Faculty of Electronics and Computer Technology and Engineering

DEVELOPMENT OF SOFTWARE APPLICATION FOR WATER SURFACE MONITORING USING AN FMCW RADAR

MUHAMMAD FAISAL HAKIMI BIN MOHD REDZUAN

Bachelor of Electronic Engineering Technology (Telecommunications) with Honours

2024

DEVELOPMENT OF SOFTWARE APPLICATION FOR WATER SURFACE MONITORING USING AN FMCW RADAR

MUHAMMAD FAISAL HAKIMI BIN MOHD REDZUAN

**A project report submitted
in partial fulfillment of the requirements for the degree of
Bachelor of Electronics Engineering Technology (Telecommunications) with Honours**

Faculty of Electronics and Computer Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

UNIVERSITI TEKNIKAL MALAYSIA MELAKA
FAKULTI TEKNOLOGI DAN KEJURUTERAAN ELEKTRONIK DAN KOMPUTER

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : **DEVELOPMENT OF SOFTWARE APPLICATION FOR SURFACE MONITORING USING AN FMCW RADAR**

Sesi Pengajian : **1-2023/2024**

Saya **Muhammad Faisal Hakimi Bin Mohd Redzuan** mengaku membenarkan laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hakmilik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (✓):

☐ **SULIT*** (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

☐ **TERHAD*** (Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

☑ **TIDAK TERHAD**

faisal

(TANDATANGAN PENULIS)

Alamat Tetap: No 25 Jalam Qamari U5/107, Taman Nusa Subang Seksyen U5, 40150 Shah Alam, Selangor

Disahkan oleh:

Ts. DR. SURAYA BINTI ZAINUDDIN
Pensyarah Kanan
Jabatan Teknologi Kejuruteraan
Fakulti Teknologi & Kejuruteraan Elektronik dan Komputer
Universiti Teknikal Malaysia Melaka (UTeM)
suraya@utem.edu.my

(COP DAN TANDATANGAN PENYELIA)

Tarikh: 14 January 2024

Tarikh: 14 January 2024

*CATATAN: Jika laporan ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh laporan ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I declare that this project report entitled “DEVELOPMENT OF SOFTWARE APPLICATION FOR WATER SURFACE MONITORING USING AN FMCW RADAR” 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.

Signature : faisal

Student Name : Muhammad Faisal Hakimi Bin Mohd Redzuan

Date : 14 January 2024

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 Electronics Engineering Technology (Telecommunications) with Honours.

Signature : ....

Supervisor Name : Ts. DR. SURAYA BINTI ZAINUDDIN

Date : 14 JANUARY 2024

Signature : ....

Co-Supervisor Name (if any) : ....

Date : ....

DEDICATION

I dedicate my bachelor's degree project with heartfelt gratitude to my parents, Mohd Redzuan Bin Mat Dom and Norisah Binti Baba. Their unwavering support, valuable advice, and financial assistance have been instrumental in shaping me into an independent and determined individual. Their life lessons have inspired me to persevere through challenges, reinforcing the belief that the most profound knowledge comes from learning through experiences and finding positivity in every setback. I extend my sincere appreciation to my dedicated supervisor, Dr. Suraya Binti Zainuddin, whose guidance and insightful ideas played a pivotal role in the successful completion of this project. I am immensely grateful for her expertise and encouragement throughout this journey. Special thanks to my friends, especially Qerabat, my fellow crew members at Rowing Stingrays, and all those who guided the project's completion. Your support and camaraderie have been invaluable. I also acknowledge the person who ignited my passion for electronic engineering and those who constantly inspired me to overcome obstacles in pursuing this field. To everyone who believed in me, thank you for being a driving force behind my academic achievements. This project is a testament to the collective encouragement and inspiration I have received from my loved ones and mentors.

ABSTRACT

Detection of water targets is an open issue. The research addresses the challenge of water surface target detection by leveraging Frequency Modulated Continuous Wave (FMCW) radar systems, specifically focusing on overcoming limitations posed by atmospheric interference, vegetation cover, and environmental noise. A significant challenge is the presence of strong water spikes or ripples, particularly when dealing with small-sized targets. These spikes can cause targets to become nearly submerged in water clusters, complicating detection. Recognizing the effectiveness of FMCW radar in all-weather conditions and its ability to penetrate vegetation, the project aims to develop a MATLAB-based algorithm for water surface detection. The algorithm undergoes validation through experiments, ensuring accurate range detection by processing real-world data. Initial steps involve target placement on a water surface, data extraction, and subsequent post-processing steps, including Fast Fourier Transform (FFT), peak detection and range estimation. The developed algorithm demonstrates successful range estimation for water surface targets, showcasing practical application effectiveness. Insights from simulation data and Signal-to-Noise Ratio (SNR) experiments guide further refinement, emphasizing calibration, noise reduction, and optimal SNR management. The project's future trajectory envisions broader applications, such as enhanced maritime surveillance, improved range resolution for FMCW radar, and collaboration with industries to maximize its potential in diverse radar applications, ensuring continuous performance improvement.

ABSTRAK

Pengesanan sasaran air adalah isu terbuka. Penyelidikan menangani cabaran pengesanan sasaran permukaan air dengan memanfaatkan sistem radar Frequency Modulated Continuous Wave (FMCW), khususnya menumpukan pada mengatasi batasan yang ditimbulkan oleh gangguan atmosfera, litupan tumbuh-tumbuhan dan bunyi persekitaran. Cabaran penting ialah kehadiran pancang atau riak air yang kuat, terutamanya apabila berhadapan dengan sasaran bersaiz kecil. Pancang ini boleh menyebabkan sasaran menjadi hampir tenggelam dalam gugusan air, menyukarkan pengesanan. Menyedari keberkesanan radar FMCW dalam keadaan semua cuaca dan keupayaannya untuk menembusi tumbuh-tumbuhan, projek ini bertujuan untuk membangunkan algoritma berasaskan MATLAB untuk pengesanan permukaan air. Algoritma menjalani pengesahan melalui eksperimen, memastikan pengesanan julat yang tepat dengan memproses data dunia sebenar. Langkah awal melibatkan penempatan sasaran pada permukaan air, pengekstrakan data dan langkah pasca pemprosesan seterusnya, termasuk Fast Fourier Transform (FFT), pengesanan puncak dan anggaran julat. Algoritma yang dibangunkan menunjukkan anggaran julat yang berjaya untuk sasaran permukaan air, mempamerkan keberkesanan aplikasi praktikal. Cerapan daripada data simulasi dan eksperimen Nisbah Isyarat-ke-Bunyi (SNR) membimbing pemurnian selanjutnya, menekankan penentukuran, pengurangan hingar dan pengurusan SNR yang optimum. Trajektori masa depan projek membayangkan aplikasi yang lebih luas, seperti pengawasan maritim yang dipertingkatkan, resolusi jarak yang lebih baik untuk radar FMCW, dan kerjasama dengan industri untuk memaksimumkan potensinya dalam aplikasi radar yang pelbagai, memastikan peningkatan prestasi yang berterusan.

