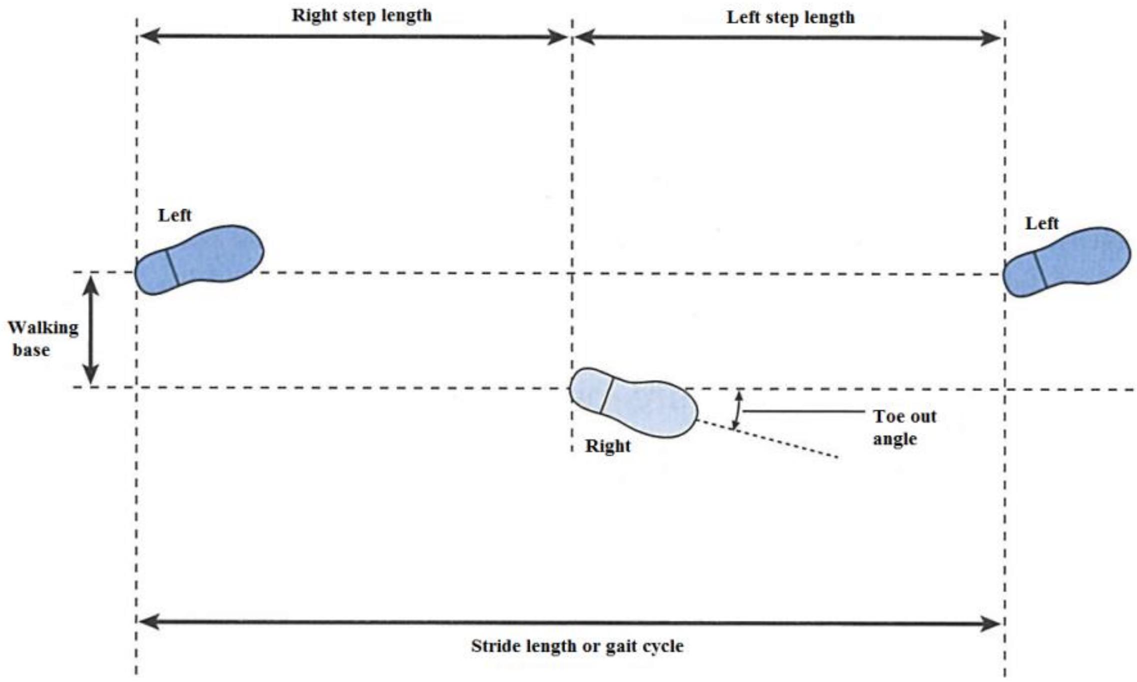


Figure 3.6: *Illustration of one gait cycle (M. W. Whittle, 2007).*

A gait cycle is described as the period from the initial contact of one limb to the point of initial contact of the same limb, and also known as stride length. The step width is determined as the medial–lateral distance between the locations of sequential left and right heel-strikes as illustrated in Figure 3.7.

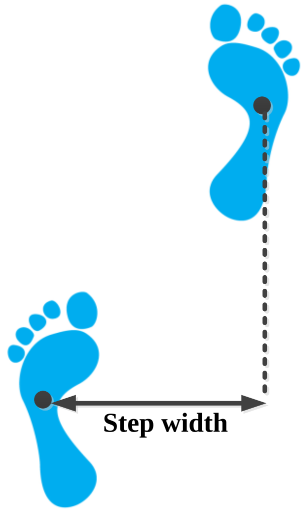


Figure 3.7: *Illustration of a step width (T.M. Owings and M.D. Grabiner, 2003).*

The step width varies depending on the age of the individual. Based on observation, the elderly had a wider step width compared to adult people (P. Robert et al., 2006). Scientific research indicates that the mean value of step width is between 7.4cm to 11.2cm (J. L. Helbostad and R. Moe-Nilssen, 2003; D. M. Wert et al., 2010). Established research shows that the step width ranges between 10.1 cm to 12.2 cm (J. H., Hollman et al., 2011). The measurements were taken from 294 older men and women, and this reflects a reliable step width value for the elderly. However, the variability of the step width depends on the style of walking and size of the foot. The largest foot width reported is 10cm, which is equivalent to a step width of 22cm (J. S. Brach et al., 2001). Meanwhile, the step length refers to the distance from a point of contact with the ground of one foot to the following occurrence of the same point of contact with the other foot as shown in Figure 3.8.

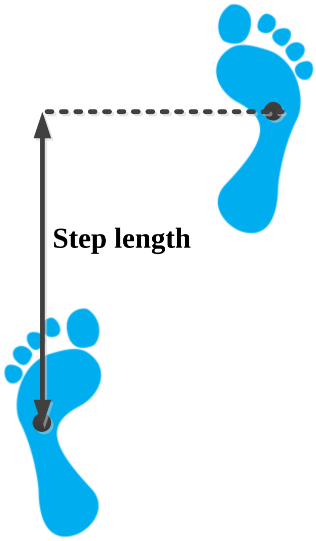


Figure 3.8: *Illustration of step length in gait analysis.*

The variability of step length depends on the age and leg length of a person. In the biomechanical study, the step length is proportional to the user's leg and height (V. Renaudin et al., 2012). The average step length of an active elderly woman is between 64.6cm to 66.3cm (B. S. Moreira et al., 2012; A. Zijlstra et al., 2008; B. S. Moreira et al., 2012), while the elderly man is between 85.6cm to 86.5cm (B. W. Schulz, 2012; Y. Taniguchi et al., 2012).

3.3 Specification of the Detection Area

Generally, the determination of a single walking path width is a very important aspect and considered as a key factor to ensure a reliable performance of the designed obstacle detection system for the elderly. A prior literature survey on gait parameters is necessary to justify the efficient path width and entire detection area for the system. The stride length is an important gait parameter which determines a suitable path width and warning consideration when the obstacle is detected in a single walking. The stride length is a combination of step width and step length which has been discussed in the previous section. Figure 3.9 represents the configuration of step width in a single completed stride length occurrence (T.M. Owings and M.D. Grabiner, 2003).

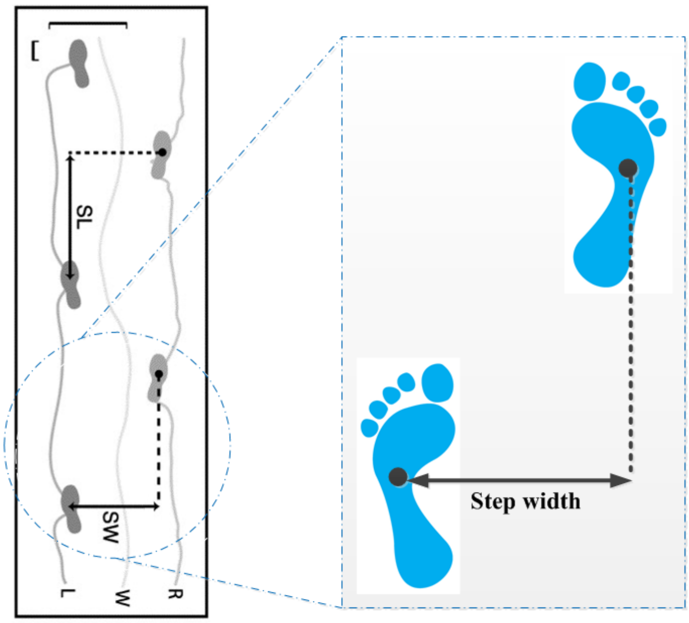


Figure 3.9: *Illustration of step width in a single stride length.*

A typical range of step width for the elderly is between 7.2 cm to 12.2 cm (J. L. Helbostad and R. Moe-Nilssen; D. M. Wert et al., 2010; J. H. Hollman et al., 2011). The largest foot width reported is 10cm which is equivalent to a step width of 22cm (J. S. Brach et al., 2001). In addition, according to a report from the Department of Transport of Western Australia (Department of Transport of Western Australia, 2012), a minimum side clearance of 0.5m is required between the path edge and adjacent hazards for shared paths. In isolated cases, (M. Tinetti, 1986) observed that an estimation walking path width required for the elderly with a frontal gait disorder is 30cm. Based on these evidences, 0.5m is satisfactory for a single path width. The path width determination is an important criterion in determining the number of sensors that could be used for an optimum detection of 0.5m width. In our work, the combinations of ultrasonic and infrared sensors are the best option to detect all types of obstacle within the setting of pathway width. According to the technical specification of the sensors (Sharp Microelectronics, 2006; MaxBotix Inc., 2007), the response time of ultrasonic sensor is approximately 50ms where it is 38ms ±10ms for infrared sensor. Since both sensors indicate fast processing time compared to the typical walking speed, which are 1.5m/s and 1.0m/s to

1.2m/s for fit adult and elderly respectively (S. Studenski et al., 2011), they were chosen in the proposed system. Hence, two important considerations should be taken in order to ensure all obstacles are detected. Firstly, the entire range of obstacle detection should be specified in terms of the minimum and maximum single path width, taking into account that the existing obstacle can be detected by at least one sensor. Secondly, for the purpose of alarm consequences, the obstacle distance should be estimated conservatively based on the worst case scenario. An optimum detection occurs when one of the feet touches the ground and any existing obstacle within the walking base region is detected. Figure 3.10 illustrates the coverage region using 3 sensors (2 infrared and 1 ultrasonic sensors) which are attached at the front part of the shoe.

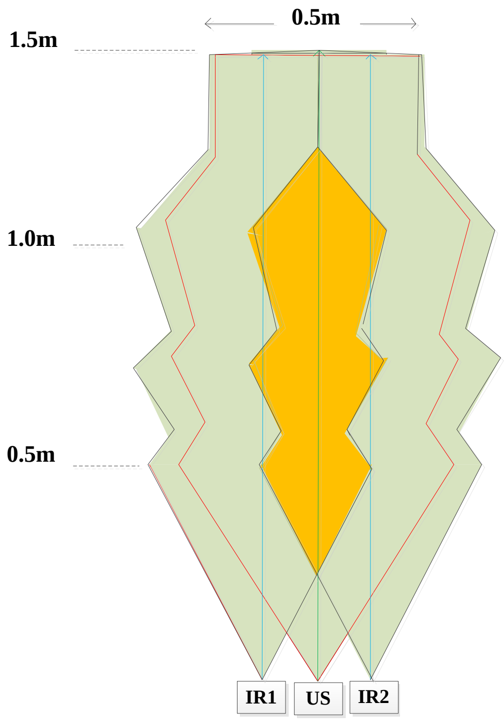


Figure 3.10: *Sensing area using 3 sensors.*

For efficient beam overlap of the sensors, non-zero beam overlap between two consecutive infrared sensors should be guaranteed and excessive beam overlap of single ultrasonic sensor should be avoided. Based on our design, using 3 sensors (2 IR and 1 ultrasonic) on one foot will cover detection of 0.5m width at 1.5m of length. Therefore, by using the same number of sensors on each foot (3 sensors on right foot and 3 sensors on left foot), these will detect obstacles within 0.75m of path width. Thus, our design is sufficient for single pathway which is 0.5m. Figure 3.11 demonstrates the effective sensing area of the system.

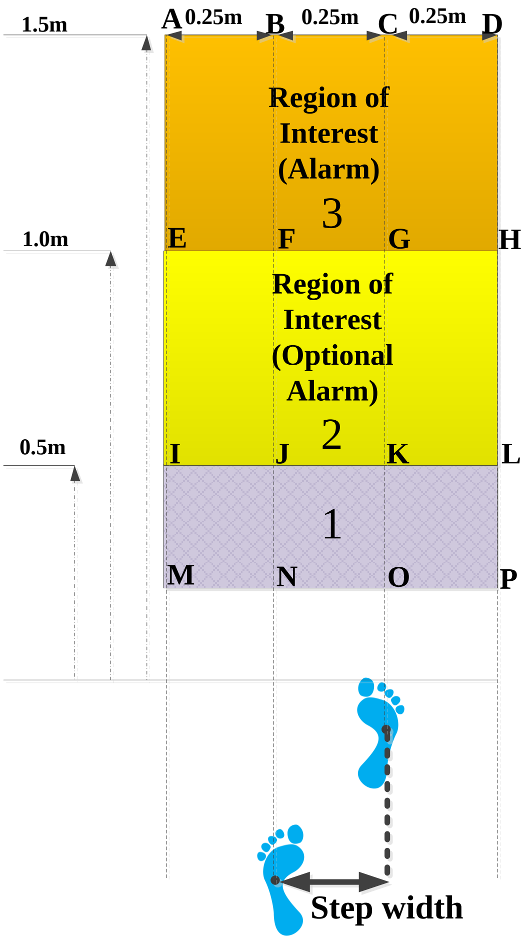


Figure 3.11: *Effective sensing area of the system.*

For alarming purposes, the sensing area of the system is divided by 3 regions. The first region is 0.2m to 0.5m which is considered too close for the alarm to set off and too late for any reaction towards the obstacle. The second region has two consequences which depend on the step length of the user. If the step length is short (less than 0.5m), then the alarm will activate when the obstacle is detected in this region. Otherwise, the alarm is in inactive mode when the step length is between 0.5m to 1.0m. Scientific research shows that the typical range of step length (see Fig. 3.12) for healthy elderly (men and women) is between 64.6 cm to 94.17 cm (A. H. Patricia and J. B. Daniel, 1986; A. H. Patricia and J. B. Daniel, 1989; A. Zijlstra et al., 2008; B. S. Moreira et al., 2012; Y. Taniguchi et al., 2012). These options have been made to ensure that no false alarms occur.

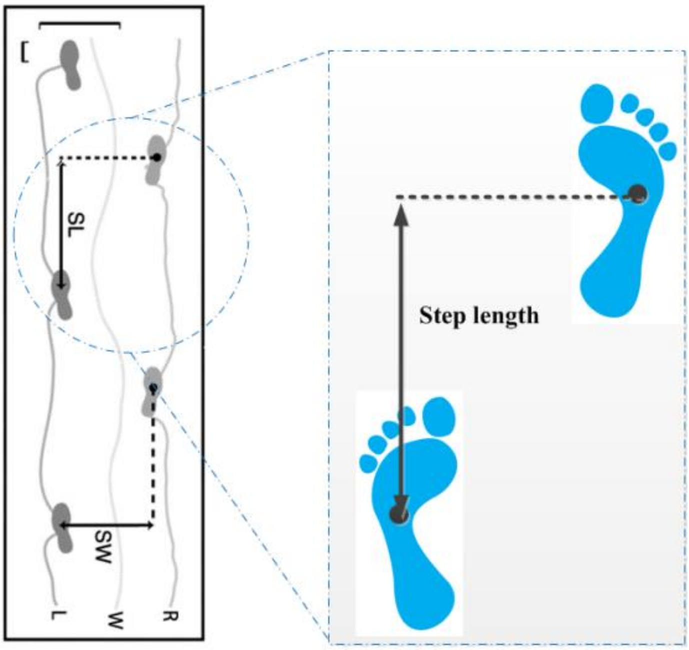


Figure 3.12: *Illustration of step length in a single stride length.*

The third region is a significant part of the entire detection area and any existing obstacle in this region must be detected for an appropriate alarm to be activated. Generally, the alarm system should be set to give enough reaction time for the user.

3.4 Spaces Consideration for the Elderly

The specification design of the pathway is significant to all pedestrians, but it is particularly imperative to those with physical disabilities who have limited travel choices and rely on the pedestrian environment. For example, the elderly, visually impaired people and children frequently rely on the familiar route to travel independently either indoor or outdoor for a variety of purposes such as shopping, recreation, exercise, and walking to school. Traditionally, the design parameters have been based on the standard size of pathway for all pedestrians, which are accessible for people of all abilities. Incorporating universal design principles of pathway development can eliminate the barriers and create a truly functional walkway system. Research indicates that older adults need more spaces compared to young adults when they travel along the pathway (L. Boodlal, 2004).

3.5 Physical Ability of the User

Physical ability is a key point for successful walking execution among the elderly. Research shows that the rates of physical limitations in daily activities for ordinary people constantly remain up to the age of 45 years old (T.M. Manini, 2011), but the trend takes several parabolic shifts upward in later adulthood. The first occurs at a fairly early age where the proportion of individuals who report limitations in usual activities increases from 6.5 to 16.9% (J. Schiller et al., 2005). At the age of 65 years old, the trend shifts upward to 26.9% and again to 45.3% at the age of 75 years old and older. Fifty-five percent of women and 38% of men over 85 years old were reported to be unable to perform a mobility task such as: walking, stooping/kneeling, writing and lifting 10 lbs (U.M. Staudinger et al., 1992). Muscle strength is a strong predictor of severe mobility limitation, poor mobility performance and mortality. Specifically, the data suggest that older adults with a low level of muscle strength have 2.6 fold greater risk of severe mobility limitation, 4.3 fold greater risks for slow gait speed and 2.1 fold greater risk of mortality compared to older adults with high muscle strength (T.M. Manini et al., 2007).

3.6 Chapter Summary

Gait analysis is a systematic study of human walking. Several parameters in gait analysis could be used in quantifying and interpreting the process of human locomotion. The spatial-temporal characteristics of a gait cycle give significant contribution to the process of designing the obstacle detection system for the elderly and people with special needs. Walking velocity is the combination of spatial (measures of distance) and temporal (measures of time) characteristics of the gait cycle. The walking speed for healthy elderly is 1.12 m/s. The stance phase is the dominant part of the gait cycle where 60% of the time spent; 40% are reserved for the swing phase. The average of step width for the elderly is between 7.4cm to 12.2cm. Subsequently, the typical step length for healthy older people varies between 64.6cm to 86. 5cm.

Wearable Obstacle Detection System

CHAPTER

4

4.0 List of Refereed Publications Produced

1. *B, Mustapha, A. Zayegh and R.K.Begg, 2015. 'Wireless Obstacle Detection based on Multiple Sensor', in* ***Proceedings of the Second International Conference on Innovative Trends in Science, Engineering and Management 2015(ICITSEM 2015),*** *25-26 February, Dubai, UAE, 2015.*

2. *B. Mustapha, A. Zayegh, and R.K. Begg, 2012. 'Design and Implementation of Wireless Obstacle Detection System for Safe Locomotion', in* ***Proceedings of the IEEE 2012 Third International Conference on Intelligent Systems Modelling and Simulation****, 8-10 February, Kota Kinabalu Malaysia, pp. 718 - 722. ISBN 978-1-4673-0886-1.*

4.1 Chapter Overview

As discussed in the previous chapter, the evolution of the wearable obstacle detection system in mobility assistive devices during walking and while performing other related activities is crucial in either providing comfort to the user or detecting obstacles, especially among the fast growing elderly population. While the current portable devices that are in use are not capable of performing the task in an efficient way in terms of hands-free and comfortability, a new wearable device instrument is obviously in dire need. To ensure that the system is measured effectively, the main components used in this system must fulfil these basic requirements which include small size, very light, unobtrusive, can be integrated with signal processing and memory, and also very low in power usage. For that reason, the integrated sensor technology is the best platform for implementation as it exhibits all the required traits as mentioned. To achieve the target, this research explores the possibility of realizing such measurement by applying several obstacle detection sensing techniques. However, there are several questions that require answering and a number of milestones that need to be achieved for the real implementation to be successful. In this chapter, the actual work and its milestones, challenges and chosen solutions are presented and discussed in detail. In elaborating and presenting the actual work on the aspect of obstacle detection, the chapter is divided into eight sections inclusive of this chapter overview.

As their names imply, each of the section presents and highlights specifically the relevant aspects according to the given names, which are: Selection and Analysis of Obstacle Detection Sensing Technique, Integration and Interfacing of Obstacle Detection Sensors, Functionality of Force Sensing Resistor, Wireless Applications, Multiple Alarming Systems and lastly, Chapter Summary and Discussion. One of the main works of the research, which is the selection of the most suitable and practical distance sensing techniques for obstacle detection, is covered in the third section. After the selection process is made as explained in that section, the work then concentrates on the integration and interfacing of the chosen obstacle detection sensors which are ultrasonic and infrared sensors with microcontroller. The implementation of wireless applications in the system is discussed in the subsequent section. The next section discusses the warning systems realization that is embedded to the device. Lastly, the Chapter Summary and Discussion highlights on the decision of the selection of components of the system.

4.2 Selection and Analysis of Obstacle Detection Sensing Technique

This chapter begins with a brief discussion on the operating principles of several identified distance sensors that may be suitable for obstacles detection. At the end of the section, the comparison of available sensors to select the most suitable sensors for the development is presented and it ends with the summary of the section. Sensor selection is a crucial activity to be considered in any system design, as it will make a great impact on the process of system performance during its entire lifetime and could even has consequences related to the quality of the product.

As explained in the previous chapter, common sensors used in distance measurement for different applications include laser sensor, vision sensor, radar sensor, ultrasonic sensors, infrared sensors, sonar sensors and proximity sensors. Most laser sensors use a visible or infrared laser beam to project a spot of light onto the target, whose distance is to be measured. The general factors to consider when specifying a laser distance sensor include maximum range, sensitivity, target reflectance and specularity, accuracy, resolution, and sample rate. The general methods used to measure distance from the spot of the target back to the light-detecting portion of the sensor include optical triangulation and time of flight distance measurement. The optical triangulation measurement is employed to measure distance with accuracy from a few microns to a few millimetres over a range of few millimetres to metres at a rate of 100 to 60,000 times per second. A single point optical triangulation system uses a laser light source, a lens and a linear light sensitive sensor. A light source illuminates a point on an object, an image of this light spot is then formed on the sensor surface, as the object is moved and the image moves along the sensor; by measuring the location of the light spot image, the distance of the object from the instrument can be determined.

The laser time-of-flight instruments offer very long range distance measurement with a trade-off between accuracy and speed. Figure 4.1 depicts the two different methods to compute range distance using laser sensors. As shown in Figure 4.1, a short pulse of light is emitted and the delay until its reflection returns is timed very accurately. Since the speed of light is known, the distance to the reflecting object can be calculated and this is referred to as the time of flight measurement. The second method to compute the range distance is by measuring the phase difference between emitted and reflected waves.

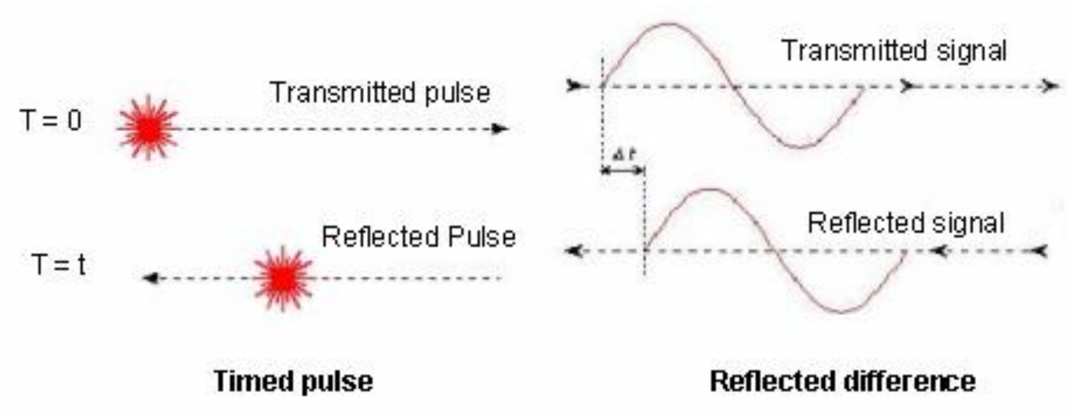


Figure 4.1: *Time of flight measurement principle of laser sensor (J. Hancock et al., 1998).*

Radar emits electromagnetic radiation. As the signal propagates, objects reflect, refract and absorb the radiation. Large reflecting objects will reflect a stronger signal. The signal strength can be different for different types of materials. A lower signal strength is received for a large obstacle with high absorptivity. Radars are generally used to detect large metallic obstacles at a distance.

The vision sensor (camera-depth image) uses time of flight principle in measuring the distance from setup point to the object or image. The time-of-flight (ToF) cameras work by measuring the phase-delay of reflected infrared (IR) light as illustrated in Figure 4.2.

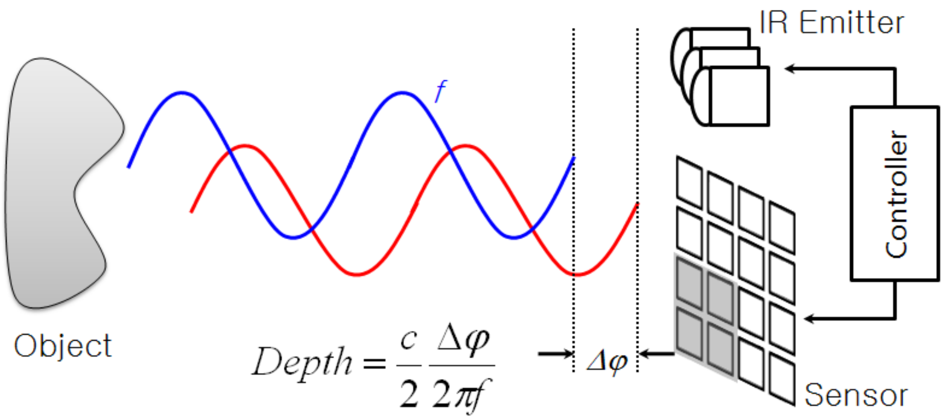


Figure 4.2: *Time of flight measurement principle of vision sensor (S. Foix et al., 2011).*

An IR wave indicated in red is directed to the target object, and the sensor detects the reflected IR component. The phase delay between emitted and reflected IR signals is measured to calculate the distance from each sensor pixel to target objects. Even though laser, radar and vision sensors have fast processing object detection, but these sensors are very expensive and require much computation time to extract useful information.

Ultrasonic sensors are relatively simple devices. The sensor sends a pulse out; the pulse will then be reflected from objects in its immediate path. When the pulse is emitted from the device, it travels through the medium until it collides with an object causing the pulse to be echoed back. Once the system receives the reflected wave, then the time difference between the firing of the pulses and the receiving of the reflected wave is proportional to the distance of the objects. Pulses can range from 40-200 kHz, but for most practical applications they are typically found to be in the range of 40-50 kHz. The equation (1) is used to calculate the distance of the obstacle, where v is the speed of sound in air and t is the time between fired pulsed and detection of the reflected wave, and theta is the angle of incidence between the wave and obstacle.

$$D = \frac{vt\cos\theta}{2} \quad (1)$$

The infrared sensors (IR) used infrared radiation, which is part of the electromagnetic spectrum. There are two types of IR sensors, IR sensors with built-in circuitry that outputs a binary result and those that provide an analogue output or multiple bit output. Sensors with a binary output are best at detecting the proximity of an object, but not necessarily the range. Thus this type of sensor can output a threshold distance and it is also among the cheapest IR sensors. The other IR sensor falls into the category of ranging sensors, which returns an output of the actual distance from the sensor to the object. This output can be returned in either analogue or digital byte.

Many IR sensors work by the process of triangulation; a pulse of light originates from the device and is either reflected back or not reflected at all. When the light is reflected back, it returns at an angle that is dependent on the distance of the obstacle, which is depicted by the Figure 4.3.

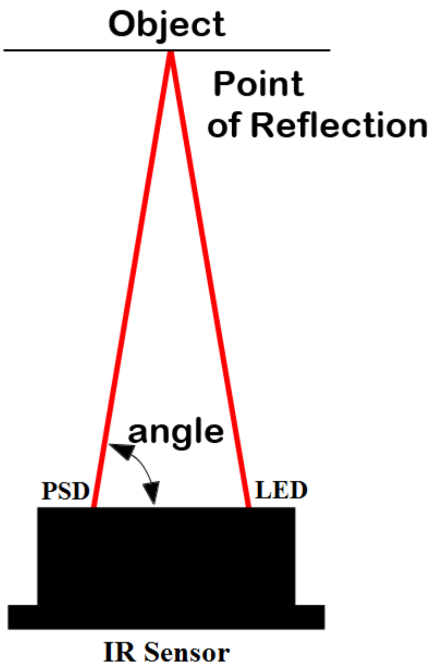


Figure 4.3: *Triangulation measurement principle of infrared sensor (Allaboutcircuits, 2015).*

Triangulation works by detecting this reflected beam angle, once the angle is known then the distance can be calculated. Tables 4.1, 4.2 and 4.3 summarized the common obstacle detection sensors which are used in the development of wearable obstacle detection system with respect to their sensing information, issues occurred when adding multiple sensors, features, and characteristic towards obstacle detection. Among the highlighted issues are interference, errors, safety and data processing.

TABLE 4.1: SUMMARY OF OBSTACLE DETECTION SENSOR ACCORDING TO SENSING INFORMATION AND ISSUES

Sensor Type	Sensing Information	Issues
Infrared	- Distance of objects directly in front of sensor - Thin beam width	- Interference between multiple IR sensors
Ultrasonic	- Distance of nearest object within viewing	- Interference between multiple sonar sensors - Errors depending on surface properties of object and angle of object to sensor
Laser	- Low wide beam-width	- Danger to surrounding Area
Lidar	- Distance of thousands of points in field of view with millimetre accuracy	- Processing and analysing lidar data sets require specialized skills and software
Camera (Mono)	- Areas of colour thought to correspond to floor	- Requires good lighting - Assumes floor to be one colour - Assumes obstacles to be a different colour from the floor
Camera (Stereo)	- Distance of objects from cameras	- Requires good lighting - Requires objects with sufficient surface detail

TABLE 4.2: SUMMARY OF COMMON OBSTACLE DETECTION SENSOR CORRESPONDING TO THEIR FEATURES OFFERED

Features	Sensor Types			
	Ultrasonic	Infrared	Vision	Laser
Easy to use interface	Yes	Yes	Moderate	Moderate
Trigger or Free-run Operation	Yes	Yes	Yes	Yes
Stable range data	Yes	Yes	Yes	Yes
Supply voltage	Very low	Low	High	High
Supply current	Very Low	Low	High	High
Environment	Indoor and Outdoor	Indoor and Outdoor	Indoor and Outdoor	Indoor and Outdoor
Cost	Low cost	Low cost	Expensive	Expensive
Range of detection	Medium and long	Short and medium	Long	Long
Response time	High	Very High	Very High	Very High
Robustness	High	High	Low	Low

TABLE 4.3: SUMMARY OF COMMON OBSTACLE DETECTION SENSOR TOWARDS THEIR OBSTACLE DETECTION CHARACTERISTICS

Sensor	**Characteristics (Obstacle detection)**
Ultrasonic	- The signal process is easy due to the slow transmission speed in air medium compared to the speed of light. - Ultrasonic wavelengths are relatively short (approximately 8.2mm at 42 kHz), which allows for high resolution in the direction of the linear distance measurement. This makes it possible to conduct highly accurate distance measurements. - Another advantage is that ultrasound is unaffected by the colour of an object and can thus be used to measure the distance from a sensor to a transparent body such as a glass object. - Ultrasonic sensor is also relatively immune to effects of light and airborne dust, which makes it useful for performing measurements in outdoor environments. - Potential error sources for the TOF systems include the following: • Variations in the speed of propagation, particularly in the case of acoustical systems. • Uncertainties in determining the exact time of arrival of the reflected pulse. • Inaccuracies in the timing circuitry used to measure the round-trip time of flight.

	• Interaction of the incident wave with the target surface.
Infrared	- Less influence on the colour of reflective objects, reflectivity. - External control circuit is unnecessary. - Voltage noise remains almost constant in the working range.
Laser	- A laser beam is bright and has low divergence beam, adequate for long distance measurement. - Sharp direction and high resolution due to smaller wavelength. - The use of laser range finding with Q-switched laser can raise serious safety issues. The Q-switched laser is a laser to which the technique of active or passive Q switching is applied, so that it emits energetic pulses.
Vision	- Employs more complicated algorithm to confirm the existence of obstacle. - Limited space to detect the obstacle when attached to the shoe.

