SONAR SENSOR FOR AN AUTONOMOUS MOBILE ROBOT

MOHAMED NAJIB RIBUAN
Msc MECHATRONICS

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NEWCASTLE UNIVERSITY
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SCHOOL OF MECHANICAL & SYSTEMS ENGINEERING

Newcastle University

Sonar Sensor for an Autonomous Mobile Robot

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Author : Mohamed Najib Ribuan

Course Title : Msc Mechatronics

Supervisor : Dr Robert Bicker & Dr John Hedley

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Declaration

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Abstract

In order to interact with environment, a mobile robot needs an external sensor especially to detect an obstacle along its path to its final destination. A sensor capable to detect any kind of object is very crucial to an autonomous mobile robot and is investigated in this works. The selection of a proper sensor is discussed in this report as well as the development of the sensor in order to achieve the functional sensor system for the application. Moreover, the performance of the constructed sensor is also presented to show the sensor capability on performing the specific task.

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CHAPTER 1

1.0 INTRODUCTION

1.1 Overview

In general, this dissertation is about to investigate an obstacle detection and collision avoidance system for a mobile robot. The system described is for a mobile robot working in indoor environment specifically in a hospital and a healthcare centre. With a rapid development of mobile robot technology, the identification of the best system for the mobile robot working in the specific condition has been very crucial. Number of factors need be considered such as performance and cost in order to determine an optimum solution to the application.

In this work, an obstacle is defined as an object which prevents the robot from moving to its goal or its final location. These objects comprise from dynamic and static obstacle. For instance, walking humans as well as patients are considered as dynamic obstacle whereas wheelchair and hospital bed are an example of static obstacle. Hence, a sensor capable for detecting these kinds of objects is very crucial to avoid any collision which would cause a chaos in the specific environment. Thus it also enables the robot to achieve its final destination such as to attend patient for serving food on supplying medicine instead of nurse assistance that experiencing shortage, currently.

Meanwhile, collision avoidance can be described as a method or way on how the robot avoid the obstacle without hitting or touching it and able to continue its path to its final location. It is important to secure the robot from colliding as it can cause harm or injury to a normal person especially to the patient. As described in obstacle detection, collision avoidance can be sub-divided into

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two parts as well, static obstacle (static environment) and collision avoidance for a moving object (dynamic environment).

The mobile robot developed in this project is aimed to give a contribution to a IWARD project which stands for Intelligent Robot Swarm for Attendance, Recognition, Cleaning and Delivery. The project aim is to give a solution of outnumbered staff in hospital/ healthcare center that becomes a critical problem in European countries especially in UK for the past few years. The robot are expected to be able to deliver support in the hospital such as monitoring hospital wards, recognizing patient who need attention, providing information about the patient location as well as cleaning and servicing patient including delivering food, medicine and clothes. The robots work in group thus beside detecting human or any obstacle it has to be able to detect their associate as well. More information about the project is available at http://www.iward.eu/cms/.

1.2 Aims and Objectives

The aim of this study was first, to produce a sensor system for obstacle detection and collision avoidance for a mobile robot. The system is only a part of a few components in the mobile robot system. Besides a wide range of sensor such as sonar, radar and lidar a proper sensor for the application need to be identified for the application. Secondly, the system developed is from off-the-shelf components both hardware and software to achieve minimal cost yet reliable to give good result. The sensor, in fact, is able to give a different output for every different distance measured continually as a result of good hardware and software implementation. Finally, the system is tested and its performance is investigated with experimental works in order to provide technical information to the developed system.

The objective of this work was to provide a detection system for a mobile robot to be able to move inside hospital/ healthcare environment without hitting any obstacle. The system will prevent the robot any collision. This is

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very crucial especially when the robot works in hospital where it has to interact with patient as well as human such as doctors, nurses and visitors Secondly, the objective of the project was to establish a low cost system for the application. The constructed system is from off-the-shelf components as the number of the robot for the application must be tremendous. However the performances of the developed sensor are uncompromising. In addition, the sensor system generated need to be flexible and able to integrate with different application. This modular concept of the system will offer an advantage to attach to any system where the obstacle detection and collision avoidance are crucial for their application.

1.3 Significance of Works

This work contributes to a number of significance subjects. First, a reliable and low cost system for obstacle detection and collision avoidance for mobile robot is produced to secure the robot from hitting any object inside a hospital or healthcare centre which might cause an injury especially to the patient. Secondly, with the capability of the system an intelligence robot is generated where it can decide the optimum path to avoid the object by processing the input from the sensor system. Consequently, this will improve the existing system which is also the third contribution of this work. Finally, with this intelligence system it might not only used for the robot but capable to integrate with different application. For example, this system might be used in automotive industry such as to the busses or heavy vehicles. It will benefit in reduction of accident rate among heavy vehicles which usually result to catastrophe.