TABLE OF CONTENTS

		PAGE
DECLARATION		
APPROVAL		
DEDICATIONS		
ABSTRACT		**iii**
ABSTRAK		**iv**
TABLE OF CONTENTS		**v**
LIST OF TABLES		**vii**
LIST OF FIGURES		**viii**
LIST OF SYMBOLS		**x**
LIST OF ABBREVIATIONS		**xi**
LIST OF APPENDICES		**xii**
CHAPTER 1	**INTRODUCTION**	**1**
1.1	Environment and Society	1
1.2	Global Issues	2
1.3	Research Background	3
1.4	Problem Statement	5
1.5	Project Objective	6
1.6	Scope of Project	6
1.7	Outline of Report	7
1.8	Summary	8
CHAPTER 2	**LITERATURE REVIEW**	**9**
2.1	Introduction	9
2.2	Type of Radar Configuration	10
2.3	Co-located Monostatic Radar Configuration	13
2.4	Basic FMCW Waveform	14
2.5	A Concept of Range Detection Using FMCW	17
2.6	Previous Recent Project	17
2.7	Radar Performance Analysis	38
2.8	Summary	39
CHAPTER 3	**METHODOLOGY**	**40**
3.0	Introduction	41
3.1	Project Workflow	42

3.1.1 Project Planning and Flowchart 44
3.2 General Model & Process Flow of The Proposed Project 46
3.3 Software Specification 48
3.4 Distance2Go Radar Module 49
3.4.1 Interface of Radar GUI 51
3.4.2 The Concept Diagram of the Proposed Model 52
3.5 Simulation 53
3.5.1 Project Flowchart 53
3.5.2 Simulation Block Diagram 55
3.6 Validation Experiment on Water Surface Target Object 56
3.6.1 Experiment Validation Block Diagram 59
3.6.2 MATLAB Post-Processing Code for Experiment Validation 60
3.6.2.1 Data Extraction 60
3.6.2.2 Fast Fourier Transform 62
3.6.2.3 Peak Detection 63
3.6.2.4 Range Estimation 64
3.7 Summary 65

CHAPTER 4 RESULTS AND DISCUSSIONS 66
4.1 Introduction 66
4.2 Simulation for FMCW Sawtooth Signal Generation 66
4.3 Analysis of Range Estimation 68
4.4 Analysis of Signal to Noise Ratio (SNR) for Experimental Data 76
4.5 Summary 81

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS 82
5.1 Conclusion 82
5.2 Recommendation 83
5.3 Project Potential 85

REFERENCES 86

APPENDICES 88

LIST OF TABLES

TABLE	TITLE	PAGE
Table 2.1: Summary of Related Previous Project		20
Table 3.1: Parameter in Distance2Go for target detection object.		58
Table 4.1: Analysis from experiment data		69
Table 4.2 Simulation post processing		71
Table 4.3: If the SNR for target range at 8 meter.		77
Table 4.4: If the SNR for target range at 9 meter		79
Table 5.1: Project Gantt Chart PSM 1		91
Table 5.2: Project Gantt Chart PSM 2		92

LIST OF FIGURES

FIGURE	TITLE	PAGE
Figure 2.1: An example of monostatic radar.		10
Figure 2.2: An example of a bistatic radar.		11
Figure 2.3: An example of a multi-static radar.		12
Figure 2.4: Triangle waveform.		14
Figure 2.5: Sawtooth waveform.		15
Figure 2.6: Ramp waveform.		15
Figure 3.1: Process flow.		43
Figure 3.2: Project planning flowchar.		45
Figure 3.3: Block Diagram.		46
Figure 3.4: Flowchart of the process flow.		47
Figure 3.5: MATLAB R2023a software for post-proessing.		48
Figure 3.6: Block diagram of Distance2Go radar module.		49
Figure 3.7: Top view of Distance2Go radar module.		50
Figure 3.8: Bottom view of Distance2Go radar module and antenna radiation pattern.		50
Figure 3.9: Example of Infineon radar GUI.		51
Figure 3.10: Conceptual diagram.		52
Figure 3.11: Experiment process flow of a monostatic FMCW radar.		54
Figure 3.12 A monostatic FMCW block diagram utilised a Distance2Go.		54
Figure 3.13: Simulation Block Diagram.		55
Figure 3.14 Illustration of experiment setup for range detection within object and RUT.		56
Figure 3.15: View outdoor experiment setup for target detection using Distance2Go module with distance 3 meter.		57

Figure 3.16: Setup outdoor radar module to detect the floating target. 57

Figure 3.17: Flow diagram for real data-experiment. 59

Figure 3.18: Load and read signal from D2G radar module. 61

Figure 3.19: Define parameter as per D2G. 61

Figure 3.20: Signal processing to estimate target range. 62

Figure 3.21:Block diagram of system (FFT). 62

Figure 3.22: Maximum peak to detect frequency beat. 63

Figure 3.23: Block diagram of the system (Peak Detection). 64

Figure 3.24: Range estimation. 64

Figure 3.25: Block diagram of the system (Range Detection). 65

Figure 4.1: FMCW baseband signal in time domain. 67

Figure 4.2: FMCW baseband signal in frequency domain. 68

Figure 4.3: Simulation Result of estimated Actual, Average of target range. 70

LIST OF SYMBOLS

τ	-	Tau
c	-	Speed of Light
f	-	Frequency
B	-	Bandwidth

LIST OF ABBREVIATIONS

FMCW	-	Frequency Modulated Continuous Waveform
FFT	-	Fast Fourier Transform
CW	-	Continuous Waveform
RF	-	Radio Frequency
D2G	-	Distance2go
MIMO	-	Multiple Input Multiple Output

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
Appendix A	Coding in MATLAB PSM 2	88

CHAPTER 1

INTRODUCTION

Chapter 1 sets the stage by giving a full study background and focusing on how the environment, society, and global issues are all connected. It shows how important it is to deal with urgent problems that affect the health of both ecosystems and human societies. The chapter starts with a clear statement of the problem, pointing out a particular issue that needs to be looked at and fixed. Using this problem statement as a starting point, the chapter explains the goals of the project, including the expected results and how they will help solve the problem. The project's scope is also spelt out, along with the limits of the study that will be done and the specific topics that will be covered. Lastly, the chapter gives an overview of the whole report. It shows how the next chapters, and their content are organized, making sure that the information flows smoothly and makes sense.

