ULTRASONIC SENSOR CONFIGURATION FOR MOBILE ROBOT NAVIGATION SYSTEMS TO ASSIST VISUALLY IMPAIRED PERSON

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

FEBRUARY 2017

Dedicated to citizens of Malaysia

ACKNOWLEDGEMENT

I would like to take this opportunity to express my greatest gratitude towards my project supervisor, Assoc. Prof. Dr. Mohamad Noh Ahmad who had guided me throughout the project. He had given me valuable information and suggestions to complete the project successfully. His supervision, guidance, encouragement, patient and financial support given throughout the project are greatly appreciated.

Sincere thanks to my parents for their caring and understanding who stood by my side all the time. I would like to thank my parents for the moral support given by them.

My appreciations also extend to my postgraduate and undergraduate mates who had given me helpful discussions and suggestions to ensure the project is completed successfully on time.

I also would like to extend my thanks to Yip Zheng Hou for allowing me to use his Assistive Guide Robot as the test bed for my research.

ABSTRACT

Ultrasonic sensor is one of the electronic components used in designing a mobile robot navigation system to assist visually impaired person. However, no guideline or algorithm has been established so far to ease the selection and determination of optimum number of ultrasonic sensors to be used and the layout for the sensors. The purpose of this study is to obtain an algorithm that can be used as a guideline for selecting appropriate ultrasonic component model. The algorithm is used for determining the optimum numbers and optimum layout for ultrasonic sensors of interest when used for a mobile robot navigation system for a 180° obstacle detection using theoretical calculations. All theoretical values obtained are compared with real-time data using an actual ultrasonic sensor placed on experimental platform. This set up is used with different numbers and placements using the selected ultrasonic sensor, HC–SR04 and is compared with the theoretical values for validation. Then, relevant equations are used to calculate the number of sensors and layout used for another ultrasonic sensor, MA40B8 to show the correctness of the equations used in this study. The MA40B8 ultrasonic sensor was originally used for a 360° obstacle detection system. It is proven that the equations used in this study are valid theoretically and experimentally. The algorithm can also be used to decide the optimum numbers and optimum layout for ultrasonic sensors for a 180° obstacle detection.

ABSTRAK

Penderia ultrasonik adalah salah satu komponen elektronik yang digunakan dalam mereka bentuk sistem navigasi robot mudah alih untuk membantu orang cacat penglihatan. Walau bagaimanapun, tiada garis panduan atau algoritma telah diwujudkan setakat ini untuk memudahkan pemilihan dan penentuan bilangan optimum penderia ultrasonik untuk digunakan dan susun atur untuk penderia. Kajian ini bertujuan mendapatkan satu algoritma yang boleh digunakan sebagai garis panduan untuk memilih model komponen ultrasonik yang sesuai. Algoritma ini digunakan untuk menentukan bilangan dan susun atur optimum untuk penderia ultrasonik yang diingini apabila digunakan untuk sistem navigasi robot mudah alih untuk mengesan halangan 180° menggunakan pengiraan secara teori. Semua nilai teori yang diperolehi dibandingkan dengan data masa nyata menggunakan penderia ultrasonik sebenar yang diletakkan di atas pelantar eksperimen. Pemasangan ini digunakan dengan bilangan dan susun atur yang berbeza menggunakan penderia terpilih ultrasonik, HC–SR04 dan dibandingkan dengan nilai teori untuk pengesahan. Kemudian, persamaan-persamaan yang berkaitan digunakan untuk mengira bilangan penderia dan susun atur untuk penderia ultrasonik yang berbeza, MA40B8 untuk menunjukkan ketepatan persamaan yang digunakan dalam kajian ini. Penderia ultrasonik MA40B8 pada asalnya digunakan untuk sistem pengesanan halangan 360°. Ia terbukti bahawa persamaan yang digunakan dalam kajian ini adalah sah secara teori dan uji kaji. Algoritma ini juga boleh digunakan untuk menentukan nombor optimum dan susun atur optimum untuk penderia ultrasonik untuk pengesanan halangan 180°.

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LIST OF ABBREVIATIONS

ETA	-	Electronic Travel Aid
GPS	-	Global Positioning System
2D	-	Two Dimensional Space
3D	-	Three Dimensional Space
SWAN	-	System for Wearable Audio Navigation
DGPS	-	Differential Global Positioning System
GIS	-	Geographic Information System or Graphical Information System
PC	-	Personal Computer
LRFR	-	Laser Range Finder Radar
OEM	-	Original Equipment Manufacturer
CCD	-	Charged – coupled Device
DC	-	Direct Current
PDA	-	Personal Digital Assistant
RFID	-	Radio-Frequency Identification
IDE	-	Integrated Development Environment
DGP	-	Digital Signal Processing
MIPS		Millions of Instruction per Second