Based on the summary in Tables 4.1 and 4.2, laser and vision sensors are expensive if compared to the ultrasonic and infrared sensors. Therefore, the ultrasonic and infrared sensors were chosen in this research because of their low cost, high resolution, robustness, lightweight and simple interfacing with the microcontroller especially for detecting static obstacles in the research and development of new devices. The use of these sensors also provides a better cost-performance ratio compared to other sophisticated imaging systems, such as the ones based on stereo vision camera, GPS or laser scanning. Table 4.4 summarizes some technical specifications of the sensors used in this research (see **Appendix A**) (MaxBotix Inc., 2007; Solarbotic, 2010). In this research, the size and weight of the sensors and their interfaces to a microcontroller are of paramount importance, because the sensors will be installed at the front of the shoes of the user.

TABLE 4.4: TECHNICAL SPECIFICATIONS OF THE ULTRASONIC AND INFRARED SENSORS (MAXBOTIX INC., 2007; SOLARBOTIC, 2010)

Sensor	Ultrasonic MaxSonar LV EZ1	Infrared Sharp GP2Y0A02YK0F
Range	0.15 – 6.45m	0.2 – 1.5m
Resolution	2.54cm	1cm
Beam Width	±30°	10°
Weight	4.3g	4.8g

4.3 Integration and Interfacing of Obstacle Detection Sensor

As discussed in detail in the previous section of this chapter, ultrasonic and infrared sensors were chosen as obstacle detection sensor for this system. These sensors are among the popular contacts-less sensors used in obstacle detection especially for static obstacle along the pathway, vehicle parking system, robotics and healthcare industries. Commonly, these sensors are integrated with signal conditioning circuit in solid packaging for easy installation and interfacing with controllers. Less wiring is needed to connect the sensors and controllers. Figures 4.4 and 4.5 demonstrate a simple interface that is required for the connection of the US and IR sensors to the microcontroller.

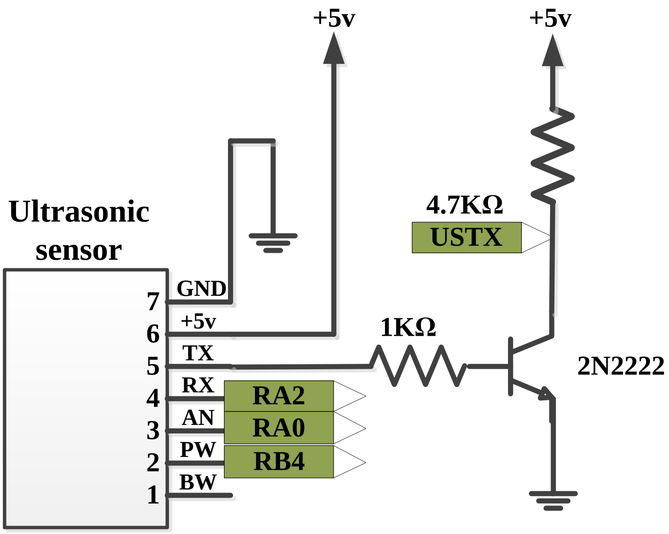


Figure 4.4: *The connection of the US sensor to the microcontroller.*

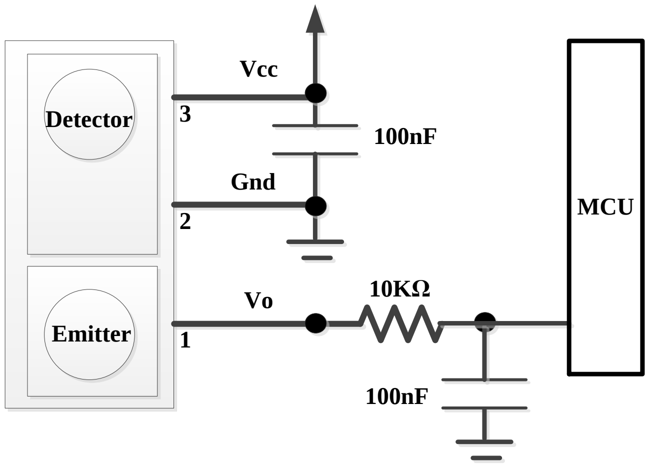


Figure 4.5: *The connection of the IR sensor to the microcontroller.*

In Figure 4.4, the transmitter and receiver circuits are packaged as one solid component where the emitter circuit radiates a pulse signal (original wave) to the object and then receives a reflection signal (reflected wave) back to receiver circuit as illustrated in Figure 4.6. The distance is measured by calculating the reflection time interval between the target and sensor (M.Ishihara et al., 2009).

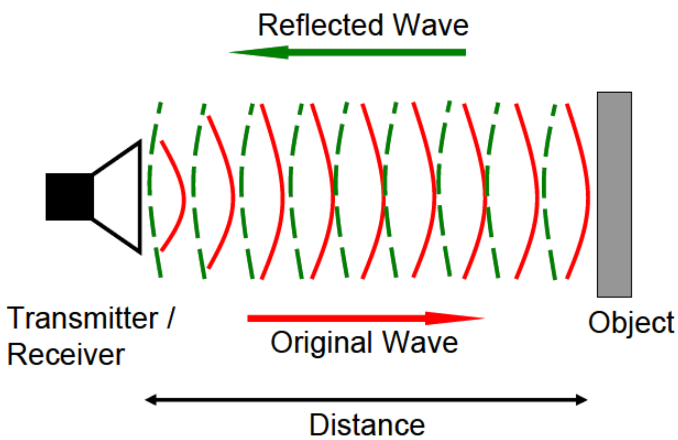


Figure 4.6: *Distance measurement process using ultrasonic sensor(M.Ishihara et al., 2009).*

In Figure 4.5, the emitter (Light Emitting Diode, LED) and detector (Position Sensitive Detector, PSD) circuits are split into two halves. The PSD is a silicon component that operates on the principle of the photoelectric effect, in which light energy is turned into electrical energy. The emitter of the infrared sensor radiates the infrared light and when the beam strikes an object, it is reflected back towards the sensor and into a focusing lens as shown in Figure 4.7. The focusing lens directs the reflected beam onto the PSD.

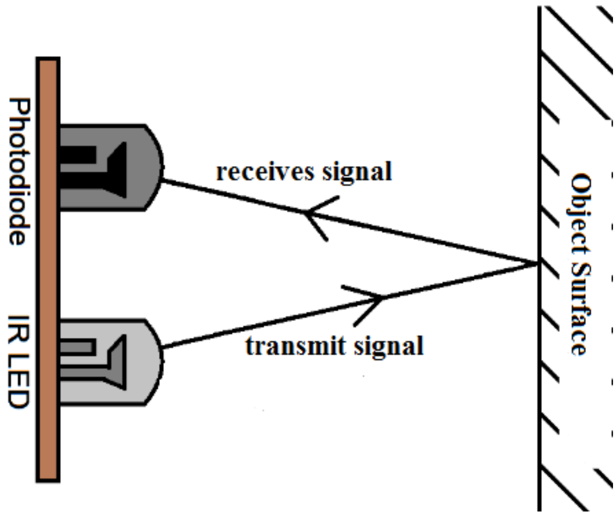


Figure 4.7: *Obstacle detection process using infrared sensor.*

4.4 **Review** of **Force Sensing Resistor (FSR)**

The advance in sensor technologies has opened up the biomechanics researchers to explore the Functional Electrical Stimulation (FES) in human walking. The FES technique is broadly used to improve or recover the damaged muscles and nerves in a disorder person (e.g., head injury, spinal cord injury, stroke or other neurological disorders) (S. Dae-Seob and H. Lee, 2011; D. Ojika, 2013). Effective functioning of the FES walking systems relies on accurate and reliable detection of gait events (e.g., toe off, heel rise and heel strike) which depends on the type of sensors and detection algorithm used. Normally, in biomechanics research, several wearable sensors are (C.A.Mecheraoui et al., 2010) proposed for the determination of gait event such as the Force Sensing Resistors (FSR) (J. Perry and J. M. Burnfield, 2009), Accelerometers (M. Hanlon and R. Anderson, 2010), Gyroscopes (P. Catalfamo et al., 2010; K. Dong-Won et al., 2011), Electromyography (EMG) (A. Boschmann et al., 2011), Tilt sensors (R.H.

Sohn et al., 2008) and Electronystagmography (ENG) (M. Hansen et al., 2004). Several wearable sensors were combined in the development of GaitShoe (S. J. M. Bamberg et al., 2008) as depicted in Figure 4.8 and Figure 4.9 to create a highly instrumented system that is capable of sensing many parameters that characterize the gait.

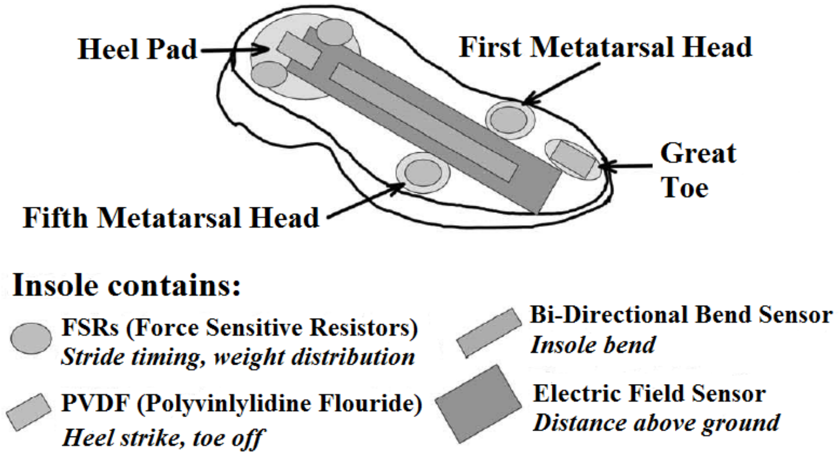


Figure 4.8: *The layout of the sensor utilized in the system (S. J. M. Bamberg et al., 2008).*

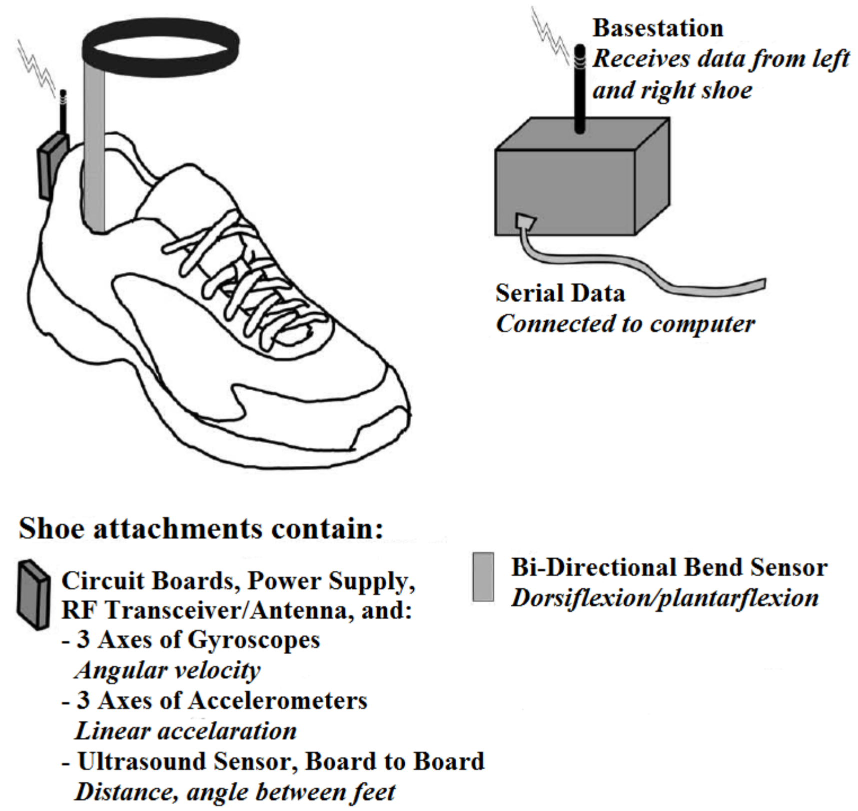


Figure 4.9: *Overall components attached to the system (S. J. M. Bamberg et al.,2008).*

Each sensor used in the GaitShoe has specific purposes depending on the gait parameters to be measured that associate with kinematics and kinetics measurement. For example, the FSR is related to kinetic measurement, which is used to measure force distribution under foot, strike timing and toe-off timing.

4.5.1 Force Sensing Resistor (FSR) Functionality

The purpose of the Force-sensing resistors (FSRs) is to detect transitions between five main phases of gait for the control of electrical stimulation (ES) while walking (B.T. Smith et al., 2002). The transition state of the five gait phases (e.g., loading response, mid-stance, terminal stance, pre-swing and swing) is described in Figure 4.10.

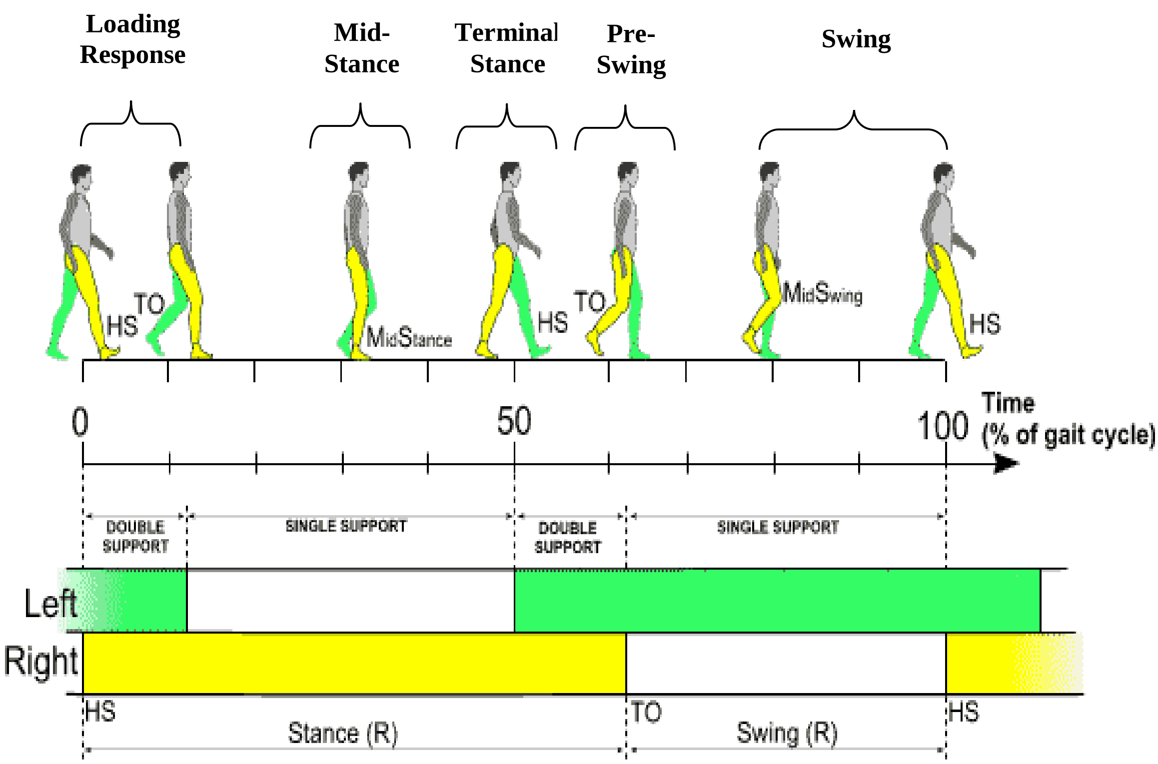


Figure 4.10: *Illustration of five gait event in gait cycle.*

The analogue FSR signals were digitized as either ON or OFF by a threshold level set at approximately 5% of the maximum signal amplitude. The swing was defined when all ipsilateral FSR's were OFF. The loading response was initiated when the heel FSR goes ON, and was terminated when either the medial or lateral FSR came ON. The mid-stance was finished when the contralateral swing phase terminates. The terminal stance ended when the ipsilateral heel was OFF. The pre-swing was terminated when both ipsilateral lateral and medial FSRs were OFF. The placement of the FSR sensors in gait transition determination is normally illustrated as in Figure 4.11.

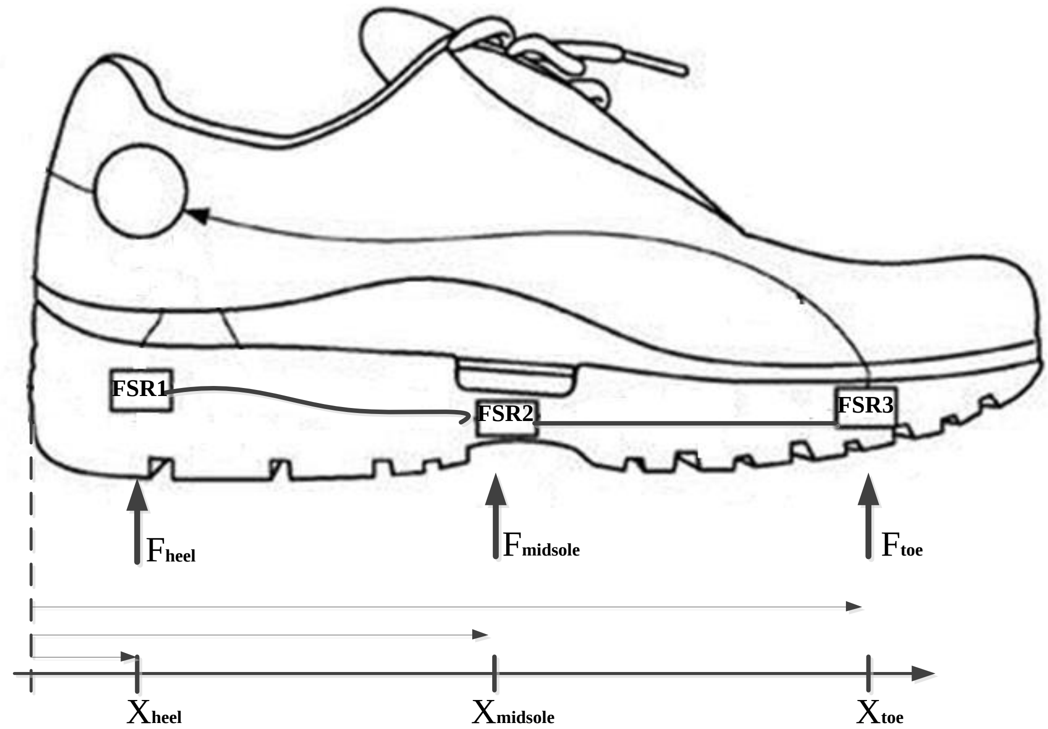


Figure 4.11: *Illustration of the FSR sensor placement for gait event determination (B. Mustapha et al., 2014).*

The placement of the sensor is based on the percentage distribution of the pressure at ipsilateral foot and contralateral foot in five phases of gait event detection as displayed in Table 4.5 (B.T. Smith et al., 2002).

TABLE 4.5: PERCENTAGE DISTRIBUTION OF THE PRESSURE AT IPSILATERAL FOOT AND CONTRALATERAL FOOT

Gait Event	Percentage of Ipsilateral Foot			Percentage of Contralateral Foot		
	Heel	Mid-foot	Toe	Heel	Heel-foot	Toe
Loading Response	7 – 54 %	3 – 23 %	1 – 8 %	1 – 8 %	1 – 8 %	-
Mid-Stance	-	2 – 14 %	1 – 7 %	-	6 – 43 %	5 – 36 %
Terminal Stance	5 – 50 %	2 – 20 %	1 – 10 %	-	2 – 20 %	-
Pre-Swing	1 – 6 %	1 – 6 %	-	8 – 50 %	3 – 19 %	3 – 19 %
Initial Swing	-	6 – 50 %	4 – 33 %	-	2 – 17 %	-

The reliability and accuracy of the FSRs obtained for the gait event determination are 94.5% (B.T. Smith et al., 2002) and 90% (J. Rueterbories et al., 2010), respectively.

4.5 Wireless Applications

Nowadays, the usage of wireless communication technology is rapidly increased in a variety of applications such as wireless sensor networks, industrial automation systems, home automation systems, remote control systems, medical care equipment, automation systems for agricultural use, and other applications. Wireless device is not only making the elderly feel comfortable while walking because of no obstruction but also for monitoring purposes. The elderly is not distracted or depressed during navigation when using wireless devices. Flexibility and easy installation make the wireless devices are suitable for mobility. Among various communication technologies, Zigbee is an emerging and very promising international standard-based wireless-communication technology. The ZigBee technology is a wireless sensor network system which ensures remote monitoring and controlling of load parameters. Some of the characteristics like low cost, low power, low data rate, easy installation, low maintenance, multiple topologies, etc., make this communication tool more suitable for a wide variety of applications compared to other short-range communication technologies.

The Zigbee technology is an industry standard and Xbee is the name of the module. Wireless communication technology is widely used by Zigbee applications such as wireless sensor networks, Zigbee home automation systems, industrial automation, remote control systems, medical care equipment and agriculture automation. Zigbee is the trending international standard for wireless communication technology. The Zigbee communication is a specification used to create a communication protocol to create a network that is built from low power digital radios. The Zigbee technology is an IEEE 802.15.4 standard and it can communicate up to 100m when it is placed to communicate with other Zigbee modules. Moreover, it can communicate over long distance when it is connected in mesh technology. Zigbee is used when we require low data rate application with long battery life and secure network. It is also low cost, low power, low data rate, easy to install, low maintenance and multiple topologies for wireless communication. These specifications made the Zigbee protocol fit to be used in a wide range of applications. The size of Xbee module as shown in Figure 4.12 has made it valuable for various wireless applications.

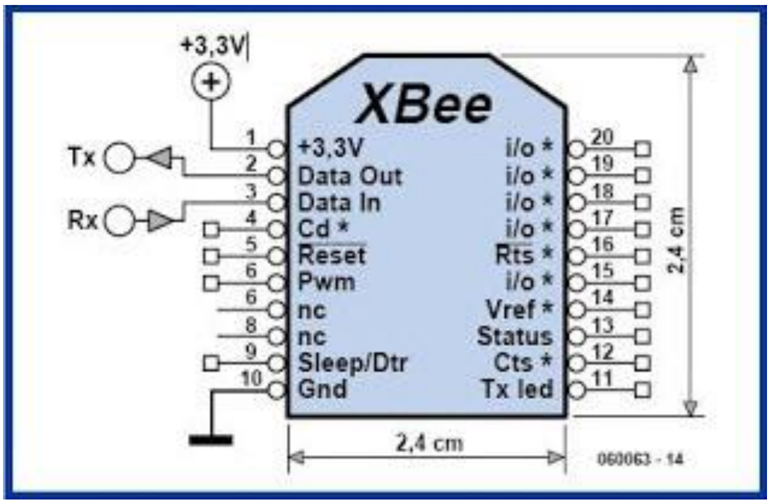


Figure 4.12: *Layout of Xbee module configuration (M. Hebel et al., 2010).*

Devices that use ZigBee are powered by battery. The IEEE 802.15.4 physical radio specification is used in unlicensed radio frequency bands like 2.4 GHz, 900 MHz and 868 MHz.

4.6 Multiple Alarming Systems

The alarming system is a very important part in the development of the obstacle detection system. It is specially designed as alerting tools to direct and inform the elderly about existing obstacles in their pathway. A systematic, explicit, comprehensive and proactive process is needed to ensure that these warning principles, and other safety and human factor considerations are addressed throughout the design and implementation of the obstacle detection system. The design concepts were based on suitability and sensitivity of the user to receive the appropriate warning messages (e.g., buzzer, vibrate, audio synthesizer or combinations) that are suits for them. The alarm interval can be change according to the gait of the user (B. Mustapha et al., 2012). Consideration was also taken when the systems are likely to be activated and which modality or modalities that is suitable to be used. The selection of the modality supplied to the system should consider all kinds of weaknesses that belong to the elderly such as earless, low vision, muscle strength and etc. To cater to all these challenges, two or more modalities are recommended for effective obstacle avoidance. Recent research found that human response is more prompt when warnings are presented in more than one modalities. Furthermore, the user also has preferences for multi modalities presentation (S. M. Belz et al., 1999; L. Yung-Ching, 2001). The use of distributed presentation increases the opportunity to display information on the nature of hazard, thereby increasing the likelihood of an appropriate response when an obstacle is detected. The auditory and haptic modalities are implanted in this research.

4.6.1 Auditory Modality

Auditory warnings use sound as a way to capture the user’s attention regardless of where the user is looking at. There are several different types of auditory modality that can be used to alert the users when an obstacle is detected such as tone (conventional), buzzer and speech (audio messages). Tone is the use of a frequency or a range of frequencies in either a continuous or intermittent signal. A speech or audio message is a spoken language that is either synthesized or digitized. It is important for the sound level to be suitable with the user’s condition and detectable above other surrounding noises. Since older people require a higher dB level than younger person, a sound level control should be considered, but should not allow it from going below a certain dB level (C.L. Baldwin, 2002). The auditory tone should be about 15dB above the masked threshold.

4.6.2 Haptic Modality

Haptic or tactile is another way of alerting the user of obstacle ahead. Haptic warnings are easily detectable and are not likely to be masked by other haptic stimuli. They do not rely on the line of sight. However, additional research needs to be conducted to make haptic warnings a viable option for the elderly. Haptic feedback uses the sense of touch and pressure on muscles and organs to give cue to the body. It is also known as tactile, kinaesthetic or proprioceptive feedback. Tactile stimulation can be accomplished through a number of different methods that present mechanical, thermal, chemical or electrical energy to the skin. These methods create tactile sensations, such as pressure, warmth and vibration. There is a large variation of sensitivity of human skin depending on where the vibrator is located on the body. The placement of tactile component or vibrator on the body must not distract the movement of the user during walking.

4.7 Chapter Summary and Discussion

Several types of common distance measurement sensors are studied and presented for consideration towards realization of a wearable obstacle detection system device. They are firstly optimized for the selection of suitable distance sensors to be used based on their physical appearance features such as robustness, length of detection, angle of coverage, structural materials, size and cost. They are then evaluated in terms of suitability for shoe application by the means of optimum and reliability of detection. The requirements for gait analysis application are also presented and used as the guidelines for the obstacle detection. The analysis of the sensing measurement techniques and comparisons with several wearable obstacle detection devices in literature are also included. The Infrared (IR) and Ultrasonic (US) distance sensors based on time-of-flight (ToF) measurement technique is preferred due to its proven practical use in other similar applications and also due to good object detection in terms of maximum range of detection that can be measured.

The selection of sensing mechanism is based on aspects of fulfilment of gait analysis needs, competitiveness of manufacturing cost and capability for total integration with circuitry for performance and system miniaturization. Among the gait analysis needs include small size, light weight and suitable range. In addition to the dependency of sensing range on signal frequency, the measureable range is also dependent on signal strength, thus the right choice of sensors is vital when designing the wearable device. This characteristic offers an additional flexibility in terms of detection range and compatibility with microcontroller and wireless transceivers modules power management.

All literatures pertaining to the selection of the main components are presented and reviewed. The literature proves that wearable system helps the user in terms of less distraction when walking. The inclusion of sensors, signal processing circuitry, microcontroller and wireless communication modules embedded to the shoe may produce a high performance obstacle detection device. In short, the objective of the study which is to explore the sensors applicability for the obstacle detection and alarming components has been selected and demonstrated. A suitable alarming technique is identified, and as a result, a wireless obstacle detection system for safe locomotion is fully designed, modelled, implemented and tested. Finally, Table 4.6 highlights the summary of determined specifications for the designed obstacle detection system.

TABLE 4.6: DESIGNED SPECIFICATIONS OF THE OBSTACLE DETECTION SYSTEM

Item	Specifications
Effective distance for obstacle detection	1.5 meter
Effective width for walking pathway	0.5 meter
Sensing environments	Indoor and outdoor
Types of obstacles	Plastic, Plywood, Concrete, Mirror, Wood
Shapes of obstacles detected	Circle, rectangular, cylinder
Minimum size of obstacle detection	6cm
Alerting Medium	Buzzer, Vibrator, Audio Messages
Alerting Pattern	3 consecutive alert sequences

System Prototype and Design

CHAPTER

5

5.0 List of Peer Reviewed Publications Produced

1. *B. Mustapha, A. Zayegh, and R.K. Begg, 2014. 'Wireless Obstacle Detection System for the Elderly and Visually Impaired People', in* ***Proceedings of the 2013 IEEE International Conference on Smart Instrumentation, Measurement and Applications (ICSIMA)****, 25-27 November, Kuala Lumpur Malaysia, pp. 1-5. ISBN 978-1-4799-0842-4.*

2. *B. Mustapha, A. Zayegh, and R.K. Begg, 2014. 'Ultrasonic and Infrared Sensors Performance in a Wireless Obstacle Detection System', in* ***Proceedings of the IEEE 2013 First International Conference on Artificial Intelligence, Modelling & Simulation****, 3-5 December, Kota Kinabalu Malaysia, pp. 487-492. ISBN 978-1-4799-3250-4.*

5.1 Chapter Overview

As mentioned in the earlier chapter, the designed prototype of the obstacle detection system comprises of two parts which are the transmitter and receiver. According to the determined specifications as discussed in Chapter 4, the intended prototype must be miniaturised for best fixing to the shoe. It is necessary that the designed prototype complies with the size of the shoe to ensure smooth and successful installation, testing and data collection. Therefore, the designed layouts for both printed circuits boards (transmitter and receiver) are then extended to include suitable interconnection and multiple layers according to the specified components. Furthermore, the testing of the prototypes requires special consideration in the form of load and burden. This is due to the fact that the users walk in different speed and style during testing.

This chapter encompasses activities towards hardware installation of the main components that include infrared sensors, ultrasonic sensor, pressure sensors, microcontroller and wireless module that is attached directly to the shoe which will be discussed in detail. The chapter is divided into six sections inclusive of this overview; the other subsections are explained next. As the name implies, the next section, hardware development and design, contains the discussion on assembling all the components needed for each part. The prototypes finalization of the obstacle detection system and its finishing are discussed in the subsequent section. Discussions and analysis on the measurement results of the prototype are discussed in the next section. Lastly, the Chapter Summary concludes the whole achievement of the design, and assembling and testing implementation of the prototype.

5.2 Hardware Development and Design

In the purpose of developing obstacle detection hardware circuit, there are several components involved. All these required items have their own functions in order to support the operation of the whole circuit in this obstacle detection system. Hardware will have a direct connection with the user since it is attached to the shoe. The design of this circuitry was done after careful considerations were made prior to developing the wearable device. The development of hardware for wearable obstacle detection system involves two parts which are the transmitter and receiver. The transmitter side consists of FSR sensors (as switching mechanism for distance sensors), IR and US sensors (as distance sensors), microcontroller unit (MCU) and wireless communication module for data (detected obstacle) transmission. The receiver comprises of second MCU, wireless communication module for data receiving and alarm units such as the buzzer, vibrator and audio messages.

5.2.1 Force Sensing Resistor

The use of FSR sensor in biomechanics research has been established for many applications or purposes. In this work, three pieces of Force Sensing Resistors (FSRs) type 402 manufactured by Interlink Electronics (Interlink Electronics, 2010) are used, which are in the circular shape as shown in Figure 5.1.