1.1 Environment and Society

The detection of the water's surface is an essential component that has implications for both the environment and society. It is an essential component in the process of determining the influence that a variety of activities, such as industrialization and urbanization, have on the surrounding environment. It is possible to gain a better understanding of the state of aquatic ecosystems and the effects of climate change through the monitoring and identification of changes that occur in bodies of water. Monitoring the amount, quality, and availability of water is an important part of water resource management, which can be assisted by water surface detection. This information is necessary for addressing the issue of water scarcity as well as planning for sustainable water usage.

In addition to that, it contributes to the monitoring of floods and the management of natural disasters by making timely warnings and evacuation preparations possible. The detection of the water's surface also has implications for the conservation of wetland areas, urban planning, the development of infrastructure, the study of climate change, as well as socioeconomic impacts such as the management of fisheries and the planning of tourism. In conclusion, precise detection of the water's surface offers useful insights that may be used to make educated decisions that contribute to the preservation of the environment and the growth of the socioeconomic system.

1.2 Global Issues

Water surface detection is linked to several important world problems. It is a key part of keeping an eye on how climate change affects water bodies around the world by keeping track of things like rising sea levels, melting glaciers, and changes in how rain falls. Also, accurate detection of water surfaces is important for figuring out how much water is available, dealing with the global water problem, making policies, and putting in place sustainable ways to manage water. Also, water surface detection helps protect and restore habitats and protect biodiversity by tracking and mapping wetlands, rivers, lakes, and coastal areas. It also helps predict and lessen the effects of natural disasters, like floods, by making early warning systems and good crisis management possible. Also, water surface detection fits with a number of Sustainable Development Goals, such as clean water and sanitation, sustainable towns and communities, taking action on climate change, finding out what lives under the water, and working with others to reach the goals. It helps with international efforts to control water, makes disaster relief and humanitarian aid easier, and helps solve the complicated problems that come up when water flows across borders. By tackling these global problems, water surface detection helps to promote sustainable growth, protect the environment, and make the world more resilient to climate change and a lack of water.

1.3 Research Background

Water surface detection is important for various reasons. It ensures safety in maritime navigation, helps monitor and manage water resources, aids in flood prediction and management, facilitates efficient irrigation and agriculture practices, supports remote sensing and mapping applications, and ensures the safety of individuals engaging in recreational activities. Accurate detection of water surfaces enables informed decision-making, resource management, and protection of lives and the environment.

There are several methods used for water surface detection. Remote sensing techniques involve using satellite imagery or aerial sensors to detect and map water surfaces. Sonar systems use sound waves to detect and map underwater surfaces. By measuring the time, it takes for sound waves to bounce back after hitting an object. Radar systems, especially synthetic aperture radar (SAR), are effective for water surface detection. Radar waves can penetrate cloud cover and are sensitive to changes in water surfaces. SAR can provide information on water extent, roughness, and surface features, making it useful for flood monitoring and maritime applications.

After studying about these three methods of detection for water surface, 2 of these methods have significant weakness that is Remote sensing for water surface detection will be disadvantage by atmospheric interference that can distort data, sensor limitations in terms of resolution and spectral sensitivity, vegetation cover that can obstruct water identification and complex water properties that are challenging to capture accurately. Second, Sonar technology for water surface detection has weaknesses including challenges with surface reflections, signal attenuation due to water properties, interference in shallow water and from bottom features, limited resolution for fine details, susceptibility to environmental noise, and limitations in adverse weather conditions. Based on this two weakness I have decided to proceed with the Radar system. Radar systems are preferred for water surface detection due to their ability to operate in all weather conditions, including rain and fog, providing continuous monitoring capabilities day and night. They offer wide coverage and high-resolution imaging, allowing for the detection of large water bodies and precise identification of water boundaries and dynamics. Radar systems can penetrate vegetation, making them suitable for monitoring water surfaces in vegetated areas, and their sensitivity to surface roughness enables the tracking of water phenomena. Additionally, radar has long-distance detection capabilities. The advantages of radar systems make them a reliable choice for diverse water surface detection applications.

In our world, radar is one of the most advanced technologies for measuringobject distances. There have been many radar systems that have been utilized for diverse reasons. Radar systems are categorized into several groups based on their operations and uses.This list covers some of the most prevalent radar systems used for various roles and by various industries. There are many types of radar such as Bistatic radar, Frequency Modulated Continuous Waveform (FMCW) radar, and Doppler radar [1].

FMCW radar is a special type of radar sensor that radiates continuous transmission power like a continuous wave radar. FMCW radar also can measure not only the distance from the target radar but also it can measure the speed of target. Unlike Continuous Waveform (CW) radar, FMCW radar may modify its operational frequency during measurement. The broadcast signal is frequency or in phase modulated. Radar measurements using runtime measurements are only physically possible with these frequency or phase variations [2]. The ability to measure very small distances to the target is one of the main properties of FMCW radar. It is also able to assess both the target range and its relative velocity simultaneously, as well as extremely high range measurement accuracy.

Radar performance is initially measured in terms of propagation efficiency in different mediums such as air, vegetation, and ground in relation to the desired detection range. The general rule is that the lower the frequency, the more efficiently radio waves propagate through the medium. Furthermore, in a condition of obscurant presence, propagation is advantageous when the Radio Frequency (RF) wavelength is substantially greater than the particle size forming the propagation. Thus, radars operate far better than optical systems in the presence of smoke, dust, fog, and rain [3].

1.4 Problem Statement

The deployment of this radar system proves highly effective in supporting target tracking, even for small targets. The tracking performance has been substantiated; however, its effectiveness is constrained by the reliance on single-radar coverage. In instances of radar shutdown or failure, coupled with the return of weak echoes from targets, the absence of alternative radar sources hampers target tracking and estimation capabilities. The presence of strong water spikes, particularly in the context of small-sized targets, exacerbates the situation. These water spikes or ripples cause targets to become nearly submerged in water clutters, stemming from the radar echo energy received within the limited perspective of a single radar. Consequently, this phenomenon leads to a significant increase in errors during the target estimation process [24]. Addressing this limitation requires exploration on radar approach, advanced signal processing, and enhanced algorithms to ensure continuous and accurate target tracking, particularly in scenarios involving small targets amidst challenging environmental conditions.

1.5 Project Objective

With regards to the problem statement discussed in previous section, the project objectives areas follows:

a) To develop a water surface detection algorithm for FMCW radar signal processing by using MATLAB.

b) To validate the range detection algorithm through the experimental data.

c) To analyse the software developed in terms of it functionality and accuracy.

1.6 Scope of Project

The scope of this project are as follows:

a) Develop a water surface detection algorithm using MATLAB for processing FMCW radar signals.

b) Validate the range detection algorithm through experiment data, ensuring its practical effectiveness.

c) Analyze the developed software in term of functionality and accuracy, meeting predefined project objectives and standards.

d) Implement initial stages involving target placement on water surface, followed by data extraction and post-processing steps such as Fast Fourier Transform (FFT), peak detection and range estimation.

