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Bachelor of Electronics Engineering Technology with Honours

ULTRASONIC DISTANCE MEASURING ROBOT (UDMERO)

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DECLARATION

I declare that this project report entitled "Ultrasonic Distance Measuring Robot" is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have checked this project report, and, in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of Bachelor of Electrical Engineering Technology with Honors (Industrial Automation & Robotics).



DEDICATION

To my beloved mother, Norhanim binti Husain, and my dear father, Rosley bin Abdul Rahman.



ABSTRACT

The growth of computer science, automatic control technology, and artificial intelligence lead to the autonomous mobile robot now being used in many different fields. Ultrasonic sensors are sensors that transmits and receives echoes to detect objects. This property is then exploited and used in the making of UDMERO, the ultrasonic distance measuring robot in this thesis. The sensors are perfect for measuring distances automatically and accurately in both easy and hard situations. The sensors work well in places where optical sensors can't work, like where there is smoke, dust, or something similar. UDMERO, which stands for ultrasonic distance measuring robot, is a robot that can automate measurements. For instance, it can find a wall in a square room that is empty, measure the distance, and figure out the area, which is then shown on an IIC LCD display. For UDMERO's mechanics, it uses a DC motor driver that is connected to two DC motors. UDMERO can be used to measure any given space with an exception of it being an empty room that is not exceed the \cup 100 1.0 sensors limitation. VERSITI TEKNIKAL MALAYSIA MELAKA

ABSTRAK

Pertumbuhan sains komputer, teknologi kawalan automatik dan kecerdasan buatan membawa kepada robot mudah alih autonomi yang kini digunakan dalam pelbagai bidang. Penderia ultrasonik ialah penderia yang menghantar dan menerima gema untuk mengesan objek. Harta ini kemudiannya dieksploitasi dan digunakan dalam pembuatan UDMERO, robot pengukur jarak ultrasonik dalam tesis ini. Penderia adalah sempurna untuk mengukur jarak secara automatik dan tepat dalam kedua-dua situasi mudah dan sukar. Penderia berfungsi dengan baik di tempat yang penderia optik tidak boleh berfungsi, seperti di mana terdapat asap, habuk atau sesuatu yang serupa. UDMERO, yang bermaksud robot pengukur jarak ultrasonik, ialah robot yang boleh mengautomasikan pengukuran. Sebagai contoh, ia boleh mencari dinding dalam bilik persegi yang kosong, mengukur jarak, dan mengetahui kawasan, yang kemudiannya ditunjukkan pada paparan LCD IIC. Untuk mekanik UDMERO, ia menggunakan pemacu motor DC yang disambungkan kepada dua motor DC. UDMERO boleh digunakan untuk mengukur mana-mana ruang dengan pengecualian sebagai bilik kosong yang tidak melebihi had penderia.

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TABLE OF CONTENTS

APPROVAL		
DECLARATION		i
APPROVAL		ii
DEDICATION		iii
ABSTRACT		iv
ABSTRAK		v
ACKNOWLEDGEM	ENTS	iii
TABLE OF CONTEN	AYSIA 4	iv
LIST OF TABLES		vi
LIST OF FIGURES		vii
LIST OF SYMBOLS		ix
LIST OF ABBREVIA	TIONS	X
LIST OF APPENDIC	اونىۋىرىسىتى تىكنىكل ملسىغ	xi
CHAPTER 11.1Background1.2Problem Statem1.3Project Objective1.4Scope of Project	INTRODUCTION SITUE AND ALAYSIA MELAKA nent ve et	1 1 1 2 2
CHAPTER 2	LITERATURE REVIEW	3
 2.1 Introduction 2.2 A Comparison I 2.2.1. Sensors 2.2.2. Sensor I 	Between Ultrasonic and Infrared in Distance Measuring Characteristics Findings	3 3 4 6
2.3 Ultrasonic Wor	king Principles	8
2.4 Ranging System 2.4.1 Ultrasor	n and Evaluation Parameters	9 10
2.4.2 Ultrasor	nic Parameters	11
2.4.2.1.	Range Of Distances And Angles	11
2.4.2.2.	Accuracy Data Of Massurement	12
2.4.2.3. 2.5 Ranging Matha	kate OI Measurement ds and Signal Processing	14 15
2.5 Ranging Metho 2.5.1. Time Of	f Flight (ToF) Method	15
2.5.1.1.	Amplitude Threshold Method (ATM)	15

		2.5.1.2. Envelope Fitting Method	17	
		2.5.1.3. Correlation Method	18	
	2.5.2.	2. Two Frequency Continuous Wave (TFCW) And Multi-Frequency		
		Continuous Waves (MFCW) Methods	20	
		2.5.2.1. Two Frequency Continuous Wave (TFCW)	20	
		2.5.2.2. Multi-Frequency Continuous Waves (MFCW)	22	
	2.5.3.	Signal Modulation Method	24	
		2.5.3.1. Binary Frequency Shift Keying (BFSK)	24	
		2.5.3.2. Amplitude Modulation (AM) Method	26	
	2.5.4.	Overall 29		
2.6	Summ	ary	30	
CHAI	PTER 3	METHODOLOGY	31	
3.1	Introdu	uction	31	
3.2	Metho	dology	32	
	3.2.1.	Schematic	33	
	3.2.2.	Hardware Development	34	
		3.2.2.1. Testing For Hardware	39	
	3.2.3.	Procedure setup	39	
3.3	Summ	ary	43	
СПАТ	OTED 4	DESULTS & DISCUSSION	11	
	IEK 4	KESULIS & DISCUSSION	44	
4.1			44	
4.2	Diffor	SIS	43	
4.5	Different Factors that affect sensor readings 4/			
4.4	Summ		51	
CHAI	PTER 5	lever mis we conclusion all	52	
5.1	Conclu	usion	52	
5.2	Future	Works RSITI TEKNIKAL MALAYSIA MELAKA	52	
REFERENCES 54			54	
		28	E	
AFFE	ANDICE		22	

LIST OF TABLES

TABLETITLE	PAGE
Table 2.1: Technical specifications on sensors	4
Table 2.2: Sensor specifications	5
Table 2.3: A comparison of the performance of numerous ATM-based range devices.	16
Table 2.4: Performance comparison of several TCW based ranging system.	21
Table 2.5: Performance comparison of several MFCW based ranging systems.	23
Table 2.6: Performance comparison of several BFSK based ranging systems.	26
Table 2.7: Performance comparison of several AM based ranging systems.	28
Table 4.1: Readings of Ultrasonic Sensor	45
Table 4.2: New Readings of Ultrasonic Sensor	46
Table 4.3: Readings on different wall	47
Table 4.4: Reading comparison with an unwanted object	48
Table 4.5: Limitation range of ultrasonic sensor UNIVERSITI TEKNIKAL MALAYSIA MELAKA	50

LIST OF FIGURES

FIGURE TITLE	PAGE
Figure 2.1: (a) HC SR-04 Ultrasonic Sensor; (b) SHARP GP2D12 IR Sensor.	5
Figure 2.2: Graph for small distance measurements	7
Figure 2.3: Graph for longer distance measurements	8
Figure 2.4: The propagation of the Ultrasonic waves	9
Figure 2.5: Schematic diagram of Ultrasonic Ranging with a pair of sensors	10
Figure 2.6: Schematic diagram of measuring range	11
Figure 2.7: The transmitted and received chirp signals	13
Figure 2.8: Diagram of the measurement of rate and distance	14
Figure 2.9: Crosstalk between driving and received signals (the brown line represents the system clock, the blue line represents the twelve electrical pulse excitation signals, and the purple line represents the receiver waveform).	16
Figure 2.10: (a) An ideal model of the received signal, (b) An example of the fitting curve.	18
Figure 2.11: The MFCW algorithm's functioning mechanism, where L denoted the overall distance between transmitter and receiver to be measured.	23
Figure 2.12: Transmitted BFSK signals with a binary code of 11010 ($d_0 = d_1 = d_3 = 0$ and the corresponding frequency is f_0 , $d_2 = d_4 = 1$ and the corresponding frequency is f_1).	24
Figure 2.13: A function diagram shows the received BFSK signal phase vs time if utilising the phase measurement method.	25
Figure 2.14: Relation between standard ToF method where $d = (c \cdot \Delta t) / 2$ and the combined method where $d = 1 / 2[(k-1) + (\Delta \theta/2\pi)] \cdot (c/\Delta f)$.	25
Figure 2.15: (a) waveform and (b) spectral density of the transmitted signal.	27
Figure 2.16: Ultrasonic waveform (a) Conventional driving signal and (b) its received waveform. (c) AMPI driving signal and (d) its received waveform.	28
Figure 3.1: Thesis Workflow	32

Figure 3.2: Schematic Design with Proteus	33
Figure 3.3: Bottom view of UDMERO	35
Figure 3.4: Top view of UDMERO	36
Figure 3.5: Front View of UDMERO	37
Figure 3.6: Rear view of UDMERO	38
Figure 3.7: The coding section of the front sensor	40
Figure 3.8: The coding section of the rear sensor	40
Figure 3.9: The procedure setup	41
Figure 3.10: The ultrasonic reading on the LCD IIC display	42
Figure 3.11: Serial Monitor reading	42
Figure 4.1: Ultrasonic Sensor Area of Detection اونيونرسيتي تيڪنيڪل مليسيا ملاك	49
UNIVERSITI TEKNIKAL MALAYSIA MELAKA	

LIST OF SYMBOLS

- δ _
- θ_0 -
- Voltage angle Phase resolution Wavelength of transmitted signals λ _



LIST OF ABBREVIATIONS

- Voltage Infrared V -
- IR _
- Ultrasonic US _



LIST OF APPENDICES

APPENDIX	TITLE	PAGE
Appendix A : Coding of U	DMERO	55
Appendix B: HCSR04 ultrasonic sensor datasheet		59
Appendix C: L298N motor driver datasheet		62



CHAPTER 1

INTRODUCTION

1.1 Background

The product's development relies mostly around the use of ultrasonic sensors to determine distance and integrating them into a robot so that it can move on its own. In a nutshell, it's like having a distance metre on wheels. UDMERO is another name for this robot.