RDOS	-	Real – time Dangling Objects
PWM	-	Pulse Width Modulation
ICSP	-	In-Circuit Serial Programming
USB	-	Universal Serial Bus
AC	-	Alternating Current
PLL	-	Phase-Locked Loop
RPM	-	Revolution per Minute
PCB	-	Printed Circuit Board
VCC	-	IC power-supply pin
GND	-	Ground pin
ECHO	-	Echo pin
TRIG	-	Trigger pin
QR	-	Quick Response

LIST OF SYMBOLS

V	-	Voltage
cm	-	centimeter
mA	-	miliAmpere
kHz	-	kiloHertz
MHz	-	MegaHertz
mm	-	milimeter
RM	-	Ringgit Malaysia
Hz	-	Hertz
O	-	Origin of Placement
r	-	Radius of Sensor placement, Overlapped ultrasonic ring radius
S_N	-	Sensor number N
w	-	Width of ultrasonic sensor
α	-	Beam width of ultrasonic sensor
θ	-	Angle between two sensors
β	-	Regular spacing between ultrasonic sensors
$\rho_{s,min}$	-	Ultrasonic sensor minimum sensing distance
$\rho_{s,max}$	-	Ultrasonic sensor maximum sensing distance

$\rho_{o,max}$	-	Maximum range of obstacle detection
$\rho_{o,min}$	-	Minimum range of obstacle detection
N	-	Number of ultrasonic sensors
S_{eff}	-	Degree of positional uncertainty of an overlapped ultrasonic sensor ring
$S(A)$	-	Area of zone A
ς	-	Reduction ratio
s	-	seconds

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CHAPTER 1

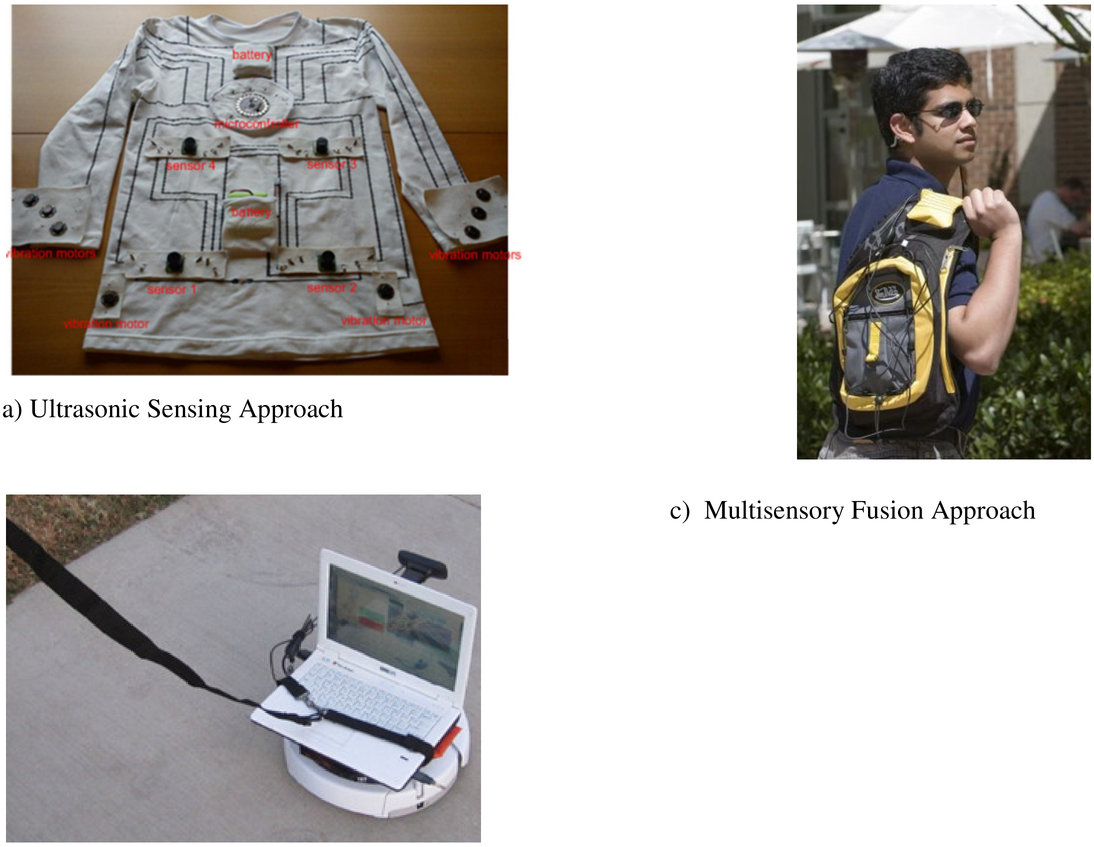
INTRODUCTION

1.1 Problem Background

Total blindness is the inability to tell light from dark, or the total inability to see. Visual impairment or low vision is a severe reduction in vision that cannot be corrected with standard glasses or contact lenses and reduces a person's ability to function at certain or all tasks (Farlex Inc., 2012). According to the latest statistics, for Malaysia, there is a prevalence of 0.5% of the population to become blind which are mainly caused by cataract, glaucoma, and retinal and corneal problems (International Agency for the Prevention of Blindness, 2015).