1.7 Outline of Report

This report comprises of five main chapters divided into several sections to provide adetailed explanation of the research. The contents of each chapter are summarized below to lay an overview guide of the study.

Chapter 1 introduces the topic and discusses how the environment, society, and global challenges are linked. It emphasizes the need to address serious issues affecting ecosystems and human societies. The chapter begins with a specific problem that needs to be addressed. The chapter describes the project's goals, expected results, and how they will address the challenge using this problem statement. The project's scope, study restrictions, and themes are also listed. Finally, it’s summaries the report. It organizes the upcoming chapters and their material to ensure smooth flow and comprehension.

Chapter two covers the literature review, a comprehensive overview of important studies. It synthesizes scientific articles, research papers, and other authoritative sources to aid understanding. This chapter also explains FMCW radar's fundamental waveform. It also discusses FMCW range detection and how to accurately estimate radar-target distance. Chapter two lays the theoretical groundwork for the rest of the course by reviewing the literature and explaining FMCW waveform and range detection.

In chapter three, the research method is explained in detail, including all the steps involved in the study. It starts by showing a conceptual diagram of the suggested model, which shows what the research framework looks like. This chapter also goes into more depth about the project's workflow, explaining the steps and activities that were done to reach the research goals. By giving a clear and organized outline of the research method, this chapter makes sure that the study is clear and can be repeated. This makes it possible for other researchers to understand the process and, if they want to, repeat it.

After elucidating the overall study methodology in earlier chapters, Chapter 4 now pivots to a focused analysis of critical components. Recognizing the iterative nature of research, we transition from BDP 1 to BDP 2, refining our approach based on ongoing insights. This chapter delves into the intricate analysis of range estimation, simulation results pertaining to the estimated actual average of the target range, and a thorough examination of the signal-to-noise ratio (SNR) within the experiment data. While preliminary results have been omitted, this strategic shift allows for a more concentrated exploration of specific aspects, paving the way for targeted improvements in subsequent stages of the project.

Finally, Chapter five presents the final summarized in conclusion. It also includes recommendations and project potential.

1.8 Summary

Chapter 1 gives a full overview of the study, focusing on how important it is that the environment, society, and global issues are all connected. It gives the history of the study and stresses how important it is to solve urgent problems that affect both natural ecosystems and human communities. The chapter makes a clear statement of the problem, pointing out a particular problem that needs attention and a solution. It says what the project's goals are, what the expected results are, and how the project will help solve the problem. The project's limits and the things that will be covered are also spelt out. Lastly, the chapter gives an overview of the rest of the report. This makes sure that the information flows smoothly from one chapter to the next. Overall, Chapter 1 sets the stage for the study by giving a clear context and direction for the next chapters, which go into more detail about the topic.

CHAPTER 2

LITERATURE REVIEW

Chapter 2 gives a full review of the literature on radar systems, with a focus on the co-located monostatic radar setup, the basic Frequency modulated continuous wave (FMCW) waveform, and the idea of using FMCW to find the distance between two objects. This part looks at the work of previous researchers in the field and shows how recent projects have helped radar technology get better. It also goes into detail about radar performance analysis, looking at the key metrics and review methods used to measure how well and how accurately radar systems work. This chapter lays the groundwork for the rest of the book by reviewing the available literature. This helps readers understand radar principles and how they can be used in real life.

2.1 Introduction

In the modern world we live in now, energy efficiency is seen as one of the most important ways to deal with growing problems like rising fuel costs, market competition, tighter regulations, climate change, and energy crises caused by running out of fossil fuels. Utilities and regulators are putting more focus on finding ways to lower distribution TL because it is a key sign of how well a system uses energy. For strategic planning and the creation of an energy-efficient distribution network, it is important for utilities to come up with a good way to analyse the size, location, and sources of TL in the system. With complete and accurate information about TL, remedial and preventive solutions for TL reduction can be planned and carried out in the right way, on time, and effectively.

2.2 Type of Radar Configuration

In radar system configuration, there are three basic configurations which are monostatic, bistatic, and multistate. Monostatic radar is a radar arrangement where the transmitter and thereceiver are all in the same location and usually form the same piece of radar equipment. Thisconfiguration allows the transmitter to be synchronized with the receiver, making implementing the timing method for measuring the target range easier [4].

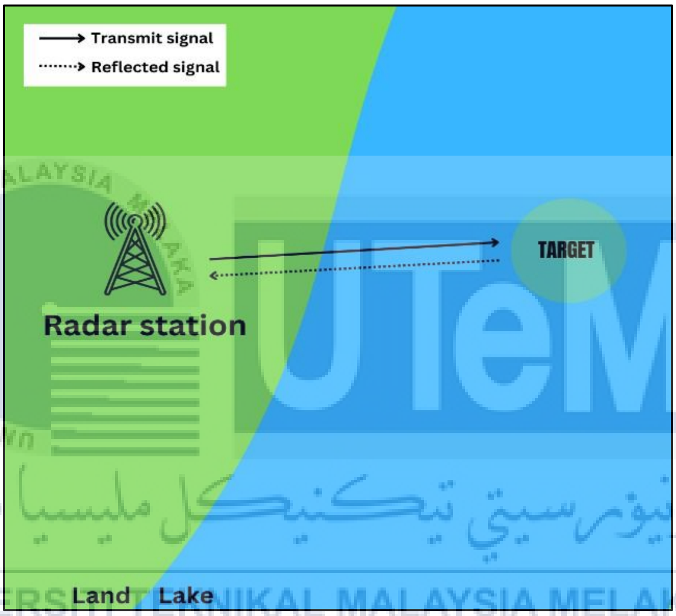


Figure 2.1: An example of monostatic radar.

Bistatic radar shares a common antenna between the transmitter and receiver and consists of separately located transmitting and receiving sites. In a bistatic radar system, the distance between the transmitting and receiving units is greater, and the parallax is usually greater. This means that a signal can also be received when the geometry of the reflecting object reflects very little or no energy in the direction of the monostatic radar (stealth technology). It is primarily used for weather radar inpractice [5].

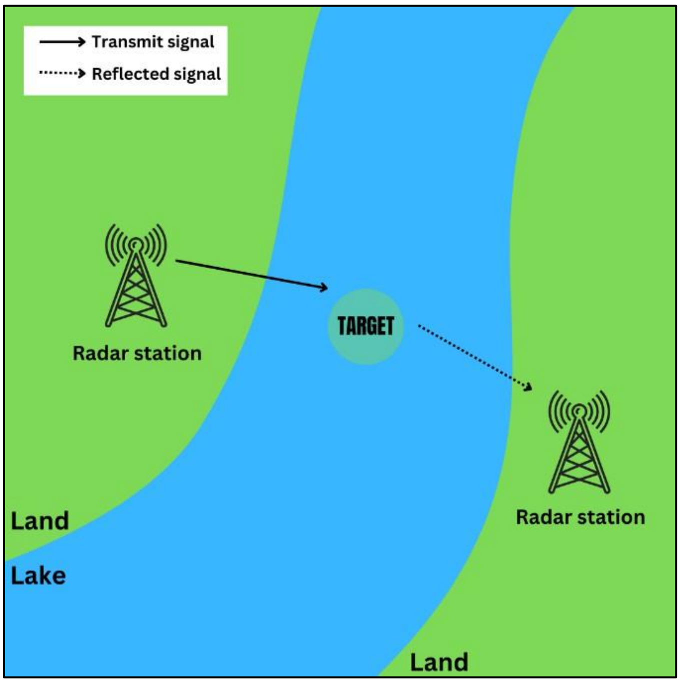


Figure 2.2: An example of a bistatic radar.