Apart from that, UDMERO operates by using ultrasonic sensors to send and receive echoes that bounce off the surface in front of it, and then calculating the distance between the sensors and the surface. In the case of UDMERO, however, the surface is limited to smooth and even walls; to be more exact, UDMERO can only calculate the size of an empty, square room. The area of the empty, square room may be identified once the measurements from the ultrasonic sensors are presented on the Liquid Crystal Display (IIC LCD) and basic calculations incorporated in the UDMERO software utilising Arduino Uno are used.

The movement of UDMERO is controlled by a programme built on an Arduino Uno, which is also connected to the motor driver. It is easier to direct the motor to travel forward or backward without having to change the polarities of the motor's connection to the circuit when utilising the motor driver. UDMERO can go forward and backwards, as well as turn left and right, thanks to the combination of the motor driver and the Arduino Uno used to develop the programme.

1.2 Problem Statement

In today's world, where Industry 4.0 is being implemented, it can be claimed that the current state of automation and data exchange in manufacturing technologies has resulted in the creation of a "smart factory." Cyber-physical systems, the internet of things (IoT), cloud computing, and cognitive computing were all introduced to make daily tasks easier. It

surely helps to relieve the strain of industrious individuals, from automated automobile manufacture to the easy use of a smart robot cleaner.

However, despite these many programmes, users still must measure certain things manually in most circumstances. For example, in the interior design industry, before a designer can move items around and decorate a room, they must first determine the exact size of the space, which they must do manually. That will undoubtedly consume time and effort. So, wouldn't it be easier if they had a tool or equipment that could automatically measure distances?

1.3 Project Objective

UDMERO has a few objectives that must be met. The objectives are:

- i) To create a mechanical robot that functions as a mobile measuring device.
- ii) To design a code that can programme the robot to follow instructions and determine the size of an empty square space.
- iii) To use an ultrasonic sensor to determine the distance between two obstacles for indoor application.

1.4 Scope of Project

There are various points that have been outlined to meet the project's goals. The primary goal of this project is to create UDMERO, a device that can take precise measurements and display results. UDMERO's microcontroller is an Arduino Uno, and the display is an IIC LCD. Ultrasonic sensors are also used by UDMERO to measure the distance between objects, in this example the walls of an empty square room and the robot itself. Finally, UDMERO will do a simple calculation in square metre, centimetre, and millimetre using the given data.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

An ultrasonic distance measurement robot may perform a variety of tasks, including determining the exact position of an object or obstacle in front of it while measuring its distance. There are various methods for determining distance without making physical contact. One method is to utilize ultrasonic waves to measure distance. For distance measurement, the ultrasonic sensor utilizes the time of flight (TOF) method, which refers to the time it takes for a pulse to travel from the transmitter to an observed object and back to the receiver [1]. The time it takes for a pulse of sound to move over a surface and return as reflected echoes is measured using an ultrasonic transducer. The distance measured by the speed of sound is calculated using this circuit. It can measure distances up to 2.5 meters using it. Putting this application on a self-moving robot can turn it into a device that can be used for a variety of tasks, including detecting the presence of targets and measuring the distance to targets in many automated factories and processing plants; it can also be used in a car to avoid collisions, and so on.

2.2 A Comparison Between Ultrasonic and Infrared in Distance Measuring

Prior to doing anything else, it is a must to first learn how to measure distances. Infrared or ultrasonic sensors are most likely to come to mind. However, there are considerations to consider when selecting which choice is the better fit for this project. Sensor selection is a challenging task for any system design, as it critically affects the system performance and its lifetime [2]. The main difference between an infrared sensor and an ultrasonic sensor is how they work. Sound waves (echolocation) are used by ultrasonic sensors to determine how far away you are from an item. IR sensors, on the other hand, employ infrared light to detect the presence of an object. These sensors' accuracy and dependability are also important differentiators. Ultrasonic sensors are more reliable and accurate than infrared sensors in most cases. An IR sensor, on the other hand, is easier to construct if the need to know is whether an object is present. However, when there is need of precision, numerical representation of distance for the project, an Ultrasonic sensor is nearly always the best option [9].

2.2.1. Sensors Characteristics

a) This finding was sourced from the research of Performance Comparison of Infrared and Ultrasonic Sensors for Obstacles of Different Materials in Vehicle/ Robot Navigation Applications by S. Adarsh in 2016. It states that the technical specifications of the sensors are shown in Table 2.1. The ultrasonic sensor is widely acknowledged as a viable solution to mapping and localization problems. One of the sensor's piezoelectric transducers creates a high-frequency sound wave (40 kHz), while another transducer detects the returning pulses (echo) in the air and transforms them to proportional voltage variation [3].

Parameters	IR Sensor (SHARP GP2Y0A21YKOF)	Ultra Sonic Sensor (HC SR-04)
Range	10cm-80cm	2cm-10m
Beam-width	75 Deg.	30 Deg.
Beam Pattern	Narrow (line)	Conical
Frequency	353 THz	40 KHz
Unit Cost	~ 750 INR.	~ 130 INR.

Table 2.1: Technical specifications on sensors

b) This next finding was sourced from the research of Performance Evaluation of Ultrasonic and Infrared Waves on Human Body and Metal Surfaces for Mobile Robot Navigation by Sankar J. in 2018. It states that in any system design, selecting appropriate sensors depending on the task requirement is difficult. This decision has a significant impact on the prototype's performance and how long it will be able to fulfil its important functions. Because of their low cost and moderate performance, the HC SR-04 and SHARP GP2D12 ultrasonic and infrared sensors (Fig. 2.1) were chosen for the study. Table 2.2 shows the physical features of the sensors mentioned above [4].



Figure 2.1: (a) HC SR-04 Ultrasonic Sensor; (b) SHARP GP2D12 IR Sensor. UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Table 2.2:	Sensor	specifications
------------	--------	----------------

Daramatars	Ultrasonic Sensor	IR Sensor
r ai aineiers	(HC SR-04)	(SHARP GP2D12)
Range	2cm-4m	10cm-80cm
Frequency	40KHz	430 THz
requency	TOTRIE	150 1112
Beam pattern	Conical	Narrow line
•		
Output	Pulse	Analog
o 1 77 14		
Supply Voltage	+5 V	+5V
Current rating	33 mA	15mA
5		
Cost	~130 INR	~1200 INR

2.2.2. Sensor Findings

To explain further regarding the performances of both sensors, the research paper, Using Ultrasonic and Infrared Sensors for Distance Measurement by Tarek Mohammad in 2009 is referred. It states that the reflectance qualities of the target have an impact on the amplitude response of infrared (IR) sensors. As a result, prior knowledge of the surface is required to use an IR sensor to precisely measure distances. To interpret IR sensor output as a distance measurement in an unknown environment, it is necessary to understand the nature of surface attributes. In this case, an ultrasonic sensor can be useful in assessing surface qualities. The collaboration of US and IR sensors is used to produce a complementary system that can provide accurate distance measurements [7]. In this paper, the Phong Illumination Model is given for detecting a surface's properties and subsequently measuring the distance to the surface. The angular location of the IR sensor is estimated as normal to the surface to make the calculation easier. The initial distance information needed to determine the parameters for this method can be obtained via an ultrasonic (US) sensor. In addition, the outcomes of the LabView-based studies are discussed.

When collecting data, more care should be used when removing things from the sensors, as a slight change in angle could result in a much different distance being displayed than the actual one. In mobile robots, IR and US sensors can be used to enhance stereo camera vision systems because they don't operate well in specific settings, such as plain walls, glass surfaces, or dim lighting. Because the US sensor had an unusable range of 0 – 50 mm and the IR sensor had been saturated in the range less than 40 cm, the author began gathering data from a distance of 50 mm. Fig. 2.2 shows the distances measured by the US and IR sensors to specified modest distances of 50 to 75 mm. The accuracy rate of the US sensor ranged from 90 to 97 percent, while the IR sensor's accuracy percentage was 92 to 95 percent. The IR sensor had a repeatability of roughly 97 percent, which was lower than the

US sensor's repeatability of around 98 percent. The US sensor's standard error was lower, ranging from 1.8 to 2.4 mm, than the IR sensor's, which ranged from 2.1 to 3.5 mm. As a result, it is concluded that the US sensor has superior resolution than the IR sensor for short distances. After then, data was collected over larger distances of 80 to 120 mm. For both sensors, the error is higher than that of the small distance analysis, as shown in Fig. 2.3 [8].