1.4 Thesis Outline

This thesis is organized as follows. Chapter 1 introduce the theme of the research is to give the reader an overview about the context of the work as

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well as the aims and the objectives of the work followed by the significance of the investigation.

In Chapter 2, the background of the project is discussed. This will cover an extensive explanation about mobile robot system as well as sensors used for obstacle detection and collision avoidance system. A wide range of sensor available for the application is also explained followed by the evaluation of each sensor to determine the best sensor for the application.

A literature review in Chapter 3 discussed about the selected type of sensor. This includes the background of the sensors, its application as well as the limitation confine the ability of the sensor.

Chapter 4 contains a detailed description of the theory and modeling of the system in order to develop the hardware and software of the system. The components involved as well as the costs incurred are also listed.

The components involved as well as the costs incurred are listed in experimental system for both hardware and software in Chapter 5. The functions of each of the component are also explained in this chapter.

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Chapter 6 explains in details about the experiment conducted to investigate the performance of the system. This includes the experiment setup, setting of equipment as well as the procedure in executing the experiment.

The result of the experiment is shown in Chapter 7. An explanation also been given on how the result is obtained to give a clear vision about the data achieve from the experiment.

Finally, the Discussion, Conclusion and Future Works are described in Chapter 8. The finding of this works is discussed and this gives the answer to the result of the works.

CHAPTER 2

2.0 BACKGROUND

2.1 Mobile Robot System

Robots ability and their function had been skyrocketed in the past few years especially in industrial application as well as educational level. More and more robots were invented with sophisticated and multitask function. Among the famous robot introduced to the public were humanoid robot Asimo by Honda Corporation and Swimming Robot from Massachusetts Institute of Technology (MIT). These progresses had showed that robots become important to human environment especially in future generation.

Generally, robot can be divided into 2 categories, industrial robot and mobile robot. Industrial robot is designed specifically for industrial application where the task may cause hazardous for human life or a repetitive job such as pick and place. Hazardous environments like excessive heat, noise, fumes and sparks in manufacturing processes; welding, spraying and moulding for instance, may put the workers to harm an injury. Therefore robot becomes perfect commutation for human in addition to decrease human error when conducting the manufacturing process which results in poor production and quality.

This industrial robot also referred as robotics arm or robot manipulator. It has several configurations such as cartesian, cylindrical, spherical, articulated and scara which actually describes the workspace of the robotics arm. The configuration is basically base on type of joint of the robot arm whether it is prismatic or revolute type joint. Nonetheless, articulated robotics arm is widely employed in many industrial applications where it comes from different number of axis which indicates the degree of freedom the robot has.

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Among manufacturer of industrial robot available in the market at present are ABB, Denso Robotics, Fanuc Robotics and Staubli Robotics.

Another category of robot is a mobile robot which becomes the topic of interest. It can be sub-divided into 3 more categories, legged robot, wheeled robot and anthropomorphic robot. Legged robot usually referred as walking robot or crawling robot is a type of robot with number of legs. The number begins from only a single leg up to twelve legs and it depends on a few aspects including robot body, stability and of course the robot functional.

In order to move, legged robot requires an analysis of foot placement which forms a point of contact with the ground referred as gait. The stride of the movement however is called trot gait. The gait analysis is different for different speed of movement such as walking and running. Therefore the analysis of the gait becomes essential since it governs the robot stability as well as the robot speed. An example of single legged robot was designed by MIT in 1995 which called 3D One-Leg Hopper and a six-leg robot, Servobot designed by Indiana University.

Wheeled robot was defined by Muir and Neuman (1986) as a robot capable of moving on any surface merely by the actuation of wheel incorporated in the robot which has constant contact with the ground. In term of stability, wheeled robot has a better stability in comparison to the legged robot especially in dynamics behaviour. However it also subjected to the wheel configuration the robot employed. In the next paragraph, wheeled robot is discussed extensively excluding the anthropomorphic robot which is briefly introduced to cover the area of investigation.

Among many types of robot, wheeled robot was the favourite for many including students, hobbyists and beginners interested in building a robot. This is because the simplicity and straight-forward functional of the components involve in constructing the robot. For instance, mobilerobots.com provides a wide rage of Pioneer robot and Seekur robot used to perform tasks like assisting in delivery and handling purposes to anti-terror equipment. Another

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example was from popular kid toys, Lego that provides HandyBug a Lego Mindstorms based robot as an early introduction for the beginner interested in mobile robot construction.