A multistatic radar system is made up of several different monostatic or bistatic radar components that are spread out in space but cover the same area. A big difference between systems with these different radar geometries is that they need to combine input from different parts. The different kinds of space in multistatic devices make it possible to see different parts of a target at the same time. The power to get information can make traditional systems better in many ways. Multistate radar, also called "multisite" or "netted" radar, is similar to the idea of "macro diversity" in communications [6].

In FMCW radar it is also called altimeter. It transmits data at a low power level. Many solid-state devices, such as magnetrons and reflex klystrons, can provide this. The super-heterodyne structure provides excellent sensitivity and stability, and it offers higher bandwidth compared to CW radar.

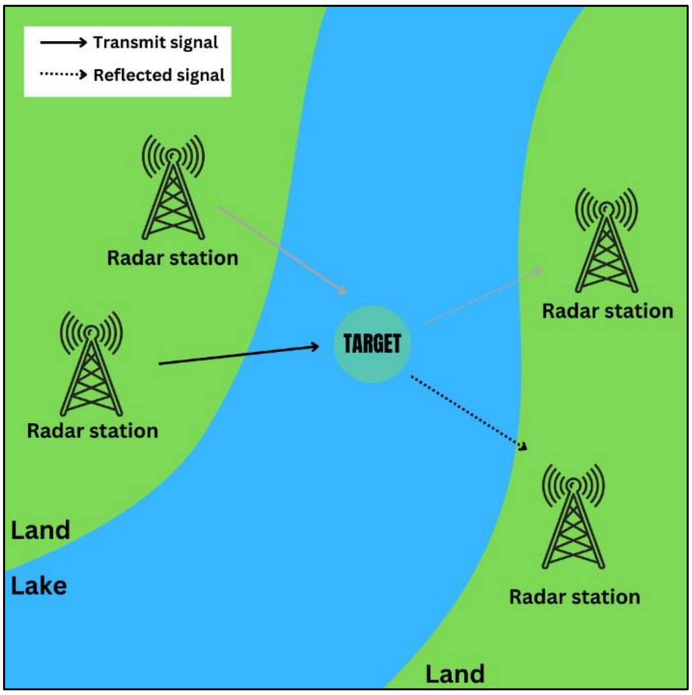


Figure 2.3: An example of a multi-static radar.

2.3 Co-located Monostatic Radar Configuration

A co-located monostatic radar configuration is a radar system in which the transmitter and receiver are located at the same physical location. This contrasts with a bistatic radar configuration, in which the transmitter and receiver are located at different locations. In a monostatic radar system, the radar antenna transmits a signal and receives the signal after it reflected off a target. The receiver processes the received signal and then extracts information about the target, such as itsrange, velocity, and angular position. The collocated monostatic radar configuration isa widely used design for radar systems because it is simple and easy to implement. Thetransmitter and receiver can be in the same housing, which makes the system more compact and easier to install. Additionally, the transmitter and receiver can be connected directly, eliminating the need for a separate transmission line. This configuration also allows for better control of the system's main lobe, the region of maximum radiation. This is important for radar systems because the main lobe is where the highest signal-to-noise ratio is achieved, and it can detect targets most accurately.

However, there are also some drawbacks to the collocated monostatic radar configuration. For example, the receiver is exposed to the same interference as the transmitter, which can affect the receiver's performance. Additionally, this configurationis less resistant to jamming than other radar configurations, as the jammer can jam boththe transmitter and the receiver.

Overall, the collocated monostatic radar configuration is a simple and widely used design that is easy to implement and has good performance in detecting targets.However, it has some limitations when compared to other configurations, but it will depend on the application and the system’s requirements.

2.4 Basic FMCW Waveform

An FMCW radar is also called an altimeter. It transmits data at a low power level. Many solid-state devices, such as magnetrons and reflex klystrons, can provide this. However, The super-heterodyne design is very sensitive and stable, and it has a wider frequency range than CW radar.

There are a few basic frequency changes, like the triangle, sawtooth, and ramp. Triangle waveforms are bidirectional waveforms that are not linear and have both positive and negative peak values. Even though it's called a triangle waveform, it's a symmetrical linear ramp waveform because it's just a voltage signal that keeps going up and down. As shown below, the rate at which the voltage changes between ramp directions are the same for both parts of the cycle [16].

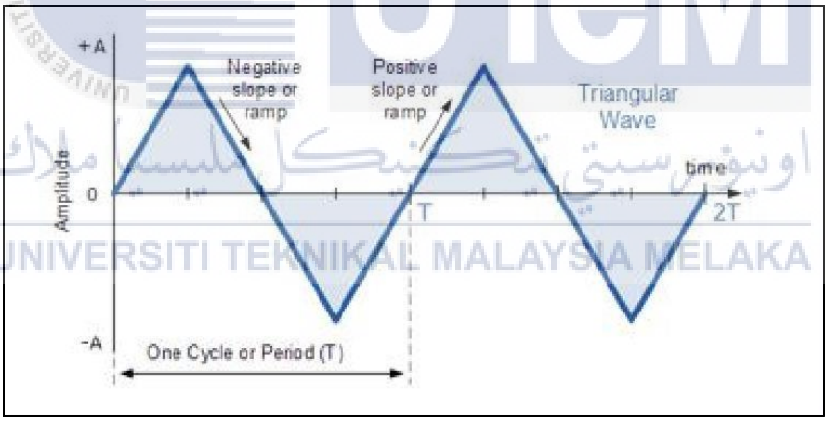


Figure 2.4: Triangle waveform.

Next, a sawtooth waveform is a different kind of periodic waveform. As the name implies, the waveform shape is reminiscent of saw blade teeth. Saw-toothedwaveforms can be mirrored by having either a slow rising but highly steep decay, or an extremely steep almost vertical rise and sluggish decay, as seen below [7].