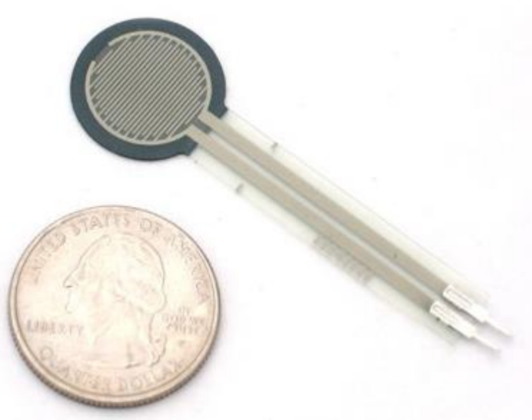


Figure 5.1: *Illustration of force sensing resistor FSR 402 from Interlink Electronics (Interlink Electronics, 2010).*

It is ideal for engineers, scientists' or researchers who need to measure forces distribution under foot without disturbing the dynamics of their tests. This sensor can be used to measure both static can dynamic forces, and are thin enough to enable non-intrusive measurement. The resistive-based technology FSR sensors are a polymer thick film (PTF) device which exhibits a decreasing trend with an increase of the force applied to the active surface. The application of force to the active sensing area of the sensor results in a change in the resistance of the sensing element in an inverse proportion to the force applied which shared similar properties with the load cell or strain gauge (Interlink

Electronics, 2010). For simple force-to-voltage conversion, the FSR device is tied to a measuring resistor in a voltage divider configuration as displayed in Figure 5.2.

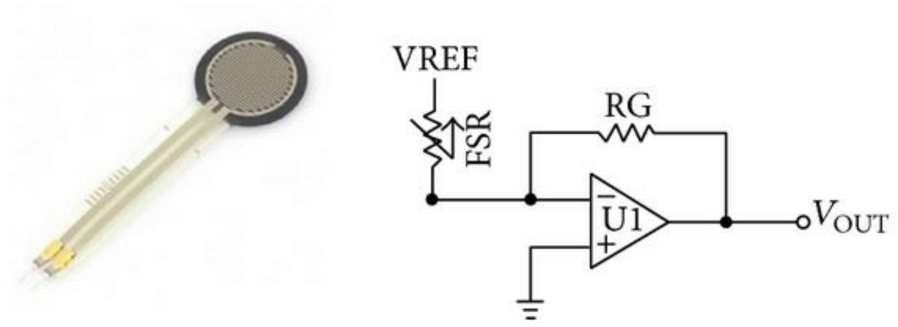


Figure 5.2: *Configuration of the FSR sensor circuit (Interlink Electronics, 2010).*

The size, shape and thickness (very thin, less than 0.5 mm) of the sensor make it suitable to be mounted on the insole position of the shoe without disturbing the user during walking. The purpose of this sensor is to ensure that the analogue distance sensor (US and IR) is only activated (sense the obstacle) when the entire sole of the foot (shoe) touches the ground. The foot is considered as fully touching the ground when all the values at the output of FSR sensors reach the setup threshold value (high pressure, low resistance). The high pressure value occurs at three top places under the foot which are heel, first metatarsal head (MTH) and toe as illustrated in Figure 5.3.

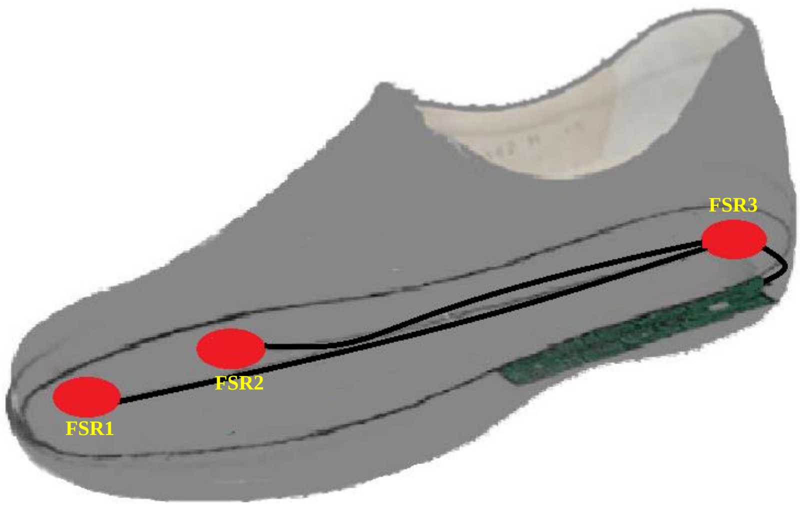
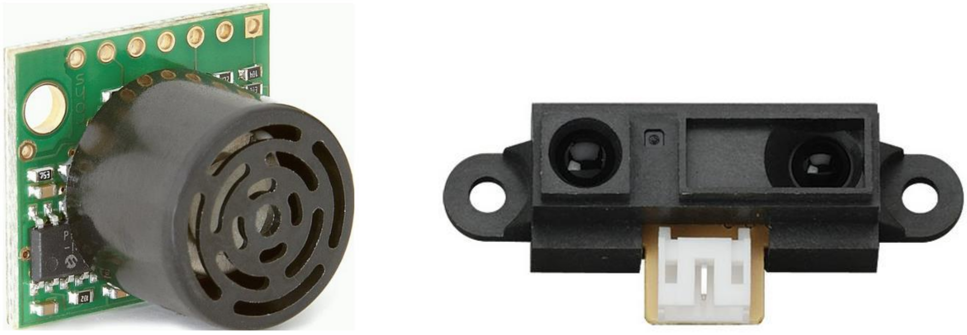


Figure 5.3: *The placement of the FSR sensors at the shoe.*

5.2.2 Obstacle Detection Sensors

In this research, the size and weight of the sensors and their interfaces to a microcontroller are the important requirements since the sensors will be installed at the front part of the shoes of the user. The ultrasonic LV EZ1 from Maxbotics and infrared GP2Y0A02YK0F from Sharp family are chosen for this project because their specifications meet with the design requirement of the system. Both sensors are non-contact analogue distance sensor as shown in Figure 5.4.



(a) Ultrasonic Sensor **(b) Infrared Sensors**

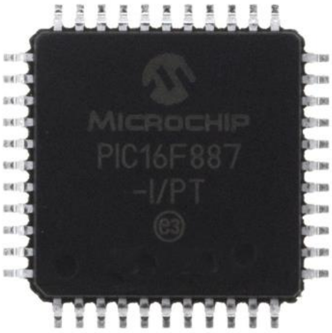
Figure 5.4: *Analogue distance sensors used for obstacle detection includes (a) Ultrasonic LV- EZ1 from Maxbotics and (b) Infrared GP2Y0A02YK0F from Sharp.*

The combination of these two medium range sensors enhances the reliable performance against the obstacle detection in a variety of shapes, sizes, materials and environment. The capabilities of the sensors towards obstacle detection have been elaborated in the previous chapter.

5.2.3 Microcontrollers

PIC microcontrollers from the Microchip Technology family are used in this system prototype due to its wide acceptance in industry, low cost, abundant information resources, easy to use, availability, versatility, ease of programming, small size and compatible for wireless application. Nevertheless, broad functionality allows this microcontroller to be physically embedded to the insole of the shoe to perform all the necessary control functions. The PIC microcontroller can also work with low cost development kits which are available in the market such as ESPIC40C. The proposed device utilized two 8 bits microcontrollers, which are PIC18F66K80 at the transmitter and PIC16F887 for the receiver as shown in Figure 5.5.

(a) PIC18F66K80



(b) PIC16F887

Figure 5.5: *The 8 bits Microchip controllers used in the proposed system (see **Appendix B**).*

Both microcontrollers bring additional value to the developed system since it offers unique and exclusive peripherals (e.g., intelligent control capabilities, communication and networking, lowest cost and smallest form factors).

5.2.4 Wireless Transceivers Modules

The developed obstacle detection system utilizes the wireless communication technology for data transmission between the transmitter and receiver unit. The Xbee transceiver module provides wireless connectivity for data transfer without using any switch or connector. This type of wireless module is based on the Zigbee network technology. The circuit operates at 3.3 V with a current of less than 40 mA during its operation and 3 mA during sleep mode. Data from the transmitter part can be transferred to a receiver in a time multiplexed manner. This means that data from the obstacle detection sensors are captured by the microcontroller at the transmitter and then transmit the signal to the receiver part through the Xbee transmitter module. The setup connection between the PIC and Xbee transmitter module is shown in Figure 5.6.

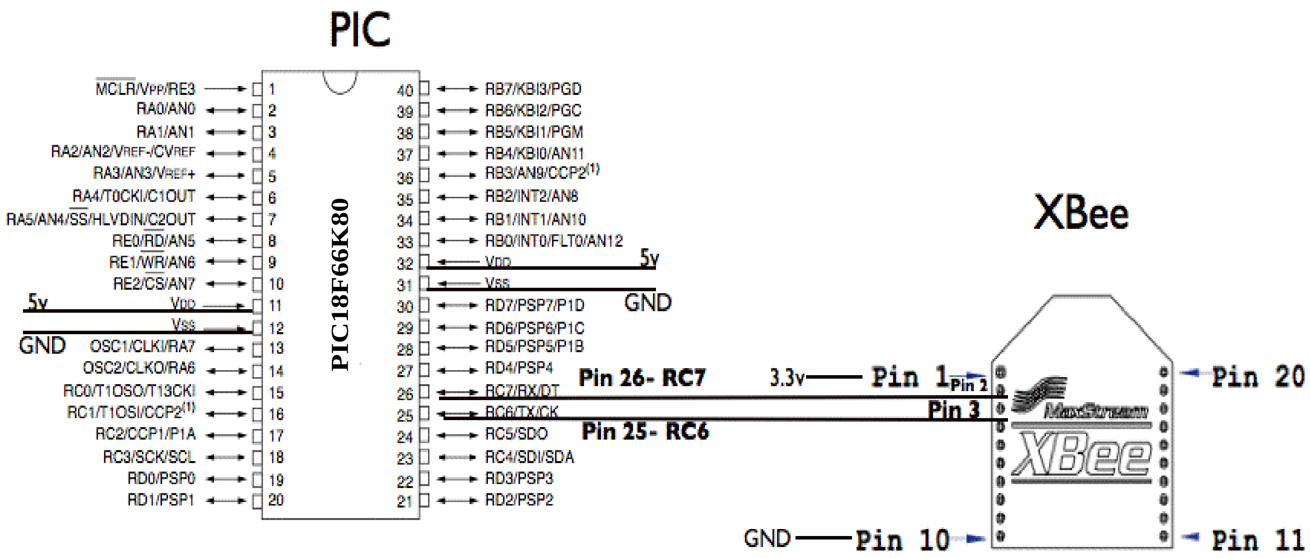
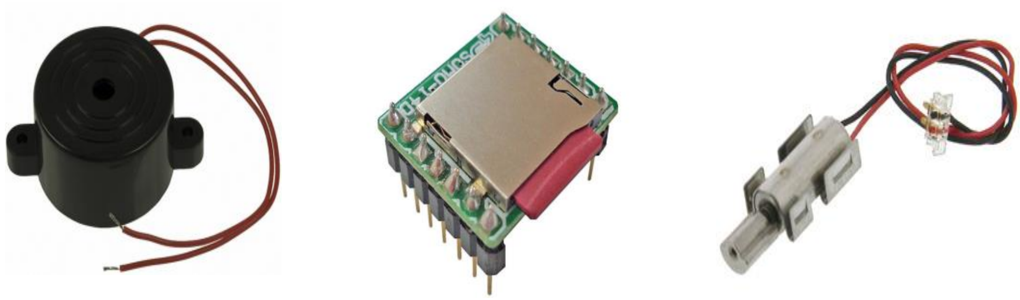


Figure 5.6: *Circuit connection between microcontroller and Xbee wireless module.*

The Xbee receiver module at the receiver part receives data and it is detected by microcontroller PIC16F887 before sending an activation signal to the user for further action.

5.2.5 Alarm Units

Auditory and tactile mechanisms are used as alerting tools to inform the user about obstacle ahead while walking. Two types of auditory feedbacks implemented in this project are buzzer and audio messages, while the DC vibrator motor is used as a tactile modality for the hearing-impaired older adults as shown in Figure 5.7. It is preferable to have an alarm unit located at a suitable position of the body to make the user response immediately when the alarm activates. The head, waist, lower arm and wrist are the usual locations for putting the alarm unit, but for most persons, placing something on the head can be uncomfortable. In this work, the upper arm is more suitable if compared to other locations in terms of the freedom factor during walking.



(a) (b) (c)

Figure 5.7: *Three types of alerting tools used in obstacle detection system prototype: (a) Buzzer ; (b) Audio Synthesizer ; (c) DC vibrator motor*

5.3 Commissioning and Testing of the Obstacle Detection System Prototype

The designed prototype consists of two modules which are the transmitter and receiver. Each transmitter module is attached to the right and left shoes respectively, which consists of FSR sensors that are placed beneath the foot, microcontroller coupled with wireless transmitter module and obstacle detection sensor which mounted to the front part of the shoe. The placement of the obstacle detection sensors and FSR sensors at front part (outsole layer) and beneath the foot (insole layer) did not affects the comfortability of the shoe. The receiver module contains the microcontroller coupled with wireless receiver module and the multiple alarm modules which are strapped to the upper arm. The prototypes of the designed system are shown in Figure 5.8.

(a) Transmitter module (b) Receiver module

Figure 5.8: *Wireless obstacle system prototype includes: (a) transmitter module; (b) receiver module*

5.4 Empirical Measurement Results on Hardware

The developed prototype has been tested for evaluating the functionality of the hardware and software implementation and performance in terms of assess capability, which creates reliable output and accuracy. It is essential to ensure that each of the individual modules is working properly and as a complete system itself.

5.4.1 Testing on Sensors Sensitivity and Angle Detection

The test has been conducted to determine the sensibility of distance sensors towards the detection of obstacles in different distances and angles. In this case, the angle refers to a sensor position that is placed against the obstacle at the front. For example, if the object is placed in front of the sensor, the angle is said 90°. If the obstacle is placed 10° to the left, then the angle would be 100°. Similarly, if the obstacle is located 10° to the right, then the angle is 80°. Meanwhile, distance is the position measured between the sensor and the obstacle. Table 5.1 shows the results obtained from the test.

TABLE 5.1: THE SENSIBILITY OF SENSORS TOWARDS DETECTION OF OBSTACLES IN DIFFERENT DISTANCES AND ANGLES

Actual distance (cm)	Measured distance in cm according to the following setting angle						
	120º	110º	100º	90º	80º	70º	60º
30	28.56	28.70	29.15	29.98	29.24	28.65	28.43
50	30.10	45.24	48.62	49.98	48.88	46.10	30.15
70	-	65.20	69.94	70.02	69.62	64.90	-
90	-	75.34	88.56	89.86	88.24	76.24	-
110	-	-	105.22	108.42	104.78	-	-
130	-	-	124.98	137.84	12370	-	-
150	-	-	144.34	148.68	143.84	-	-
170	-	-	-	168.55	-	-	-

The results reveal that the detection sensors are able to detect obstacles from 30 cm to 1.7 m when facing 90º angles. When the obstacle is at 10º to the right and left of 90º, the sensors are able to detect the possible obstacle up to 150 cm. The sensors can still detect obstacles at wider angles (left and right) for distances less than 110 cm. It is clearly shown that the system is adequate to detect all possibilities of obstacles that existed along the typical pathway of 0.5 m (Department of Transport of Western Australia, 2012). Based on 0.5 m of path width, the possible angle of obstacle detection can be determined using the trigonometry equation as illustrated in Figure 5.9.

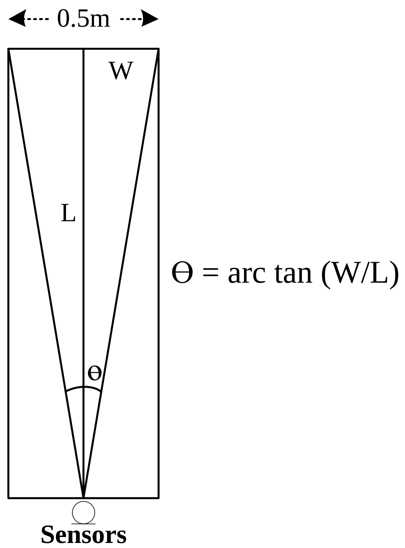


Figure 5.9: *Calculation of possible angles of detection.*

Table 5.2 shows the calculation of the angles of detection according to the path width of 0.5 m and the variable of length (L) of obstacles.

TABLE 5.2: CORRESPONDING ANGLES FOR OBSTACLE DETECTION TOWARDS THE VARIABLE OF LENGTH (L)

Length (L)	Angle
1.5m	10º
1.3m	11º
1.1m	13º
0.9m	16º
0.7m	20º
0.5m	27º

In comparison with the length of set distance and the location of obstacles, the test results of angular detection obtained are quite similar to the calculated angles. The results were measured in the form of voltage (volt) before converting to distances (cm). The output voltages of the sensors are depicted in Figure 5.10.

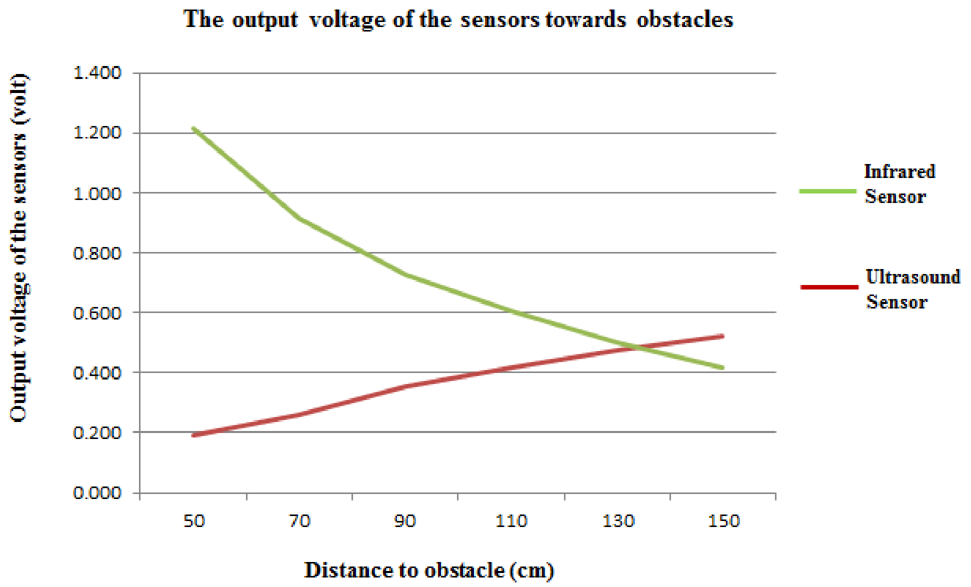


Figure 5.10: *Measurement of output voltage at different angles and distances.*

As the distance increases, the voltage measured across the output from the ultrasound sensor also increases. The linear curve indicates that the ultrasonic sensor output is directly proportional to the measured distance. This phenomenon occurred due to ultrasonic sensor that measures the pulse-width modulation (PWM), which is directly proportional to the round trip delay time and distance measured (A. K. Shrivastava et al., 2010). Therefore, when the round trip delay increases, the distance also increases. The correlation between distance measured and round trip delay can be expressed in Equation (1).

$$D = \frac{1}{2}Ct \qquad (1)$$

Where,

D= distance of sensor to the target

C=speed of sound in air

t=round trip delay of ultrasonic pulse

The output voltage of the sensor can be obtained from Equation 2.

$$V_o = DV_i \qquad (2)$$

Where,

V_o= Output voltage of the sensor

D = distance of sensor to the target

V_i = Volts per inch (scaling)

However, the output voltage measurement from the infrared sensors demonstrates that these sensors have a nonlinear characteristic, and the output voltage decreases when the distance increases. It is also clearly shown that the voltage decreases when the angles decrease to the right and left of the reference point (90 degree). Figure 5.11 illustrates the effects of the measured voltage at the IR sensor output when the incident angles are varied.

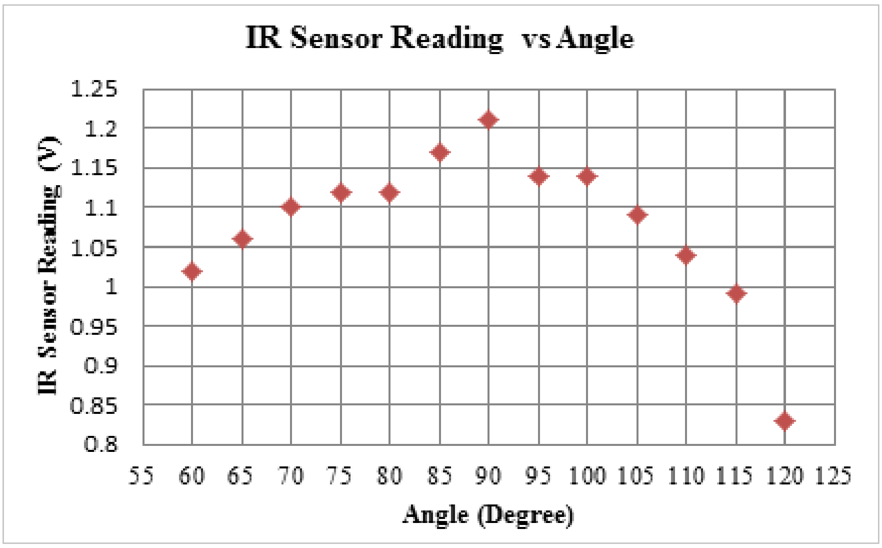


Figure 5.11: *Data collected from a flat surface of 50 cm from IR sensor at different angles.*

5.4.2 Testing on Different Surface Colours of Obstacle

Several colours of obstacle have been selected and tested accordingly. The colours of the surface of obstacle include white, black, red, yellow, blue and green. In this experiment, the measurement was conducted from 50 cm to 150 cm which are active walking regions for the users to react if an obstacle is detected. Based on the voltage-distance characteristics of the sensors, it is clearly shown that the ultrasonic sensor does not depend on to the surface colour of obstacle. However, the measurement results obtained from infrared sensors proved that colour gives small effects to the detection measurement of obstacles but still in acceptable range. The measurement differences due to the colour of obstacle have not affects to the overall detection system. The voltage-distance characteristics of the sensors output are shown in Figures 5.12 and 5.13.

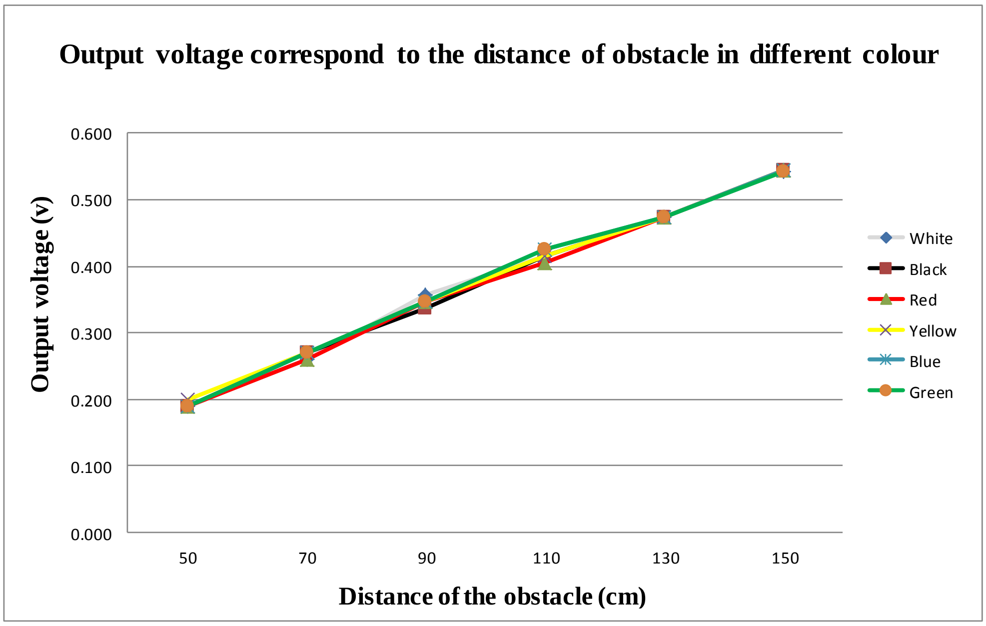


Figure 5.12: *Measurement result for the US sensor.*

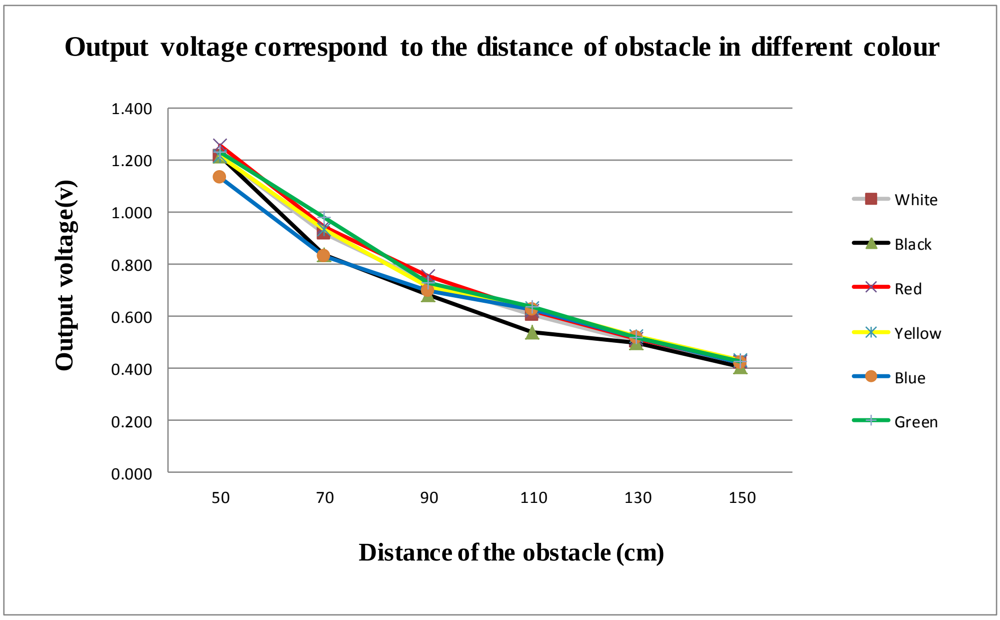


Figure 5.13: *Measurement results of the IR sensor.*

According to the plotted graph of the IR sensor measurement, the non-linear characteristics of the output voltage are obtained. The aforementioned sensor output voltage shows the smallest voltage values corresponding to farther objects. When the detected obstacle is too close to the sensor, the voltage measured is increased. Similar results are found when the incident angle is increased. Environmental conditions could influence the measurement results such as sunlight and artificial lights unless the external source is directly pointed towards the sensor (Y. T. Win et al., 2011).

The average output voltage value of the IR sensor that corresponds to the distance of obstacle obtained is similar with the technical datasheet produced by Sharps (Solarbotics, 2010). Because of the non-linearity of output, data linearization must be applied to determine the distance measured. Data linearization is done using the nonlinear curve fitting method. Using the datasheet provided by Solarbotics, we used a fourth degree approximation method to obtain a close fitting formula to identify the distance in cm from the voltage as shown in Equation (3).

$$M_d\ (cm) = 162537x^4 - 129.893x^3 + 382.268x^2 - 512.611x + 306.439 \tag{3}$$

Where,

M_d = Measured distance (see **Appendix C** for examples calculation)

Table 5.3 and Table 5.4 highlight the measurement results of the sensors detection towards surface colour of obstacle for both indoor and outdoor environments.

TABLE 5.3: COMPARISONS BETWEEN THE SENSORS DETECTION TOWARDS SURFACE COLOUR OF OBSTACLE FOR INDOOR ENVIRONMENT

Actual distance (cm)	Average measured distance for different surface colours of obstacles (cm) [**Indoor**]					
	White	Black	Red	Yellow	Blue	Green
50	49.92	49.96	49.07	51.22	51.80	49.56
70	68.26	73.64	67.18	68.90	73.81	66.96
90	91.65	92.53	88.73	91.32	92.70	90.35
110	108.88	115.18	106.26	106.79	108.43	107.66
130	126.66	127.10	125.36	124.62	124.83	125.15
150	145.60	144.81	144.84	144.08	145.34	144.96

TABLE 5.4: COMPARISONS BETWEEN THE SENSORS DETECTION TOWARDS SURFACE COLOUR OF OBSTACLE FOR OUTDOOR ENVIRONMENT

Actual distance (cm)	Average measured distance for different surface colours of obstacles (cm) [**Outdoor**]					
	White	Black	Red	Yellow	Blue	Green
50	49.42	49.42	49.42	52.02	49.42	49.42
70	69.96	67.36	67.36	69.96	69.96	69.96
90	87.65	90.25	90.25	90.25	90.25	90.25
110	107.94	105.33	105.33	107.94	110.54	110.54
130	123.28	123.28	123.28	123.28	123.28	123.28
150	141.49	141.49	141.49	141.49	141.49	141.23

5.4.3 Testing on Different Types of Obstacle Materials

The test was performed on several types of obstacle materials such as wood, plastic product, mirror, plywood and concrete. The testing consisted of collecting data from a range of sensors at fixed distances. Each experiment was run for a number of times for each distance to confirm the repeatability of the system. Figure 5.14 shows the results of the detection of 5 types of obstacle materials placed at a distance of 50 cm from the shoe sensors.

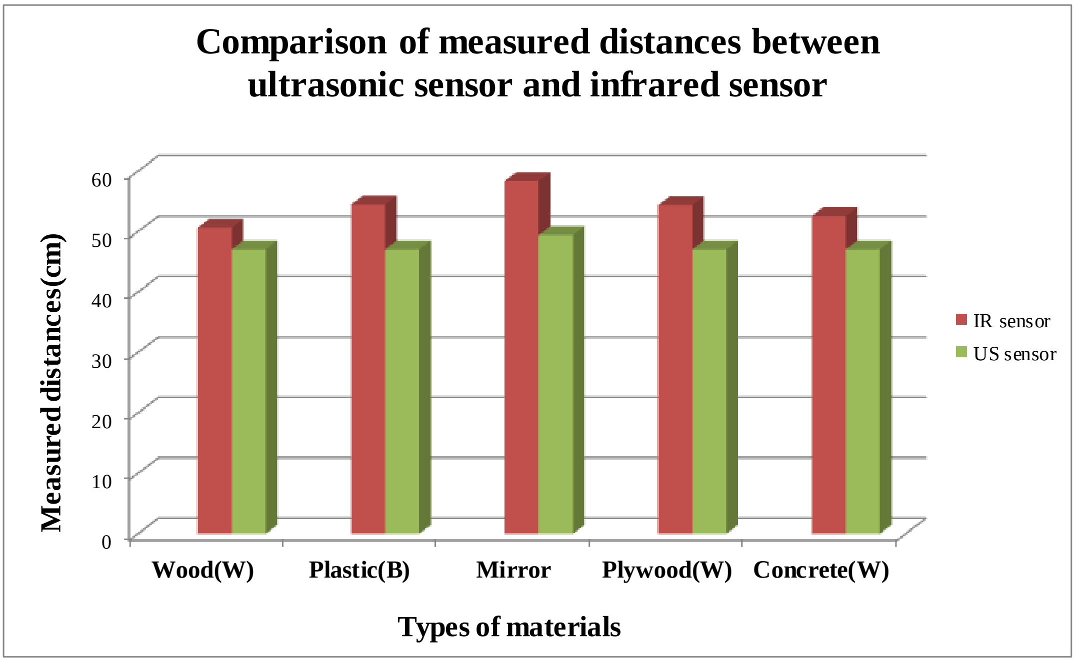


Figure 5.14: *Measured distances of the ultrasonic and infrared sensors for different types of obstacles at a distance of 50 cm.*

5.4.4 Testing on Different Sizes of Obstacle

The developed prototype system has also been tested to evaluate the sensors' capability to sense obstacles (objects) of varied sizes and for different distances. Table 5.5 shows the results obtained from the experiments for both indoor and outdoor environments.