Figure 2.2: Graph for small distance measurements



Figure 2.3: Graph for longer distance measurements

The inaccuracies revealed by the ultrasonic (US) and infrared (IR) sensors were closer in this scenario, ranging from 1.9 to 3.6 mm. The accuracy rate of the US sensor was from 95 to 97 percent, whereas the accuracy percentage of the IR sensor was approximately 97 percent. In the second analysis, the repeatability of both sensors was around 98 percent.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA 2.3 Ultrasonic Working Principles

As for the project ultimately, the ultrasonic sensor is chosen. Ultrasonic vibrations are created and detected using ultrasonic vibrations. Ultrasonic waves have the same physical properties as sound waves in plastic materials, and their propagation and absorption in diverse media are governed by the same rules that govern sound transmission. Ultrasonic vibrations may easily travel through most liquids and metals, as well as many other materials such as glass, ceramics, plastic, and concrete.

Ultrasonic sensors sense sound rather than light and are useful in situations where photoelectric sensors are ineffective [5]. They are ideal for clear object recognition, clear

label detection, and liquid level monitoring, all of which are difficult for photoelectric sensors to handle because to target translucency. The ultrasonic sensor is unaffected by target color or reflectivity and may work successfully in high-glare settings.

When supplied with 4.5V to 5.5V, the ultrasonic sensor sends out a 40kHz pulse burst and then waits for an echo from the object it hits. The receiver subsequently receives the echo, and the distance is calculated as indicated in figure 2.3. Because the normal 40kHz pulse burst is typically used to detect distances of 2.5 metres or less, a higher pulse excitation is necessary to measure distances greater than that.



Ultrasonic sensor applications are common in industries, where they are primarily used for item detection [6]. Ultrasonic sensors, for example, are utilized in the robotics and automotive sectors to measure the height of objects moving past the sensors. This allows them to keep track of the objects and ensure that the product line adheres to the product standards.

2.4 Ranging System and Evaluation Parameters

The ultrasonic sensor is the most important part of the ultrasonic range system. The system measures the ultrasonic wave transmitted and received by the transducer and converts it to distance measurement to complete the range system's function [10].

2.4.1 Ultrasonic Ranging

In pulse-echo mode or pitch-catch mode, the ultrasonic sensor emits ultrasonic waves and catches the echo from the object using the same sensor or another transducer. The length, s, between the ultrasonic transducer and the object is estimated in the pulse-echo mode by evaluating the time, t, between the transmitter and the receiver signals, as shown in Equation (2.1), where c is the sound velocity in the medium.

$$s = \frac{ct}{2} \tag{2.1}$$

Figure 2.4 shows the distance between the plane where ultrasonic sensors are placed and the target object, d, for a pair of ultrasonic sensors operated in pitch-catch mode. In practise, d is much larger than h, the length between the two sensors, thus h can be neglected. As a result, in this configuration, d=s and equation (2.2) can also be applied.



Figure 2.5: Schematic diagram of Ultrasonic Ranging with a pair of sensors

2.4.2 Ultrasonic Parameters

2.4.2.1. Range Of Distances And Angles

Figure 2.5 depicts the effective range of ultrasonic ranging as a sector in twodimensional space or a conical shape in three-dimensional space. The beam spread angle, which is related to the transducer's directivity, is shown in the picture; L_{min} and L_{max} are the closest and farthest distances that may be measured, respectively. The dead zone of the transducer, which is connected to ultrasonic propagation in the near field, determines L_{min} . The length of the excitation pulses affects the dead zone as well. Although the more energy provided and hence the greater signal quality upon reception, the longer the excitation signal is, the larger the blind area. The longitudinal dispersion parameters of the ultrasonic wave determine L_{max} . In typically, an ultrasonic ranging sensor's measuring range is 2 cm–5 m to provide adequate echo signal reception.



Figure 2.6: Schematic diagram of measuring range

2.4.2.2. Accuracy

The accuracy of both the transmission time t and the sound velocity c determines the precision with which distances are measured. As explained below, the gain in transmit time is the most crucial of these. When employing the direct transit time method, the precision of transmit time is dictated by the accuracy of detecting the received time of ultrasonic waves. Second, the phases of transmitted ultrasonic waves can be monitored in order to obtain temporal information for distance estimations. When the phase technique and frequency modulated continuous waves (FMCWs) approach are utilised, the transit time is calculated mostly indirectly. Range resolution, also known as axial resolution, is related to distance accuracy. To distinguish the movement of a target along a single axis, the axial distance between measured sites B and C in Figure 2.6 is necessary.

As a result, range resolution is the highest level of accuracy that ultrasonic ranging devices may reach. When using the phase technique, the distance correlates to the phase value, and the range resolution is given by where σ_I is the phase method's distance resolution, θ_0 is the phase resolution, c, is the sound velocity, and f is the transducer frequency.

$$\sigma_1 = \frac{c(\theta_0)}{f(360^o)} \tag{2.3}$$

FMCWs, also known as chirps, are extensively applied in ultrasonic first in the radar, then in nondestructive testing applications, then in ultrasonic medical imaging, and ultrasonic ranging to increase the range of interest and improve measurement resolution. Figure 2.6 shows how the broadcast and received signals can be expressed.



Figure 2.7: The transmitted and received chirp signals

 T_s is the difference between t_1 and t_2 , Bc is the difference between f_1 and f_2 , is the time delay of received signals compared to transmitted signals, and f_b is the difference frequency between transmitted and received signals.

The FMCWs method's range resolution is where σ_2 is the method's distance resolution, c is the sound velocity, and B_c is the scanning bandwidth. Where the equation goes,

$$\sigma_2 = \frac{c}{2B_c} \tag{2.4}$$

The scanning bandwidth determines the range resolution of the FMCWs technique. For great range resolution, large bandwidth transducers are necessary. It's worth noting that range resolution refers to the measurement precision in an ideal scenario. Many other factors, such as the hardware and the echo signal processing method, will influence the accuracy in practice.

2.4.2.3. Rate Of Measurement

The measurement rate is equal to the time per each measurement. When a single sensor is used in a ranging system to perform pulse-echo mode, the sensor is frequently set up to wait for a reflected echo before firing the next pulse. The pulse-echo method's maximal measurement rate is as follows:

Maximum measurement rate
$$=$$
 $\frac{1}{t_{tof}} = \frac{c}{2d}$ (2.5)

The link between measuring rate and measuring distance is depicted in Figure 2.7, which indicates that the measuring rate falls inversely with distance. The measuring rate for a 5 m object is just 34 Hz, which is inadequate for many applications, such as dynamic monitoring of the blade tip distances between the upper and bottom blades.



Figure 2.8: Diagram of the measurement of rate and distance

Finally, the measuring range, measuring precision, and measuring rate influence the efficiency of an ultrasonic ranging system, and it should be built to satisfy the actual measurement requirements.

2.5 Ranging Methods and Signal Processing

Ultrasonic range methods are classed as time of flight (ToF), two frequency continuous wave (TFCW), and multi-frequency continuous waves (MFCW), binary frequency shift keying (BFSK), amplitude modulation, and signal coding based on the observed characteristics and kind of sent wave. These tactics are discussed in further detail in the subsections that follow.

2.5.1. Time Of Flight (ToF) Method

The ToF method is the most popular. The transmitter puts out basic singlefrequency sequence pulses, and the receiver decodes the echo signal to estimate the time of flight of ultrasonic waves, which may then be paired with the sound velocity to calculate distance. For acquiring correct time information in the ToF method, the amplitude threshold, envelope fitting, and correlation approach are all essential tools.

2.5.1.1. Amplitude Threshold Method (ATM)

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Due to its simplicity and ease of implementation, as well as its high calculation speed and inexpensive hardware cost, ATM is the most widely utilized.

Figure 2.8 shows examples of driving and received signals. The amplitude detection of the received signal is conducted according to the amplitude threshold, and the initial time of the driving signal is denoted by T_0 . Due to the existence of noise, the amplitude threshold is usually set at 3 to 5 times the noise level. The time is given as T_1 when the amplitude passes the threshold, and the flight time is $t=T_1T_0$. Crosstalk can cause an electrical signal fluctuation in the receiver before the ultrasonic echo arrives, as seen in Figure 2.8, which

can be filtered out using hardware isolation or filtering algorithms. The performance of the ATM-based ranging system is presented in the table below.



Figure 2.9: Crosstalk between driving and received signals (the brown line represents the system clock, the blue line represents the twelve electrical pulse excitation signals, and the purple line represents the receiver waveform).

,a 20

Table 2.3: A comparison of the performance of numerous ATM-based range devices.