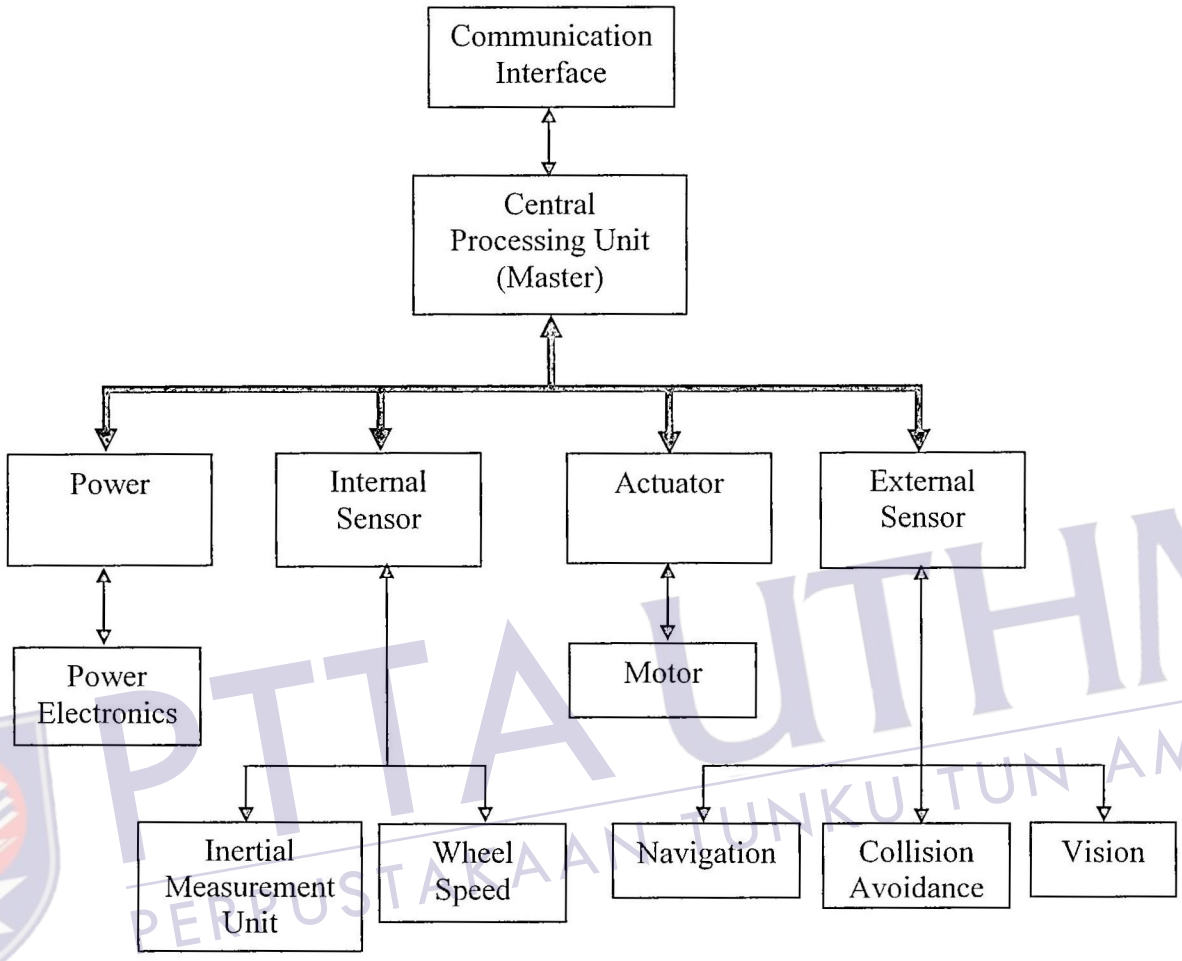

Figure 2.1 Mobile robot system components

Basically, a mobile robot consists of a system illustrated in Figure 2.1. The system comprises of Central Processing Unit (Master) as the main controller of the robot. It controls each sub-component of the system such as Power Component, Internal Sensor Component, Actuator Component and External Sensor Component. These sub-components will send the information as an input to the master controller whenever it is needed and this is in fact a two way communication between the master and the sub-components. There are numbers of communication protocol between the CPU and its sub-component

available such as RS 232, RS 485, Modbus and Control Area Network (CAN) bus subject to the requirement of speed and number of sub-component.

Power component provides the power supply for all the electrical and electronic components in the robot system. Since it has to be mobile, the power component usually acquired from battery pack or rechargeable battery. The battery type includes lead-acid, nickel-cadmium (NiCd), nickel metal hydride (NiMH) and lithium-ion (Li-Ion) cell. Number of aspects need to be put into consideration in order to select a proper type of power pack. For instance, the operating voltage, output current, operating time, charging time and total weight of the power pack are among the important elements to think as it determines the operating time of the robot in total.

Meanwhile, an autonomous power system is a power component with its own power management system capable to acknowledge the main controller about the level of the power available. Upon receiving the information, it will decide to go to the docking station for recharging thus preventing the robot from stalling on the pathway. Since the power required to operate the robot is a direct current (DC) supply a power electronics module is required for charging the battery at the docking station where the normal operating voltage and frequency is 240 VAC and 50 Hz.