TABLE 5.5: MEASUREMENT RESULTS FOR THREE SIZES OF OBSTACLE FOR INDOOR AND OUTDOOR ENVIRONMENTS

Size of obstacle	Setting distance (cm)	Measured distance for indoor (cm)	Measured distance for outdoor (cm)
6 cm x 14 cm	50	48.72	48.26
	70	68.58	68.58
	90	88.90	86.36
	110	109.22	106.68
	130	129.54	127.00
	150	149.86	149.86
	170	168.32	167.86
10 cm x 20 cm	50	48.26	48.26
	70	69.04	68.58
	90	86.36	88.90
	110	108.68	106.68
	130	132.08	128.70
	150	149.86	149.32
	170	168.76	168.20
15 cm x 25 cm	50	50.80	49.52
	70	71.12	69.04
	90	91.44	88.90
	110	111.76	108.64
	130	129.54	129.00
	150	149.86	149.52
	170	168.87	168.54

It is clearly shown that all obstacles are detectable within the setting range (50 cm to 170 cm) for both environments either indoor or outdoor.

5.4.5 Testing on Different Shapes of Obstacle

Further measurement has been carried out for different shapes of obstacle such as rectangular, circle and cylinder. According to the measurement results, we found that the sensors do not have a problem in detecting different kinds of shapes. The experimental results for several shapes of obstacle at different distances for both indoor and outdoor environments are provided in Table 5.6.

TABLE 5.6: MEASUREMENT RESULTS FOR THREE SHAPES OF OBSTACLE FOR INDOOR AND OUTDOR ENVIRONMENTS

Shape of obstacle	Actual Distance (cm)	Measured distance (cm)	Measured distance (cm)
		Indoor	Outdoor
Rectangular	50	50.42	48.70
	70	69.15	67.00
	90	90.44	87.20
	110	109.82	107.20
	130	130.04	127.40
	150	149.97	148.20
Circle	50	49.42	52.02
	70	69.96	69.96
	90	90.25	90.25
	110	110.54	107.94
	130	123.28	123.28
	150	136.03	136.29
Cylinder	50	49.96	50.25
	70	73.64	69.79
	90	92.53	91.21
	110	115.18	108.87
	130	127.10	125.62
	150	147.81	145.44

5.4.5 Testing on Alarm Units Functionality

The functionality of the alarms was also tested and successfully activated according to the setting of distance as required by the user. All 3 types of alarms are working well as presented in Table 5.7.

TABLE 5.7: THE ALARMS ACTIVATION FOR SETTING DISTANCE STAGES

State	Buzzer	Vibrator	Audio Messages
0 **(Obstacle > 1.5 m)**	**OFF**	**OFF**	**OFF**
1 **(1.1 m < Obstacle ≤ 1.5 m)**	**ON**	**ON**	**ON**
2 **(0.8 m < Obstacle ≤ 1.2 m)**	**ON**	**ON**	**ON**
3 **(0.4 m < Obstacle ≤ 0.8 m)**	**ON**	**ON**	**ON**

Table 5.7 shows that the entire alarm unit is triggered when obstacles are detected within 0.4 m to 1.5 m from the user.

5.5 Discussion on Hardware Analysis

The installation of hardware components such as sensors, wireless transceiver, microcontroller units and alarms unit are highlighted with clear indication of their major attributes. The fast processing time of the obstacle sensors needs a stable clock signal to be supplied to the microcontrollers for consistency and reliable measurements of obstacle detection. Introducing the external quartz oscillator to the microcontrollers could increase the stability of the system performance during measurement. The quartz oscillator is connected to the microcontrollers to provide a stable clock as shown in Figure 5.15.

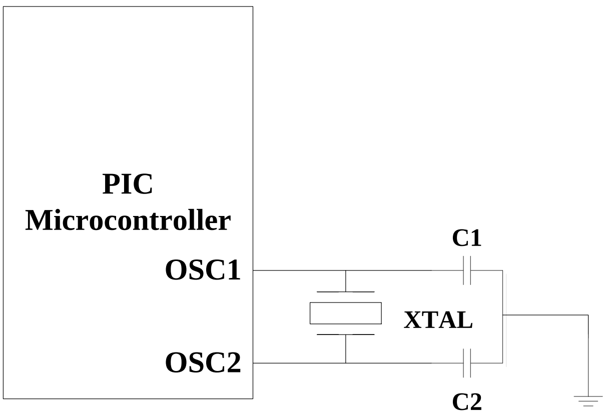


Figure 5.15: *Connection of a crystal oscillator to a microcontroller.*

The function of the crystal oscillator is to avoid any interference on lines in which the microcontroller receives a clock. The use of small size components in this system prototype makes it easier to be embedded to the shoe for final adjustment and performance optimization. To ensure the stability of data transmission between two separated units (transmitter and receiver), the hardware prototype employed the Zigbee wireless transceiver due to their best performance compared to the RF wireless modules.

5.6 Chapter Summary

The designs of the hardware prototype of an obstacle detection system for the elderly locomotion are described. The transmitter and receiver parts of the project are clearly explained which include the switching control sensors (FSR), obstacle detection sensors (Ultrasonic and Infrared), microcontrollers and complementary circuits, wireless transceiver modules for signal transmission from the transmitter to receiver parts, development board for the microcontrollers, alarming components at receiver end, complete circuit integration for both transmitter and receiver, sensors detection sensitivity and angle detection testing for the setting pathway configuration and finally, the output voltage measurements at several distances for sensors calibration towards obstacle detection. All the steps are performed successfully. The results of each of the steps are recorded, displayed and discussed in detail. The key findings of the work in this chapter cover the capability of the US and IR sensors to detect obstacles in a variety of angle directions, colours of obstacles, materials of obstacles, and sizes of obstacles at different distances from 30 cm to 170 cm.

From the electrical design and testing aspects of the developed obstacle detection system, the accuracy of obstacle detection is very important and thus it is discussed in detail. To verify this, the measured results are compared with the actual values from the design stage. The comparison results reveal that the measured distances of obstacles are in an acceptable range. The results prove that the hardware circuits are working properly as required. This is very crucial to ensure the achievability of target specification as outlined during the design and optimization stage.

System Performance and Accuracy

CHAPTER

6

6.0 List of Peer Reviewed Publications Produced

1. *B. Mustapha, A. Zayegh, and R.K. Begg, 2014. 'Microcontroller Based Wireless Obstacle Detection System for the Elderly', in* ***Proceedings of the 4th International Conference on Artificial Intelligence with Applications in Engineering and Technology (ICAIET), 2014****, 3-5 December, Kota Kinabalu Malaysia, pp. 325-329. ISBN 978-1-4799-7909-7.*

6.1 Chapter Overview

As highlighted in the previous chapter, the overall system performance and accuracy of the developed obstacle detection system depend on both parts of hardware which are transmitter and receiver. According to the stated specifications, the system prototype at transmitter must be able to detect front obstacles along the pathway in order to activate the alarms at the receiver end, which then, alerts the user of the existing obstacle ahead. It is necessary for the data transmission between transmitter and receiver to be at high rates without any loss of signal or information to ensure smooth and successful delivery of alarming system. Consequently, the designed algorithm for both hardware (transmitter and receiver) should be highly intelligent and powerful in order to achieve high detection rates. Moreover, appropriate programming skills are applied for multitasking functions such as switching mechanism, detecting obstacles and alerting system.

This chapter encompasses activities towards the development of software based on specific instructions and algorithms for the designed hardware prototype. The chapter is divided into six sections inclusive of this overview; the other subsections are explained next. As the name implies, the next section, software development and implementation, contains discussion on the initialization and programming needed for each part. The final algorithm and process of the obstacle detection and alarming stages are elaborated in the subsequent section. Discussions on system performance and empirical measurement results are presented in the next section. The next section also discusses on the system accuracy of obstacle detection. Lastly, the Chapter Summary concludes the whole achievement of the system.

6.2 Software Development and Implementation

The entire performance of obstacle detection depends on the interface of software designed. The MPLAB software package is chosen as a software-development tool in developing the control software of the project whereas the Hi-Tech PICC compiler is used in software development for writing the program in C language. All programs related to obstacle detection, wireless data transmission and alarming execution are uploaded onto microcontrollers using PICKIT 2 or PICKIT 3. A friendly graphical user interface (GUI) is essential for data collection to measure the reliability of the system being developed.

6.3 System Algorithm and Process

This proposed system has two distinct goals, which are detecting obstacles and alerting the user by the means of buzzer, vibration and audio messages. The algorithm of the overall process of the proposed system is described below:

1. Start
2. Port Initialization
3. Microcontroller
   - Call to read FSR1
   - Call to read FSR2
   - Call to read FSR3
4. If FSR1 & FSR2 & FSR3 ≥ 200 (threshold value)
   - Yes, then go to 5
   - No, then return to 3
5. Microcontroller enables the US and IR sensors
6. US and IR sensors are ready to detect an obstacle
7. Microcontroller reads signals from sensors and calculates the distance value of US and IR sensors
8. The ADC in the microcontroller converts the distances analogue value to digital value
9. Microcontroller sends the digitized data (distance) to wireless transmitter module
10. Wireless transmitter module decodes and sends the digital data to wireless receiver module through antenna
11. Wireless receiver module receives the modulated signal through antenna, performs demodulation, and passes the signal to the microcontroller
12. Microcontroller decodes and converts the distance value to TTL level logic data
13. Microcontroller displays the distance value and triggers the alarm based on the value of the distance

14. Microcontroller triggers specific alarm (buzzer, vibrator or audio messages) based on the user requirement

15. End

The flowchart in Figure 6.1 illustrates the overall process of the entire system.

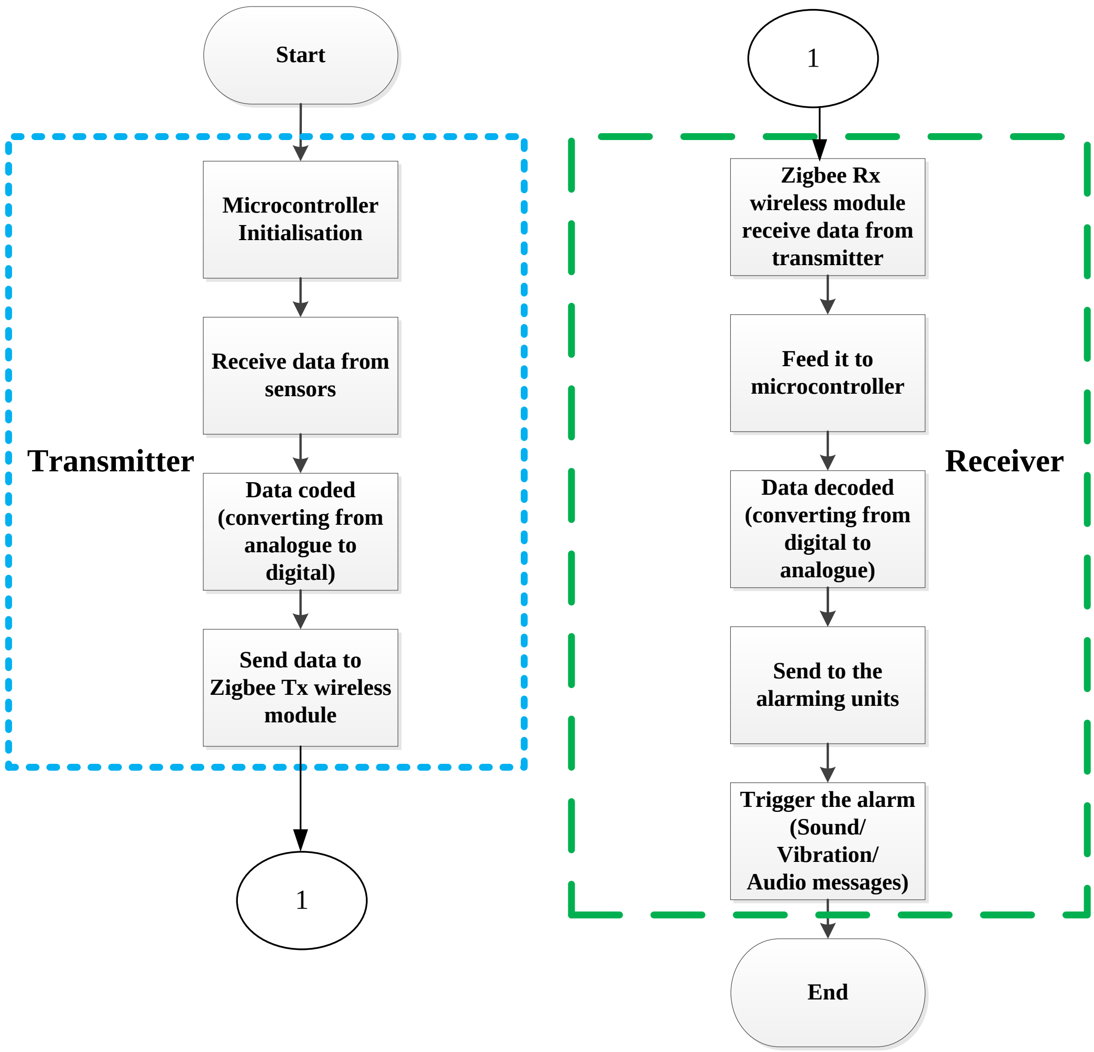


Figure 6.1: *Overall process of the system.*

As discussed in the earlier chapter, the smart alarming algorithm as shown in Figure 6.2 is required for alerting the user when the obstacle is detected in front of the users (see **Appendix D** for the microcontrollers codes).

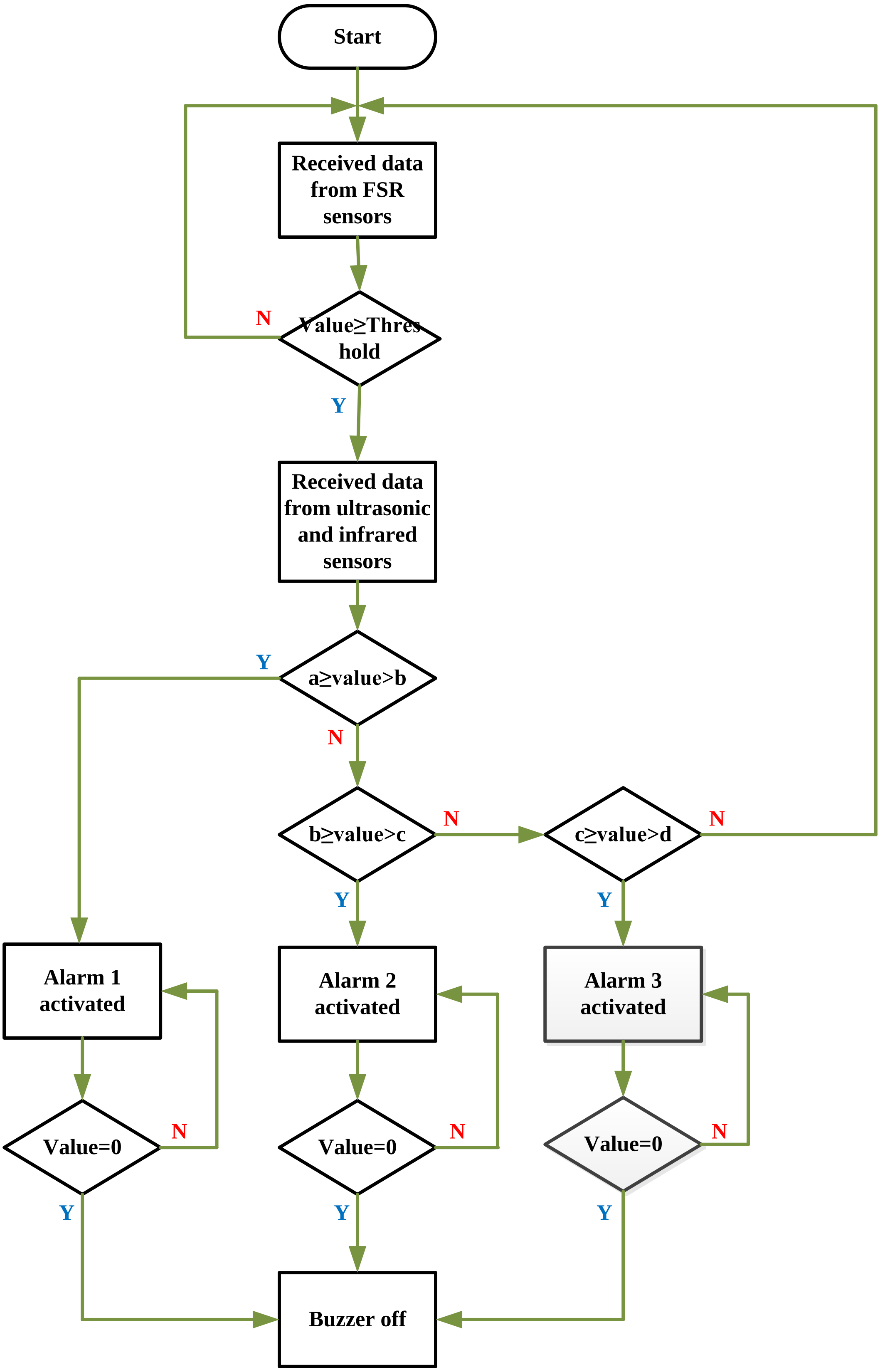


Figure 6.2: *Flowchart of the smart algorithm for obstacle detection.*

The developed algorithm is supposed to activate the alarms according to the specification of document during the design stages. The details of the alarming algorithm are as explained below:

i. Start.

ii. Both right and left leg sensors are activated.

iii. Sensors start sensing to detect obstacles while sending echo signal as a transmitter signal and the receiver receives the trigger signal.

iv. If yes, and any object detected, then the sensor send interrupt to the microcontroller to check whether the obstacle is detected by right leg sensor or left leg sensor.

v. If no, then both sensors start sensing again.

vi. If the right leg sensor or left leg sensor detects the object, then it immediately starts measuring distance from the obstacle.

vii. If the object is detected at a distance of greater than 100cm and less than 150cm, then the memory of audio signal is selected and played on the speaker or headphones by using the 3.3 audio jack.

viii. If the object is detected at a distance of greater than 100cm and less than 150cm by the right leg sensor, it plays the audio signal ‘you are close to the obstacle, turn left’ or if the left leg sensor detects the obstacle, it plays the audio signal ‘you are close to the obstacle, turn right’.

ix. If the object does not detect anything in between the range of 100cm to 150cm, then it branches to greater than 50cm to less than 100cm and automatically checks for proper audio signal and plays it on the speaker or headphones by using the 3.3mm audio jack.

x. If the object is detected at a distance of greater than 50cm to less than 100cm by the right leg sensor, it plays the audio ‘you are too close to the obstacle, turn left’ or if the left leg sensor detects the obstacle, it plays the audio signal ‘you are too close to the obstacle, turn right’.

xi. If there was no object detected in between the range of 50cm to 100cm, then it finally checks for greater than 0cm to less than 50cm; if its yes, then it automatically goes to memory, selects proper audio signal and plays it on the speaker or headphones by using the 3.3mm audio jack.

xii. If the object is detected at a distance of greater than 0cm to less than 50cm at the right leg sensor, it plays the audio ‘stop and turn left’ or if the left leg sensor detects the obstacle, it plays the audio signal ‘stop and turn right’.

xiii. If it is no in these three cases and the obstacle detected is equidistant from both right and left leg sensors, it selects from the memory proper audio signal to play on the speaker or headphones by using the 3.3 mm audio jack.

xiv. If the object is detected in front of both right and left leg sensors, then it plays the audio signal ‘stop and choose your direction’.

The process is continuously run until the user stops walking. The types of alarms activated at different ranges of distance can be adjusted by the user before he or she starts walking. The alarm setup is divided into four stages as below:

i. Distance exceeds 1.5m; no alarms

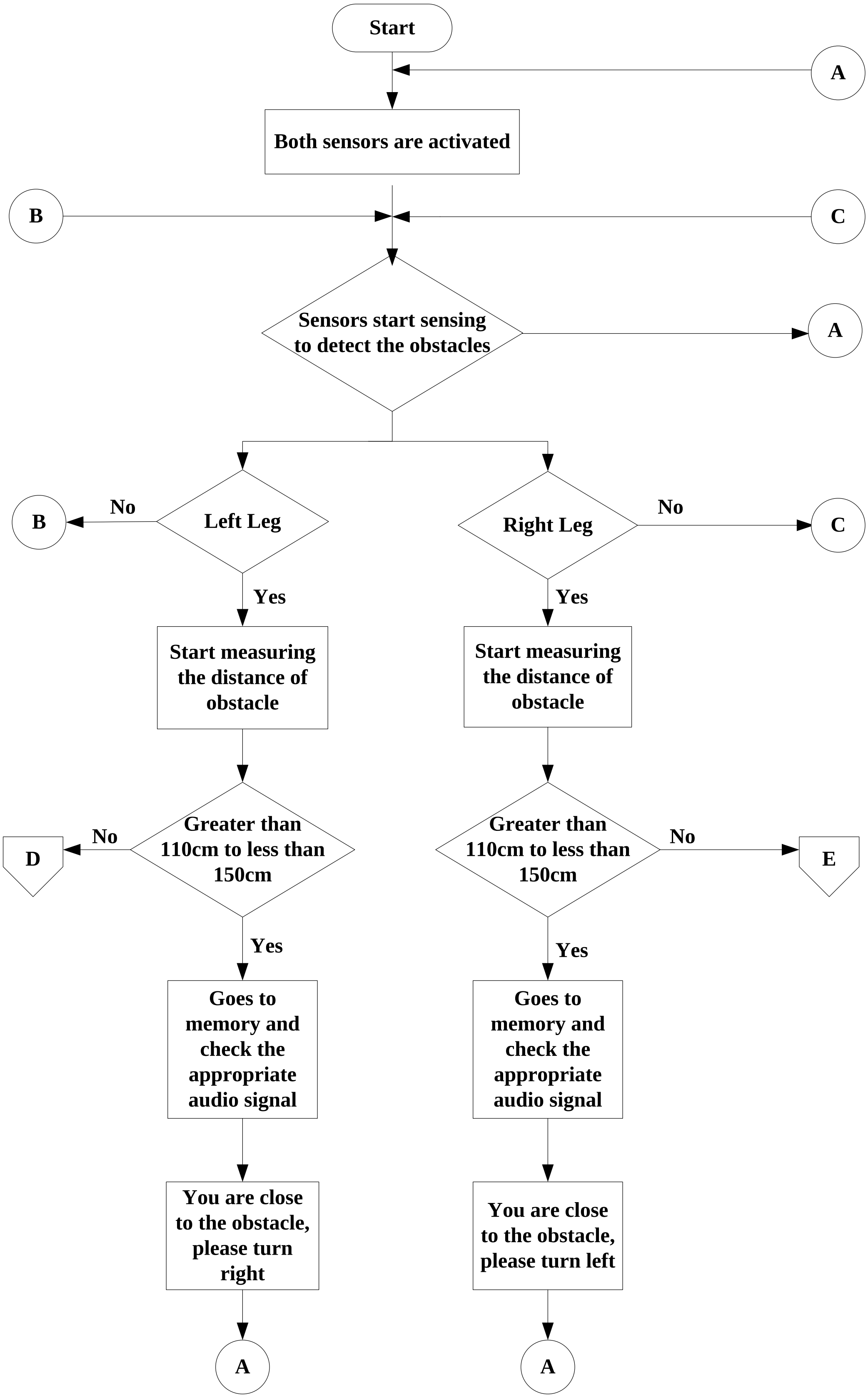
ii. Distance between 1.2m to less than or 1.5m; all alarms are activated in low intensity condition

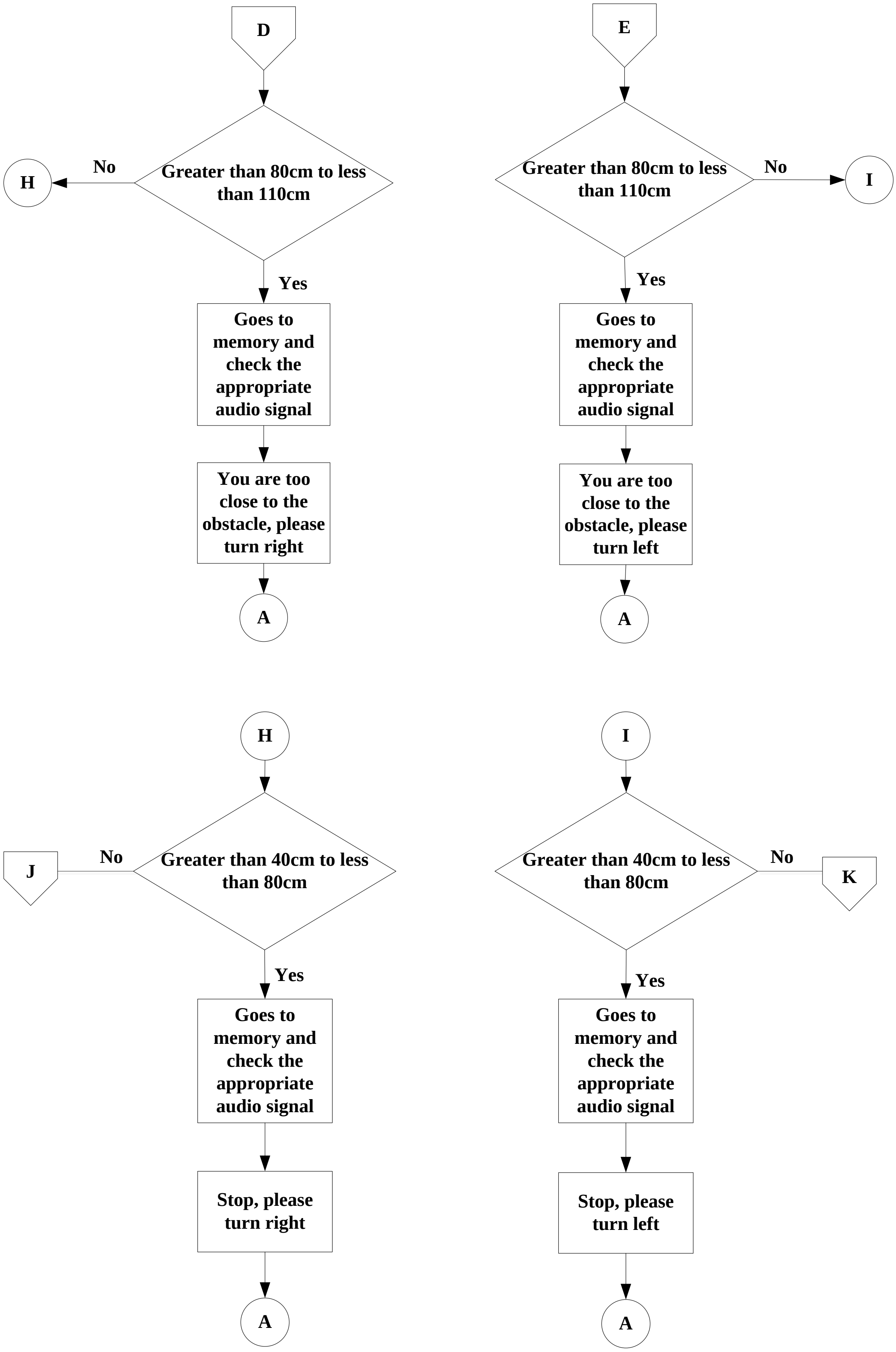
iii. Distance between 0.8 to less than or 1.2m; all alarms are activated in moderate intensity

iv. Distance between 0.4m to less than or 0.8m; all alarms are activated in high intensity

To conclude, the entire alarm unit is triggered when obstacles are detected within 0.4m to 1.5m from the user. When distances to obstacles are greater than predefined target distance of 1.5 m, alarms are not initiated and thus the user is free to walk through the path way. Even though three alarm units are available for use, the user may choose any combination of them (one, two or all) to be activated depending on the user's physiological condition such as hearing less, vision less or both. For example, users who have problems with vision may choose to select audio messages for alerting them when an obstacle is detected. Otherwise, the vibrator is the best option for users with hearing and vision difficulties. The vibration intensity could be adjusted according to the sensitivity of the user's skin. The volume of the audio messages is also adjustable for multi user's application.

All alarms will be triggered simultaneously if the user chooses more than one type of alarm. The alarms are activated ('ON') till all the sensors detects the obstacle and its automatically stop ('OFF') when the users avoiding the obstacle or the obstacle is not in the range of sensing detection area. Figure 6.3 shows the flowchart of the process on how the alarm system is activated to help the user avoid obstacles during walking.


Start
A
Both sensors are activated
B
C
Sensors start sensing to detect the obstacles
A
B
No
Left Leg
Right Leg
No
C
Yes
Yes
Start measuring the distance of obstacle
Start measuring the distance of obstacle
D
No
Greater than 110cm to less than 150cm
Greater than 110cm to less than 150cm
No
E
Yes
Yes
Goes to memory and check the appropriate audio signal
Goes to memory and check the appropriate audio signal
You are close to the obstacle, please turn right
You are close to the obstacle, please turn left
A
A


D
Greater than 80cm to less than 110cm
No
H
Yes
Goes to memory and check the appropriate audio signal
You are too close to the obstacle, please turn right
A
E
Greater than 80cm to less than 110cm
No
I
Yes
Goes to memory and check the appropriate audio signal
You are too close to the obstacle, please turn left
A
H
Greater than 40cm to less than 80cm
No
J
Yes
Goes to memory and check the appropriate audio signal
Stop, please turn right
A
I
Greater than 40cm to less than 80cm
No
K
Yes
Goes to memory and check the appropriate audio signal
Stop, please turn left
A

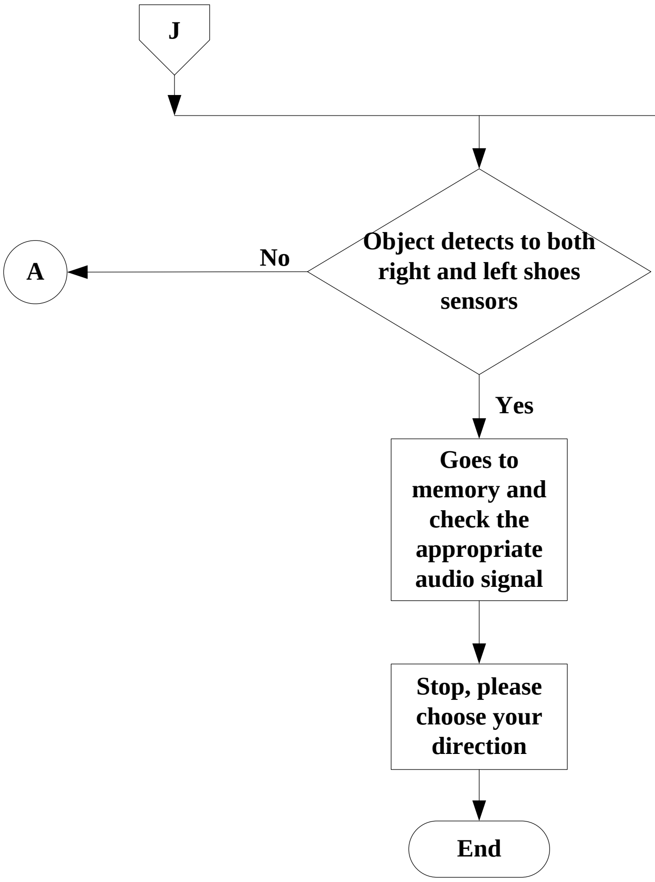


Figure 6.3: *Flowchart of the alarm system designed.*

6.4 System Performance and Empirical Measurement Results

The performance of the entire system is affected by three major components, which are obstacle detection sensors (US and IR) at the transmitter, data transmission (wireless transceiver modules) and the functionality of multi alarms at the receiver. All components are supported by smart programs which are related and connected to each other. Both obstacle detection sensors perform reliable detection towards the obstacles at determined distances. There is no doubt about the stability and consistency of wireless data transmission since the Xbee wireless transceiver modules use the IEEE 802.15.4 network protocol. This network protocol enhances the wireless devices for fast communicating from point to point and produces high-throughput between wireless sensor networks. The Xbee wireless modules come with the X-CTU program developed by Digi International Company.