Range	Accuracy	Transducer Type
1300 mm	1.3 mm	PMUT with 215 kHz
500 mm	0.63 mm	PMUT with 97 kHz and 96 kHz
1000 mm	4 mm	PMUT with 77.34 kHz
5000 mm	4 mm	Conventional bulk transducers with 35 kHz
100 mm	0.5 mm	Conventional bulk transducers with 40 kHz

When compared to standard bulk sensors, the PMUT's optimum range is approximately around 1 m. The narrower the measurement range is, the higher the accuracy may be achieved, as demonstrated in Table 2.3, due to improved SNR of the echo signal. T1 is an inaccuracy in the received signal and does not precisely represent the arrival time of the echo signal. This is because there is noise, and the amplitude threshold has been established. Because the propagation distance varies, this error cannot be corrected as a systematic error. Furthermore, this method is susceptible to noise, and the system will interpret high-level noise as an echo signal on rare occasions. To solve this difficulty, the researcher devised the double threshold method, often known as the sliding window method. A window of width N shifts along the echo signal one sample at a time. At each window AALAYSI. location, the number of samples that surpass the set threshold is determined. ToF is estimated if this quantity surpasses the second condition, m. This approach is resilient to noise peaks because it detects the target using m samples rather than a single sample with a single threshold. In the range of 100–600 mm, the researcher reports a measuring accuracy of 0.69 اوىيۇم,سىتى تيكنىكل مليسى mm.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA 2.5.1.2. Envelope Fitting Method

To tackle the problem of the ATM technique in detecting the initial time of the echo signal, the curve fitting methodology can be utilised to fit the envelope of the echo signal, find the starting point of the echo signal, and create the unbiased estimator of ToF. Figure 2.9(a) shows the ideal model of the received signal explored in, where V_r is the received signal and V_{renv} is the received signal's envelope.



Figure 2.10: (a) An ideal model of the received signal, (b) An example of the fitting curve.

Figure 2.9(b) illustrates how to construct the envelope curve using either the peak amplitude and duration of each cycle or the parabolic model. The time corresponding to the point where the amplitude of the envelope curve equals 0 is used as the initial time of the received signal. According to the study, the above method can achieve measurement precision of 0.7 mm over a distance of 3000 mm and 0.3 mm over a distance of 1000 mm. It can obtain more accuracy within the same range when compared to the ATM technique in Table 2.4. In practise, the received signal envelope deviates due to device performance, noise, and other variables. As a result, the envelope fitting method has less flexibility.

2.5.1.3. Correlation Method

In general, the correlation method is thought to be the best ToF estimation technique [25]. It calculates the cross-correlation between the received echo signal and the transmitted signal, then determines the flight duration based on the cross-correlation signal's maximum value. The cross-correlation signal X_C is calculated for a given sequence of transmitted and received signals $y_p(kT_S)$ and $y_E(kT_S)$, where T_S is the sampling time.

$$X_{C} = \sum_{m=1}^{+\infty} y_{p}(kT_{s}). y_{E}(kT_{s} + nT_{s})$$
(2.6)

The peak lag is proportional to ToF, therefore the observed distance R can be calculated using the ToF and the peak location of X_C .

$$R = (\tau_{max}.T_s - TOE).c - R_{cal}$$
^(2.7)

where τ_{max} is the lag of the greatest peak, which is proportional to the time of arrival (TOA), TOE is the time of ultrasonic signal emission, and R_{cal} is a calibration constant that includes all the system's fixed delays and is independent of range. The correlation technique has a precision of 3.9 mm in the 30-450 mm range with a PMUT of 214 kHz and 1.2 mm in the 2300 mm range with a chirp of 15–40 kHz. Even greater accuracy can be achieved by using the spline interpolation method. On the other side, the processing time will be extended. The precision in the range of 200–1000 mm can reach 0.25 mm, and the working time is 0.3 s. Furthermore, a combination of methods can be used to obtain the flight duration to improve accuracy over a larger distance. The distance inaccuracy for one wavelength scale is corrected using cross-correlation, and the subwavelength range is refined using a phase-shift technique. A 1 mm range resolution is reported for distances up to 3000 mm, while a 0.5 mm accuracy is reported for distances up to 5000 mm. In conclusion, because ATM requires less computation, it is easier and faster to utilise than the envelope fitting and correlation algorithms. As a result, it can be used to track moving targets. The envelope fitting method is limited by the envelope model and has a processing time of 6 to 8 milliseconds. While the correlation approach is slower in terms of processing speed than ATM, it can achieve 0.7 milliseconds in compared to 0.07 milliseconds in ATM using the same processing gear. It's vital to remember that measurement accuracy is influenced not only by the processing method, but also by the devices' performance and the measuring environment. The method for producing ToF should be determined depending on the accuracy, processing speed, and measurement goal speed requirements for each given measurement.

2.5.2. Two Frequency Continuous Wave (TFCW) And Multi-Frequency Continuous Waves (MFCW) Methods

When compared to the traditional ToF approach, the TFCW and MFCW methods obtain the time delay using phase difference measurement and give improved measurement precision at the expense of measurement range.

2.5.2.1.Two Frequency Continuous Wave (TFCW)

To use TFCW methods, the transmitter sends two continuous wave excitation signals with the frequencies of f_1 and f_2 ($f_1 < f_2$), and the phase shifts of the two signals can be evaluated when the waves reach the receiver. The transmitter-to-receiver distance can therefore be expressed as $d = \left(n_1 + \frac{\theta_1}{2\pi}\right)\lambda_1$ (2.8) $d = \left(n_1 + \frac{\theta_1}{2\pi}\right)\lambda_2$ (2.9)

where θ_1 and θ_2 are the phase shifts of two received signals compared to transmitted signals at frequency f_1 and f_2 , respectively, and λ_1 and λ_2 are the wavelengths of transmitted signals. As a result, the phase shift can be written as,

$$\theta_2 - \theta_1 = \Delta \theta - 2\pi (n_2 - n_1) \tag{2.10}$$

(2, 10)

.

where $\Delta \theta$ is,

$$\Delta\theta = 2\pi d \left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right) \tag{2.11}$$

There are only two possible values for the integer *n*: $n_2=n_1$ and $n_2=n_1+1$. The following Algorithm 1 can be used to calculate the difference in phase shifts: If *n*: $n_2=n_1$, then $\theta_2 - \theta_1 = \Delta \theta$.
If $n_2 = n_1 + 1$, then $\theta_2 - \theta_1 = \Delta \theta - 2\pi$.

Therefore, the measured distance, d, can be expressed as,

$$d = \frac{\Delta\theta}{2\pi} \cdot \frac{c}{\Delta f}$$
(2.12)

where $\Delta f = f_2 - f_1$. As a result, the measuring range in a particular sound propagation medium is determined by the phase shift difference and frequency difference. The range can be extended to the wavelength corresponding to Δf , and the phase resolution determines the accuracy. The highest phase resolution is determined by the hardware system's clock frequency; for example, using a 40 MHz clock to phase count a 40 kHz signal yields a maximum precision of 0.1 percent. The distance resolution in actual measurements can reach 1 percent wavelength. The TFCW approach was used in all the author references, and the performance of the measuring system is reported in Table 3.

Table 2.4: Performance comparison of several TCW based ranging system.

Range	Accuracy	Signal Frequency
30 mm~100 mm	1.5 mm	39.85 kHz and 40.6 kHz
50 mm~200 mm**	0.1362 mm	40 kHz and 40.82 kHz
10 mm~110 mm.SITI	TEK 2.5 mm_ MA	LAY S94.21 kHz and 95.59 kHz

Table 2.4 shows that TFCW is suitable for measuring a distance over a short distance. The phase detection method can be used with additional ways such as the amplitude of the waveform to obtain a resolution of 1.5 percent wavelength at a distance of 550-1450mm, allowing the range to be expanded with two different frequencies waves.

2.5.2.2.Multi-Frequency Continuous Waves (MFCW)

According to the ranging principle of TFCW, its minimum range of resolution is $c / (\Delta f. 360^\circ) (m / ^\circ)$. This means that a greater frequency difference can yield better definition, but the measuring range is shortened. As a result, the TFCW method is unable to meet both the minimal resolution and maximum range requirements. The MFCW method, which evolved from the TFCW method and measures range using three frequencies of ultrasonic waves, can meet all of the criteria at the same time.

Figure 2.10 depicts the operating principle of MFCW. Assume that the sent continuous waves of different frequencies have frequencies of f_1 , f_2 and f_3 ($f_1 < f_2 < f_3$), and that the phase shifts of the received and transmitted signals are φ_1 , φ_2 , and φ_3 respectively. $\Delta \varphi_1$ is the phase difference between phases φ_1 and φ_2 , and $\Delta f_1(\Delta f_1 = f_1 - f_2)$ is the equivalent frequency difference. Similarly, $\Delta \varphi_2$ is the phase difference between phases φ_1 and φ_3 , and $\Delta f_2(\Delta f_2 = f_1 - f_3)$ is the corresponding frequency difference. The calculation for distance is,

$$L = Int \left[\frac{\Delta \varphi_1}{2\pi} \cdot \frac{\Delta f_2}{\Delta f_1} \right] \cdot \frac{c}{\Delta f_2} + Int \left[\frac{\Delta \varphi_2}{2\pi} \cdot \frac{f_1}{\Delta f_2} \right] \cdot \frac{c}{\Delta f_1} + \frac{\varphi_1}{2\pi} \cdot \frac{c}{f_1}$$
(2.13)

 $c / \Delta f_2(m^o)$ determines the initial step, which yields the maximum resolution scale. $c / \Delta f_2(m^o)$

 $\Delta f_1(m/^\circ)$ determines the initial step, which yields the maximum resolution scale. $c \neq \Delta f_1(m/^\circ)$ determines the giving of finer resolution in the second step. $c \neq (360^\circ, f_1) \ (m/^\circ)$ determines the maximum level of resolution in the final phase. Because most commercial ultrasonic transducers have a small bandwidth of 40 ± 2 kHz, the greatest resolution of FMCW of frequencies $f_1 = 40.0 \text{ kHz}$, $f_2 = 39.9 \text{ kHz}$, $f_1 = 38.0 \text{ kHz}$ is 0.0243 mm/degree.