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Internal sensor for a mobile robot can be described as a sensor which provides information for its own system. For instance, an encoder placed on the motor shaft will give information about position and rotating direction upon controlling the motor. Another example of internal sensor is Inertial Measurement Unit where it comprises an accelerometer for acceleration measurement and gyroscope to maintain the orientation of the robot.

For a basic mobile robot that only can move without carrying any task the actuator involves is merely a motor to drive the robot. There are a few factors that must be put into account when selecting the motor. The total weight of robot, maximum speed, operating speed, power consumption as well as torque generated by the motor and wheel configuration are things need to be

considered before choosing number and type of motor that will be used. Several type of motors available for selection including stepper motor, brushed motor, brushless motor and smart motor available from Animatics.

In contrast, an External Sensor Component consists of a number of sensors to make the robot interacts with the environment. For example a navigation system, collision avoidance system and vision system enable the robot interprets the condition of the surrounding before make a decision to proceed into the next action. Moreover these systems will reflect the intelligence of the robot whether it achieves fully autonomous robot or required an assistant in order to operate decently.

In robot navigation system, among technology offered for the system are Light Detection and Ranging (LIDAR), Radio Detection and Ranging (RADAR), Sound Detection and Ranging (SONAR), beacon light and Radio Frequency (RF) tags. However, each of the sensors operates in different principle hence its application is determined by the suitability of sensor used. Moreover the price of the unit also needs to be considered since a top-notch item comes with high price tag. For instance, LMS 200 LIDAR sensor from SICK Company will cost about GBP 2500 per unit which able to give 3D images for the navigation system.

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Likewise, navigation system and vision system of the robot also comes from advance technology. The higher resolution of the coloured camera in a small compact package came with expensive price. Nevertheless, with fast development of personal computer (PC) and faster internet connection speed lead to a cheaper webcam for video conferences which later adapted to the robot vision system. Consequently numerous tasks such as capturing or identifying object can be performed by the robot before the manipulation of object is executed in order to complete a particular task.

On the other hand, collision avoidance system offers a vast selection of sensors. It begins with contact type sensor such as microswitch which is actually a mechanical type of switch usually used as bumper sensor. This kind

of sensor also referred as tactile sensor. An alternative to this sensor is a proximity sensor which responds as mechanical switch that initiates switch action when an object is close to the sensor. Proximity sensor is classified as a non-contact sensor but in a very short range up to 30 centimeter. Contrary, a distance/ range sensor provides information of a distance between the robot and the obstacle. It is also a non-contact type of sensor capable to measure up to 30 meter. The next topic will discussed about proximity sensors followed by sensors for ranging which is the topic of investigation.

2.2 Proximity Sensors

Since the tactile sensor required direct contact between the obstacle and the robot it is always preferred as the fail-safe mode sensor in case the proximity sensors or the range sensor unable to detect the object. However, with the demand of good reliablity and durability as well as good performance proximity sensor becomes an alternative to the tactile sensor. Proximity sensor can be classified into 6 categories - magnetic, inductive, ultrasonic, microwave, optical and capacitive sensor. Table 2.1 summarises the principle of proximity sensors as well as the advantage and disadvantages of each type of the sensors.

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Table 2.1 Type of proximity sensors

Sensor type	Principle	Advantage	Disadvantage
Magnetic (Reed switch)	An external magnetic flux from object pulls the flexible reed together to make a close circuit for the electrical diagram	Cheap and robust device	Not suitable for bouncing and vibrating application Small range
Magnetic (Hall – effect)	An external magnetic field induced a small voltage across a conductor carrying	Good stability and sensitivity. Fast response time.	Output voltage determined by material-dependent Hall coefficient Small range

	current		
Magnetic (Magnetoresistive)	An external magnetic field cause changing in direction of magnetization of conductive material change the resistivity of the material	Greater range than Hall-effect and good temperature stability	Nonlinear and bistable in internal magnetization direction Small range
Inductive	Current is induced in a coil wounding around ferrite when object close to the electromagnetic field	Suitable for metallic object	Limited sensing range Small range
Capacitive	Different dielectric value of object give different capacitive value between the electrodes	Capable to detect metallic and non-metallic object	Sensitive to temperature and humidity Small range
Ultrasonic	Transmitter generates ultrasonic wave and receiver detect the reflected echo and calculate time of flight to determine the range	Capable to detect liquid and solid object	Detection range depends on emitted power, reflectivity, cross-sectional area and directivity Long range
Microwave	Same principle as ultrasonic but using microwave wavelength	Capable to determine speed using Doppler shift analysis	High operating frequency distort surrounding electrical equipment Long range
Optical	Reflected light from light source is detected by receiver – photodiode	Extendable using fibre optic cable into hazardous area	Interference from ambient light source Medium to long range