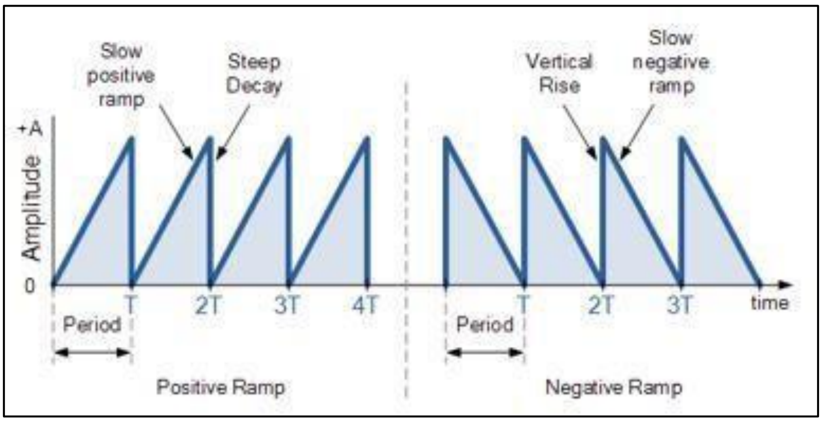


Figure 2.5: Sawtooth waveform.

Furthermore, a ramp waveform is one that climbs to its maximum value and thendrops almost vertically. A negative ramp is also conceivable, in which the signal steadily declines from a maximum to a low value and then rises with a near vertical slopeto the maximum value again.

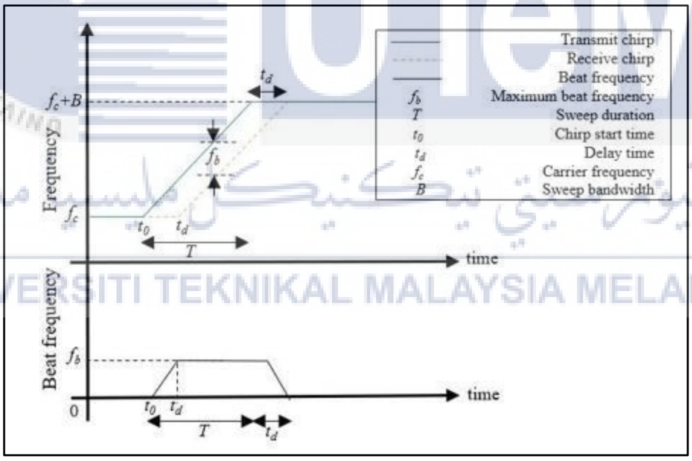


Figure 2.6: Ramp waveform.

The solid line depicts the frequency of the broadcast signal as a function of time,while the dotted line depicts the frequency of a reflected signal from a single stationarytarget. Round-trip delay denotes the delay caused by the sent pulse needing to travel tothe destination and return. Next, for the beat frequency as a function of time, it can be shown that for the beat frequency to reach a value that may be utilized to estimate the distance to the target, a fall and rise duration equal to the round-trip delay is necessary [8].The range calculation for a Frequency Modulated Continuous Wave (FMCW) radar can be determined using the following formula:

$$Range = (c * \Delta f * \tau) / (2 * B)$$

Where:

- Range is the calculated distance to the target in meters.
- c is the speed of light (approximately 3 x 10^8meters per second).
- Δf is the frequency sweep or frequency modulation range in hertz.
- τ is the time it takes for one complete sweep or modulation period in seconds.
- B is the bandwidth of the transmitted signal in hertz.

The basic idea behind this equation is that the range is proportional to the time it takes for the signal to move to the target and back, and inversely proportional to the signal's bandwidth.

2.5 A Concept of Range Detection Using FMCW

An antenna transmit a radar signal, which is reflected on the product's surface and received after t seconds. The FMCW-radar emits a high-frequency signal that increases in frequency linearly during the measurement phase, known as frequency sweep. With time delay, t, the signal is emitted, reflected from the measuring surface, and received. T=2d/c is the delay time, where d is the product surface distance and c are the speed of light. For further signal processing, the difference Δf between the actual send and receive frequencies is computed. The discrepancy grows in direct proportion to the distance travelled. A large frequency difference corresponds to a long distance and vice versa.

2.6 Previous Recent Project

Previous recent projects, which used nearly identical software to innovate and develop the new project, were chosen to develop a concept for improving and mitigating the disadvantages. Table 2.1 offers a comparison table for ten various studies relevant to this project, so that we may enhance or prevent the project's drawbacks after studying them.

Table 2.1: Summary of Related Previous Project

No.	Author	Title	Year	Method	Parameter	Result
1	[9]	Human Target Detection, Tracking, and Classification Using 24-Ghz FMCW Radar.	2019	A doppler-compensated angle-of-arrival estimate method and a one-class support vector machine are shown to improve the performance of human recognition and tracking. The highest distance and angle errors of the completed radar sensor are 25 cm over a measuring range of 18 m and 10° over a two-sided angle sweep of 65°, respectively. The maximum range precision is 0.9 m. The open-source	FMCW radar 24Ghz ISM band. A 24Ghz monolithic microwave integrated circuit is used to make a radio frequency unit. A low-noise fractional-N phase-locked loop is used to make an FMCW ramp and stabilise the frequency. 5V gives power to sensors.	The alpha-beta filter was chosen as a tracking method, and so were the other algorithms. They can all be run on a microcontroller and work well. When the developed radar system and algorithm were put through thorough testing, the results were convincing. Similar radar systems have the same accuracy in distance and angle, the same precision, and the same maximum range. It was shown that the proposed system can find and follow up to five moving people over

				library LIBSVM was picked as an SVM implementation because it has both a C interface and a MATLAB interface for exploratory experiments.		a range of more than 100 degrees and up to 20 metres.
2	[10]	Multi-target Detection and Tracking with 8Ghz FMCW Radar System	2020	Methods for finding and following multiple targets with an 8 GHz FMCW radar system To use a radar system to find many targets, a new signal processing path must be built that is different from both multiple input, multiple output, and multiple input, single output. A time domain moving	Starting frequency is 7.3Ghz, bandwidth is 1Ghz, time between chirps is 2.6ms, sweep time is 0.082ms, number of chirps per frame is 16, number of samples per chirp is 512, and time between frames is 0.0416s.	Based on the results of simulations and experiments, multi-target recognition and tracking work well in a number of different situations. The method for finding and following different objects makes it easy to tell them apart. The method for finding and following multiple targets works well with two or three targets. But as

				window will be used to figure out the angle of the target. An updated multi-target detection algorithm will be used to find and track targets. This will cut down on background noise and improve the accuracy of identification. Methods for tracking more than one target that use a data connection can also help when targets show and disappear.		the number of targets goes up, so does the efficiency of finding angles.
3	[11]	Short Range Height Classification in FMCW Radar	2021	Small range-based algorithm FMCW radar technology is what is offered. The method	Short-range FMCW 78Ghz with a 2Ghz bandwidth, MIMO setup with 12	When figuring out the height of different targets with a set threshold of 0.3m, correct classification