Figure 2.11: The MFCW algorithm's functioning mechanism, where L denoted the overall distance between transmitter and receiver to be measured.

Table 2.5: Performance comparison of several MFCW based ranging systems.

Rango	Accuracy	Signal Frequency
1500 mm	0.05 mm	40.0 kHz 39.9 kHz and 38.0 kHz
<100 mm	0.0711 mm	497.0 kHz, 496.8 kHz and 487 kHz
100 mm~300 mm	1.8208 mm	492 kHz, 491.8 kHz and 490 kHz

Finally, the MFCW method has better accuracy over a larger variety (1500 mm in Table 2.5) than the TFCW approach (70150 mm in Table 2.4). The phase measurement accuracy specifies the optimum range of both the TFCW and the MFCW, whereas the frequency difference determines the measurement accuracy of the TFCW. The measurement period lengthens and the measurement rate decreases as the transmitter must emit two or three distinct frequency signals in succession.

1.4

2.5.3. Signal Modulation Method

2.5.3.1. Binary Frequency Shift Keying (BFSK)

It's when a binary input signal that oscillates among logic 0 and logic 1 alters the centre or frequency response, similar to how frequency modulation works. Figure 2.11 provides an illustration of a sent BFSK signal.





UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Using methods such as phase measurements, correlation calculations, or a set of methods, the input signal can be analysed to obtain the ToF data and compute the distance. It's possible that the phase measurement method will be employed first. It is possible to see how the procedure works in Figure 2.12. Second, correlation calculation can be employed as a polarity correlation function because most of those signals are always a logic one or a logic zero. Third, to complete ranging, the phase-shift detection method can be paired with direct ToF measurement. The target distance is calculated as $d = (c. \Delta t) / 2$, where Δt is the ToF and d is the number of regions displayed in Figure 2.13. The performance achieved by different processing methods is summarized in Table 2.6.



Figure 2.13: A function diagram shows the received BFSK signal phase vs time if utilising the phase measurement method.



Figure 2.14: Relation between standard ToF method where $d = (c \cdot \Delta t) / 2$ and the combined method where $d = 1 / 2[(k-1) + (\Delta \theta/2\pi)] \cdot (c/\Delta f)$.

Range	Accuracy	Signal Processing Method
~5 m	1 mm	Phase measurement
0.5 m~4 m	/	Correlation algorithm
~7.2 m	6.2 cm	Correlation algorithm
~6 m	0.05 mm	ToF and phase shift

Table 2.6: Performance comparison of several BFSK based ranging systems.

2.5.3.2. Amplitude Modulation (AM) Method

The AM approach includes adding varying amplitude data to the ultrasonic transmitted signal to improve measurement precision, measurement rate, and other aspects. The first application is the multi - frequency amplitude modulation method (MFAM) based on phase monitoring. The recovered echo signal can be depicted as if the emitter is powered by a steady sine wave

$$V_R(t) = A\sin(\omega t + \varphi)$$
(2.14)

where A is the echo signal's peak amplitude, ω is the resonant angular frequency, and φ is the phase shift, which is proportional to the distance measured. Assume the carrier and modulation signals are both sinusoidal signals with no phase shift.

$$V_T(t) = A_m [1 + m \sin(\omega_m t)] A_c \sin(\omega_c)$$
(2.15)

where A_m and A_c are the modulated signal and carrier signal peak amplitudes, respectively; ω_m and ω_c are the modulated signal and carrier signal angular frequencies, respectively; and *m* is the modulation index, which determines the modulating signal to carrier signal amplitude ratio.



Figure 2.15: (a) waveform and (b) spectral density of the transmitted signal.

Using MFAM, the measuring range may be expanded to 10 m, and the precision can be measured in mm. The measuring system's performance is unaffected by the loss of the first part of the received signal, which may be too weak to detect, because the distance information is obtained from the envelope of the received signal. The sinusoidal envelope of AM ultrasonic sounds can be extracted in real time using the sliding discrete Fourier transform (SDFT) technique. Furthermore, for static objects, the present technique for 25 Hz modulation has a range of 13.72 m and an update rate of 3200/s. The modulating frequency is proportional to the update rate of moving objects. With a transient update rate of around 8/s, 25 Hz modulation is appropriate for detecting static and slow-moving targets.

Modulation Method	Range	Accuracy
MFAM	~1.5 m	2 mm
MFAM	~13.72 m ~3 m	1.343 mm
AM + PM	0.1 m~0.5 m	0.02 mm
AM + PM	0.05 m~0.5 m	0.2 mm
AM + PM	0.05 m~1 m ~2 m	0.06 mm 0.15 mm

Table 2.7: Performance comparison of several AM based ranging systems.

The ToF is obtained from the peak of the received signals in the second application, which uses a combination of amplitude modulation and phase modulation (AM + PM). As seen in Figure 2.15, amplitude modulation and phase inversion (AMPI) of the transmitted wave sharpens the peak of the received signal envelope. This is because after the conventional excitation wave, several periods of signal with opposite phases are added to reduce the trailing part of the signal that is not expected to appear, and the effect is more obvious when the coefficient $k = A_2 / A_1$ (A_1 and A_2 are the amplitudes of the AMPI driving signal) is larger. Its sharp envelope improves the peak time measurement accuracy.



Figure 2.16: Ultrasonic waveform (a) Conventional driving signal and (b) its received waveform. (c) AMPI driving signal and (d) its received waveform.

The measurement accuracy of the peak time of the received signal can be enhanced by using AM + PM since the inertia delay is reduced. Table 2.7 summarises the performance of the ranging system. In the short distance range, measuring precision may be as high as 0.02 mm, which is less than 0.3 percent wavelength, effectively enhancing ranging accuracy. As a result, MFAM is better suited to applications requiring a fast update rate and a broad range, whereas AM + PM is better suited to applications requiring high precision and a limited range.

2.5.4. Overall

The method of ultrasonic ranging and how its signals are processed are grouped, and the measurement system's performance is looked at. By using the ATM, envelope fitting, or correlation method, you can get the measurements from the ToF method. ATM is the easiest to use, has the fastest processing speed, and can be used for the most things. The envelope model puts limits on the envelope fitting method, which makes it slower to process but more accurate in theory. The correlation method takes an average amount of time to process, but it works better overall. Both TFCW and MFCW methods get results by using multi-frequency measurement signals based on phase detection. Compared to the ToF method, this method has a smaller measurement range and a longer measurement time, but it gives more accurate measurements. The BFSK and AM methods modulate the signals that are sent, which can improve the quality of the signals that are received. This can increase the range or accuracy of measurements. The BFSK method uses binary coding to control the frequency of the signals being sent. The accuracy of this method can be as high as 0.05 mm within 5 m. The AM method changes the strength of the signals being sent, and the accuracy within 0.5 m can reach 0.02 mm. The signal coding method can stop crosstalk between multiple sensors and speed up the rate of measurement from 10 m away.

2.6 Summary

Since the ultrasonic sensory is known for ages, it is not an unusual use for in an industrial field and many more. For this project, the purpose revolves more on the accuracy of the ultrasonic sensor itself. To measure distance of an area and implement it onto the robot so that it can move on its own. To give readings and display on real time. Basically, it is like having a distance measuring meter on wheels. With the research papers mentioned as references, the quality of the reading should hopefully be the most trusted and most effective. The techniques and methods should be adapted accordingly to achieve the right objectives. The different approaches of the previous analysis will be taken accounted for, to create a more advanced findings on said field of research.



CHAPTER 3

METHODOLOGY

3.1 Introduction

The completion of UDMERO relies on the workflow planned as shown in Figure 3.1. For the early stages of the project, the main work done revolves around doing research and gathering information on projects that are like this one which is the Ultrasonic Distance Measuring Robot. Then, the process of circuit design is started by using the Circuito.io software. This is to get a clear view on how the Arduino Uno will be used to control the three other major components which are the ultrasonic sensor, motor driver and the IIC LCD.

When the design of the circuit is complete, the hardware of UDMERO was developed. The Arduino Uno was connected to a motor driver which is connected to two DC motors. This will be the one that controls the movement of UDMERO. Then, the Arduino Uno is also connected to the IIC LCD and three ultrasonic sensors. After everything is properly connected following the schematic, the components were installed onto a chassis that is used as the body of UDMERO.

Next, the coding part of the project is started. The coding of the whole system also involves the three major components which are the motor driver, the ultrasonic sensors, the IIC LCD display and some other minor components like the calculations to obtain the area of an empty square room. This coding will then be uploaded to the Arduino to see whether it can work as programmed or not.