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2.3 Sensors for Ranging

Due to limited capability of the proximity sensor distance sensor is preferred especially for an intelligent system in an autonomous mobile robot. It provides the information concerning the range between the robot and the obstacle. This input is very crucial for the system in order to detect the distance of the object before it can decide the way to prevent it. Basically distance sensor is an enhancement of proximity sensor which also a non-contact type of sensor. With the implementation of ranging technique the distance sensor can be realized based on ultrasonic, microwave and optical proximity sensor. Among ranging technique used for distance sensors are:

1. Time-of-flight
2. Triangulation
3. Frequency modulation
4. Phase-shift modulation
5. Intensity of return signal
6. Interferometry
7. Swept focus

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Nevertheless not each of the technique can be applied to the sensors. For example, the first two techniques can simply adapted to these 3 sensors which also known as SONAR – ultrasonic sensor, RADAR – microwave sensor and LIDAR – optical/ light sensor. Although the third and forth technique can be implemented with radar and lidar the last three technique is adaptable only to the lidar type of sensor. Hence the proper selection of sensor with the right ranging technique is important which can accommodate the specification requirement. The next topic will discuss on the selection of sensor suitable for obstacle detection and collision avoidance application for an autonomous mobile robot.

2.4 Specification Requirement and Sensor Evaluation

In order to identify the suitable type of sensor to be used in the application, a specification requirement of the sensor need to be studied. This specification requirement contributes in selecting the right sensor over a wide range of sensor available. Furthermore, it also provides a guideline in term of the aspects need to be considered for each type of the sensor entirely without excluding or missing any potentially type of sensor available.

Table 2.2 simplifies sensor evaluation with respect to the sensor specification requirement. 4 types of sensors were accessed and rated from 0 to 3. The total score in the highest value indicates the most suitable sensor for the application. Consequently it summarizes the process of sensor selection which is very complicated and confusing without a proper and systematic approach.

Table 2.2 Evaluation table of type of sensor

Requirement	**Type of sensor**			
	Sonar	**Radar**	**Infrared**	**Lidar**
Measuring range	3	2	1	1
Operating Frequency	3	1	0	0
Beam angle	3	3	1	1
Reflectivity	3	2	1	1
Accuracy	2	2	3	3
Power	3	2	1	1
Weight	3	3	2	0
Cost	3	3	3	0
Total score	23	18	12	7

Note:

0 – Not suitable 1 – Suitable as last resort 2 – Almost suitable

3 – Very suitable

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Concerning the measuring range, sonar offers from 0.15 meter to 10.6 meter which meets the requirement of the application. However radar provides longer range up to 15 meter but the minimum range of 1.5 meter limits the selection. An infrared offers maximum range of 30.5 meter whereas the longest range offered by lidar from 1 meter minimum distance to 100 meter maximum distance. Due to above requirement range, the infrared and lidar were rated as a last resort.

In term of operating frequency, sonar operates within 1 kilo Hertz (kHz) to 350 kHz, followed by radar from 1 Giga Hertz (GHz) to 300 GHz. A much higher frequency offered by both infrared and lidar is not suitable since high frequency will affects the electrical equipment especially in the hospital or healthcare indoor environment.

For a ring sensor that covers around the robot body, beam angle is important as it dictates the number of sensor used for the system. Although a high number of sensors will give accurate result, the processing time to scan all the sensors might consume longer time thus resulting slow speed to the robot. Both sonar and radar provide 10° to 35° beam angle whilst very narrow beam offer by infrared and lidar range from 0.3 mili radian (mrad) to 0.5 mrad.

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Another requirement need to be considered for the sensor is the reflectivity. The reflectivity of wave depends on its wavelength as well as the frequency. High frequency wave will penetrate object such as plastic bottle or cardboard. Thus a low frequency suits the application since it will reflect almost all of the objects and in this case, sonar wave reflects most of the object in comparison with the rest sensors.

Accuracy is another element to be put into account as it governs the performance of the sensor. Sonar offers accuracy as smallest as ± 3 centimeter (cm) as well as radar in term of short range measurement but infrared and lidar provide better accuracy of ± 0.5 cm.

Regarding power consumption, sonar operates at the lowest voltage among the three at 5 VDC. The small power requirement is crucial as it will dictates the number of power supply such as battery pack needed. The low amount of power consumption also contributes to longer operating hour and it is very important especially for mobile system.

Another aspect associated with the power consumption is a weight. A heavyweight system required more power to the motor for moving thus a very lightweight system is far better to the system. Among those four, sonar ranging system comes with only under 0.3 kg instead almost 1 kg weight for both infrared and lidar.

Finally, the cost for the complete system also plays significant role. Again, sonar offers a very cheap system in comparison with the rest of the system that is important especially when a number of systems are required to accomplish the complete detection system of the robot.