				helps self-driving cars figure out how well travelers can see things in the moving direction. Using the resolvability of multipath components reflected from an object by a radar system, the method compares the associated detections over time with boundary curves. A 78 GHz MIMO radar device was used to model and test the idea behind the algorithm.	virtual receiver channels (3 emitters and 4 receivers). The radar monitor was put in front of the car, about 0.6 metres off the ground. Different targets with heights between 0.1 and 1.5 m.	decisions were made with 60–90% trust. Using an ego-velocity estimating method to get rid of velocity mismatches can improve the accuracy of the height classification technique.
4	[12]	Moving and Stationary Target Detection scheme using	2017	Make a goal-tracking stage with clustering, data link, track administration, and a track	The signal processing settings were made with a range-bin size of 0.5 m, a	Before Doppler processing, a moving target indicator is suggested to tell the difference

		coherent Integration and Subtraction for Automotive FMCW radar system.		filter.Lastly, the target classification stage picks range, velocity, and angle-ROIs (Regions Of Interest) based on the target track output and looks at the 3D profiles made by the target recognition phase. A 24 GHz FMCW transceiver and a single antenna are used to test the suggested radar signal processing system. We used Matlab on a host PC to build the necessary methods, which we then used on raw data from the data recording device.	velocity-bin size of 0.5 km/h, and observed speeds from -15 to 15 km/h. Because the designed radar sensor only has one receiving antenna, the only information about the object that can be seen is its distance and speed. For high-accuracy level readings, DGIST made a 24 GHz FMCW transceiver with a single antenna in the shape of a horn.	between moving target components and fixed target components. This was done so that a weak target wouldn't be hidden by a lot of clutter. During the target tracking stage, we use a track management approach to fix any missed targets and get rid of any ghost targets. Lastly, for target categorization, we made a type of architecture that uses the range-, Doppler-, and angle-profiles of an identified target to put it into a group. In a lab test with a 24 GHz radar sensor, the target recognition stage and profile

						selection for target categorization in the planned radar signal processing system were proven to work.
5	[13]	Development of Short - Range Ground Surveillance Radar for Moving Target Detection	2015	Used a 2D-FFT method and a windowing method to reduce the distortion caused by changes in frequency so that we could recognize moving things. Also, we made a moving target extraction method to pull moving targets out of the errors that were left over. We made a 24GHz FMCW radar setup with parts	Centre Frequency (Ghz): 24, Bandwidth (Mhz): 200, Pulse Repetition Time (us): 40, Ramp Size in One Frame: 32, ADC Sampling Rate (Mhz): 1, Sample Size in One Ramp: 40, FMCW: 24Ghz.	They showed an idea for a short-range ground monitoring radar that can find moving things. Before FFT processing, we used window functions to get rid of the distortion output that we didn't want. Also, before thresholding, moving targets were pulled out of the leftover distortions using a new method for identifying moving targets. The new 24GHz FMCW radar transceiver and

				for the front end and the back end. The back-end module's microprocessor was updated with a new program.		antennas were used to test a new target recognition processing system that was built into a microprocessor. Based on what we learned from tests on a real road, we can assume that the new system can spot a moving car.
6	[14]	River surface analysis and characterization using FMCW radar.	2022	In addition to measuring the speed and distance of the water's surface, the goal is to find other characteristics that can be used to describe the water's properties. In addition to the usual hydrological factors, these things could help make flood warning systems better. Special	The review of range-Doppler plots and the time-averaged velocity distribution of the envelope velocity distribution based on the integration of several range-Doppler frames give a lot of information. These	When you take the average of the time series plots, you get a characteristic velocity profile over range. This can be used to describe the flow of a river by its maximum mean speed and the width of the velocity profile. The resulting pictures of the reflection centres found by the radar give interesting

				care is given to the information gained from the time series of the FMCW data about how the water surface changes over time.	evaluations include a wide range of information about the real water surface that goes beyond the usual water level and flow speed. Four different rivers were used to test how well these traits can be taken out, which lets us finally describe these rivers. In particular, the time sequence of the envelope velocity distribution over distance, which includes all frames, makes it possible to	information about how these reflection centres change and move in space and time. This shows that the statistical interference-based Fresnel method is the most important part of radar backscattering on rivers. Using these 2-D plots of the envelope speeds over time, it was possible to describe the different river surfaces and find out which branches were moving. By tracking the movement of the branch, these shapes can be separated from the movement of the water.

					do a thorough analysis of how the reflection centres at the surface of the river move over time.	
7	[15]	Frequency Modulated Continuous Wave Radar Design and Simulation	2018	To make a model of an FMCW radar system that can measure the distance and speed of a target within one kilometre for targets with about the same RCS as a car.	The parts and their signal outputs were modelled using a mix of pure MATLAB code and helper objects from the Antenna, Communications, DSP, and Phased Array Toolbox add-ons.	Then, the radar's functions were simulated, and findings were found. As shown, theoretically calculated numbers tended to match up well with measured results from simulations. With the simulated radar system, valid measures of distance and speed were made, and all of the project's goals were met.
8	[16]	Educational Low-Cost C-Band FMCW Radar System Comprising	2021	Low-cost frequency-modulated continuous wave (FMCW) radar	The FMCW radar system was used to find a metal	The suggested low-cost FMCW radar system was tested in a room kept at

		Commercial Off-the-Shelf Components for Indoor Through-Wall Object Detection.		device in the C-band for metal detection through walls indoors. Indoor remote sensing uses, such as detecting and positioning objects through walls, are necessary for the internet of things or "super-connected societies" to be fully realised.	item behind a plywood wall that was 4 cm thick (see Figure 9). The radar and target were put on a wooden table that was 80 cm high. A piece of board 4 cm thick was put 1 m from the radar. Both the width and the height of the boards were 2 metres. Then, a metal item was put behind the wall, and the Rx signal was analysed using the algorithm that was just explained. The object was	25 °C to see how well it worked. The distance between the radar and a 30 cm x 30 cm copper plate was determined. As was seen, the DC shift was taken out successfully, and the peak signal strength was clearly seen to make measuring distance easier. Figure 7 shows what happens when the DC offset explained in (5) is taken away. Here's how to figure out the time-varying distance (R) between the radar and the item. In (6), B is the suggested FMCW radar system's bandwidth, fB is the beat frequency, T is the time it takes for

					put at a number of R between 2.5 and 4 m, as shown in Figure 9a. The results of the measurements are shown in Figure 10. They show the FFT size of the signal in the range bin over the range. As you can see, the biggest difference between the real and estimated places is 10 cm, and the average error in the range is 5.6 cm. The suggested FMCW radar system has a high accuracy	the frequency to rise, and c is the speed of light. When the FMCW radar's beat frequency is equal to fB, the FMCW radar's maximum detection range (RM) is reached. In this study, the value of RM was found to be 56.3 m, which is enough for use indoors. As shown in (7), the suggested FMCW radar system (BW: 110 MHz) has a theoretical range resolution (Rres) of 1.36 m. By using the wide frequency, it can be made better.