Then, UDMERO is tested in an empty square room, and it will run its program which is to measure the area of the empty square room. Afterwards, the measurement obtained will be compared to the measurement taken manually of the area as to compare just how accurate UDMERO's measurement is. Then all the data are collected and analysed and finally the whole project is documented.

3.2 Methodology



Figure 3.1: Thesis Workflow

3.2.1. Schematic

Proteus software was used to generate the circuit diagram. Before moving on to creating the prototype, it is necessary to complete the connections and perform a quick simulation to make sure they are accurate. The schematic diagram from chapter 3 served as the basis for the diagram.



All connections are made to the Arduino Uno, which is the main component of UDMERO, as shown in Figure 3.4. Numerous input and output pins on the Arduino Uno can be connected to other devices in accordance with the program's instructions and the device's intended use. The power adapter or the Vin pin can be used to supply the Arduino's required voltage of 7 to 12 volts. However, the Vin port does not have a voltage regulator like the power jack, thus if the voltage exceeds the rating, there is a chance of burning the Arduino board. The two DC motors can be controlled for both speed and rotation direction by connecting the L298N H-bridge module to a microcontroller like the Arduino Uno. It is connected to the motor driver's OUT1–OUT4 left and right ports, which divide the left motor from the right motor. In addition, the motor driver connects to the Arduino port numbers 2-

7 through four input pins and two enable pins. It is connected to pins EnA and EnB for ports 2 and 7, respectively. Depending on the coding, these pins are actually the ones that control the motor's speed. The OUT1-OUT4 pins are used to connect the remaining port segments 3-6. Due to the fact that the motor driver has two power pins, the +12V pin and the +5V pin, it may run on either a 12 Volt or a 5 Volt supply.

Because DC motors obey their drivers, they move more quickly the greater the voltage. It includes four pins for the ultrasonic sensors, all of which are connected to the Arduino Uno. The +5V pin and the ground pin are each linked to the device's power and ground pins, respectively. 5 Volts are needed for the ultrasonic sensor to switch on. The trigger pin and the echo pin are the next two pins on it. The trigger and echo pins of sensor 1 (front) are connected to pins 11 through 10, and those of sensor 2 (rear) are attached to pins 8 and 9.

Finally, the IIC liquid crystal display (IIC LCD). It only has four pins, the first two of which are the ground and VCC pins, which are connected to the Arduino Uno's +5V pin. The IIC LCD's contrast can then be adjusted using the associated potentiometer. It then contains the SCL pin, which is the clock whether it will read or write to the IIC LCD, and the SDA pin, which is used to send commands or data to the IIC LCD.

3.2.2. Hardware Development

The development of the prototype is carried out when the code has been submitted, indicating that all connections have been made correctly when all the components light up.

Firstly, the chassis was built on the bottom side of the body, connected to it is the two DC motors that were screwed as shown in figure 3.3 below.



ALAYS/

Figure 3.3: Bottom view of UDMERO

The wires from the motors are connected based on the output port on the left and right side to the motor driver L298N located on top of the body. These motors will control the movement of UDMERO should it moves forward or backward; left or right depending on the coding of the program. Then on the top side, the components were arranged and connected as shown in Figure 3.4 based on the connections of the schematic diagram.



Figure 3.4: Top view of UDMERO

The Arduino Uno is positioned somewhat in front so that connecting it to the other components will be simpler and more accessible. Two 9V batteries are installed at the side of the motor driver L298N, which is mounted to the back of the body. The Arduino Uno has all of the wires connected. The LCD IIC display was then mounted right up front, immediately behind the front ultrasonic sensor. The component that displays the measured length, breadth, and distance is this one.



Figure 3.5: Front View of UDMERO

As shown in Figure 3.5, an ultrasonic sensor that serves as the front sensor was mounted to the body's arc on the front side. All of its wires are linked to the Arduino Uno's pins in the appropriate ways. The sensor was positioned there to take distance measurements as well as to make sure that UDMERO wouldn't run into any walls that would skew the readings.

Then lastly, on the back side of the body, another ultrasonic sensor is installed that acts as the rear sensor. Shown in the Figure 3.6 below, it is placed at the outer back of the UDMERO, again as to measure the distance of the rear wall and also to prevent from collision.



3.2.2.1. Testing For Hardware

Before installing all the components on the chassis, each one of the components were tested. By connecting it to the power supply, the components were turned on for a period to check whether it will burn or short circuit. For the DC motors, each motor was directly connected to a battery and the rotation of the motor were observed. Without the use of programming, the motor reacts to power, meaning the higher the power of the battery the faster the rotation of the motor. Then for the other components such as the Arduino Uno, the ultrasonic sensors and the IIC LCD, by ensuring that it can be turned on means that the components work fine.

3.2.3. Procedure setup

By employing sonar to determine distance to an object, the HC-SR04 ultrasonic sensors offer outstanding non-contact range detection with high precision and dependable results. It can measure objects from 2 cm to 4 metres when given a 5 volt DC source from the Arduino Uno and a trigger input pulse width of 10 seconds. In this thesis, the readings obtained manually and those obtained utilising ultrasonic sensors are contrasted. The proportion of error is derived by dividing the value of the manually taken reading by the value of the average reading acquired from the sensors.

Theoretically, the ultrasonic sensors can measure a distance of up to 4 metres. Despite the fact that the measurement is made in an empty room with a length of about 2.8 metres, the scope of this reading analysis is constrained. UDMERO is consequently placed at one wall, while another object is placed at the other. Then, utilising the front and back sensors combined, three readings are taken to ascertain how precisely the sensors operate. The three readings were then summed and divide to take the average. All this while a measuring tape was used to take the actual reading.

The coding that enabled said measurements is designed to total the readings of both sensors with an addition of the length between the sensors in this case the body of the robot itself. So the calculation is as follows:

58	
59	void usReadCmfront() {
60	<pre>currentMillisfront = millis();</pre>
61	if (currentMillisfront > previousMillisfront + FrontUSPeriod) {
62	digitalWrite(trigPinFront, LOW); //clears the trig pin set low
63	delayMicroseconds(2);
64	digitalWrite(trigPinFront, HIGH);
65	delayMicroseconds(10);
66	<pre>digitalWrite(trigPinFront, LOW);</pre>
67	long durationFront = pulseIn(echoPinFront, HIGH, 38000); //reads the echo pin returns the sound wave travel time in microseconds
68	distanceFront = durationFront * 0.034 / 2; //Time of flight equation: Speed of soundwave divided by 2
69	if (distanceFront > MaxDistance) distanceFront = MaxDistance; //Apply limits
70	if (distanceFront == 0) distanceFront = MaxDistance;
71	<pre>previousMillisfront = currentMillisfront; //update the prevmillis</pre>
72	length = (distanceRear + distanceFront) + 28; // 24 + 2front + 2rear cm between ultrasonic sensors
73	width = (distanceRear + distanceFront) + 28; // 24 + 2front + 2rear cm between ultrasonic sensors
74	area = length * width;
75	Illevial print/Unicharcoformet, U.
	ALAYSIA
	Figure 3.7. The coding section of the front sensor
	i igure contration contration of the front sensor
07	



UNIVERSITI TEKNIKAL MALAYSIA MELAKA Figure 3.8: The coding section of the rear sensor

The measurements was held in an empty room that spans for 283 cm in length. The UDMERO is connected to the pc with the coding uploaded. Then it is programmed to display the front sensor readings and rear sensor readings. Not only that, it is also included for the calculation of the length which is the front summed with the rear, and also summed with the length between the two sensors.



Figure 3.9: The procedure setup

The procedure starts with the measuring tape being pulled to the very end of wallto-wall distance. The reading was 283 cm long, acts as the maximum range of the measurements as the room tested was only that much in length. Then the UDMERO is placed one end of the wall but remains 2 cm in between the rear sensor. This means that with the addition of the robot's length or the distance between sensors, and the measurements of the front sensor, the LCD IIC will display the total length of the distance. This is because as mentioned, the coding that has been programmed into the microcontroller Arduino Uno has been calculated. The reading was also showed in the serial monitor of the Arduino IDE software.



Figure 3.10: The ultrasonic reading on the LCD IIC display



Figure 3.11: Serial Monitor reading

3.3 Summary

This part outlines the proposed process for creating a self-contained robot that detects the walls of a square room and calculates the dimensions. The recommended methodology's major goal is to create a fully functional, basic, but effective distance measuring mobile robot that does not compromise the accuracy of the data. The methods also aimed to make use of widely available and inexpensive components that may be used to create something completely different. The method's ultimate goal is to achieve not only the maximum level of accuracy, but also to make the ultrasonic distance measuring robot easy to construct and use in practise.



CHAPTER 4

RESULTS & DISCUSSION

4.1 Introduction

The HC-SR04 ultrasonic sensor uses sonar to measure the distance to an object. It gives accurate and stable readings without having to touch the object. It has a trigger input pulse width of 10μ s and can be powered by 5 Volts DC. It can measure from 2 cm to 4 metres.

In this thesis, readings from ultrasonic sensors and readings taken by hand are compared. To figure out the percentage error, the value of the reading that was taken by hand is subtracted from the average reading that was taken by the sensors and then divided by the value of the reading that was taken by hand.