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CHAPTER 3

3.0 LITERATURE REVIEW

3.1 Background of Sonar

Sound Navigation and Ranging or SONAR is one of the energy available to be exploited in our environment. It is in fact an acoustical energy that operates between 20 kilo Hertz (kHz) to 200 Mega Hertz (MHz) frequencies. Figure 3.1 shows the segment of frequency range of acoustical energy. This range operates above the human hearing limit in comparison to acoustic wave which enable us to listen to the music and speaking with colleague.

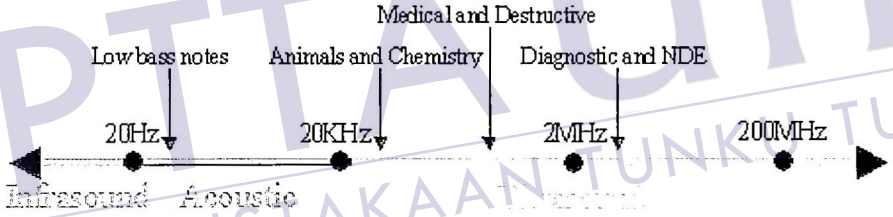

Figure 3.1 Acoustical energy frequency ranges *(source: http://en.wikipedia.org/wiki/Image:Ultrasound_range_diagram.png)*

Sonar often referred as ultrasonic wave or ultrasound, unlike acoustic wave is capable to propagate in many medium such as water, air and vacuum environment. Thus it offers a wide range of application. In addition, it is easily implemented without requirement of any of transmitting medium such as wires or cables to transmit the energy.

Sonar was recognized and had been used in many applications since it was first introduced backed in 1918 for position, velocity and orientation of underwater object measurement [Ulrich, 1983]. A vast number of researches had been conducted to expand the application of the sensor and mobile robot

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system had never left to take the advantages of the development. Despite it was first discovered in underwater application, sonar technology was implemented broadly in air propagation since it perform better than in underwater environment.

Sonar wave is generated from a transducer which receives an input from a voltage applied to the transducer. The transducer range from 3 types; magnetostrictive, piezoelectric and electrostatic. However, Campbell suggested magnetostrictive type of transducer was primarily used for high-power sonar and cleaning applications [Campbell, 1986].

Piezoelectric type of transducer changes its dimension when electrical potential is applied to its terminal. It will start to vibrate when the electrical potential oscillates at the crystal's resonant frequency. Campbell investigated that even a large force is generated only a small displacement of oscillation occurred resulting the sonar generated by piezoelectric type of transducer propagates effectively in solid and liquid medium rather than in the air [Campbell, 1986]. Furthermore, Everett stated mechanical inertia associated with the vibrating crystal results latency to achieve full performance as well as longer time to meet settling time after the voltage was removed [Everett, 1995].

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In contrast, electrostatic transducer generates small forces with large displacement amplitude thus works efficiently in the air in comparison with the piezoelectric transducer. In addition, Campbell also stated that a low-inertia foil membrane in the electrostatic transducer results in fast response both in generate and degenerate of the sonar wave [Campbell, 1986]. Meanwhile, Everett claimed electrostatic transducer has a broadband of frequency range but limited to several hundred kilohertz in contrast to megahertz range in piezoelectric transducer [Everett, 1995].

From the findings discussed in the previous paragraph, it can conclude that electrostatic type transducer gives quick response in comparison with piezoelectric type of transducer. Hence the electrostatic transducer turns to be

the most popular transducer in air propagation whereas the piezoelectric transducer best used in underwater environment.

3.2 Sonar Application

Sonar was first been used in an underwater application such as depth measurement as well as deep water fish finding [Frederikson & Howard, 1974]. The application was then exploited for underwater automatic camera focusing [Biber, et al., 1980].

However the application of sonar exploded enormously in an industrial measurement system especially in industrial process control [Asher, 1983], safety interlocks for dangerous machinery [Irwin & Caughman, 1985], non-destructive testing [Campbell, 1986], liquid level measurement [Shirley, 1989], stock measurement [Shirley, 1991] and intruder detection for security purposes [Smurlo & Everett, 1993]. Medical sector also takes the benefits of the ultrasound with sonography that provides medical imaging for woman pregnancy.

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The technology was only adapted in robotic application beginning early 80's after a microswitch system was found inadequate for nursing robot produced by Borenstein [Borenstein, 1985]. The application of employing sonar in mobile robot continually extended for collision avoidance [Everett, 1985; Borenstein, 1988], position location [Dunkin, 1985; Figueroa & Mahajan, 1994] velocity measurement [Milner, 1990], map-building [Chong, 1999], navigation [Choi, 2003; Belkhous, 2005] and wall following [Fazli, 2004]. Nevertheless, it also benefits the handicaps whose rely on wheelchair for their mobility where the sonar provides an obstacle detection system to the wheelchair [Sabatini, 1995; Castillo, 2006].