One of the biggest challenges by blind people is when they are moving outdoors where there are uneven terrains, obstacles such as cars, rocks and holes and not knowing where to go without the ability to see. Traditionally, blind people use walking sticks or guide dogs to help them move around and they are limited to move only around familiar places. Navigation is the science (or art) of directing the course of a mobile robot as it traverses the environment (Ratner and McKerrow, 2003). Inherent in any navigation scheme is the desire to reach a destination without getting lost or crashing into another object. Thus in conclusion, the navigation problem is to find a path from start to goal, which meets the task constraints, and to traverse that path without collision.

Nowadays, guide cane and guide dog are still the mainstream of aids and appliances for visually impaired people to navigate safely against obstacles and other hazards. Guide cane is cheap and portable, but requires in-depth training to use it effectively. When blind people are being trained to use a guide cane, there are several factors that they will affect how long it will take for them to get use to using one to move independently, especially when travelling outdoors. According to Bickford (1996), the three main factors that affect the training time needed are the background of the blind person with how familiar they are travelling at certain outdoor areas, the aptitude of the blind person whether they are willing to be more dependent on themselves or are they more comfortable with someone travelling with them and the amount of time the blind person puts into applying what they have practiced into their daily lives. On the other hand, according to VisionAware (2015), a guide dog is very expensive and while it can provide companionship for the blind, will add more responsibility for the blind as the guide dogs need grooming, feeding and health care for it to remain healthy. In addition, guide dogs also needed to be constantly put into use so that the guide dogs do not forget their training and have maybe 8-10 years of good service before they are considered too old to be reliable. Therefore, the development of an alternative aid that requires minimum maintenance and fast to adapt for use in a form of engineering system is strongly required. Figure 1.1 shows several examples of various navigation systems for the blind people developed so far by Bahadir *et al.* (2012), Galatas *et al.* (2011) and Georgia Tech (Science Daily, 2006).



a) Ultrasonic Sensing Approach

b) Vision – Based Positioning Approach

c) Multisensory Fusion Approach

Figure 1.1 Various Outdoor navigation systems for blind people

As of date, as technology continues to evolve, several new systems have been created to help the blind people navigate their way around in particular to detect obstacles during outdoor excursions using a variety of different sensors or systems. Several of the most popular approaches to develop an outdoor navigation system are the ultrasonic sensing, vision-based positioning, global positioning systems (GPS) and the multisensory approach.

One of the known approaches is the vision-based obstacle detection. These systems use image processing techniques to enable the system to identify the path to be taken and the obstacles in the path. Most people who used this approach normally use the images captured to determine if the object is an obstacle. This method need to use the correct method of image filtering and processing to differentiate between the many objects captured in the image, which in failing to do so will cause improper identification of the object or ignoring an obstacle that must be avoided. Some systems developed using this method is less effective outdoors to compensate for the system's increase in accuracy and performance (Galatas *et al.*, 2011), false readings when conditions are met (Weichselbaum *et al.*, 2013) or inaccurate reading due to camera setting used and the environment lighting (Murthy and Varaprasad, 2014).

Another approach used in designing outdoor navigation systems is using Global Positioning Systems (GPS) to determine their location and the path to their destination. The outdoor navigation of visually impaired people is based on data from the GPS maps and Geographic Information Systems (GIS) such as Wayfinder Access (Wayfinder Systems AB), Trekker and BrailleNote GPS (Human Ware), MobileGeo (Code Factory) and Drishti (University of Florida) (Ivanov, 2012). This system however is only most effective outdoors and is unable to be used in regions with insufficient detailed GPS maps or no existing maps at all. This system also normally is paired with voice synthesizer to help guide the user to the desired destination.

Ultrasonic approach is another popular method in designing outdoor navigation system, in particular detecting objects within the sensors range. This approach is one of the most popular approaches used to detect obstacles for an outdoor navigation system. The sensor can be placed on a mobile platform or placed somewhere on the user's body or belonging to detect the obstacles in the direction the sensor is pointing to. The number of ultrasonic sensors used in each approach differs according to sensor specification and system requirement although no proper guideline or algorithm has been established to determine the optimum number of sensors used.

There are also other approaches used for outdoor navigation systems that were less well known. Some researchers used a device that records the direction of the planned routes and guides the blind person via voice synthesizer. Other researchers used Radio Frequency Identification (RFID) approach in developing their navigation system for the blind person. Some even used a laser scanner to detect obstacles for their navigation system although it could only be used indoors (Fu *et al.*, 2012).