According to the theory, the ultrasonic sensors can measure distances up to 4 metres. In real life application the project is targeted to be tested on multiple occasions. To test and improve the accuracy of the robot, there is a lot of aspect that should be taken in consideration. Therefore, the experiment is done on various factors that could affect the sensor reading. The data is recorded and analyze.

4.2 Analysis

For the first experiment, to test the sensors accuracy, there were three readings of length recorded. Then it is totaled and divided to get the average readings. Next, the readings were to be compared with the actual readings from the measuring tape. Considering the range of ultrasonic sensor could go up to 400 cm, nevertheless, the range of the actual length was scoped to the room that the procedure was executed. Hence, the maximum length was 283 cm. To determine the minimum, the interval used was 20 cm. The object was put from the furthest than nearest to the UDMERO accordingly. For the actual readings below 43 cm, however, the ultrasonic reading could not be collected. This is because the robot's body itself is 24 cm in length. It can still be measured however, but only with one of the sensors used and the program coding altered. This shows that the ultrasonic sensor limit of range does take effect on the readings. Then finally, the percentage error of the measurements was to be calculated and analyzed. The readings are as follows:

				1 1 1	
FRONT	+ REAR SENS	ORS cm	AVERAGE	ACTUAL	PERCENTAGE
1 st Reading	2 nd Reading	- 3 rd Reading		LARCIN	EKKOK 70
-	-	-	-	3	-
-	-	-	-	23	-
45	46	46	45.67	43	6.21
64	65	65	64.67	63	2.65
83	84	84	83.67	83	0.81
102	103	103	102.67	103	0.32
121	122	123	122.00	123	0.81
140	141	141	140.67	143	1.63
160	160	160	160.00	163	1.84
178	179	179	178.67	183	2.37
198	199	199	198.67	203	2.13
216	219	218	217.67	223	2.39
236	237	238	237.00	243	2.47
256	257	257	256.67	263	2.40
278	279	279	278.67	283	1.53

Table 4.1: Readings of Ultrasonic Sensor

The table above shows there is an increase and decrease trend of the sensor reading compared to the actual reading. As mentioned before, there is no reading for the measurements below 43 cm. However, up until 283 cm, the percentage error of the measurements can be observed. There is a spike of error at the 43 cm readings. Then the errors decrease as the length increase but at the 283 cm reading however, the error has a slight increase again. There are a few potential causes for this. First off, any acoustic noise that is present at the frequency that the ultrasonic sensor is tuned to may interfere with the output of that sensor. This includes loud noises with a high pitch, such a whistle or someone gasping. It also can be caused by the waves of ultrasonic absorbed by soft surfaces or reflected by uneven surfaces, and resulting the wave transmitted could not returned to the receiver. Next, another experiment is conducted. An even bigger space area is used to test the maximum limit range of the ultrasonic sensor which is 400 cm in length. From this new data, the error is much more pattern-like. The data is recorded as follows:

ىۋىرىسىتى ئىكىنەmcm مايسىيا ملاك			in %
ULTRASONIC SENSORS	ACTUAL DISTANCE L	ALAYERRORELAK	A PERCENTAGE ERROR
43	40	3	7.50
52	50	2	4.00
73	70	3	4.29
93	90	3	3.33
141	140	1	0.71
200	200	0	0.00
249	250	1	0.40
288	290	2	0.69
337	340	3	0.88
377	380	3	0.79
397	400	3	0.75

Table 4.2: New Readings of Ultrasonic Sensor

Based on these new findings, it can be seen that the percentage error is lesser as the distance increases contrary to before. This shows that the distance between the sensor and object could affect the readings. An ultrasonic sensor is unable to produce a signal and simultaneously pick up a signal coming back from a target. The ultrasonic waves propagate in the air and is reflected back when it meets an obstacle. The wave by the transmitter could be disrupted up close. The time taken for the wave to return to the receiver has been rattled. From here, it can be seen that percentage error is highest when the distance is 400 cm in length. Therefore, a further study is required in order to improve the reading so that this project is much more accurate to be used.

4.3 Different Factors that affect sensor readings

112	6.6.		
in cm in cm in cm			
ACTUAL DISTANCE	EKNIK DRY WALLYSIA M READING	ELACONCRETE WALL READING	
50	52	52	
100	101	100	
150	151	149	
200	200	196	
250	249	247	
300	298	298	
350	347	346	
400	397	396	

Table 4.3: Readings on different wall

Based on the findings in table 4.3 above, the result shows that the reading on dry wall is closer to the actual rather than the concrete wall. Though both readings gave the same at initial however as the actual distance increase, the difference in sensor readings can be more clearly visible. From the ultrasonic working principle, the wall material could affect the sensor reading due to the fact that concrete wall has an irregular surface contrary to the dry wall which has smoother surface. The wave that bounced onto the wall might not be reflected back to its' receiver in the right angle that may causes the data interference. From this comparison between the dry wall and concrete wall, it is much more accurate for this prototype to be used in a room with dry walls or any material that has a flat and smooth surface in order to minimize the ultrasonic wave loss.

Fa	in cm	
ACTUAL DISTANCE	ULTRASONIC SENSOR	STARTING POINT of MEASUREMENT ERROR
50	52	44
U60VERSITI T	EKNIKAL M3 LAYSIA M	ELAKA 52
70	72	57
80	82	62
90	91	66
100	100	70
150	147	83
200	197	88
250	246	91

 Table 4.4: Reading comparison with an unwanted object

Next, the prototype is tested to take measurements but with an unwanted object in the way. This is to test with the presence of another obstacle, the ultrasonic sensor is unable to differentiate the actual distance intended which is the wall of the room and any other objects nearby. To test this theory, firstly, the robot is placed on one end and the object measured on the other. Then, another object is placed within the range in between. The unwanted object is moved around to the initial point where the readings are finally disrupted. The data is recorded in table 4.4 and illustrated in figure 4.1. The result shows that different lengths give different starting point of error. Based on the findings, it is concluded that to gain maximum accuracy of the project, the UDMERO is to be placed in an empty room to avoid any object around the sensor interrupting the measurements. Just as the scope of the project has mentioned before.



Figure 4.1: Ultrasonic Sensor Area of Detection

Lastly, to demostrate that there is a limitation range in the ultrasonic sensor, another experiment is held. From the sensor's data sheet it is said that it has a range of 2 cm up to 400 cm (4 metres). Therefore, no reading can be found beyond those range. In addition, the protoype built has include another limit that is below 40 cm of measurement. This is because the distance between front sensor and rear sensor or the robot's length itself is 24 cm in length. The data of testing is recorded in table 4.5 below. From the result, any actual distance out of the 40 - 400 cm range has no reading.

in cm		
ACTUAL DISTANCE	ULTRASONIC SENSOR	
10	no reading	
20	no reading	
30	no reading	
40	42	
50	53	
کنیکل ملیس60 ملاک	63 يو م سيتى بې	
UNIVERSITI TEKNIKAL M		
80	81	
90	91	
100	101	
150	147	
200	196	
250	244	
300	292	
350	347	
400	392	
450	no reading	
500	no reading	

Table 4.5: Limitation range of ultrasonic sensor

4.4 Summary

The UDMERO, which has distance measurement ultrasonic sensors, can offer the ideal platform for real-time data collection. Selecting the best sensor for a particular type of obstacle can undoubtedly be aided by statistical comparison of the distance data (measured distance) from sensors with the real distance. Though multiple factors were taken considered to maximize accuracy, this prototype has still a lot of room for improvement. The limitations of the ultrasonic sensor have affected the measurements taken. Therefore, it is important to further research on how to improve on better measuring techniques. This include improvement on coding, sensor calibration or positioning, and a controlled environment of obstacles that is to be measured.



CHAPTER 5

CONCLUSION

5.1 Conclusion

The idea for this thesis is to make a robot that can measure distance by using ultrasonic sensors. The robot's name is UDMERO, and it is set up to measure a square room that is empty. UDMERO is a fully automated robot, which means it can do all of its tasks without being controlled remotely. Arduino Uno is the microcontroller for UDMERO, and it controls all of the parts, like the motor driver, ultrasonic sensors, and IIC LCD.

The ultrasonic sensors send out echoes that bounce off the walls of the room and back to the sensor's receiver, which then calculates the measurement. The measurement will then be shown on an IIC LCD screen that is connected to the sensors. From UDMERO, you can find out how big the empty square room is in centimetres and metres square. The reading will then be compared to a manual measurement of the same room's size to see how accurate it is.

5.2 Future Works

In general, UDMERO is a robot that measures distance with an ultrasonic sensor. Even though the main purpose of UDMERO for this thesis is to measure the area of a square room that is empty, with more research and development, it could measure the area of a room that has things in it or isn't a square. Also, an ultrasonic sensor or other sensor that uses echoes or sonar can be used to map a room instead of just measuring its size. This is because the ultrasonic sensor works by using echoes. Then, UDMERO can be accessed online with a more advanced microcontroller or by adding a shield to an Arduino. The data can be used for designs and other things. Aside from that, the design of the robot and the parts that make it work could also be better. The robot could be made smaller so it could move through tight or crowded spaces and measure distances that people can't do by hand.