The X-CTU software is specifically developed for testing signal strength of the Xbee wireless modules. The strength of the wireless signal will be displayed on the graphical user interface (GUI) screen by clicking on the menu ‘Range Test’ as shown in Figure 6.4.

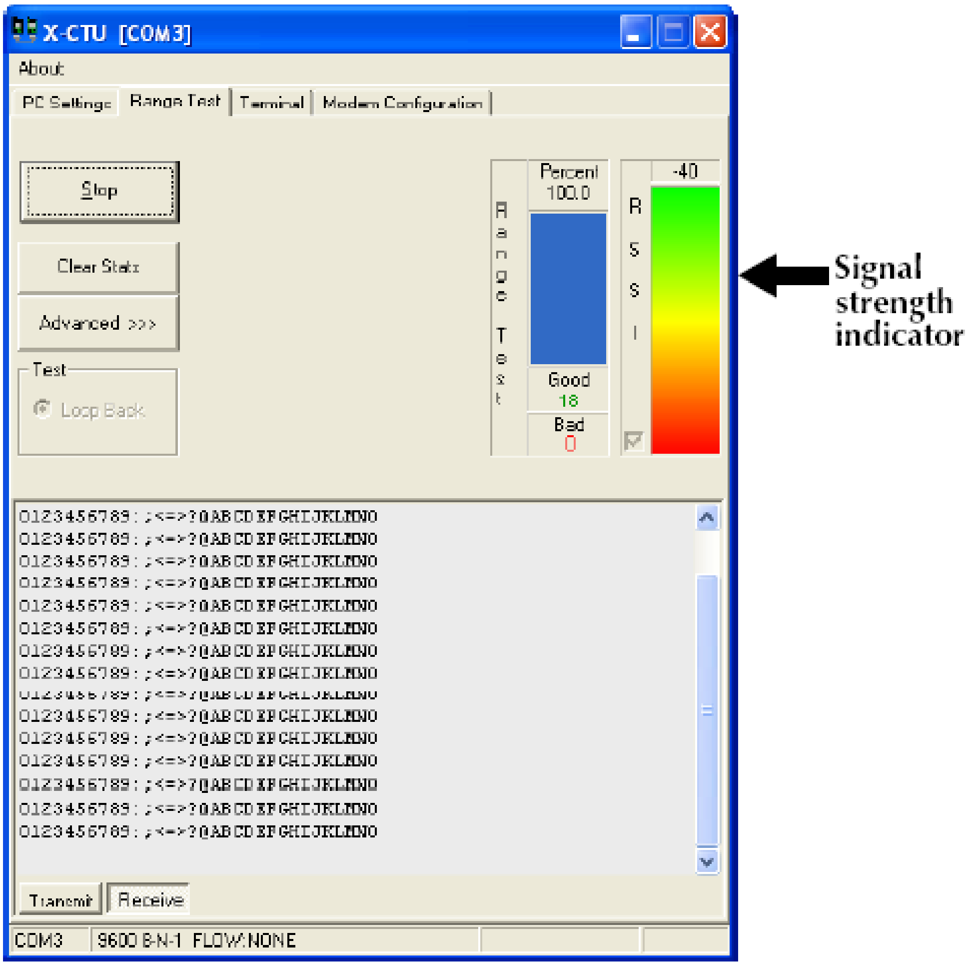


Figure 6.4: *Range test user interface for wireless data transmission.*

The percentage of successful packet data transmission and received strength signal indicator (RSSI) status are useful information before deploying the devices to the main board of the network system. The wireless link between transmitter (attached to the shoe) and receiver (attached to the upper arm) units is shown in Figure 6.5. The average distance between transmitter and receiver units for all users is very short (approximately ranging from 1.5m to 2m).

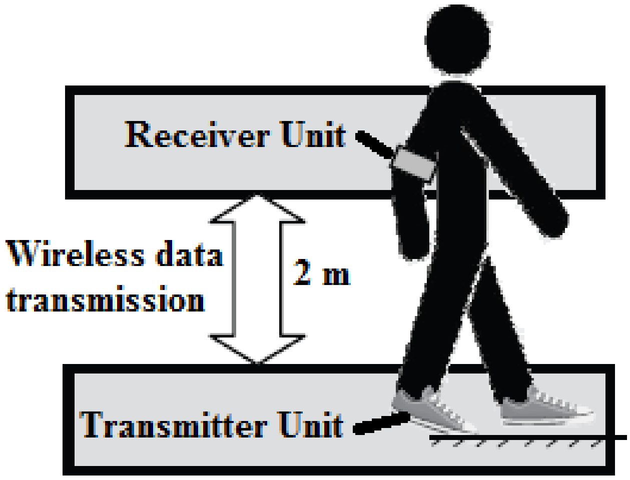


Figure 6.5: *Average distance for wireless data transmission.*

Tables 6.1 and 6.2 highlight the result of the system integration for different colours of surface obstacle and different types of obstacle materials. The obstacles have been placed starting from 50cm to 150cm from the user with 20cm interval. Randomly data selected method in SPSS packages software has been used to analyse the consistency and reliability of sensor detection towards surface colour of obstacle and different types of obstacles materials.

TABLE 6.1: DESCRITIVE STATISTICS ANALYSIS OF SENSORS DETECTION FOR DIFFERENT COLOURS OF SURFACE OBSTACLE

Color	N	Minimum	Maximum	Mean	Std. Deviation
White_US	16	37.00	37.00	37.0000	.00000
White_IR	16	156.00	170.00	161.8750	3.87943
Black_US	16	39.00	40.00	39.0625	.25000
Black_IR	16	205.00	219.00	212.8125	4.49027
Red_US	16	37.00	37.00	37.0000	.00000
Red_IR	16	234.00	244.00	240.8125	2.53558
Yellow_US	16	37.00	37.00	37.0000	.00000
Yellow_IR	16	235.00	248.00	240.9375	3.56780
Blue_US	16	37.00	37.00	37.0000	.00000
Blue_IR	16	237.00	247.00	242.0000	2.78089
Green_US	16	37.00	37.00	37.0000	.00000
Green_IR	16	245.00	253.00	248.0000	2.47656
Valid N (listwise)	16				

TABLE 6.2 DESCRIPTIVE STATISTICS ANALYSIS OF SENSORS DETECTION FOR DIFFERENT TYPES OF OBSTACLE MATERIALS

Material	N	Minimum	Maximum	Mean	Std. Deviation
Wood_US	16	47.08	47.08	47.0800	.00000
Wood_IR	16	49.27	52.73	50.6747	.94640
Plastic_US	16	47.08	47.08	47.0800	.00000
Plastic_IR	16	52.53	56.48	54.4798	1.06962
Mirror_US	16	49.42	49.42	49.4200	.00000
Mirror_IR	16	55.91	61.53	58.3609	1.57562
Plywood_US	16	47.08	47.08	47.0800	.00000
Plywood_IR	16	53.21	55.91	54.4033	.85331
Concrete_US	16	47.08	47.08	47.0800	.00000
Concrete_IR	16	51.24	53.92	52.5853	.80828
Valid N (listwise)	16				

Descriptive statistical analysis as stated in Table 6.1 shows that the standard deviation values for the sensors is very low; less than 1cm for ultrasonic and less than 5cm for infrared sensor. Meaning that, there are no significant differences of obstacle detection towards different colour of surface obstacle. Both obstacle sensors are able to detect the obstacle in any form of colour (e.g., white, black, red, yellow, blue and green) for continuous-time measurement in all environments. The results also show that the measurement values from the sensors are reliable for different types of materials such as wood, plastic, mirror, plywood and concrete as shown in Table 6.2. The results indicate remarkable consistency of obstacle detection since the standard deviation achieved is less than 5cm for both obstacle sensors. Standard deviation value represented in Table 6.1 and Table 6.2 is obtained by using a formula in equation 4.

$$SD = \sqrt{\frac{\sum|x-\bar{x}|^2}{n-1}} \qquad (4)$$

Where,

SD = Standard deviation

x = distance measurement value in the data set

$\bar{x}$ = mean of distance measurement value

n = number of data points

6.5 Discussion on System Accuracy

The proposed system has been tested for determining its functionality and accuracy of sensing in the detection area. The test was performed for several determined distances and different types and sizes of the obstacle such as wood, plastic product, mirror, plywood and concrete. The testing consisted of collecting data from the range sensors at fixed distances. Each experiment was run a number of times for each distance to confirm the repeatability of the system. The distance measurement technique used in this experiment is based on the time of flight principle, which emits the pulse, and then measures the reflected pulse. Normally, the popular method of distance measurement used for infrared sensor is the triangulation method (R. Siegwart et al., 2011; Solarbotics, 2010). The output voltage generated by the IR sensor verses the distance of the obstacle is shown in Figure 6.6.

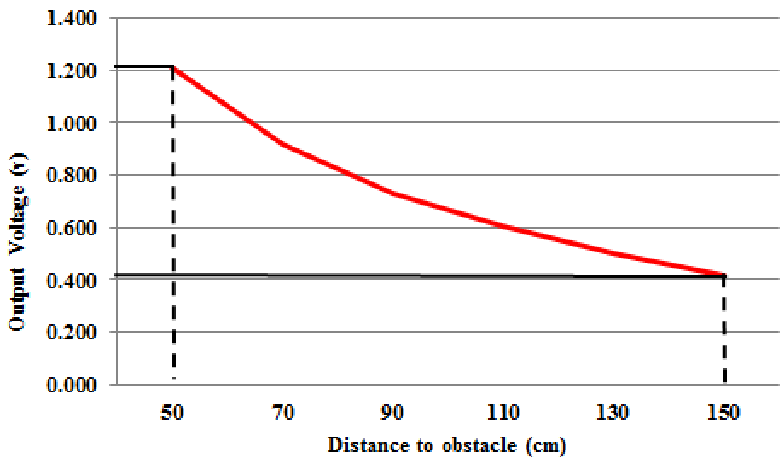


Figure 6.6: *Output pattern of infrared sensor.*

There are several methods to calibrate the infrared sensor output such as fractional function, lookup table, gradient-based interpolation, nonlinear regression, best fitting equation and etc. In our work, the best fit equation was used to calculate the distance as shown in Figure 6.7.

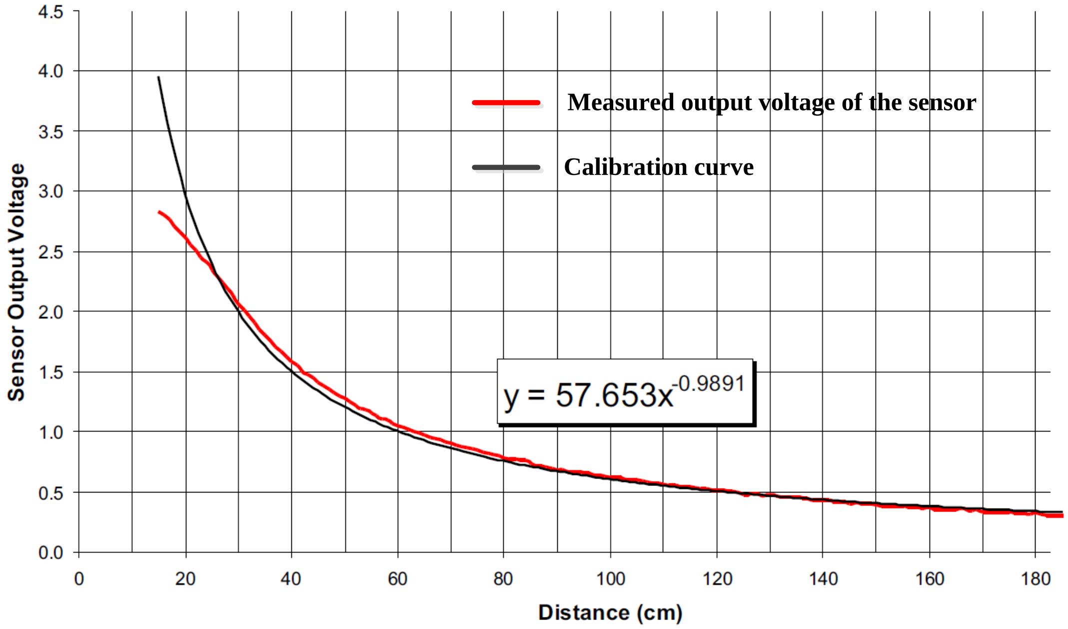


Figure 6.7: *Infrared calibration average voltage best fit equation (Solarbotics, 2010).*

The distance measurement using ultrasonic sensor is relatively easier compared to the infrared sensor. Generally, in several industrial applications, the pulse-echo technique is utilized to measure obstacle distances in the air medium. In this method, a short pulse train is generated by the transducer, which propagates the target and reflects it back, and received by the same sensor as shown in Figure 6.8. The transmitted signal is a noise-free signal, while the received pulse-echo signal is an attenuated and delayed version of generated signal plus the white-noise (A. Naik and M.S. Panse, 2012). The distance will be measured by calculating the reflection time interval between the target and sensor.

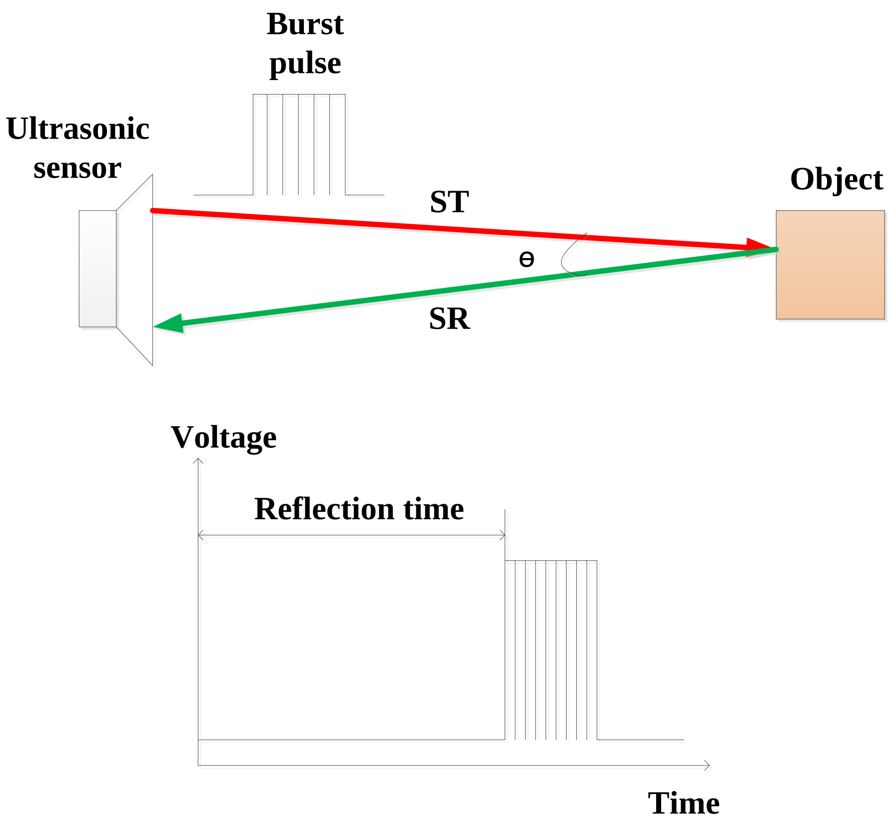


Figure 6.8: *Distance measurement process using ultrasonic sensor (M. Ishihara et al., 2009).*

The accuracy of these sensors is consistent for either indoor or outdoor environments as shown in Table 6.3, and Table 6.4 for several colours and multiple sizes of obstacles. The percentage of detection accuracy is highly dependable for both sensors at determined distances varying from 50cm to 150cm which has 20cm interval for each measurement. The detection score achieved for each distance varies from 94.15% (minimum) to 99.72% (maximum). The average percentage accuracy of the obstacle detection for the surface colours of obstacle at determined distances either indoor or outdoor varies from 95.40% to 99.67%. These percentages of accuracy show that both sensors (US and IR) could detect the obstacle correctly for each setting distances. The percentage difference between the detection of indoor and outdoor environment is less than 5% for all sensors for each determined distances based on all types of surface colours and sizes of obstacles.

TABLE 6.3: THE AVERAGE PERCENTAGE ACCURACY OF THE SENSORS DETECTION TOWARD SURFACE COLOUR OF OBSTACLE AT DETERMINED DISTANCES

Surface colour of obstacle	Actual Distance (cm)	Percentage of accuracy (%)		Average percentage of accuracy (%)
		Indoor	Outdoor	
White	50	99.84	98.84	99.34
	70	97.51	99.94	98.73
	90	98.17	97.39	97.78
	110	98.98	98.13	98.56
	130	97.43	94.83	96.13
	150	97.07	94.33	95.70
Black	50	99.92	98.84	99.38
	70	94.80	96.23	95.52
	90	97.19	99.72	98.46
	110	95.29	95.75	95.52
	130	97.77	94.83	96.30
	150	96.54	94.33	95.44
Red	50	98.14	98.84	98.49
	70	95.97	96.22	96.10
	90	98.59	99.72	99.16
	110	96.60	95.75	96.18
	130	96.43	94.83	95.63
	150	96.56	94.33	95.45
Yellow	50	97.56	95.96	96.76
	70	98.43	99.94	99.19
	90	98.53	99.72	99.13
	110	97.08	98.13	97.61
	130	95.86	94.83	95.35
	150	96.05	94.33	95.19
Blue	50	96.40	98.84	97.62
	70	94.56	99.94	97.25
	90	97.00	99.72	98.36
	110	98.57	99.51	99.04
	130	96.02	94.83	95.43
	150	96.89	94.33	95.61
Green	50	99.12	98.84	98.98
	70	95.66	99.94	97.80
	90	99.61	99.72	99.67
	110	97.87	99.51	98.69
	130	96.27	94.83	95.55
	150	96.64	94.15	95.40

TABLE 6.4: THE AVERAGE PERCENTAGE ACCURACY OF THE SENSORS DETECTION TOWARD MULTIPLE SIZES OF OBSTACLE

Size of Obstacle	Actual Distance (cm)	Percentage of accuracy (%)		Average percentage of accuracy (%)
		Indoor	Outdoor	
6cm x 14cm	50	97.44	96.52	96.98
	70	97.97	97.97	97.97
	90	98.78	95.96	97.37
	110	99.29	96.98	98.14
	130	99.65	97.69	98.67
	150	99.91	99.91	99.91
10cm x 20cm	50	96.52	96.52	96.52
	70	98.63	97.97	98.30
	90	95.96	98.78	97.37
	110	98.80	98.80	98.80
	130	98.40	99.00	98.70
	150	99.91	99.55	99.73
15cm x 25cm	50	98.40	99.04	98.72
	70	98.40	98.63	98.52
	90	98.40	98.78	98.59
	110	98.40	98.76	98.58
	130	99.65	99.23	99.44
	150	99.91	99.68	99.80

The detection accuracy of the sensors towards different shapes of obstacle has slightly decreased for tested environments at determined distances. However, the average percentage of accuracy toward multi shapes obstacle is still in acceptable range as demonstrated in Table 6.5. The empirical results state that the average detection accuracy towards tennis ball (circle) at 150cm of distance from the user is 90.78%. The tennis ball size used in the measurement is 6.54 – 6.86 cm (standard diameter), which is considered smaller, but the sensors can still detect it. The overall performances of the sensors to detect the obstacle are satisfactory regardless of their colours, sizes and variety of shapes of the obstacle.

TABLE 6.5: THE AVERAGE PERDENTAGE OF ACCURACY OF THE SENSORS DETECTION TOWARD DIFFERENT SHAPES OF OBSTACLE

Shape of obstacle	Actual Distance (cm)	Measured distance (cm)	Measured distance (cm)	Percentage of accuracy (%)		Average percentage of accuracy (%)
		Indoor	Outdoor	Indoor	Outdoor	
Rectangular	50	50.42	48.70	99.16	97.40	98.28
	70	69.15	67.00	98.79	95.71	97.25
	90	90.44	87.20	99.51	96.89	98.20
	110	109.82	107.20	99.84	97.45	98.65
	130	130.04	127.40	99.97	98.00	98.99
	150	149.97	148.20	99.98	98.80	99.39
circle	50	49.42	52.02	98.84	95.96	97.40
	70	69.96	69.96	99.94	99.94	99.94
	90	90.25	90.25	99.72	99.72	99.72
	110	110.54	107.94	99.51	98.13	98.82
	130	123.28	123.28	94.83	94.83	94.83
	150	136.03	136.29	90.69	90.86	90.78
cylinder	50	49.96	50.25	99.92	99.50	99.71
	70	73.64	69.79	94.80	99.70	97.25
	90	92.53	91.21	97.19	98.66	97.93
	110	115.18	108.87	95.29	98.97	97.13
	130	127.10	125.62	97.97	96.63	97.30
	150	147.81	145.44	98.54	96.96	97.75

6.6 Chapter Summary

The fixing, testing, tuning and finalization of the designed wireless obstacle detection system for the elderly are described. Each procedure of the system integration is explained, including the algorithm and software development, programming languages, setting configuration and compilation of the microcontroller, data transmission of the wireless transceiver modules, alarming stages algorithm and flowchart, sensors performance, system accuracy, complete programming packages on microcontroller, alarms performance and finally, the overall system implementation. All steps are successfully performed. The results of each of the steps are recorded, displayed and discussed in detail. The key findings of the work in this chapter cover the system performance, accuracy and analysis.

From the measurement aspect of the obstacle detection, the functionality and sensitivity of the distance sensors are of great importance and are discussed in detail. To verify this, the measured results are compared with the actual distance values from the design stage. The comparison shows very acceptable distance measurement determined at the output of the obstacle detection sensors. The result proves that the programming stage is very important to ensure the achievability of the object detection as outlined during the design and optimization stage. Further work then includes the study of the alarming devices which are purposely designed to be activated when the obstacle is detected according to varying distances. This is the final part of the research where the sensing capability is studied and highlighted. Due to the fact that each user has different styles of walking (gait), this final job is also very complicated and challenging, especially in the aspects of alerting the area of human body and the suitability of alarms types. A combination of three alarms can alert the user if such obstacle is detected at difference distances.

With the completion of the alerting matter, the research work is now completed successfully. Results from both finite element analysis and experimental works have proven that the sensors are capable of detecting various types of obstacles materials, surface colours of obstacles and sizes of obstacles. Therefore, the mission is now accomplished.

Discussion, Conclusion and Future Recommendations

CHAPTER

7

7.0 Chapter Overview Review

This chapter discusses the completion of this research project and summarizes the possible succession of the research. It also highlights the accomplishments of this research and how the work addresses the objectives proposed in Chapter 1 which include:

- Optimal sensor requirement for obstacle detection system.
- Comparative Study of Obstacle Detection Techniques.
- Development and Characterization of Alarming Modality.
- The Prototype Development *of* Wearable Wireless Obstacle Detection System.
- Testing and Tuning of Wireless Obstacle Detection System.

In Chapter 2, a comprehensive literature review of the present state-of-the-art mobility assistive devices concluded the limitations of the obstacle detection and feedback modality, especially for helping the elderly and visually impaired people in daily navigation. For instance, the commonly assistive devices used for obstacle detection involve the use of sensors that are not only susceptible to erroneous detection, but also require multiple expensive tools and may not be suitable for outdoor environment. Similarly, for the obstacle detection measurement, commonly reported limitations include limited measurable detection of obstacle materials, false detection and bulkiness. Therefore, the proposed obstacle detection device could address this problem as it is proven to be hands-free, cheap, miniaturized and comfortable to dress in during navigation.

Following Chapters 3, involving the study of human physiology and gait analysis for space consideration on pathway navigation. Chapter 4 details the selection and analysis of obstacle detection sensing technique, choosing the suitable obstacle detection sensors, introducing the FSR sensor for switching component, wireless application and highlight alarm devices for guiding modality in navigation. Chapter 5 presents the assessment of the developed hardware, designs and implementations and software for obstacle detection, particularly in application to the transmitter of the obstacle detection system which is introduced in this thesis. Testing and commissioning of the system prototype have been carried out in accordance with the use of industry standard procedures and criteria. Some prior experiments that tested the effectiveness of the obstacle detection sensors in real time for indoor and outdoor environment are also presented in this chapter.

Chapter 6 is dedicated to the system performance and accuracy, which evaluates the obstacle detection algorithm and software development that guide the user in navigation from one starting point to another or several destination points. Then, the summaries of achievements are drawn from the findings, as well as the limitations. Short discussion and overall performance is also outlined in this chapter. The summary of the work and conclusion are discussed in next section. Finally, last section highlights some recommendations for future research directions and potential works that could be undertaken to extend the study described in this thesis.

7.1 Summary of Achievements

The findings of this thesis such as ideas, designs and implementations of the distance sensors for obstacle detection and alarming modality that have been reported in related publications are listed in the 'List of Peer Reviewed Publications' section of selected chapter. Finally, the research carried out in this work has specifically achieved the following results:

1. So far, the mobility assistive device involves the use of canes, walkers and sophisticated robotic wheelchair. These devices prohibit the user to move freely in real world environment. For the first time, hands-free wireless obstacle detection system is proposed to help the elderly in navigation.

2. Various distance sensors are analytically investigated to identify the one that is most suitable for obstacle detection. The most suitable sensors are ultrasonic and infrared sensors, which are not just proven to be low cost, but also in terms of response performance and high speed detection rates.

3. While ultrasonic and infrared sensors are generally optimized for many other applications, there is no reported work in the literature that includes specific analysis result performed to identify and propose an optimized wireless obstacle detection system for the elderly.

4. This research is the first to come up with the design, modelling and implementation details of a combination of two distance sensors for effective obstacle detection. This relatively new mobility assistive device which is proven to be hands-free, wireless compatible and miniaturized supports the realization of highly mobile on-shoe real world navigation.

5. This research has proposed, designed, optimized and produced a prototype for obstacle detection that assists the elderly to move from one place to another with multiple warning feedbacks.

6. This research has also successfully designed and produced a hands-free obstacle detection system that could be attached to the shoe.

7.2 Discussion and Overall Performance

This research developed a hands-free device which is applicable for obstacle detection and gives warning signal to the user during navigation. The capabilities of the proposed system were not optimized in this thesis since the designed prototype was not installed to the insoles of the shoe due to the large size of the device. One way in which this might be realized is by converting the hardware transmitter to integrated circuit (ICs) through the chips fabrication process and using miniatures with IR and US sensors for obstacle detection. The obstacle detector has been integrated with the FSRs sensors to avoid false detection occurring during walking. The strategy used for avoiding false detection of the obstacles is implemented by putting the FSR sensors at the sole of the shoes. The FSR sensors serve as a digital switch and control the function of the sensor.

The ultrasonic and infrared sensors start to sense the front obstacles only if all the FSR sensors are experiencing high pressure. The real pathway obstacle is considered true when the entire foot touches the ground and real signal would be sent to the transmitter. Then the user will be steered towards the pathway journey, overcoming different additional navigation problems, such as detecting and escaping from trapping zones or walking in relatively unknown environments. Additionally, a newly smart shoe should be designed for installing the transmitter. The results of this research suggest that the transmitter section should be miniaturized as an integrated circuit in order to be integrated in the shoe sole and the algorithms presented in this research should be extended to make them more robust for both indoor and outdoor environments. Future work can easily integrate the sensor on microchip.

This research has high potential to be applied to the healthcare industry for the development of navigation aids (obstacle detector) with multiple modalities feedback for the elders and visually impaired people. The implementation of the developed obstacle detection system does not affect the nature life of the surrounding area due to the sensors used are identically safer. In terms of design aspects and suitability, it is more convenient to use because the system could be embedded to the outsole (e.g., US and IR sensors) and insole (e.g., FSR sensors) of the shoe. The proposed system will not be affected by the environment. Therefore it is suitable for obstacle detection applications in the walking route for both indoor and outdoor environment when compared to other assistive devices such as Le Chal, (A. Sharma, 2010), Smiling Shoe (D. Simsik et al., 2012), VitaliSHOE (Project VitaliSHOE, 2010) and Project Biosensing (F. Vlaskamp et al., 2011). The SMILING shoe is a complex mechatronical system that requires interaction of various sensors data, mechanical components, and human activity in order to keep body balance while walking to avoid falls. Specific training should be provided to the user for better performances and only suitable for gait training. Whereas, VitaliSHOE and Project Biosensing are specifically designed to aids the user in rehabilitation process during walking. Specifically, VitaliSHOE is developed for patient movement monitoring during walking which is aim to prevent fall and injuries. Instead, the biosensor project is designed to assess the gait characteristics of patients during rehabilitation exercises such as body acceleration, angle of the knee, foot pressure and repetitive loading patterns of the knee joint during the execution of daily activities.

7.3 Summary and Conclusion

Based on extensive literature review on both obstacle detection and communicating alerting signal, a wireless obstacle detection system that is able to detect obstacles and can give alarms to the elderly to avoid the detected obstacle in pathway navigation is developed. The wireless obstacle detection system prototype has been successfully designed implemented and tested in this thesis.

In short, the research has been carefully endeavoured and managed that made the achievement of the targeted work that encompasses the transformation of conceptual ideas into a device possible. This is really an interesting journey, but undoubtedly, continuous hurdles and bumpy rides have clearly proven that it is a very challenging one, too. One of the biggest challenges is to attach the transmitter part of the system prototype on both shoes. The inclusion of the system prototyping and testing in the project execution has also increased the difficulty level of this research as all design works must be reliably modelled, precisely engineered, real industry technology compatible and technically justified. This includes mastering the microcontroller programming to capture all input data from the obstacle sensors. As the input data is successfully captured and processed at the transmitter part, it is then wirelessly sent to the receiver. After performing all the tasks mentioned here, this research is undoubtedly a life changing experience that enables mastering of a wide spectrum of engineering expertise and skills.

7.4 Recommendation for Future Work

Due to the time constraints in developing, examining and implementing this thesis, some further areas of work that may be carried out in the future are discussed in this section. For the sake of knowledge expansion, it is therefore listed here for consideration in future research. Based on the observations while executing this study, the following future research works are suggested:

1. In order to detect the stairs in home navigation, the obstacle detection system should be integrated with the sensor camera system, which gives sufficient information of the detected obstacles and location.

2. The proposed system currently offers accurate detection, but to deliver intelligent guiding in terms of obstacle avoidance, implementing newly developed neuro-fuzzy controller algorithm into microcontroller programming is recommended. The use of newly designed microcontroller which has big memory and built-in digital filters that could reduce noise attenuation in signal transmission is recommended.
3. For excellent guiding system in outdoor navigation, the developed system could integrate with the GPS system and RFID that provide real information for route mapping localization and identifying the current location.
4. Regarding power consumption of the developed system, a battery level monitoring circuit should be implemented in the system to establish the obstacle detection accuracy. Insufficient supply of voltage will affect the accuracy of obstacle detection.
5. Due to technology miniaturization and reduced costs in electronic industry, new sensing element, integrated chips technologies and newly designed shoe could be implemented in the developed system. For instance, all these components should be embedded into flexible textile shoe which is lighter in weight and convenient to dress up in for walking.