However, in collision avoidance system alone many had investigated the best strategy and method to employ the sonar system in the mobile robot application. Borenstein suggested that the strategy of collision avoidance

depends entirely on the performance of the ultrasonic sensor [Borenstein, 1988]. Despite the suggestion, he introduced Virtual Force Field (VFF) that comprised certainty grids for obstacle representation and potential field for navigation in order to improve inaccurate result from the sonar sensor as well as sensor fusion [Borenstein, 1989]. This significant finding benefits for the robot to move at higher speed and need not to stop in front of the obstacle as part of the method to avoid the object. The ability of sonar ring for laptop based robot had been demonstrated by Davidson and won Scavenger Hunt Competition with the established system [Davidson, 2005]. However poor angular precision limits the sensor to be used in localization application.

However, in map building application, Chong has demonstrated the use of sonar ring and implementation of Kalman filter as well as Julier-Uhlmann-Durrant-Whyte Kalman filter to improve the accuracy [Chong, 1999]. Meanwhile, in visual navigation system, Choi has demonstrated the use of sonar with CCD camera where shadow region occurred and cause problematic to the CCD camera and solved by sonar assistant [Choi, 2003].

Fazli, however proposed a system referred as advanced sonar ring capable to follow various shapes such as square, circle, concave as well as convex corner [Fazli, 2004]. The applications include wall following, obstacle avoidance and mapping by employing perpendicular movement of robot to the nearest object in the left side while supervising the distance to the wall to maintain the desired range. An explanation of advanced sonar ring by Fazli is also discussed in the next topic.

3.3 Sonar Limitation

Even tough sonar had been used widely in many application, it still have limitation and encounters problems. Borenstein discussed extensively the limitation of the ultrasonic sensor in obstacle avoidance application [Borenstein, 1988]. The obvious problems associate with sonar was

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interference or noise especially from neighbouring sensor that is very difficult to filter [Borenstein, 1989].

In general, sonar performance is influenced by following factors:

1. Beam angle
2. Operating frequency
3. Environment such as temperature, medium, pressure, interference from acoustic and radio frequency
4. Target consideration such as composition, size, shape and orientation of object.

However, the first two factors are manageable from the physical construction of the sensor. Hence the last two factors need an extra consideration and can be highlighted as interference and reflectivity problem.

Tsuzuki proposed a special configuration of sensor by widen the obstacle detection range where he located the sensor in right and left side of the robot in such a way that the entire area in front of the robot is covered [Tsuzuki, 1994]. However this is only applicable for square shaped robot. Sabatini, proposed sensor fusion consists of sensor array from sonar sensor as well as infrared detector to overcome the noise problem [Sabatini, 1995]. Nevertheless, the low-cost microcontroller employ with the sensor without computational and sophisticated digital signal processing technique with introduction of time-of-flight estimator proposed by Sabatini was for obstacle avoidance for a wheelchair [Sabatini, 1995].

A significant contribution was made by Borenstein where he introduced Error Eliminating Rapid Ultrasonic Firing (EERUF) [Borenstein, 1995]. The system enables fast firing and eliminates crosstalk with noise rejection capability. This works result in multiple robot collaboration even the same operating frequency is used and higher speed for robot movement is achieved.

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The exploitation of sonar sensor continues to improve the performance in robot application by introduction of sonar ring. Basically sonar ring is an array of sonar sensor arranged in circle shaped to cover the 360° around the robot. Yata stated that sonar ring is the favourite sensor for indoor mobile robot due to its simplicity and provide omni-directional distance information [Yata, 1999]. He proposed a system capable to measure accurate beam angle of reflecting point in single measurement by using difference of time-of-flight with simultaneous transmit and receive of all direction resulting fast measurement. Unfortunately the system still have a fault by overlapping echoes cause hiding of reflecting points near by. Consequently, the system is difficult to apply in complicated environment.

The popularity of sonar had never been stopped even some had investigate an infrared sensor for replacing sonar to eliminate noise problem [Reddy, 2004]. Instead Fazli proposed a sonar ring with Digital Signal Processing (DSP) capability referred as advanced sonar ring [Fazli, 2004]. Even the work have problem with cycle hopping, the solution for the problem was described extensively using interpolation solution and experiment data were demonstrated as well.

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The advanced sonar ring introduced by Fazli was in response with conventional sonar ring that difficult to perform application such as map building and localization due to low speed, inaccurate and interference from the conventional sonar ring [Fazli, 2004b]. The system offers accurate distance and bearing information using matched filtering technique as well as simultaneous firing by transmit coding based on pulse duration to distinguish with neighbouring transmitter. The DSP is able to sample 12 bit amplitude resolution at 1 miliseconds sample time and processed to give measuring range of 0.2 milimeter and 0.1° bearing [Fazli, 2005].

CHAPTER 4

4.0 THEORY AND MODELLING

4.1 Sound Navigation and Ranging (SONAR)

SONAR is actually an acronym for Sound Navigation and Ranging which basically exploits an ultrasonic/ acoustical energy as a sensor for measurement application such as distance, position and velocity measurement. It was discovered from animals like bats and dolphins which is how they detect an object along its path thus avoiding from hitting the object. Sonar operates above the normal limit of human hearing range from 20 kHz to 200 kHz.