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APPENDICES

Appendix A : Coding of UDMERO

#include <LiquidCrystal_I2C.h>

LiquidCrystal_I2C lcd(0x27, 16, 2); // set the LCD address to 0x3F for a 16 chars and 2 line display #define max_distance 200 // Maximum distance we want to ping for (in centimeters).

const int trigPinFront = 11; const int echoPinFront = 10;const int trigPinRear = 9; const int echoPinRear = 8; const int MaxDistance = 400; //400cm = 4 meters int m1 = 6; ALAYS int $m^2 = 5$; int m3 = 4; int m4 = 3; int s1 = 7: int $s^2 = 2$; unsigned long currentMillisfront; unsigned long previousMillisfront; unsigned long currentMillisrear; unsigned long previous Millisrear; const unsigned long FrontUSPeriod = 50; //time to wait for front ultrasonic to activate const unsigned long RearUSPeriod = 50;int distanceFront = 0; //current ultrasonic distance reading int distanceRear = 0; int length = 0; int width = 0; int area = 0: boolean stop = true; void setup() { Serial.begin(9600); lcd.init(); lcd.clear(); lcd.backlight(); pinMode(trigPinFront, OUTPUT); pinMode(echoPinFront, INPUT); pinMode(trigPinRear, OUTPUT); pinMode(echoPinRear, INPUT); pinMode(m1, OUTPUT); pinMode(m2, OUTPUT); pinMode(m3, OUTPUT);

```
pinMode(m4, OUTPUT);
 analogWrite(s1, 255); //right motor
 analogWrite(s2, 255); //left motor
ļ
void loop() {
 usReadCmfront();
 usReadCmrear();
 //Serial.print("Distancefront: ");
 //Serial.print(distanceFront);
 //Serial.println(" cm");
 //Serial.print("Length: ");
 //Serial.print(length);
 //Serial.println(" cm");
 motorMove();
}
void usReadCmfront() {
 currentMillisfront = millis();
 if (currentMillisfront > previousMillisfront + FrontUSPeriod) {
  digitalWrite(trigPinFront, LOW); //clears the trig pin set low
  delayMicroseconds(2);
  digitalWrite(trigPinFront, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPinFront, LOW);
  long durationFront = pulseIn(echoPinFront, HIGH, 38000);
                                                                 //reads the echo pin
returns the sound wave travel time in microseconds
                                                      //Time of flight equation: Speed
  distanceFront = durationFront * 0.034 / 2;
of soundwave divided by 2
  if (distanceFront > MaxDistance) distanceFront = MaxDistance; //Apply limits
  if (distanceFront == 0) distanceFront = MaxDistance;
  previousMillisfront = currentMillisfront; //update the prevmillis
  length = (distanceRear + distanceFront) + 28; // 24 + 2front + 2rear cm between
ultrasonic sensors
  width = (distanceRear + distanceFront) + 28; //24 + 2front + 2rear cm between
ultrasonic sensors
  area = length * width;
  //Serial.print("Distancefront: ");
  //Serial.print(distanceFront);
  //Serial.println(" cm");
  //lcd.setCursor(0, 0);
                           // Sets the location at which subsequent text written to the
LCD will be displayed
  //lcd.print("DistFron: "); // Prints string "Distance" on the LCD
  //lcd.setCursor(9, 0);
  //lcd.print(distanceFront); // Prints the distance value from the sensor
  //lcd.setCursor(14, 0);
  //lcd.print("cm");
  //delay(150);
 }
}
```

56
```
void usReadCmrear() {
 currentMillisrear = millis();
 if (currentMillisrear > previousMillisrear + RearUSPeriod) {
  digitalWrite(trigPinRear, LOW); //clears the trig pin set low
  delayMicroseconds(2);
  digitalWrite(trigPinRear, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPinRear, LOW);
  long durationRear = pulseIn(echoPinRear, HIGH, 38000);
                                                              //reads the echo pin
returns the sound wave travel time in microseconds
  distanceRear = durationRear * 0.034 / 2:
                                                      //Time of flight equation: Speed of
soundwave divided by 2
  if (distanceRear > MaxDistance) distanceRear = MaxDistance; //Apply limits
  if (distanceRear == 0) distanceRear = MaxDistance;
  previousMillisrear = currentMillisrear;
                                            //update the prevmillis
  length = (distanceRear + distanceFront) + 28; // 24 + 2front + 2rear cm between
ultrasonic sensors
  width = (distanceRear + distanceFront) + 28; // 24 + 2front + 2rear cm between
ultrasonic sensors
  area = length * width; ***
  //Serial.print("Distancerear: ");
  //Serial.print(distanceRear);
  //Serial.println(" cm");
                          // Sets the location at which subsequent text written to the
  //lcd.setCursor(0, 1);
LCD will be displayed
  //lcd.print("DistRear: "); // Prints string "Distance" on the LCD
  //lcd.setCursor(9, 1);
  //lcd.print(distanceRear); // Prints the distance value from the sensor
  //lcd.setCursor(14, 1);
  //lcd.print("cm");
  //delay(150);
                 VERSITI TEKNIKAL MALAYSIA MELAKA
 }
}
void motorMove() {
 if (stop == true, distanceRear >= distanceFront && distanceRear >= 20 && 20 >=
distanceFront <= 10) {
  digitalWrite(m1, LOW):
  digitalWrite(m2, HIGH);
  digitalWrite(m3, HIGH); //reverse
  digitalWrite(m4, LOW);
  stop = false;
 } else if (stop == true, distanceRear <= 15) {
  digitalWrite(m1, LOW);
  digitalWrite(m2, LOW);
  digitalWrite(m3, LOW); //stop
  digitalWrite(m4, LOW);
  lcd.setCursor(0, 0);
                       // Sets the location at which subsequent text written to the LCD
will be displayed
  lcd.print(F("Frn: ")); // Prints string "Distance" on the LCD
                                           57
```

lcd.setCursor(4, 0); lcd.print(distanceFront); lcd.setCursor(7, 0); // Sets the location at which subsequent text written to the LCD will be displayed lcd.print(F("Rer: ")); // Prints string "Distance" on the LCD lcd.setCursor(11, 0); lcd.print(distanceRear); lcd.setCursor(0, 1); // Sets the location at which subsequent text written to the LCD will be displayed lcd.print(F("Length: ")); // Prints string "Distance" on the LCD lcd.setCursor(7, 1); lcd.print(length); // Prints the distance value from the sensor lcd.setCursor(14, 1); lcd.print(F("cm")); Serial.print("Length: "); Serial.print(length); Serial.println(" cm"); stop = false;} else if (stop == true, length ≥ 0 && distanceRear <= distanceFront && distanceRear <= 15) { digitalWrite(m1, LOW); digitalWrite(m2, LOW); digitalWrite(m3, HIGH); //stop digitalWrite(m4, LOW); } } UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Appendix B: HCSR04 ultrasonic sensor datasheet



NOV Ground ITI TEKNIKAL MALAYSIA MELAKA

Electric Parameter

Working Voltage	DC 5 V
Working Current	15mA
Working Frequency	40Hz
Max Range	4m
Min Range	2cm
MeasuringAngle	15 degree
Trigger Input Signal	10uS TTL pulse
Echo Output Signal	Input TTL lever signal and the range in proportion
Dimension	45*20*15mm



Attention:

 The module is not suggested to connect directly to electric, if connected electric, the GND terminal should be connected the module first, otherwise, it will affect the normal work of the module.

 When tested objects, the range of area is not less than 0.5 square meters and the plane requests as smooth as possible, otherwise, it will affect the results of measuring.

www.Elecfreaks.com



Appendix C: L298N motor driver datasheet







Connection Examples:

Controlling 2-DC Motor with +5V Arduino onboard Power Supply:

Below is the circuit connection use the on-board +5V power supply from Arduino board, and should be done without the 5V Enable Jumper on (Active 5V). This connection can drive two 5V DC motors simultaneously.



```
pinMode(IN1, OUTPUT);
pinMode(IN2, OUTPUT);
pinMode(IN3, OUTPUT);
pinMode (IN4, OUTPUT);
1
void loop()
ł
// Rotate the Motor A clockwise
digitalWrite(IN1, HIGH);
digitalWrite(IN2, LOW);
 delay(2000);
 // Motor A
digitalWrite(IN1, HIGH);
 digitalWrite(IN2, HIGH);
 delay(500);
 // Rotate the Motor B clockwise
digitalWrite(IN3, HIGH);
digitalWrite(IN4, LOW);
 delay(2000);
 // Motor B
 digitalWrite(IN3, HIGH);
 digitalWrite(IN4, HIGH);
 delay(500);
 // Rotates the Motor A counter-clockwise
digitalWrite(IN1, LOW);
digitalWrite(IN2, HIGH);
 delay(2000);
                 MALAYS/4
 // Motor A
 digitalWrite(IN1, HIGH);
 digitalWrite(IN2, HIGH);
 delay (500);
// Rotates the Motor B counter
digitalWrite(IN3, LOW);
                                      -clockwise
 digitalWrite(IN4, HIGH);
 delay(2000);
 // Motor B
digitalWrite(IN3, HIGH);
digitalWrite(IN4, HIGH);
delay(500);
ł
            $
                                                              d,
          UNIVERSITI TEKNIKAL MALAYSIA MELAKA
                                                                           www.handsontec.com
       5
```