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APPENDIX
A
Ultrasonic and Infrared Sensor Datasheets

GP2Y0A02YK

Long Distance Measuring Sensor

■ Features

1. Less influence on the colors of reflected objects and their reflectivity, due to optical triangle measuring method
2. Distance output type
   (Detection range:20 to 150cm)
3. An external control circuit is not necessary
   Output can be connected directly to a microcomputer

■ Applications

1. For detection of human body and various types of objects in home appliances, OA equipment, etc

■ Absolute Maximum Ratings

(T_a=25°C)

Parameter	Symbol	Rating	Unit
Supply voltage	V_{CC}	−0.3 to +7	V
*1 Output terminal voltage	V_O	−0.3 to V_{CC} +0.3	V
Operating temperature	T_{opr}	−10 to +60	°C
Storage temperature	T_{stg}	−40 to +70	°C

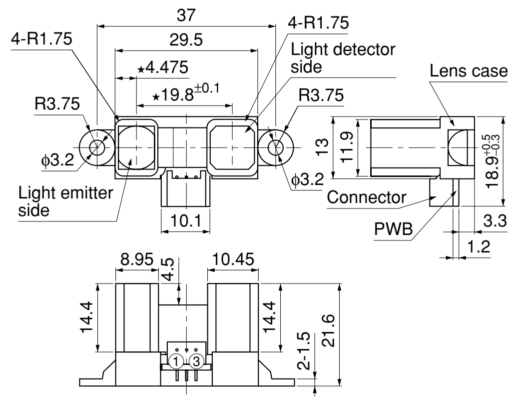
*1 Open collector output

■ Recommended Operating Conditions

Parameter	Symbol	Rating	Unit
Operating Supply voltage	V_{CC}	4.5 to 5.5	V

■ Outline Dimensions

(Unit : mm)



Terminal connection
① V_O
② GND
③ V_{CC}

❈ The dimensions marked ★ are described the dimensions of lens center position.
❈ Unspecified tolerance : ±0.3mm

■ Electro-optical Characteristics

(T_a=25°C, V_{CC}=5V)

Parameter	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Distance measuring range	ΔL	*2 *3	20	–	150	cm
Output terminal voltage	V_O	*2 L=150cm	0.25	0.4	0.55	V
Difference of output voltage	ΔV_O	*2 Output change at L=150cm to 20cm	1.8	2.05	2.3	V
Average dissipation current	I_{CC}	–	–	33	50	mA

Note) L:Distance to reflective object
*2 Using reflective object:White paper (Made by Kodak Co. Ltd. gray cards R-27 · white face, reflective ratio;90%)
*3 Distance measuring range of the optical sensor system

Fig.1 Internal Block Diagram

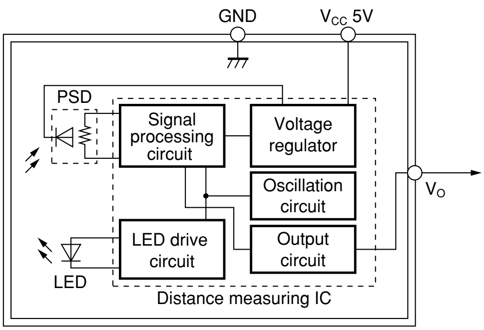


Fig.2 Timing Chart

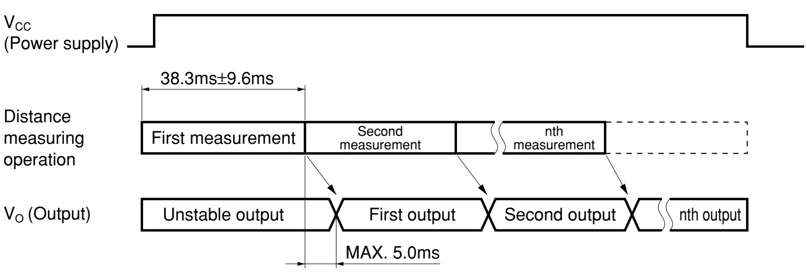
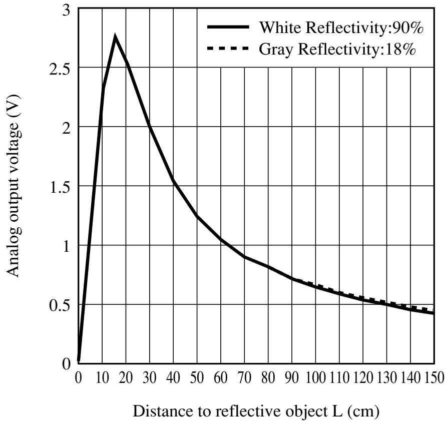


Fig.3 Analog Output Voltage vs. Distance to Reflective Object



NOTICE

- The circuit application examples in this publication are provided to explain representative applications of SHARP devices and are not intended to guarantee any circuit design or license any intellectual property rights. SHARP takes no responsibility for any problems related to any intellectual property right of a third party resulting from the use of SHARP's devices.
- Contact SHARP in order to obtain the latest device specification sheets before using any SHARP device. SHARP reserves the right to make changes in the specifications, characteristics, data, materials, structure, and other contents described herein at any time without notice in order to improve design or reliability. Manufacturing locations are also subject to change without notice.
- Observe the following points when using any devices in this publication. SHARP takes no responsibility for damage caused by improper use of the devices which does not meet the conditions and absolute maximum ratings to be used specified in the relevant specification sheet nor meet the following conditions:

  (i) The devices in this publication are designed for use in general electronic equipment designs such as:
  --- Personal computers
  --- Office automation equipment
  --- Telecommunication equipment [terminal]
  --- Test and measurement equipment
  --- Industrial control
  --- Audio visual equipment
  --- Consumer electronics

  (ii) Measures such as fail-safe function and redundant design should be taken to ensure reliability and safety when SHARP devices are used for or in connection with equipment that requires higher reliability such as:
  --- Transportation control and safety equipment (i.e., aircraft, trains, automobiles, etc.)
  --- Traffic signals
  --- Gas leakage sensor breakers
  --- Alarm equipment
  --- Various safety devices, etc.

  (iii) SHARP devices shall not be used for or in connection with equipment that requires an extremely high level of reliability and safety such as:
  --- Space applications
  --- Telecommunication equipment [trunk lines]
  --- Nuclear power control equipment
  --- Medical and other life support equipment (e.g., scuba).

- Contact a SHARP representative in advance when intending to use SHARP devices for any "specific" applications other than those recommended by SHARP or when it is unclear which category mentioned above controls the intended use.
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-
- Contact and consult with a SHARP representative if there are any questions about the contents of this publication.

LV-MaxSonar®-EZ™ Series

High Performance Sonar Range Finder

MB1000, MB1010, MB1020, MB1030, MB1040

With 2.5V - 5.5V power the LV-MaxSonar-EZ provides very short to long-range detection and ranging in a very small package. The LV-MaxSonar-EZ detects objects from 0-inches to 254-inches (6.45-meters) and provides sonar range information from 6-inches out to 254-inches with 1-inch resolution. Objects from 0-inches to 6-inches typically range as 6-inches[1]. The interface output formats included are pulse width output, analog voltage output, and RS232 serial output. Factory calibration and testing is completed with a flat object. **[1]See Close Range Operation**

Features

- Continuously variable gain for control and side lobe suppression
- Object detection to zero range objects
- 2.5V to 5.5V supply with 2mA typical current draw
- Readings can occur up to every 50mS, (20-Hz rate)
- Free run operation can continually measure and output range information
- Triggered operation provides the range reading as desired
- Interfaces are active simultaneously
- Serial, 0 to Vcc, 9600 Baud, 81N
- Analog, (Vcc/512) / inch
- Pulse width, (147uS/inch)
- Learns ringdown pattern when commanded to start ranging
- Designed for protected indoor environments
- Sensor operates at 42KHz
- High output square wave sensor drive (double Vcc)

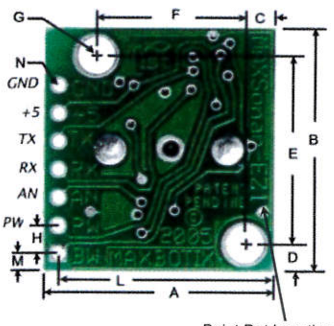
Benefits

- Very low cost ultrasonic rangefinder
- Reliable and stable range data
- Quality beam characteristics
- Mounting holes provided on the circuit board
- Very low power ranger, excellent for multiple sensor or battery-based systems
- Fast measurement cycles
- Sensor reports the range reading directly and frees up user processor
- Choose one of three sensor outputs
- Triggered externally or internally

Applications and Uses

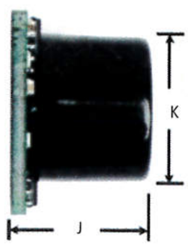
- UAV blimps, micro planes and some helicopters
- Bin level measurement
- Proximity zone detection
- People detection
- Robot ranging sensor
- Autonomous navigation
- Multi-sensor arrays
- Distance measuring
- Long range object detection
- Wide beam sensitivity

LV-MaxSonar-EZ Mechanical Dimensions



Paint Dot Location

A	0.785"	19.9 mm	H	0.100"	2.54 mm
B	0.870"	22.1 mm	J	0.610"	15.5 mm
C	0.100"	2.54 mm	K	0.645"	16.4 mm
D	0.100"	2.54 mm	L	0.735"	18.7 mm
E	0.670"	17.0 mm	M	0.065"	1.7 mm
F	0.510"	12.6 mm	N	0.038" dia.	1.0 mm dia.
G	0.124" dia.	3.1 mm dia.	weight, 4.3 grams		



Part Number	MB1000	MB1010	MB1020	MB1030	MB1040
Paint Dot Color	Black	Brown	Red	Orange	Yellow

Close Range Operation

Applications requiring 100% reading-to-reading reliability should not use MaxSonar sensors at a distance closer than 6 inches. Although most users find MaxSonar sensors to work reliably from 0 to 6 inches for detecting objects in many applications, MaxBotix® Inc. does not guarantee operational reliability for objects closer than the minimum reported distance. Because of ultrasonic physics, these sensors are unable to achieve 100% reliability at close distances.

Warning: Personal Safety Applications

We do not recommend or endorse this product be used as a component in any personal safety applications. This product is not designed, intended or authorized for such use. These sensors and controls do not include the self-checking redundant circuitry needed for such use. Such unauthorized use may create a failure of the MaxBotix® Inc. product which may result in personal injury or death. MaxBotix® Inc. will not be held liable for unauthorized use of this component.

About Ultrasonic Sensors

Our ultrasonic sensors are in air, non-contact object detection and ranging sensors that detect objects within an area. These sensors are not affected by the color or other visual characteristics of the detected object. Ultrasonic sensors use high frequency sound to detect and localize objects in a variety of environments. Ultrasonic sensors measure the time of flight for sound that has been transmitted to and reflected back from nearby objects. Based upon the time of flight, the sensor then outputs a range reading.

Pin Out Description

Pin 1-BW-*Leave open or hold low for serial output on the TX output. When BW pin is held high the TX output sends a pulse (instead of serial data), suitable for low noise chaining.

Pin 2-PW- This pin outputs a pulse width representation of range. The distance can be calculated using the scale factor of 147uS per inch.

Pin 3-AN- Outputs analog voltage with a scaling factor of (Vcc/512) per inch. A supply of 5V yields ~9.8mV/in. and 3.3V yields ~6.4mV/in. The output is buffered and corresponds to the most recent range data.

Pin 4-RX– This pin is internally pulled high. The LV-MaxSonar-EZ will continually measure range and output if RX data is left unconnected or held high. If held low the sensor will stop ranging. Bring high for 20uS or more to command a range reading.

Pin 5-TX- When the *BW is open or held low, the TX output delivers asynchronous serial with an RS232 format, except voltages are 0-Vcc. The output is an ASCII capital "R", followed by three ASCII character digits representing the range in inches up to a maximum of 255, followed by a carriage return (ASCII 13). The baud rate is 9600, 8 bits, no parity, with one stop bit. Although the voltage of 0-Vcc is outside the RS232 standard, most RS232 devices have sufficient margin to read 0-Vcc serial data. If standard voltage level RS232 is desired, invert, and connect an RS232 converter such as a MAX232. When BW pin is held high the TX output sends a single pulse, suitable for low noise chaining. (no serial data)

Pin 6-+5V- Vcc – Operates on 2.5V - 5.5V. Recommended current capability of 3mA for 5V, and 2mA for 3V.

Pin 7-GND- Return for the DC power supply. GND (& Vcc) must be ripple and noise free for best operation.

Range "0" Location

The LV-MaxSonar-EZ reports the range to distant targets starting from the front of the sensor as shown in the diagram below.

Range Zero

The range is measured from the front of the transducer.

In general, the LV-MaxSonar-EZ will report the range to the leading edge of the closest detectable object. Target detection has been characterized in the sensor beam patterns.

Sensor Minimum Distance

The sensor minimum reported distance is 6-inches (15.2 cm). However, the LV-MaxSonar-EZ will range and report targets to the front sensor face. Large targets closer than 6-inches will typically range as 6-inches.

Sensor Operation from 6-inches to 20-inches

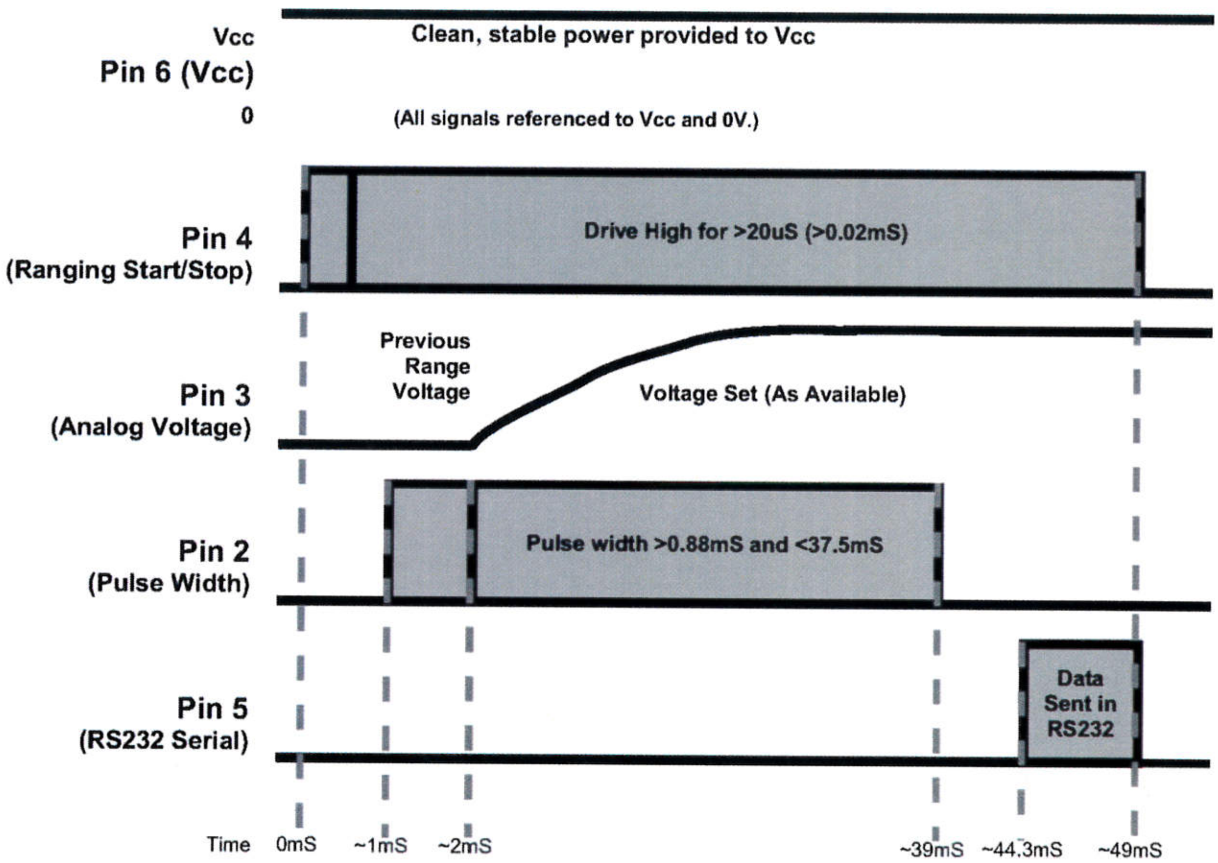
Because of acoustic phase effects in the near field, objects between 6-inches and 20-inches may experience acoustic phase cancellation of the returning waveform resulting in inaccuracies of up to 2-inches. These effects become less prevalent as the target distance increases, and has not been observed past 20-inches.

General Power-Up Instruction

Each time the LV-MaxSonar-EZ is powered up, it will calibrate during its first read cycle. The sensor uses this stored information to range a close object. It is important that objects not be close to the sensor during this calibration cycle. The best sensitivity is obtained when the detection area is clear for fourteen inches, but good results are common when clear for at least seven inches. If an object is too close during the calibration cycle, the sensor may ignore objects at that distance.

The LV-MaxSonar-EZ does not use the calibration data to temperature compensate for range, but instead to compensate for the sensor ringdown pattern. If the temperature, humidity, or applied voltage changes during operation, the sensor may require recalibration to reacquire the ringdown pattern. Unless recalibrated, if the temperature increases, the sensor is more likely to have false close readings. If the temperature decreases, the sensor is more likely to have reduced up close sensitivity. To recalibrate the LV-MaxSonar-EZ, cycle power, then command a read cycle.

Timing Diagram



Timing Description

250mS after power-up, the LV-MaxSonar-EZ is ready to accept the RX command. If the RX pin is left open or held high, the sensor will first run a calibration cycle (49mS), and then it will take a range reading (49mS). After the power up delay, the first reading will take an additional ~100mS. Subsequent readings will take 49mS. The LV-MaxSonar-EZ checks the RX pin at the end of every cycle. Range data can be acquired once every 49mS.

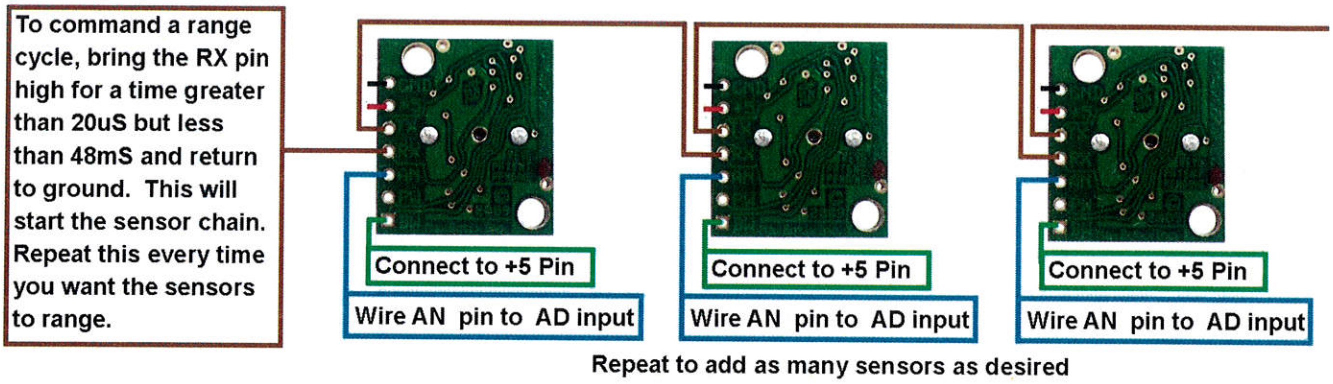
Each 49mS period starts by the RX being high or open, after which the LV-MaxSonar-EZ sends the transmit burst, after which the pulse width pin (PW) is set high. When a target is detected the PW pin is pulled low. The PW pin is high for up to 37.5mS if no target is detected. The remainder of the 49mS time (less 4.7mS) is spent adjusting the analog voltage to the correct level. When a long distance is measured immediately after a short distance reading, the analog voltage may not reach the exact level within one read cycle. During the last 4.7mS, the serial data is sent.

The LV-MaxSonar-EZ timing is factory calibrated to one percent at five volts, and in use is better than two percent. In addition, operation at 3.3V typically causes the objects range, to be reported, one to two percent further than actual.

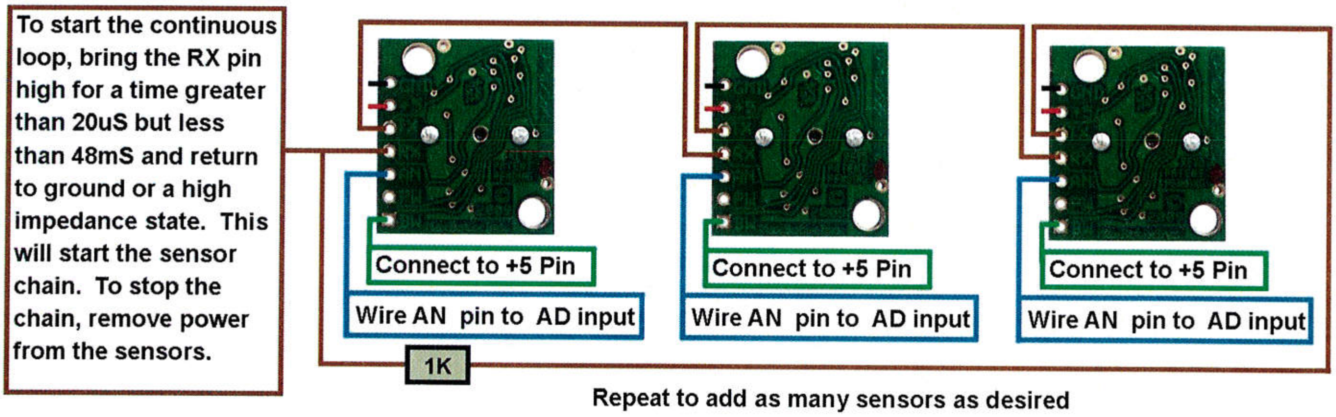
Using Multiple Sensors in a single system

When using multiple ultrasonic sensors in a single system, there can be interference (cross-talk) from the other sensors. MaxBotix Inc., has engineered and supplied a solution to this problem for the LV-MaxSonar-EZ sensors. The solution is referred to as chaining. We have 3 methods of chaining that work well to avoid the issue of cross-talk.

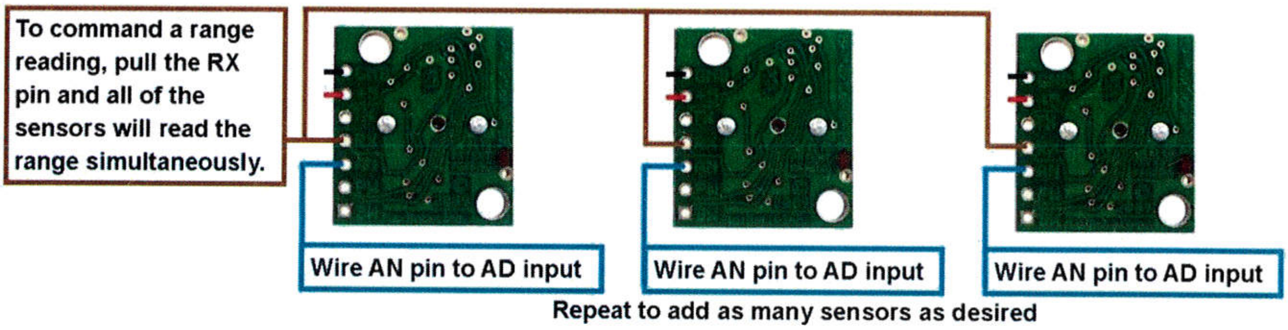
The first method is AN Output Commanded Loop. The first sensor will range, then trigger the next sensor to range and so on for all the sensor in the array. Once the last sensor has ranged, the array stops until the first sensor is triggered to range again. Below is a diagram on how to set this up.



The next method is AN Output Constantly Looping. The first sensor will range, then trigger the next sensor to range and so on for all the sensor in the array. Once the last sensor has ranged, it will trigger the first sensor in the array to range again and will continue this loop indefinitely. Below is a diagram on how to set this up.



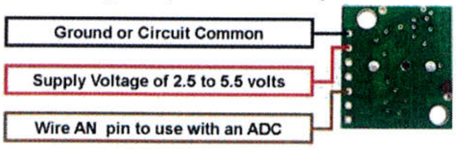
The final method is AN Output Simultaneous Operation. This method does not work in all applications and is sensitive to how the other sensors in the array are positioned in comparison to each other. Testing is recommend to verify this method will work for your application. All the sensors RX pins are conned together and triggered at the same time causing all the sensor to take a range reading at the same time. Once the range reading is complete, the sensors stop ranging until triggered next time. Below is a diagram on how to set this up.



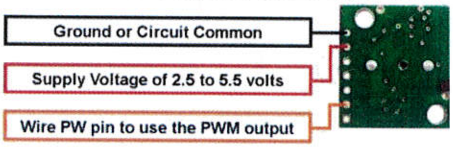
Independent Sensor Operation

The LV-MaxSonar-EZ sensors have the capability to operate independently when the user desires. When using the LV-MaxSonar-EZ sensors in single or independent sensor operation, it is easiest to allow the sensor to free-run. Free-run is the default mode of operation for all of the MaxBotix Inc., sensors. The LV-MaxSonar-EZ sensors have three separate outputs that update the range data simultaneously: Analog Voltage, Pulse Width, and RS232 Serial. Below are diagrams on how to connect the sensor for each of the three outputs when operating in a single or independent sensor operating environment.

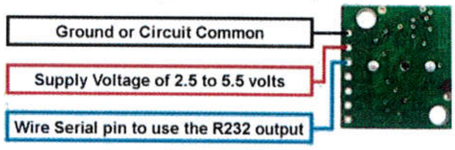
Analog Output Sensor Operation



Pulse Width Output Sensor Operation



Serial Output Sensor Operation



Selecting an LV-MaxSonar-EZ

Different applications require different sensors. The LV-MaxSonar-EZ product line offers varied sensitivity to allow you to select the best sensor to meet your needs.

The LV-MaxSonar-EZ Sensors At a Glance

People Detection Wide Beam High Sensitivity		Best Balance	Large Targets Narrow Beam Noise Tolerance	
MB1000	MB1010	MB1020	MB1030	MB1040

The diagram above shows how each product balances sensitivity and noise tolerance. This does not effect the maximum range, pin outputs, or other operations of the sensor. To view how each sensor will function to different sized targets reference the LV-MaxSonar-EZ Beam Patterns.

Background Information Regarding our Beam Patterns

Each LV-MaxSonar-EZ sensor has a calibrated beam pattern. Each sensor is matched to provide the approximate detection pattern shown in this datasheet. This allows end users to select the part number that matches their given sensing application. Each part number has a consistent field of detection so additional units of the same part number will have similar beam patterns. The beam plots are provided to help identify an estimated detection zone for an application based on the acoustic properties of a target versus the plotted beam patterns.

Each beam pattern is a 2D representation of the detection area of the sensor. The beam pattern is actually shaped like a 3D cone (having the same detection pattern both vertically and horizontally). Detection patterns for dowels are used to show the beam pattern of each sensor. Dowels are long cylindered targets of a given diameter. The dowels provide consistent target detection characteristics for a given size target which allows easy comparison of one MaxSonar sensor to another MaxSonar sensor.

People Sensing: For users that desire to detect people, the detection area to the 1-inch diameter dowel, in general, represents the area that the sensor will reliably detect people.

For each part number, the four patterns (A, B, C, and D) represent the detection zone for a given target size. Each beam pattern shown is determined by the sensor's part number and target size.

The actual beam angle changes over the full range. Use the beam pattern for a specific target at any given distance to calculate the beam angle for that target at the specific distance. Generally, smaller targets are detected over a narrower beam angle and a shorter distance. Larger targets are detected over a wider beam angle and a longer range.

APPENDIX

B

Microcontrollers Datasheets

PIC16F887 MICROCONTROLLER – DEVICE OVERVIEW

The PIC16F887 is one of the latest products from *Microchip*. It features all the components which modern microcontrollers normally have. For its low price, wide range of application, high quality and easy availability, it is an ideal solution in applications such as: the control of different processes in industry, machine control devices, measurement of different values etc. Some of its main features are listed below.

- **RISC architecture**
  - Only 35 instructions to learn
  - All single-cycle instructions except branches
- **Operating frequency 0-20 MHz**
- **Precision internal oscillator**
  - Factory calibrated
  - Software selectable frequency range of 8MHz to 31KHz
- **Power supply voltage 2.0-5.5V**
  - Consumption: 220uA (2.0V, 4MHz), 11uA (2.0 V, 32 KHz) 50nA (stand-by mode)
- **Power-Saving Sleep Mode**
- **Brown-out Reset (BOR) with software control option**
- **35 input/output pins**
  - High current source/sink for direct LED drive
  - software and individually programmable *pull-up* resistor
  - Interrupt-on-Change pin
- **8K ROM memory in FLASH technology**
  - Chip can be reprogrammed up to 100.000 times
- ***In-Circuit Serial Programming* Option**
  - Chip can be programmed even embedded in the target device

- **256 bytes EEPROM memory**
  - Data can be written more than 1.000.000 times
- **368 bytes RAM memory**
- **A/D converter:**
  - 14-channels
  - 10-bit resolution
- **3 independent timers/counters**
- **Watch-dog timer**
- **Analogue comparator module with**
  - Two analogue comparators
  - Fixed voltage reference (0.6V)
  - Programmable on-chip voltage reference
- **PWM output steering control**
- **Enhanced USART module**
  - Supports RS-485, RS-232 and LIN2.0
  - Auto-Baud Detect
- **Master Synchronous Serial Port (MSSP)**
  - supports SPI and I2C mode

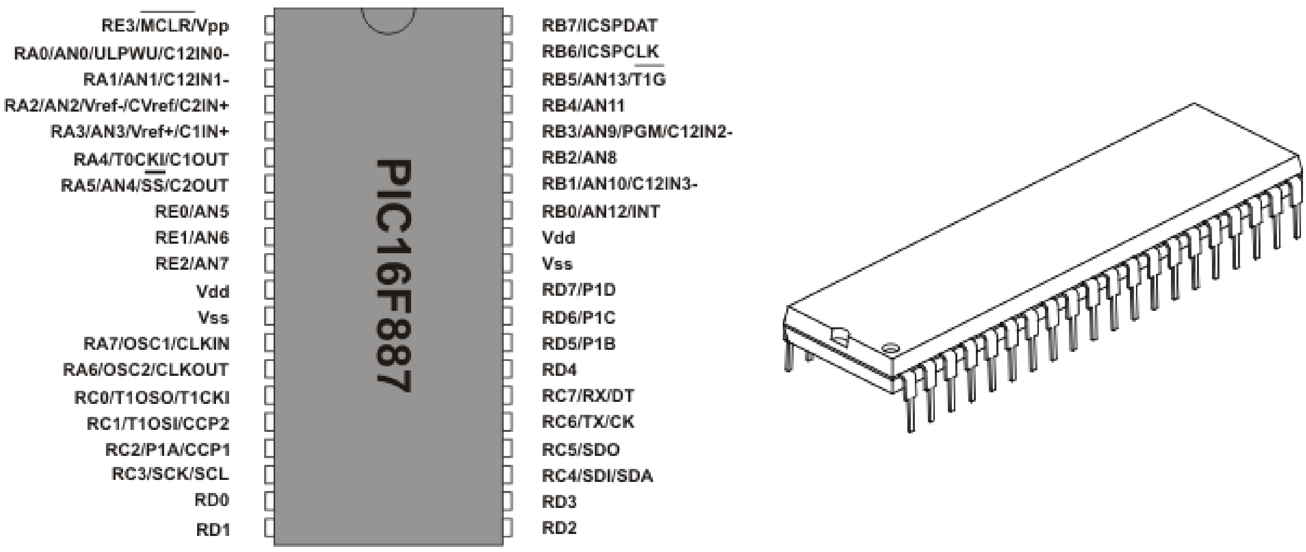


Fig. 1-1 PIC16F887 PDIP 40 Microcontroller

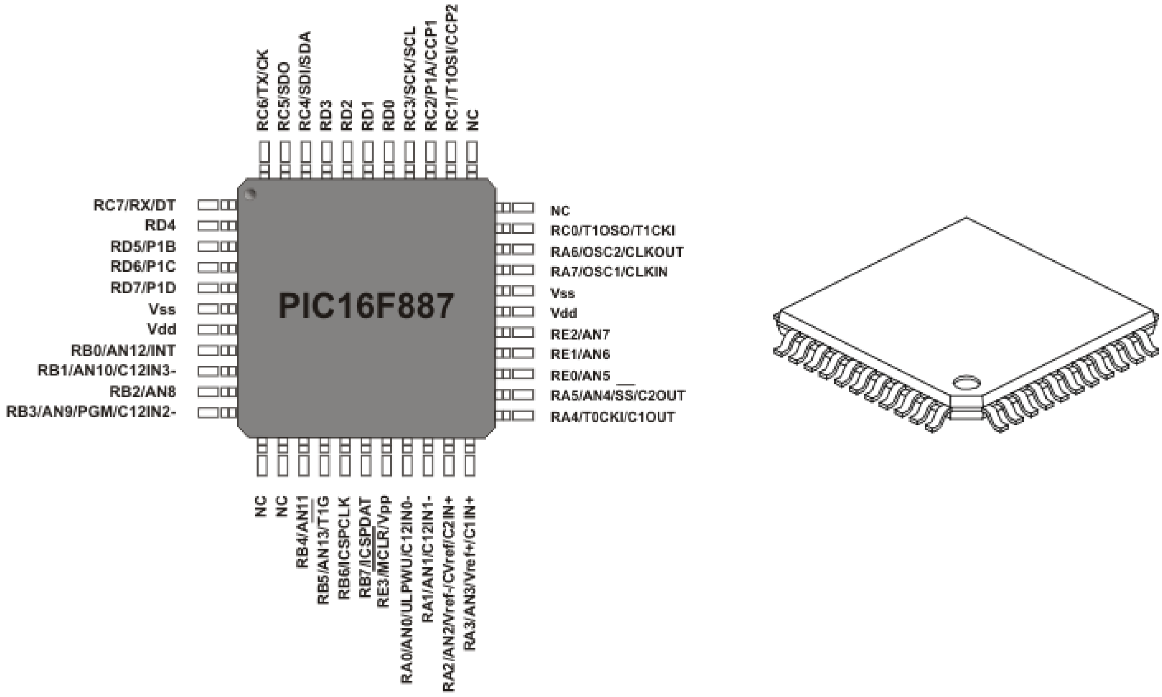


Fig. 1-2 PIC16F887 QFN 44 Microcontroller

Pin Description

As seen in Fig. 1-1 above, the most pins are multi-functional. For example, designator RA3/AN3/Vref+/C1IN+ for the fifth pin specifies the following functions:

- RA3 Port A third digital input/output
- AN3 Third analog input
- Vref+ Positive voltage reference
- C1IN+ Comparator C1positive input

The following tables, refer to the PDIP 40 microcontroller.