A good example on how it works can be best described on how human can listen to the music. The sound from speaker was in fact a conversion of electrical energy to the acoustical energy. This energy propagates in the air and captured by our ears so as we can hear or listen to the radio or a hi-fi system. However in this example the operating frequency was within human hearing whereas the sonar operates beyond the normal frequency of human hearing.

To generate and detect the ultrasonic wave a transducer is required. A transducer that generates the sonar wave is referred as transmitter whilst a transducer that detects the signal was referred as receiver. In selecting the transducer, the operating frequency of the transducer is the most important part to consider in the first place. It will in fact specify the propagation speed of the wave and this is very crucial in calculation of the measurement.

Apart from the transducer, an electrical circuit capable to produce an input to the transducer as well to detect the signal is required. This is achieved from an electronics components and microcontroller that constructed the circuit to

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control the transmitting and receiving of sonar signal. This will covered extensively in the following chapter.

4.2 Time-of-Flight (TOF)

As mentioned in Chapter 2, time-of-flight is one of the ranging systems available to incorporate in the distance measurement application. This type of ranging technique is implemented in this works due to its simplicity. As the name implies, TOF utilizes the time period of the sonar wave travels in the air once it was transmitted and received at the receiver after it was reflected from an object. Figure 4.1 illustrates the principle of the TOF ranging system.

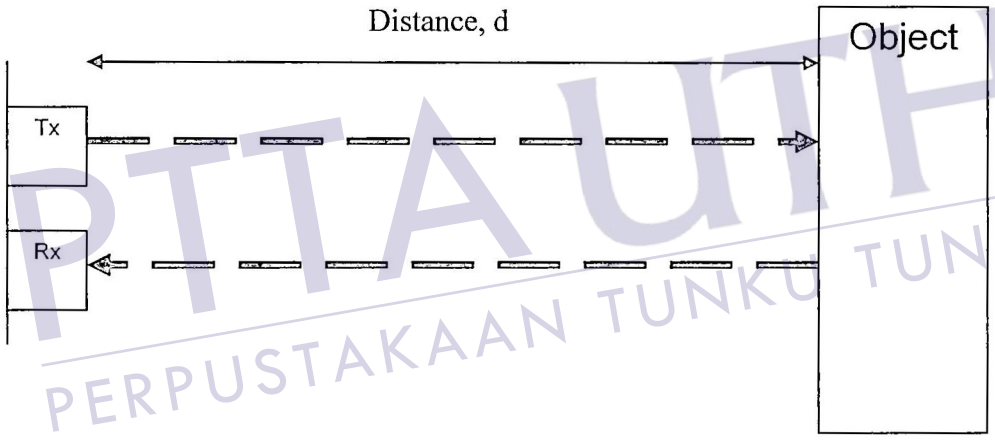

Figure 4.1 Time-of-flight ranging technique

The technique imposed by using 2 transducers configuration; one as a transmitter (Tx) and another as a receiver (Rx) whilst it is also possible to use a single transducer as the transmitter and receiver in the same time. However this configuration will limit the shortest detection limit of the sensor since a short period of time must be allocated to let the sonar wave transmitted before the sensor change its mode as a receiver. Nevertheless for a sonar-ring system that occupied a number of sensor, this configuration could save half of the budget since it only need half number of sensors in comparison to the 2 transducer configuration. Apparently, both operate in similar principle in order to obtain the distance between the transducer and the object.

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The distance of the object from the sensor is obtained by solving the following equation:

$$d = \frac{v \times t}{2} \qquad 1.0$$

where,

d = distance between the sensor and the object

v = speed of sound transmits in the air (343 m/s)

t = time traveled by the sonar wave (s)

The time will start counting when the transmitter generates the sonar wave. The sonar will travel in the air and back to the receiver after hitting the object. Once the chirp is detected by the receiver, the timing will stop counting and the distance is achieved by solving equation 1.0. The numerator 2 from the equation signifies the cycle of the transmission of the echo. For the transmitter and receiver located in opposite direction, the numerator 2 is replaced by 1.

Consequently, the timing pulse is very crucial as it governs the accurate result of the distance measurement. In this works, the microcontroller was designated to perform these processes. The following sub-topic will explain the role of the microcontroller to achieve the distance measurement.

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4.3 PIC Microcontroller

The microcontroller is required to execute the following tasks:

1. To trigger the sonar echo from transmitting circuit according to operating frequency of the signal
2. To set/ enable the timing pulse once the trigger pulse is detected by the microcontroller
3. To detect the reflected echo by its receiving circuit
4. To disable the timing pulse once the echo is detected
5. To send an output where its pulse width is proportional to the measured distance.

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