There also attempt to use multisensory fusion approach to overcome the shortcomings of some approaches. This approach uses two or more of the approaches mentioned earlier to improve the accuracy and performance of the navigation system which at times will lead to an increase in cost. One of the most popular approaches to be used in the multisensory fusion approach is the ultrasonic sensor which is used to detect the obstacles that the system will find when in use. The ultrasonic sensor gives an accurate reading for the distance of the obstacles it will find as long they are at the same level as the ultrasonic sensor.

1.2 Problem Statement

Considering the range the sensor coverage and price per unit when compared to infrared or laser sensors or vision based methods, the ultrasonic sensor is within reasonable price and it covers the range within a certain angle range as well as the direction the sensor is facing. Ultrasonic sensors are also be used for indoor or outdoor navigation.

For an efficient obstacle detection using ultrasonic sensors, an appropriate ultrasonic sensor model needs to be selected among the many variations available today. Typically the data provided in the datasheet of an ultrasonic sensor includes range, detection angle and supply voltage as well as the size of the sensor. However among the ultrasonic sensor approaches done so far, none have reported why a particular ultrasonic sensor model was selected to be used in their work. The lack of studies on factors to be considered in selecting an appropriate ultrasonic sensor model needs to be addressed.

On top of it, the range of a single typical ultrasonic sensor does not cover the minimum of 180° coverage in front of the navigation system since most ultrasonic sensors beam width does not exceed 90° each and the use of placing a single ultrasonic sensor on a rotating platform will leave blind spots on the direction the sensor is not facing. Thus, for full coverage multiple ultrasonic sensors will be needed to cover the range of 180° to increase the accuracy and decrease the scan time (Jung *et al.*, 2007).

Even if a suitable ultrasonic sensor model is chosen, it also leads to several other problems. Multiple high directivity ultrasonic sensors are more costly compared to multiple low directivity ultrasonic sensors especially to ensure all the possible obstacles are detected. As a method to reduce the cost of developing the system, multiple low directivity ultrasonic sensors would be used instead (Kim and Kim, 2011). The use of multiple ultrasonic sensors needs to address the optimum layout and number of ultrasonic sensors used as well as the best range for the ultrasonic sensors used for a 180° coverage efficient obstacle detection.

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1.3 Objective

The objectives of this research are as follows:

i. To determine the optimum number of ultrasonic sensors for obstacle detection in 180° coverage
ii. To obtain the optimum layout based on the optimum number of ultrasonic sensors for 180° coverage
iii. To determine the best detection range of 180° coverage for the sensor selected

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1.4 Scope of Work

This research concentrates on the hardware and experimental testing of a selected ultrasonic sensor model to compare the theoretical results obtained based on the same model.

However, there are several limitations that need to be noted for the experiments done in this research. The results obtained are done based on the experiments conducted using ultrasonic sensor model HC–SR04. Another limitation is that the research concentrates on obstacle detection for only 180° facing the front. The sensors are also placed 5 cm above ground, which was determined after several testing to ensure that the sensors only detect the obstacles in front of it as the mobile platform moves. The size of the platform also depends on the size of the chosen ultrasonic sensor and the number of ultrasonic sensors used.

Thus, the research done can be used as a guideline to help select the most suitable ultrasonic sensor and determine the optimum number of sensors, layout and range for the model used for obstacle detection for a 180° angle. The theoretical formulae used in this research can be used for other ultrasonic models by replacing the necessary values with the models corresponding specifications.

To process the data from the ultrasonic sensors, an Arduino Mega 2560 microcontroller is used, as it has sufficient amount of ports that will allow the interface between the chosen number of ultrasonic sensor with the microcontroller, to convert the distance readings obtained from the sensor to a readable format that can be used by the Arduino Interface program at the speed of 16 MIPS throughput at 16 MHz. The Arduino Interface program is also run from an ACER TravelMate 6292 laptop which allows the measurements obtained from the sensor to be read and allows future adjustments to be made accordingly.

1.5 Thesis Layout

The remaining contents of this thesis are presented in this section.

Chapter 2 will discuss the literature review of researches and theories related covering the different approaches used in creating a navigation system for blind people such as ultrasonic sensing, vision-based positioning, Global Positioning System (GPS) and multisensory approach.

Chapter 3 explains the methodology used to achieve the objectives of the research. It also discusses how to obtain the theoretical values of the optimum number of ultrasonic sensors and layout for the sensors in the same chapter. The experimental setup used for the data collection as well as the electronics used are also explained.

Chapter 4 discusses the results of the research. Comparisons between the experimental results with the theoretical values were also made.

Chapter 5 concludes the findings based on the research done. Recommendations for future research were also suggested.

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