Table 1-1 Pin Assignment

Name	Number (DIP 40)	Function	Description
RE3/MCLR/Vpp	1	RE3	General purpose input Port E
		MCLR	Reset pin. Low logic level on this pin resets microcontroller.
		Vpp	Programming voltage
RA0/AN0/ULPWU/C12IN0-	2	RA0	General purpose I/O port A
		AN0	A/D Channel 0 input
		ULPWU	Stand-by mode deactivation input
		C12IN0-	Comparator C1 or C2 negative input
RA1/AN1/C12IN1-	3	RA1	General purpose I/O port A
		AN1	A/D Channel 1
		C12IN1-	Comparator C1 or C2 negative input
RA2/AN2/Vref-/CVref/C2IN+	4	RA2	General purpose I/O port A
		AN2	A/D Channel 2
		Vref-	A/D Negative Voltage Reference input
		CVref	Comparator Voltage Reference Output
		C2IN+	Comparator C2 Positive Input
RA3/AN3/Vref+/C1IN+	5	RA3	General purpose I/O port A
		AN3	A/D Channel 3
		Vref+	A/D Positive Voltage Reference Input
		C1IN+	Comparator C1 Positive Input
RA4/T0CKI/C1OUT	6	RA4	General purpose I/O port A
		T0CKI	Timer T0 Clock Input
		C1OUT	Comparator C1 Output
RA5/AN4/SS/C2OUT	7	RA5	General purpose I/O port A
		AN4	A/D Channel 4
		SS	SPI module Input (*Slave Select*)
		C2OUT	Comparator C2 Output
RE0/AN5	8	RE0	General purpose I/O port E
		AN5	A/D Channel 5
RE1/AN6	9	RE1	General purpose I/O port E
		AN6	A/D Channel 6
RE2/AN7	10	RE2	General purpose I/O port E
		AN7	A/D Channel 7
Vdd	11	+	Positive supply
Vss	12	-	Ground (GND)

Table 1-1 cont. Pin Assignment

Name	Number (DIP 40)	Function	Description
RA7/OSC1/CLKIN	13	RA7	General purpose I/O port A
		OSC1	Crystal Oscillator Input
		CLKIN	External Clock Input
RA6/OSC2/CLKOUT	14	OSC2	Crystal Oscillator Output
		CLKO	Fosc/4 Output
		RA6	General purpose I/O port A
RC0/T1OSO/T1CKI	15	RC0	General purpose I/O port C
		T1OSO	Timer T1 Oscillator Output
		T1CKI	Timer T1 Clock Input
RC1/T1OSO/T1CKI	16	RC1	General purpose I/O port C
		T1OSI	Timer T1 Oscillator Input
		CCP2	CCP1 and PWM1 module I/O
RC2/P1A/CCP1	17	RC2	General purpose I/O port C
		P1A	PWM Module Output
		CCP1	CCP1 and PWM1 module I/O
RC3/SCK/SCL	18	RC3	General purpose I/O port C
		SCK	MSSP module Clock I/O in SPI mode
		SCL	MSSP module Clock I/O in I^2C mode
RD0	19	RD0	General purpose I/O port D
RD1	20	RD1	General purpose I/O port D
RD2	21	RD2	General purpose I/O port D
RD3	22	RD3	General purpose I/O port D
RC4/SDI/SDA	23	RC4	General purpose I/O port A
		SDI	MSSP module *Data* input in SPI mode
		SDA	MSSP module *Data* I/O in I^2C mode
RC5/SDO	24	RC5	General purpose I/O port C
		SDO	MSSP module *Data* output in SPI mode
RC6/TX/CK	25	RC6	General purpose I/O port C
		TX	USART Asynchronous Output
		CK	USART Synchronous Clock
RC7/RX/DT	26	RC7	General purpose I/O port C
		RX	USART Asynchronous Input
		DT	USART Synchronous Data

Table 1-1 cont. Pin Assignment

Name	Number (DIP 40)	Function	Description
RD4	27	RD4	General purpose I/O port D
RD5/P1B	28	RD5	General purpose I/O port D
		P1B	PWM Output
RD6/P1C	29	RD6	General purpose I/O port D
		P1C	PWM Output
RD7/P1D	30	RD7	General purpose I/O port D
		P1D	PWM Output
Vss	31	-	Ground (GND)
Vdd	32	+	Positive Supply
RB0/AN12/INT	33	RB0	General purpose I/O port B
		AN12	A/D Channel 12
		INT	External Interrupt
RB1/AN10/C12INT3-	34	RB1	General purpose I/O port B
		AN10	A/D Channel 10
		C12INT3-	Comparator C1 or C2 Negative Input
RB2/AN8	35	RB2	General purpose I/O port B
		AN8	A/D Channel 8
RB3/AN9/PGM/C12IN2-	36	RB3	General purpose I/O port B
		AN9	A/D Channel 9
		PGM	Programming enable pin
		C12IN2-	Comparator C1 or C2 Negative Input
RB4/AN11	37	RB4	General purpose I/O port B
		AN11	A/D Channel 11
RB5/AN13/T1G	38	RB5	General purpose I/O port B
		AN13	A/D Channel 13
		T1G	Timer T1 External Input
RB6/ICSPCLK	39	RB6	General purpose I/O port B
		ICSPCLK	Serial programming Clock
RB7/ICSPDAT	40	RB7	General purpose I/O port B
		ICSPDAT	Programming enable pin

PIC18F66K80 FAMILY

28/40/44/64-Pin, Enhanced Flash Microcontrollers with ECAN™ and nanoWatt XLP Technology

Power-Managed Modes:

- Run: CPU on, Peripherals on
- Idle: CPU off, Peripherals on
- Sleep: CPU off, Peripherals off
- Two-Speed Oscillator Start-up
- Fail-Safe Clock Monitor (FSCM)
- Power-Saving Peripheral Module Disable (PMD)
- Ultra Low-Power Wake-up
- Fast Wake-up, 1 μs, Typical
- Low-Power WDT, 300 nA, Typical
- Run mode Currents Down to Very Low 3.8 μA, Typical
- Idle mode Currents Down to Very Low 880 nA, Typical
- Sleep mode Current Down to Very Low 13 nA, Typical

ECAN Bus Module Features:

- Conforms to CAN 2.0B Active Specification
- Three Operating modes:
  - Legacy mode (full backward compatibility with existing PIC18CXX8/FXX8 CAN modules)
  - Enhanced mode
  - FIFO mode or programmable TX/RX buffers
- Message Bit Rates up to 1 Mbps
- DeviceNet™ Data Byte Filter Support
- Six Programmable Receive/Transmit Buffers
- Three Dedicated Transmit Buffers with Prioritization
- Two Dedicated Receive Buffers

ECAN Bus Module Features (Continued):

- 16 Full, 29-Bit Acceptance Filters with Dynamic Association
- Three Full, 29-Bit Acceptance Masks
- Automatic Remote Frame Handling
- Advanced Error Management Features

Special Microcontroller Features:

- Operating Voltage Range: 1.8V to 5.5V
- On-Chip 3.3V Regulator
- Operating Speed up to 64 MHz
- Up to 64 Kbytes On-Chip Flash Program Memory:
  - 10,000 erase/write cycle, typical
  - 20 years minimum retention, typical
- 1,024 Bytes of Data EEPROM:
  - 100,000 Erase/write cycle data EEPROM memory, typical
- 3.6 Kbytes of General Purpose Registers (SRAM)
- Three Internal Oscillators: LF-INTOSC (31 KHz), MF-INTOSC (500 kHz) and HF-INTOSC (16 MHz)
- Self-Programmable under Software Control
- Priority Levels for Interrupts
- 8 x 8 Single-Cycle Hardware Multiplier
- Extended Watchdog Timer (WDT):
  - Programmable period from 4 ms to 4,194s
- In-Circuit Serial Programming™ (ICSP™) via Two Pins
- In-Circuit Debug via Two Pins
- Programmable BOR
- Programmable LVD

TABLE 1: DEVICE COMPARISON

Device	Program Memory	Data Memory (Bytes)	Data EE (Bytes)	Pins	I/O	CTMU	12-Bit A/D Channels	CCP/ ECCP	Timers 8-Bit/16-Bit	EUSART	Comparators	ECAN™	MSSP	BORMV/LVD	DSM
PIC18F25K80	32 Kbytes	3,648	1,024	28	24	1	8-ch	4/1	2/3	2	2	1	1	Yes	No
PIC18LF25K80	32 Kbytes	3,648	1,024	28	24	1	8-ch	4/1	2/3	2	2	1	1	Yes	No
PIC18F26K80	64 Kbytes	3,648	1,024	28	24	1	8-ch	4/1	2/3	2	2	1	1	Yes	No
PIC18LF26K80	64 Kbytes	3,648	1,024	28	24	1	8-ch	4/1	2/3	2	2	1	1	Yes	No
PIC18F45K80	32 Kbytes	3,648	1,024	40/44	35	1	11-ch	4/1	2/3	2	2	1	1	Yes	No
PIC18LF45K80	32 Kbytes	3,648	1,024	40/44	35	1	11-ch	4/1	2/3	2	2	1	1	Yes	No
PIC18F46K80	64 Kbytes	3,648	1,024	40/44	35	1	11-ch	4/1	2/3	2	2	1	1	Yes	No
PIC18LF46K80	64 Kbytes	3,648	1,024	40/44	35	1	11-ch	4/1	2/3	2	2	1	1	Yes	No
PIC18F65K80	32 Kbytes	3,648	1,024	64	54	1	11-ch	4/1	2/3	2	2	1	1	Yes	Yes
PIC18LF65K80	32 Kbytes	3,648	1,024	64	54	1	11-ch	4/1	2/3	2	2	1	1	Yes	Yes
PIC18F66K80	64 Kbytes	3,648	1,024	64	54	1	11-ch	4/1	2/3	2	2	1	1	Yes	Yes
PIC18LF66K80	64 Kbytes	3,648	1,024	64	54	1	11-ch	4/1	2/3	2	2	1	1	Yes	Yes

1.0 DEVICE OVERVIEW

This document contains device-specific information for the following devices:

- PIC18F25K80
- PIC18F26K80
- PIC18F45K80
- PIC18F46K80
- PIC18F65K80
- PIC18F66K80
- PIC18LF25K80
- PIC18LF26K80
- PIC18LF45K80
- PIC18LF46K80
- PIC18LF65K80
- PIC18LF66K80

This family combines the traditional advantages of all PIC18 microcontrollers – namely, high computational performance and a rich feature set – with an extremely competitive price point. These features make the PIC18F66K80 family a logical choice for many high-performance applications where price is a primary consideration.

1.1 Core Features

1.1.1 nanoWatt TECHNOLOGY

All of the devices in the PIC18F66K80 family incorporate a range of features that can significantly reduce power consumption during operation. Key items include:

- **Alternate Run Modes:** By clocking the controller from the Timer1 source or the Internal RC oscillator, power consumption during code execution can be reduced.
- **Multiple Idle Modes:** The controller can also run with its CPU core disabled but the peripherals still active. In these states, power consumption can be reduced even further.
- **On-the-Fly Mode Switching:** The power-managed modes are invoked by user code during operation, allowing the user to incorporate power-saving ideas into their application's software design.
- **nanoWatt XLP:** An extra low-power BOR and low-power Watchdog timer

1.1.2 OSCILLATOR OPTIONS AND FEATURES

All of the devices in the PIC18F66K80 family offer different oscillator options, allowing users a range of choices in developing application hardware. These include:

- External Resistor/Capacitor (RC); RA6 available
- External Resistor/Capacitor with Clock Out (RCIO)
- Three External Clock modes:
  - External Clock (EC); RA6 available
  - External Clock with Clock Out (ECIO)
  - External Crystal (XT, HS, LP)
- A Phase Lock Loop (PLL) frequency multiplier, available to the external oscillator modes which allows clock speeds of up to 64 MHz. PLL can also be used with the internal oscillator.
- An internal oscillator block that provides a 16 MHz clock (±2% accuracy) and an INTOSC source (approximately 31 kHz, stable over temperature and V_{DD})
  - Operates as HF-INTOSC or MF-INTOSC when block is selected for 16 MHz or 500 kHz
  - Frees the two oscillator pins for use as additional general purpose I/O

The internal oscillator block provides a stable reference source that gives the family additional features for robust operation:

- **Fail-Safe Clock Monitor:** This option constantly monitors the main clock source against a reference signal provided by the internal oscillator. If a clock failure occurs, the controller is switched to the internal oscillator, allowing for continued low-speed operation or a safe application shutdown.
- **Two-Speed Start-up:** This option allows the internal oscillator to serve as the clock source from Power-on Reset, or wake-up from Sleep mode, until the primary clock source is available.

1.1.3 MEMORY OPTIONS

The PIC18F66K80 family provides ample room for application code, from 32 Kbytes to 64 Kbytes of code space. The Flash cells for program memory are rated to last up to 10,000 erase/write cycles. Data retention without refresh is conservatively estimated to be greater than 20 years.

The Flash program memory is readable and writable. During normal operation, the PIC18F66K80 family also provides plenty of room for dynamic application data with up to 3.6 Kbytes of data RAM.

1.1.4 EXTENDED INSTRUCTION SET

The PIC18F66K80 family implements the optional extension to the PIC18 instruction set, adding eight new instructions and an Indexed Addressing mode. Enabled as a device configuration option, the extension has been specifically designed to optimize re-entrant application code originally developed in high-level languages, such as 'C'.

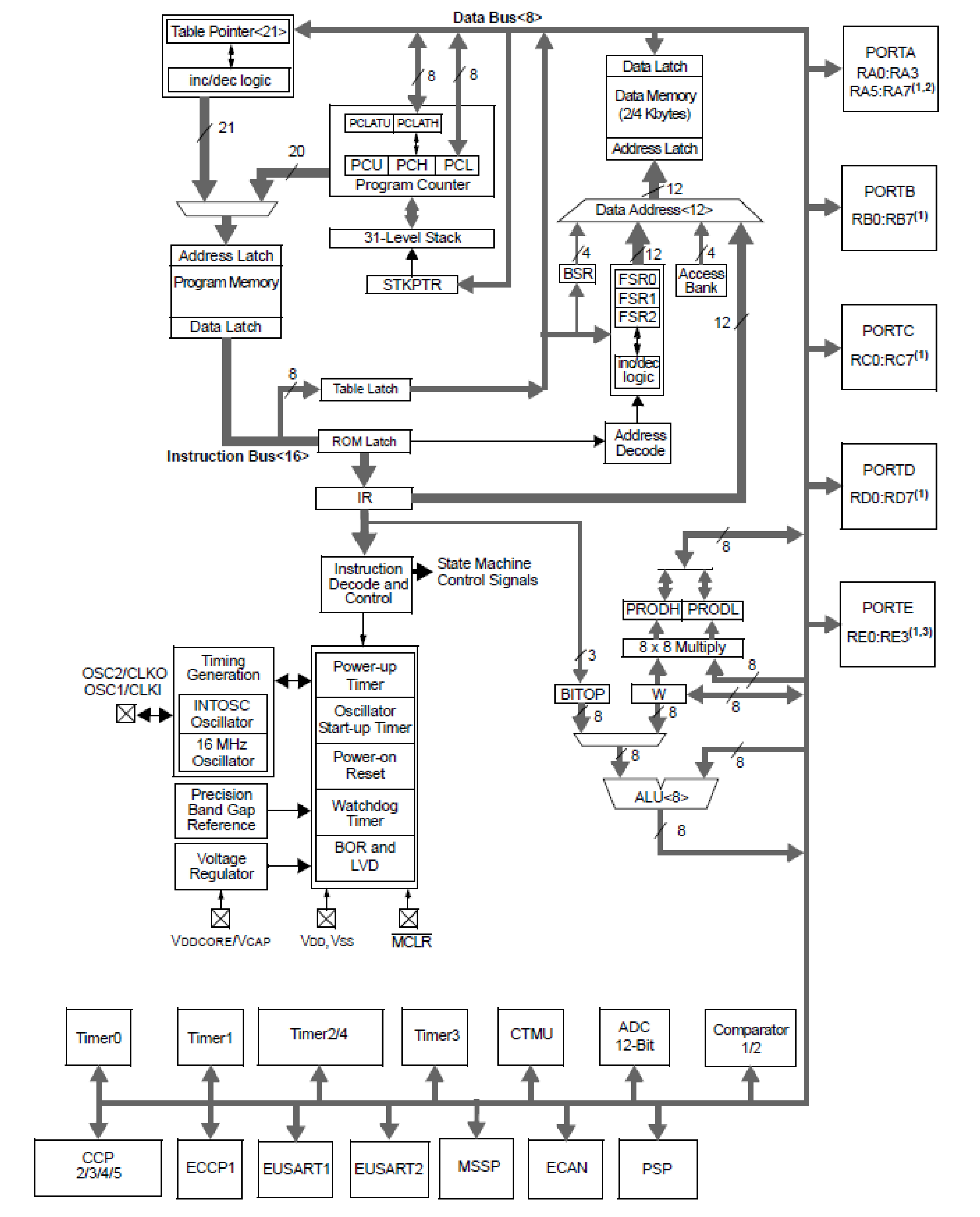
TABLE 1-1: DEVICE FEATURES FOR THE PIC18F2XK80 (28-PIN DEVICES)

Features	PIC18F25K80	PIC18F26K80
Operating Frequency	DC – 64 MHz	
Program Memory (Bytes)	32K	64K
Program Memory (Instructions)	16,384	32,768
Data Memory (Bytes)	3.6K	
Interrupt Sources	31	
I/O Ports	Ports A, B, C	
Parallel Communications	Parallel Slave Port (PSP)	
Timers	Five	
Comparators	Two	
CTMU	Yes	
Capture/Compare/PWM (CCP) Modules	Four	
Enhanced CCP (ECCP) Modules	One	
Serial Communications	One MSSP and Two Enhanced USARTs (EUSART)	
12-Bit Analog-to-Digital Module	Eight Input Channels	
Resets (and Delays)	POR, BOR, RESET Instruction, Stack Full, Stack Underflow, $\overline{\text{MCLR}}$, WDT (PWRT, OST)	
Instruction Set	75 Instructions, 83 with Extended Instruction Set Enabled	
Packages	28-Pin QFN-S, SOIC, SPDIP and SSOP	

TABLE 1-2: DEVICE FEATURES FOR THE PIC18F4XK80 (40/44-PIN DEVICES)

Features	PIC18F45K80	PIC18F46K80
Operating Frequency	DC – 64 MHz	
Program Memory (Bytes)	32K	64K
Program Memory (Instructions)	16,384	32,768
Data Memory (Bytes)	3.6K	
Interrupt Sources	32	
I/O Ports	Ports A, B, C, D, E	
Parallel Communications	Parallel Slave Port (PSP)	
Timers	Five	
Comparators	Two	
CTMU	Yes	
Capture/Compare/PWM (CCP) Modules	Four	
Enhanced CCP (ECCP) Modules	One	
Serial Communications	One MSSP and Two Enhanced USARTs (EUSART)	
12-Bit Analog-to-Digital Module	Eleven Input Channels	
Resets (and Delays)	POR, BOR, RESET Instruction, Stack Full, Stack Underflow, $\overline{\text{MCLR}}$, WDT (PWRT, OST)	
Instruction Set	75 Instructions, 83 with Extended Instruction Set Enabled	
Packages	40-Pin PDIP and 44-Pin QFN and TQFP	

FIGURE 1-2: PIC18F4XK80 (40/44-PIN) BLOCK DIAGRAM



Note 1: See Table 1-5 for I/O port pin descriptions.

2: RA6 and RA7 are only available as digital I/O in select oscillator modes. For more information, see **Section 3.0 "Oscillator Configurations"**.

3: RE3 is only available when the MCLR Configuration bit is cleared (MCLRE = 0).

TABLE 1-6: PIC18F6XK80 PINOUT I/O DESCRIPTIONS

Pin Name	Pin Num	Pin Type	Buffer Type	Description
$\overline{MCLR}$/RE3	28			
$\overline{MCLR}$		I	ST	Master Clear (input) or programming voltage (input).This pin is an active-low Reset to the device.
RE3		I	ST	General purpose, input only pin.
OSC1/CLKIN/RA7	46			
OSC1		I	ST	Oscillator crystal input.
CLKIN		I	CMOS	External clock source input. Always associated with pin function, OSC1. (See related OSC1/CLKI, OSC2/CLKO pins.)
RA7		I/O	ST/ CMOS	General purpose I/O pin.
OSC2/CLKOUT/RA6	47			
OSC2		O	—	Oscillator crystal output. Connects to crystal or resonator in Crystal Oscillator mode.
CLKOUT		O	—	In certain oscillator modes, OSC2 pin outputs CLKO, which has 1/4 the frequency of OSC1 and denotes the instruction cycle rate.
RA6		I/O	ST/ CMOS	General purpose I/O pin.

Legend: I^2C™ = I^2C/SMBus input buffer; ST = Schmitt Trigger input with CMOS levels; I = Input; P = Power; CMOS = CMOS compatible input or output; Analog = Analog input; O = Output

APPENDIX C

Examples of Calculation for Measured Distance

Examples of calculation using infrared sensor to determine measured distance value in cm

Let the measurement data taken as shown in Table below:

Distance of the obstacle (cm)	Measured value (v)	Measured value (cm)	
50	1.214	50.4155	→ Example 1
70	0.917	69.1527	→ Example 2
90	0.727	90.44072	
110	0.604	109.8209	
130	0.502	130.0413	
150	0.418	149.9685	

Using the datasheet, we did a fourth degree approximation to get a close fitting formula to find the distance in cm from the voltage. Here is the formula we used:

Distance = $16.2537 * x^4 – 129.893 * x^3 + 382.268 * x^2 – 512.611 * x + 306.439$

*Where x=voltage read on ADC.

Example 1:

X=1.214

$$\begin{aligned} Distance = {} & 16.2537(1.214^4) - 129.893(1.214^3) + 382.268(1.214^2) \\ & - 512.611(1.214) + 306.439 \end{aligned}$$

$$= 35.3042 – 232.4030 + 563.3850 – 622.3098 + 306.439$$

$$= 50.4154$$

Example 2:

X=0.917

$$\begin{aligned} Distance = {} & 16.2537(0.917^4) - 129.893(0.917^3) + 382.268(0.917^2) \\ & - 512.611(0.917) + 306.439 \end{aligned}$$

$$= 11.493 – 100.1599 + 321.445 – 470.064 + 306.439$$

$$= 69.153$$

APPENDIX

D

Codes of the Program for Microcontrollers

at Transmitter and Receiver

MICROCONTROLLER PROGRAMMING AT RECEIVER

```
/*************************************************************************/
/*            WIRELESS OBSTACLE DETECTION SYSTEM                        */
/*            PHD RESEARCH AT VICTORIA UNIVERSITY                       */
/*  FILE       : Main RxBoard.c                                         */
/*  DATE       : 03,JUN 2012                                            */
/*  CPU        : PIC16F887                                              */
/*  Description :                                                       */

/*************************************************************************/
//HEADER FILE************************************************************
#include <pic.h>
//BITS
CONFIGURATION**********************************************************
__CONFIG(0x2FF4);
__CONFIG(0x3FFF);
//FUNCTION
DECLARATION************************************************************
void Initialize(void);
void msDelay(unsigned int);
void Display(unsigned char);
unsigned char RemoteRead(void);
void LCDWrite(unsigned char);
void Putchar(unsigned char);
void PutBit(unsigned char);
void PutHex(unsigned char);
void PutHex2(unsigned int);
void Print(const char *);
void PrintInt(unsigned int);
void LCDInit(void);
unsigned int eeprom_readw(unsigned char);
void eeprom_writew(unsigned char, unsigned int);
//MACRO
DEFINITION*************************************************************
#define LO          0
#define HI          1
#define HSEC 50
#define TMRKEY      30
#define TMRBUZ      30
#define TMRVIB      200
#defineLED1  RB0
#defineLED2  RB1
#defineLED3  RB2
#defineLED4  RB3
#defineVIBR  RD7                //Vibrator
#defineBUZZ  RD6                //Buzzer
#defineSW1          RE0
#defineSW2          RE1
#defineSW3          RE2
//Voice Module
```

```
#defineVCLK RC3
#defineVDAT RC1
#defineVRST  RC0
//LCD
DEFINITION*************************************************************
#define RS              RB5                 //LCD Command/Data          0:Command
1:Data
#define EN              RB4                 //LCD Enable           0:Disable 1:Enable
#define LDATA           PORTB               //LCD Data Port
#define LCDBIT4                             //4-bit lcd data bus
#define LSHIFT          0                   //LCD Shift Bit
#define LMASK           0b11110000    //LCD Mask Data for 4-bit Mode
#define CLS             0x01          // Clear screen.
#define COB             0x0F          // Cursor ON, blink.
#define DON             0x0C          // Display ON.
#define LINE1           0x80          // LCD Line 1
#define LINE2           0xC0          // LCD Line 2
//MOVEMENT
DIRECTION********************************************************
#define REMSW1          'A'
#define REMSW2          'B'
#define REMSW3          'C'
#define SYNC0x00
#define HEADER          0x40
#define HEADERL         0x41
#define HEADERR         0x42
#define ADCMAX          6
#define DATMAX          (ADCMAX)
#define BUFMAX          (1+DATMAX+1) //(Header+DATMAX+CheckSum)
//Range
#define RNGMAX          (ADCMAX*3)
//Voice
#define VFMIN           0x0000        //Min File
#define VFMAX           0x01FF        //Max File
#define VVOLL           0xFFF0
#define VVOLH           0xFFF7
#define VPLAY           0xFFFE        //Play-Pause
#define VSTOP           0xFFFF
#define RXCNT           48
#define BUFLEN          24
#define DATLEN          18
#define TMRRXD          3
#define RANGE1          50
#define RANGE2          100
#define RANGE3          150

//PUBLIC VARIABLE******************************************************
static bit blinkbit;            //Blink Bit
static bit secbit;                    //One Sec Bit
//
```

```
near unsigned char TmrSec,hSec,mSec,TmrKey,TmrBuz,TmrVib,TmrVoice,TmrRxd;
near unsigned int TmrDelay;
//
unsigned char Sensor1,Sensor2,Sensor3;
unsigned char Sensor4,Sensor5,Sensor6;
unsigned char DataFlag,Type1,Type2;
unsigned char Range1,Range2,Range3;
unsigned char RemoteTask,LRT;
unsigned char Blink,Mode,Task;
unsigned char BuzTask,BuzCnt;
unsigned char VibTask,VibCnt;
unsigned char VTask,VNum;
unsigned char OUT;
unsigned char d0,d1,d2,d3;
unsigned char BufCnt,PacketCnt;
unsigned char Buffer[BUFMAX];
unsigned char Range[RNGMAX+1];
unsigned int VCmd;
//
unsigned char RxCnt,RxChar,RxFlag,RxLast,RxBuf[RXCNT];
//unsigned char DatCnt,DatChar,DatFlag,DatLast,DatBuf[BUFLEN];
//
//FUNCTION PROTOTYPE**********************************************
void Initialize(void);
void Key1_Pressed(void);
void Key2_Pressed(void);
void Key3_Pressed(void);
void TxChar(unsigned char);
void TxHex(unsigned char);
unsigned char uart_rec(void);
unsigned char read_packet(void);
void MenuDisp(unsigned char);
//
void BuzzerTask(void);
unsigned char SensorDecode(void);
void VibrateTask(void);
void VoicePlay(unsigned int);
void VoiceTask(void);
//
//INTERRUPT*******************************************************
static void interrupt isr(void)
{
	unsigned char b,d;
	//Timer0
	if(TMR0IF){		//TMR0IF : PIC16F88
		TMR0=100;	//set 10ms preload
		TMR0IF = 0;	//clear interrupt flag
		//
		if(TmrKey) TmrKey--;
		if(TmrBuz) TmrBuz--;
```

```
		if(TmrVib) TmrVib--;
		if(TmrVoice) TmrVoice--;
		if(TmrDelay) TmrDelay--;
		//if(TmrRxd) TmrRxd--;
		//
		if(hSec) hSec--;
		if(!hSec){
			hSec=HSEC;
			blinkbit = ~blinkbit;
			if(blinkbit){
				secbit=1;
				if(TmrSec) TmrSec--;
			}
		}
	}
	//
	if(RCIF){			// No need to clear RCIF flag,
		RxChar = RCREG;	// MCU will clear it once read
		if(RxCnt<RXCNT){
			RxBuf[RxCnt++]=RxChar;
		}
		if(RxLast==0x0D && RxChar==0x0A) RxFlag=1;
		RxLast=RxChar;
		//TmrRxd=TMRRXD;
	}
}
//IO INITIALIZE*****************************************************
void Initialize(void)
{
	//
	PORTA=0x00;
	PORTB=0x00;
	PORTC=0x00;
	PORTD=0x00;
	PORTE=0x00;
	//set I/O input output
	ANSEL=0x00;
	ANSELH=0;
	TRISA = 0b11111111;			//configure PORTA as output
	TRISB = 0b11000000;
	TRISC = 0b11110000;
	TRISD = 0b00000000;
	TRISE = 0b00001111;		//configure PORTE as output
	//setup USART
	SPBRG = 25;				//set baud rate
	RCSTA = 0x90;
	TXSTA = 0x24;
	RCIE = 1;
	//Timer&interrupt
	OPTION_REG=0b00000101;		//16.384mS
```

```
	T0IE=1;PEIE=1;GIE=1;
}
//Mili-Second Delay(max 65535ms)***
void msDelay(unsigned int ms)
{
	unsigned char i;
	while(ms){
		ms--;
		i=122;			//4MHz clock
		//i=244;			//8MHz clock
		while(i) i--;
	}
}
//MAIN
FUNCTION************************************************************
void main(void)
{
	//assign variable
	unsigned char Cmd,a,d,i,j;
	//unsigned int dd;
	Initialize();
	LCDInit();
	//Init variables
	hSec=HSEC;RxCnt=0;RxFlag=0;BuzTask=0;BuzCnt=0;VibTask=0;VibCnt=0;
	//Read Setting from EEPROM
	a=1;	//EEPROM start address
	DataFlag=1;
	VRST=1; NOP();
	VCLK=1; NOP();
	VDAT=0; NOP();
	//Init variables
	Blink=0;OUT=0;Cmd=0;BufCnt=0;Mode=0;Task=0;VTask=0;
	Range1=0;Range2=0;Range3=0;
	PacketCnt=0;
	TxChar('A');
	Putchar('A');
	//
	//MenuDisp(0);
	//
	while(1)					//infinity loop
	{
		CLRWDT();
		//Check Remote Command
		if(RxFlag)
		{
			Cmd=SensorDecode();
			if(RxCnt>DATLEN)
			{
				j=0;
				for(i=DATLEN;i<RxCnt;i++)
```

```
			{
				a=RxBuf[i];
				RxBuf[j]=a;
				j++;
			}
			RxCnt -= DATLEN;
		}
		else
		{
			RxCnt=0;
		}
		RxFlag=0;
	}

	//Cmd=RemoteRead();
	if(Cmd){
		LED1=1;
		PacketCnt++;
		TmrDelay=500;		//Delay no data
		DataFlag |= 0x02;	//Data receive flag
		//
		//Display(Cmd);
		Cmd=0;
		for(i=1;i<=DATMAX;i++){
			d=Buffer[i];
			if(Mode==0)
			{
				a=((i-1)%3)*4;
				if((i-1)/3)
				{
					LCDWrite(LINE2+a);
				}
				else
				{
					LCDWrite(LINE1+a);
				}
				PrintInt(d);
				Putchar(' ');
			}
		}
		for(i=0;i<BUFMAX;i++)
			TxHex(Buffer[i]);
		TxChar(0x0D);
		TxChar(0x0A);
		//
		LCDWrite(LINE1+12);
		PrintInt(PacketCnt);
		Putchar(' ');
		Putchar(' ');
		//
```

```
		LCDWrite(LINE2+12);
		Putchar(Range3+'0');	//left    - IR3
		Putchar(Range1+'0');	//center - ultrasonic
		Putchar(Range2+'0');	//right  - IR2
		//
		LED1=0;
	}else if(!TmrKey){
		if(!SW1){
			TmrKey=TMRKEY;
			Key1_Pressed();
		}
		if(!SW2){
			TmrKey=TMRKEY;
			Key2_Pressed();
		}
		if(!SW3){
			TmrKey=TMRKEY;
			Key3_Pressed();
		}
	}
	if(!TmrDelay && !Mode)
	{
		BuzTask=9;
		VibTask=9;
		Range1=0;
		Sensor1=255;
	}
	//
	if(DataFlag==3 && !Mode){
		//SENSOR1
		switch(Range1){
		case 0:
			d=RANGE3;	//(Range[3]);
			if(Sensor1<d && !BuzTask){
				BuzCnt=1;BuzTask=1;Range1=1;
			}
		break;
		case 1:
			d=RANGE2;	//(Range[2]);
			if(!BuzTask){
				if(Sensor1<(d-2)){
					VibCnt=2;VibTask=1;BuzCnt=2;BuzTask=1;
					Range1=2;
				}
				else if(Sensor1>(d+2)){
					BuzTask=9;
					Range1=0;
				}
				else{
					BuzCnt=1;BuzTask=1;
```

```
            }
        }
    break;
    case 2:
        d=RANGE1;   //(Range[1]);
        if(!BuzTask){
            if(Sensor1<(d-2)){
                VibTask=4;BuzTask=4;Range1=3;
                VoicePlay(1);
            }
            else if(Sensor1>(d+2)){
                BuzCnt=1;
                BuzTask=1;
                Range1=1;
            }
            else{
                BuzCnt=2;
                BuzTask=1;
            }
        }
    break;
    case 3:
        d=RANGE1;   //(Range[1]);
        if(Sensor1>d){
            BUZZ=0;VIBR=0;Range1=0;BuzTask=9;
        }
    break;
    }
    //Reset Range1
    d=RANGE3;   //(Range[3]);
    if(Sensor1>d && Range1 && !TmrBuz){
        Range1=0;
    }
    //SENSOR2
    switch(Range2){
    case 0:
        d=RANGE3;   //(Range[6]-20);
        if(Sensor2<d && !BuzTask){
            BuzCnt=1;BuzTask=1;Range2=1;
        }
    break;
    case 1:
        d=RANGE2;   //(Range[5]-20);
        if(Sensor2<d && !BuzTask){
            BuzCnt=2;BuzTask=1;Range2=2;
        }
    break;
    case 2:
        d=RANGE1;   //(Range[4]-20);
        if(Sensor2<d && !BuzTask){
```

```
            BuzCnt=5;BuzTask=1;VibCnt=1;VibTask=1;
            Range2=3;
            //
            if(Range3<3 && VTask==0){
                VoicePlay(2);
            }
        }
break;
case 3:
        //
break;
}
//Reset Range2
d=RANGE3;   //(Range[6]);
if(Sensor2>d && Range2 && !TmrBuz){
        Range2=0;
}
//SENSOR3
switch(Range3){
case 0:
        d=RANGE3;   //(Range[9]-20);
        if(Sensor3<d && !BuzTask){
            BuzCnt=1;BuzTask=1;Range3=1;
        }
break;
case 1:
        d=RANGE2;   //(Range[8]-20);
        if(Sensor3<d && !BuzTask){
            BuzCnt=2;BuzTask=1;Range3=2;
        }
break;
case 2:
        d=RANGE1;   //(Range[7]-20);
        if(Sensor3<d && !BuzTask){
            BuzCnt=5;BuzTask=1;VibCnt=1;VibTask=1;
            Range3=3;
            //
            if(Range2<3 && VTask==0){
                VoicePlay(3);
            }
        }
break;
case 3:
break;
}
//Reset Range3
d=RANGE3;   //(Range[9]);
if(Sensor3>d && Range3 && !TmrBuz){
        Range3=0;
}
```

```
		}
		BuzzerTask();VibrateTask();VoiceTask();
		}
}

//BUZZER
void BuzzerTask(void)
{
	switch(BuzTask){
	case 0:
	break;
	case 1:
		if(!TmrBuz){
			BUZZ=1;
			TmrBuz=TMRBUZ;
			BuzTask=2;
		}
	break;
	case 2:
		if(!TmrBuz){
			BUZZ=0;
			BuzCnt--;
			if(BuzCnt){
				TmrBuz=TMRBUZ;
				BuzTask=1;
			}else{
				TmrBuz=250;
				BuzTask=3;
			}
		}
	break;
	case 3:
		if(!TmrBuz){
			BuzTask=0;
		}
	break;
	case 4:
		BUZZ=1;TmrBuz=250;BuzTask=5;
	break;
	case 9:
		BUZZ=0;TmrBuz=0;BuzTask=0;
	break;
	}
}
unsigned char SensorDecode(void)
{
	unsigned char a,b,d,i,j;

	if(RxCnt<DATLEN) return 0;
	d=1;
```

```
	//DatCnt=0;
	i=0; j=0;
	while(i<(DATLEN-2))
	{
		a=RxBuf[i++];
		if('0'<=a && a<='9') a-='0';
		else if('A'<=a && a<='F') a-='7';
		else {d=0; a=0;}
		b=RxBuf[i++];
		if('0'<=b && b<='9') b-='0';
		else if('A'<=b && b<='F') b-='7';
		else {d=0; b=0;}
		a<<=4;
		a|=b;
		Buffer[j++]=a;
	}
	if(!d) return 0;
	Sensor1=Buffer[1];		//Ultrasonic
	if(Buffer[0]==HEADERL)
		Sensor2=Buffer[2];	//Left - IR_Left
	if(Buffer[0]==HEADERR)	//Right - IR_Right
		Sensor3=Buffer[3];
	return 1;
}
//VIBRATOR
void VibrateTask(void)
{
	switch(VibTask){
	case 0:
	break;
	case 1:
		if(!TmrVib){
			VIBR=1;TmrVib=TMRVIB;VibTask=2;
		}
	break;
	case 2:
		if(!TmrVib){
			VIBR=0;
			VibCnt--;
			if(VibCnt){
				TmrVib=TMRVIB;
				VibTask=1;
			}else{
				TmrVib=100;VibTask=3;
			}
		}
	break;
	case 3:
		if(!TmrVib){
			VibTask=0;
```

```
		}
	break;
	case 4:
		VIBR=1;TmrVib=0;VibTask=0;
	break;
	case 9:
		VIBR=0;TmrVib=0;VibTask=0;
	break;
	}
}
//VOICE
void VoicePlay(unsigned int VoiceNum)
{
	if(VTask) return;
	VCmd = VoiceNum;
	VTask = 1;
	LCDWrite(LINE1+12);
	PutHex2(VCmd);
}
void VoiceTask(void)
{
	static unsigned char i;
	switch(VTask){
	case 0:

	break;
	case 1:
		VRST=0;TmrVoice=2;VTask=2;
	break;
	case 2:
		if(!TmrVoice){
			VRST=1;TmrVoice=30;VTask=3;
		}
	break;
	case 3:
		if(!TmrVoice){
			VCLK=0;TmrVoice=2;VTask=4;
		}
	break;
	case 4:
		if(!TmrVoice){
			i=16;
			VTask=5;
		}
	break;
	case 5: //set data
		VCLK=0; NOP();
		if(VCmd & 0x8000)
		{
			VDAT=1; NOP();
```

```
		}else{
			VDAT=0; NOP();
		}
		VTask=6;
	break;
	case 6: //raise clock
		VCLK=1; NOP();
		VCmd<<=1;
		i--;
		if(i){
			VTask=5;
		}else{
			TmrVoice=3;
			VTask=7;
		}
	break;
	case 7:
		if(!TmrVoice){
			LCDWrite(LINE1+12);
			Print("    ");
			VCmd=0;
			VTask=0;
		}
	break;
	}
}
void MenuDisp(unsigned char Disp)
{
	unsigned char b,d;

	LCDWrite(LINE1);
	Print("                ");
	LCDWrite(LINE1);
	switch(Disp)
	{
		case 0:
			if(DataFlag & 0x01) Putchar('*');	//EEPROM setting is valid
			else Putchar('x');			//EEPROM setting is invalid
			//Print(" ONLINE     ");
		break;
		case 1:
			Print("0.5:");
			LCDWrite(LINE1+4);
			PrintInt(Range[1]);
			LCDWrite(LINE1+8);
			PrintInt(Range[4]);
			LCDWrite(LINE1+12);
			PrintInt(Range[7]);
		break;
		case 2:
```

```
				Print("1.0:");
				LCDWrite(LINE1+4);
				PrintInt(Range[2]);
				LCDWrite(LINE1+8);
				PrintInt(Range[5]);
				LCDWrite(LINE1+12);
				PrintInt(Range[8]);
			break;
			case 3:
				Print("1.5:");
				LCDWrite(LINE1+4);
				PrintInt(Range[3]);
				LCDWrite(LINE1+8);
				PrintInt(Range[6]);
				LCDWrite(LINE1+12);
				PrintInt(Range[9]);
			break;
			case 4:
				Print("Vibrate : ");
				if(VIBR) Print("ON ");
				else Print("OFF");
			break;
			case 5:
				Print("VOICE MODE: ");
				LCDWrite(LINE1+12);
				PrintInt(VNum);
			break;
		}
}
//SW1 PRESSED
void Key1_Pressed(void)
{
		Mode++;
		if(Mode==5) VNum=1;
		if(Mode>5) Mode=0;
		MenuDisp(Mode);
}
//SW2 PRESSED
void Key2_Pressed(void)
{
		unsigned char a;
		if(Mode==0) return;
		if(Mode<4){
			a=Mode;
			Range[Mode]=Sensor1;
			eeprom_write(a,Sensor1);
			a+=3;
			Range[Mode+3]=Sensor2;
			eeprom_write(a,Sensor2);
			a+=3;
```

```
			Range[Mode+6]=Sensor3;
			eeprom_write(a,Sensor3);
		}else if(Mode==4){
			BUZZ=1; NOP();
			VIBR=1; NOP();
		}else if(Mode==5){
			if(!VTask){
				VNum++;
				if(VNum>10) VNum=1;
			}
		}
		MenuDisp(Mode);
}
//SW3 PRESSED
void Key3_Pressed(void)
{
		if(Mode==4){
			BUZZ=0; NOP();
			VIBR=0; NOP();
		}else if(Mode==5){
			if(!VTask){
				VoicePlay(VNum);
			}
		}
		//MenuDisp(Mode);
}
// ============ UART FUNCTIONS ==============
void TxChar(unsigned char byte)
{
		CLRWDT();
		while(!TXIF) continue;		//Set when register is empty
		TXREG = byte;
}
void TxHex(unsigned char byte)
{
		unsigned char d;
		d = (byte>>4)+'0';
		if(d>'9') d+=7;
		TxChar(d);
		d = (byte & 0x0F)+'0';
		if(d>'9') d+=7;
		TxChar(d);
}
// ============ LCD FUNCTIONS ===============
#ifdef LCDBIT4
void LCDWriteNibble(unsigned char nd)
{
		unsigned char b,d;
		//bit shuffle
#ifdef LSHUFF
```

```
	d=0;
	if(nd & 0x01) d|=0x08;		//b0=b3
	if(nd & 0x02) d|=0x04;		//b1=b2
	if(nd & 0x04) d|=0x02;		//b2=b1
	if(nd & 0x08) d|=0x01;		//b3=b0
#else
	d=nd;
#endif
	//
	d=(d<<LSHIFT);			//shift data into position
	//
	b=(LDATA & LMASK);		//backup others bit
	b |= d;				//combine data
	LDATA=b;			//store data
	NOP(); NOP(); NOP();
	EN=HI;
	NOP(); NOP(); NOP();
	EN=LO;
}
#endif
//Write data to LCD
void LCDWrite(unsigned char d)
{
#ifdef LCDBIT4
	//4-bit Mode
	LCDWriteNibble(d>>4);
	LCDWriteNibble(d & 0x0f);
	msDelay(1);
#endif
}
//Print one character on LCD
void Putchar(unsigned char d)					// Write data
{
	RS=HI;
	LCDWrite(d);
	RS=LO;
}
//Print 8bit data
void PutBit(unsigned char d)
{
	unsigned char i;
	for(i=0;i<8;i++){
		if(d & 0x80)
			Putchar('1');
		else
			Putchar('0');
		d <<= 1;	//shift to upper bit
	}
}
void PutHex(unsigned char d)
```

```
{
	unsigned char h;
	h = (d>>4)+'0';
	if(h>'9') h+=7;
	Putchar(h);
	h = (d & 0x0F)+'0';
	if(h>'9') h+=7;
	Putchar(h);
}
void PutHex2(unsigned int dd)
{
	unsigned char d;
	PutHex((unsigned char)(dd>>8));
	PutHex((unsigned char)(dd));
}
//Print constant string
void Print(const char *str)
{
	while(*str){
		Putchar(*str);
		str++;
	}
}
//Print integer variable
void PrintInt(unsigned int dd)
{
	unsigned char i=0,j,abuf[5];
	//convert
	do{
		j=dd%10;		//ambil 'sa'
		abuf[i]=j+'0';	//number to ascii
		dd=dd/10;		//buang 'sa'
		i++;			//next digit
	}
	while(dd);			//ulang selagi dd ada nilai
	//print
	while(i){
		i--;
		Putchar(abuf[i]);
	}
}
//Initialize LCD
void LCDInit(void)
{
	//Step 1: Init I/O after power up
	RS=0; EN=0;  LDATA = 0;	// RS=LO, EN=LO, Data=LO;
	msDelay(300);			// Power up delay
#ifdef LCDBIT4
	LCDWriteNibble(0x03);		// Set "8-bits" mode.
	msDelay(7);				// Power up delay
```

```
	LCDWriteNibble(0x03);	// Set "8-bits" mode.
	msDelay(2);			// Power up delay
	LCDWriteNibble(0x03);	// Set "8-bits" mode.
	msDelay(2);			// Power up delay
	LCDWriteNibble(0x02);	// Set "4-bits" mode.
	msDelay(2);
	LCDWrite(0x28);			// Set "4-bits" mode.
	msDelay(2);
#endif
#ifdef LCDBIT8
	LCDWrite(0x38);			// Set "8-bits" mode.
#endif
	LCDWrite(DON);			// Execute Display ON/OFF control Instruction
	LCDWrite(CLS);			// Execute Display Clear Instruction
	LCDWrite(LINE1);		// Set display buffer at first line
}
```

MICROCONTROLLER PROGRAMMING AT TRANSMITTER

```
/**************************************************************************/
/*           WIRELESS OBSTACLE DETECTION SYSTEM                          */
/*           PHD RESEARCH AT VICTORIA UNIVERSITY                         */
/*  FILE       :main.c                                                   */
/*  DATE       :Fri, Jun 15, 2012                                        */
/*  DESCRIPTION :Main Program                                            */
/*                                                                       */
/*  AUTHOR                 DATE         DESCRIPTION                      */
/*  BAHARUDDIN          15-06-2012   Original                            */
/*                                                                       */
/*  BAHARUDDIN          17-08-2012     Redesign board, new sensor GP2Y0A02YK  */
/*  BAHARUDDIN          14-10-2012     Average ADC with 'AVGMAX'         */
/*           14-06-2013  Change Micon to PIC18F46K80                     */
/*           29-11-2013  FSR condition from OR to AND                    */
/*           17-01-2014  New PCB, Micon PIC18F26K80                      */
/*            27-06-2014  Micon PIC18F66K80                              */
/*                Change compiler to Hitec C                             */
/*                    Use XBEE Pro as wireless communication             */
/*                    Ultrasonic reading only at UART1                   */
/**************************************************************************/
/***************************************************************************
Force Sensitive Resistor 0.5"
-----------------------------
1 - RE0 - AN5
2 - RE1 - AN6
3 - RE2 - AN7

GP2Y0A02YK0F
------------
1 - RA2 - AN2
2 - RA3 - AN3

Ultrasonic Range Finder
-----------------------
1 - UART - RD6 - Tx2
***************************************************************************/
//
/** I N C L U D E S **/
#include "io_def.h"
// #include <usart.h>

//---------------------------------------------------------------------------
// Constant/Macro Definition
#define SYNC 0x00
//#define HEADER    0x41    //LEFT
//#define HEADER    0x42    //RIGHT

#define ADCMAX     6        //ADC Channel Count
#define TXDMAX     (1+ADCMAX+1)      //(Header+ADCMAX+CheckSum)
```

```
#define AVGMAX     2          //Average Data buffer
#define FSR_ON       180
#define IR_MAX       15

//---------------------------------------------------------------------------
// Variables Definition
unsigned char HEADER;
unsigned char AdcH;
unsigned char AdcL;
unsigned char AvgH;
unsigned char AvgL;
unsigned char DatH;
unsigned char DatL;
unsigned char AdcSeq;
unsigned char StepFlag;
unsigned char SDist,CDist;
unsigned char RxCnt,RxFlag;
unsigned char LChar,RxChar;
unsigned char TxdBuf[TXDMAX];
unsigned char RxdBuf[RX2MAX];
unsigned char Adc8,Avg8;
unsigned int Adc16,Avg16;
unsigned char AdcBuf[ADCMAX][AVGMAX];

unsigned char TmrRxd,TmrTxd,TmrStep;

const unsigned char IR_cm[] =  { 10, 20, 30, 40, 50, 60, 70, 80,
90,100,110,120,130,140,150,160};
const unsigned char IR_Dat[] = {165,138,102, 82, 66, 56, 48, 44, 39, 35, 31, 28, 26, 24, 22,
21};
//---------------------------------------------------------------------------
// Function Declaration
//void InterruptHandlerHigh(void);
void main(void);
void HardwareInit(void);
//---------------------------------------------------------------------------
// High priority interrupt vector
//#pragma code InterruptVectorHigh = 0x08
//void InterruptVectorHigh(void)
//{
//  _asm
//    goto InterruptHandlerHigh //jump to interrupt routine
//  _endasm
//}
//---------------------------------------------------------------------------
// High priority interrupt routine
//#pragma code
//#pragma interrupt InterruptHandlerHigh
//void InterruptHandlerHigh()
void interrupt InterruptHandlerHigh()
```

```
{
	unsigned char i,d;
	unsigned int dd;
	//TIMER0 INTERRUPT SERVICE FOR 10ms INTERVAL
	if(TMR0IF){		//Timer1 Interrupt
		//8bit mode (10ms)
		TMR0L=100;	//timer preload
		TMR0IF=0;	//Clear Interrupt Flag
		//IntFlag<<=1;
		//if(!IntFlag) IntFlag=0x01;
		//
		if(TmrRxd){
			TmrRxd--;
			if(!TmrRxd){
				RxFlag=1;
			}
		}
		if(TmrTxd) TmrTxd--;
		if(TmrStep) TmrStep--;
		//LED=!LED;
	}
	//UART Receive
	if(RC1IF){			// no need to clear RCIF flag
		RxChar = RCREG1;	// MCU will clear it once read the data
		if(RxChar=='R') RxCnt=0;
		//RC1IF=0;
		//LED=1;
		//if('a'<=RxChar && RxChar<='z') RxChar-=0x20;  //UpperCase
		if(RxCnt<RX2MAX){
			RxdBuf[RxCnt++]=RxChar;
			//RxBuf[RxCnt]=0x00;
		}
		//
		//TmrRxd=TMRRXD;
		if(RxCnt==5){
			// RxFlag=1;
			dd = 0;
			for(i=1;i<4;i++){
				d = RxdBuf[i];
				if('0'<=d && d<='9'){
					dd *= 10;
					dd += (d-'0');
					//Putchar(d);
				}else goto SKIP;
			}
			if(dd<=254){
				CDist = (unsigned char)dd;
				if(CDist<SDist){
					SDist=CDist;
				}
```

```
					}
					RxCnt=0;
				}
SKIP:
				//
				LChar=RxChar;
				//
		}
}
//---------------------------------
// Approx ms delay
void msDelay(unsigned int ms)
{
		unsigned char i;
		while(ms){
				ms--;
				i=244;				//4MHz clock
				//i=244;				//8MHz clock
				while(i) i--;
		}
}
void TxChar(unsigned char byte)
{
		ClrWdt();
		while(!PIR1bits.TX1IF) continue;	//Set when register is empty
		TXREG = byte;
}
void TxHex(unsigned char byte)
{
		unsigned char d;
		d = (byte>>4)+'0';
		if(d>'9') d+=7;
		TxChar(d);
		d = (byte & 0x0F)+'0';
		if(d>'9') d+=7;
		TxChar(d);
}
void Send_Packet(void)
{
		unsigned char i;
		//Clocking for a while before sending the data so that the TX and RX are in sync
		//for (i = 0; i < 2; i++) TxChar(SYNC);
		//Transmit the packet using UART
		//for (i = 0; i < TXDMAX; i++) TxChar(TxdBuf[i]);
		for (i = 0; i < TXDMAX; i++) TxHex(TxdBuf[i]); TxChar(0x0D); TxChar(0x0A);
}
//unsigned int AdcRead(unsigned char ChNo)
unsigned char AdcRead(unsigned char ChNo)
{
		//
```

```
	ADCON0 = ((ChNo<<2)|0x01);
	//
	//Nop();Nop();Nop();Nop();Nop();Nop();
	Nop();Nop();
	//
	ADCON0bits.GO=1;
	Nop();
	Nop();
	while(ADCON0bits.GO);
	//
	Nop();Nop();Nop();Nop();Nop();Nop();
	AdcH = ADRESH;
	AdcL = ADRESL;
	//
	//AdcH &= 0x0F;	//mask bit11_9
	Adc16 = (AdcH & 0x0F);
	Adc16 <<= 8;
	Adc16 |= AdcL;
	Adc8 = Adc16/16;
	//
	return (AdcH & 0xF0);
}
void HardwareInit(void)
{
	unsigned char i;
	//Set Internal Oscillator
	//OSCCON = (0x70+0x02);	//8MHz
	//OSCCON = (0x60+0x02);	//4MHz

	//Clear Output
	PORTA = 0;PORTB = 0;PORTC = 0;LATA = 0;LATB = 0;LATC = 0;
	//Analog selection
	ANCON0 = SELA;
	ANCON1 = SELB;
	//Set Input/Output
	TRISA = PCRA;
	TRISB = PCRB;
	TRISC = PCRC;

	//ADC Configuration
	ADCON1 = 0b00110000;	//ADREF+ -> 4.096V
	ADCON2 = 0b10000111;	//Right Justify, 12TAD, FRC

	//Configure USART
//	OpenUSART(USART_TX_INT_OFF | USART_RX_INT_ON |
USART_ASYNCH_MODE | USART_EIGHT_BIT | USART_CONT_RX |
USART_BRGH_LOW, BAUD_RATE_GEN);
//	baudUSART(BAUD_8_BIT_RATE | BAUD_AUTO_OFF);

	//Set Timer0 Control Register
```

```
	//INTCON = 0x20;		//disable global and enable TMR0 interrupt
	//INTCON2 = 0x84;		//TMR0 high priority
	//RCONbits.IPEN = 1;		//enable priority levels
	//8bit mode, 10ms interrupt (100tick/sec)
	T0CON = 0b11000101;			//4MHz 8bit,T0PS=1:64
	//T0CON = 0b11000111;		//16MHz 8bit,T0PS=1:256
	TMR0IE = 1;
	TMR0IP = 1;

	//UART1 for RF Transmitter
	SPBRG=25;			//9600bps 4MHz
	//SPBRG=207;			//207=1200,25=9600bps :
4MHz,BRGH=1,BRG16=0
	RCSTA=0x90;			//
	TXSTA=0x24;			//
	BAUDCON1bits.BRG16=0;
	BAUDCON1bits.RXDTP=1; //Invert receive signal as MB1010 datasheet
specification
	//TXSTAbits.BRGH=1;
	//RCSTAbits.SPEN = 1;
	PIE1bits.RC1IE = 1;
//	RCSTAbits.CREN = 0;		//disable receiver
	//TXSTAbits.TXEN = 1;

	//UART2 for Ultrasonic Sensor
//	SPBRG2 = 25;				//25=9600bps :
4MHz,BRGH=1,BRG16=0
//	RCSTA2=0x90;			//
//	TXSTA2=0x24;			//
//	BAUDCON2bits.BRG16=0;
//	BAUDCON2bits.RXDTP=1; //Invert receive signal as MB1010 datasheet
specification
//	TXSTA2bits.BRGH=1;
	//RCSTA2bits.SPEN = 1;
	//RCSTA2bits.CREN = 1;
	//TXSTA2bits.TXEN = 0;		//disable transmitter
	/* Enable Receive Interrupt */
//	PIE3bits.RC2IE = 1;
	/* Enable interrupt priority */
	RCONbits.IPEN = 1;
	/* Make receive interrupt high priority */
	IPR3bits.RC2IP = 1;
	//IPR1bits.TXIP = 1;
	INTCONbits.PEIE = 1;
	INTCONbits.GIEH = 1;		//enable interrupts

}

//DSP1
void DigitalSignalProcessing1(unsigned int Adc)
```

```
{
	DatH=AvgH;
	DatL=AvgL;
}

//Digital Signal Processing for Sharp GP2Y0A02YK Infrared Ranger
//Dist(cm)=(A+B*X)/(1+C*X+D*X*X)
//X=Sensor Voltage
//A=0.008271
//B=939.6
//C=-3.398
//D=17.339
unsigned char IR_Dist(unsigned char Adc)
{
	unsigned char i,j;

	for(i=0;i<(IR_MAX-1);i++)
	{
		if(Adc>=IR_Dat[i]) return IR_cm[i];
	}
	return IR_cm[i];
}

// ==================================
// ULTRASONIC SENSOR MODULE
// ==================================
void UltrasonicRead(void)
{
	unsigned char i,d;
	unsigned int dd;
	if(RxCnt==5){
		//
		dd = 0;
		for(i=1;i<4;i++){
			d = RxdBuf[i];
			if('0'<=d && d<='9'){
				dd *= 10;
				dd += (d-'0');
				//Putchar(d);
			}else return;
		}
		if(dd<=254){
			CDist = (unsigned char)dd;
			if(CDist<SDist){
				SDist=CDist;
			}
		}
	}
}
```

```
//------------------------------------------------------------------------
// Main Program
void main(void)
{
	unsigned char cs,d,i,j,k;
	unsigned int dd;
	OSCCON = 0b01010010;	//INTOSC 4MHz
	i=255; while(i) i--;
	HEADER = eeprom_read(0x00);
	//eeprom_write(0x00,0x41);	//left
	//eeprom_write(0x00,0x42);	//right
	HardwareInit();
	LED=1;
	msDelay(300);
	TxHex(HEADER); TxChar(0x0D); TxChar(0x0A);
	LED=0;
	TxdBuf[0]=HEADER;
	//
	TmrRxd=0;TmrTxd=TMRTXD;TmrStep=0;StepFlag=0;RxCnt=0;AdcSeq=0;
	SDist=0;
	CDist=0;
	//while(1){msDelay(500);LED=~LED;}
	//while(1){if(!TmrTxd){TmrTxd=TMRTXD;LED=~LED;}}
	//
	while(1){
		//
		ClrWdt();
		//
		if(!TmrTxd)
		{
			//
			//msDelay(500);
			TmrTxd=TMRTXD;
			//LED=1;
			//
			k=1;
			//Read Sensor ADC
			TxdBuf[k]=CDist;		//Ultrasonic
			k++;
			if(!AdcRead(8)) TxdBuf[k]=IR_Dist(Adc8); //IR - Left
			k++;
			if(!AdcRead(10)) TxdBuf[k]=IR_Dist(Adc8);	//IR - Right
			k++;
			if(!AdcRead(0)) TxdBuf[k]=Adc8;	//FSR1
			//TxdBuf[k++]=AdcH;
			//TxdBuf[k++]=AdcL;
			k++;
			if(!AdcRead(1))	TxdBuf[k]=Adc8;	//FSR2
			k++;
			if(!AdcRead(2))	TxdBuf[k]=Adc8;	//FSR3
```

```
			k++;
			/*
			AdcBuf[0][AdcSeq]=CDist;		//Ultrasonic
			AdcBuf[1][AdcSeq]=AdcRead(8);	//IR - Left
			AdcBuf[2][AdcSeq]=AdcRead(10);	//IR - Right
			AdcBuf[3][AdcSeq]=AdcRead(0);	//FSR1
			AdcBuf[4][AdcSeq]=AdcH; //AdcRead(1);	//FSR2
			AdcBuf[5][AdcSeq]=AdcL; //AdcRead(2);	//FSR3
			AdcSeq++;
			if(AdcSeq>=AVGMAX) AdcSeq=0;
			//Calculate Average
			*/
			//
			cs=0;
			for(i=0;i<=ADCMAX;i++)
			{
				cs += TxdBuf[i];
			}
			TxdBuf[k] = cs;

			//Foot step algorithm
			if(StepFlag)
			{
				if(TxdBuf[4]>=FSR_ON || TxdBuf[5]>=FSR_ON ||
TxdBuf[6]>=FSR_ON) TmrStep=100;
				if(TmrStep==0) StepFlag=0;
			}
			else
			{
				//if(TxdBuf[4]>=200 || TxdBuf[5]>=200 || TxdBuf[6]>=200)
				if(TxdBuf[4]>=FSR_ON && TxdBuf[5]>=FSR_ON &&
TxdBuf[6]>=FSR_ON)	//2013-11-29
				{
					LED=1;
					Send_Packet();
					StepFlag=1;
					TmrStep=100; //100tick=1sec
				}
			}
			//
			//Send_Packet();
			LED=0;
			//
		}
	}
}


//-------------------------------------------------------------------------
```