					at a distance of 5.6 cm, but its range resolution is only 1.4 m.	
9	[17]	FMCW Radar with enhanced resolution and processing tine by beam switching	2021	Radar systems can find angular targets with high precision by using a method called switched time-domain beamforming at the transmitter and pattern-multiplication and multi-channel processing at the receiver. The four different angles (the beams) split the space being looked at into four parts, which are then put back together in a process called	Antenna arrays made with substrate-integrated waveguides (SIW) and a 4x4 Butler matrix (BM) beamformer. The radar sends out a frequency-modulated continuous-wave (FMCW) signal at 24 GHz. By moving the four input ports of the BM at the right time, it can scan the horizontal plane. Also,	The suggested radar system has a high angular resolution, a wide field of view (FOV), and a short processing time (40 ms). This gives it better performance than similar SIMO and MIMO radar systems. The system uses a Butler matrix for broadcast and sum-and-delay processing at the receiver. This lets each beam be processed by SIMO radar on its own. The angle resolution above the angle between the two

				Power Plus (Pwr+), which stands for the power and addition operations that are done in the processing. After delay-and-sum beamforming is used for each of the BM switching angles, the individual target answers are added together using a multiplication method. This gives better angular resolution and a working time that is competitive. Both the SIW Butler matrix and the radar antenna that goes with it have	targets were placed 2 metres away from the radar and at different angles so that readings could be taken.	targets makes it so that there is only one point in the view. When room, implementation costs, and a more advanced beamformer are taken into account, more views can be added. Overall, the suggested radar architecture gives short-range target detection applications better resolution and less time to process data.

				been detailed and tested in the real world.		
10	[18]	Radical: A synchronized FMCW radar, Depth, IMU and RGB Camera Data Dataset with Low- Level FMCW Radar Signal.	2021	FMCW radar's traditional signal processing path, so that deep neural nets can use it better. Section IV of the paper talks about the system's design, what it can do, and what it can't do. Section V also talks about how the system was used in different situations and how it was set up. In Section VI, a high-resolution velocity estimation and temporal synchronisation job and a small object radar	There are a number of factors about the RaDICaL dataset and system. On page 7, for example, the study talks about how different radar configurations are calibrated and how parameter estimation is done when the radar is set up to match a maximum depth of about 10 m. The study also talks about the	This paper shows baseline results and gives examples of how recent improvements in deep learning could help get better object detection from FMCW radars in cars. The paper also urges other researchers to do better than their baseline, to improve early-stage preprocessing, and to come up with new network architectures that are good for object recognition and fusion using low-level radar signals that were not available before. The paper also gives information about

				signature classification task are used to show what the dataset and system can do.	parameters for placing bounding boxes in the range-azimuth frame and figuring out where projected bounding boxes should be placed in the radar frame.	the dataset and system hardware BOM, as well as design files that can be made on a 3D printer.
11	[19]	A New Model for Human Running Micro-Doppler FMCW Radar Features	2023	Using frequency-modulated continuous wave (FMCW) radar to measure and analyse the tiny movements of people, especially when they are running. In this study, the method involves collecting radar data from people who are	Include the centre frequency, the sampling frequency, the frequency modulation time, the number of pulses per frame, and the bandwidth. The radar system used in the experiment is linked to	The recommended human running model, which looks at human radar features based on the modulation effect of human micro-motion on FMCW radar, had an overall fit rate of 90.6% and a fit rate of 90% or higher for every part of the human body. The human running model was

				running, processing and analysing this data to find features that are related to their micro-motion, and then sharing the results. Then, using these features, a new model for human-run micro-Doppler FMCW radar features is made.	these parameters. The centre frequency is 77 GHz, the sampling frequency is 2.5 MHz, the frequency modulation time is 50 s, there are 128 pulses per frame, and the bandwidth is 4000 MHz. During the experiment, these parameters were chosen to make it easier to find the person's target.	used on a real FMCW radar verification platform where runners were recorded at a distance of 10 m. Based on the results of the trial, the human running model moved from 6 metres away from the FMCW radar to 2 metres away. With the suggested human running model and the study of micro-Doppler features in radar reflections, these results show that FMCW radar can be used to find and study human targets.
12	[20]	Detection of Electronic Devices Using FMCW Nonlinear Radar	2022	Used a nonlinear radar technique based on harmonics to find electronic devices. The	Used a nonlinear radar technique based on harmonics to find	They experimented with employing a harmonic-based nonlinear radar technique to get the apparent and

				apparent and nonlinear RCS (Radar Cross Section) of several electronic gadgets were acquired by experimentation employing target. Additionally, it provided an equation that could be used to directly calculate the nonlinear RCS. The authors used this technique to show how well nonlinear radar works for locating electronic gadgets.	electronic devices. It carried out an experiment using targets to measure the apparent and nonlinear RCS (Radar Cross Section) of various electronic devices. They also provided an equation that could be used to directly calculate the nonlinear RCS. This technique shows how well nonlinear radar works for finding electronic gadgets.	nonlinear RCS of various electrical devices. An illustration of the received power of the harmonic response from one of the targets (i.e., the laptop) is shown in the presented received power level of the harmonic responses of each target. A nonlinear FMCW radar equation was created and it can be used to calculate the targets' maximum detectable range.

13	[21]	Method for Improving Range Resolution of Indoor FMCW Radar Systems Using DNN	2022	Employing Deep Neural Networks (DNN) to increase the range resolution of indoor FMCW RADAR systems. They suggest utilizing DNN to increase object recognition by reducing side lobes and enhancing range resolution in the signal.	FMCW RADAR operates by sending a signal modulated in frequency and then catching the signal modulated in frequency and then catching the signal that is reflected from a target. Equation (2) gives the FMCW RADAR distance formula, which takes into account a number of factors, including the speed of light, frequency difference, and temporal	Improve the range resolution of indoor FMCW RADAR systems by using Deep Neural Networks (DNN). The authors propose that the range resolution of the RADAR system can be enhanced by employing DNN approaches, such as reducing side lobes and boosting the capacity to recognize objects.

					difference. By reducing the side lobes of the signal and enhancing range resolution, the suggested method uses DNN to improve the ability to differentiate objects.	
14	[21]	FMCW Radar System for Transponder Identification	2018	FMCW (Frequency Modulated Continuous Wave) radar for transponder identification. It explores the application of FMCW radar systems in localizing and tracking targets, as well as evaluating the	In order to perform its functions, the FMCW radar system for transponder identification makes use of a variety of parameters, as detailed in the accompanying PDF. The system utilizes a carrier	Results for both inside and outside use of the FMCW radar system. The data include values for the range, the frequency of the shift, and the orientation angle. In an indoor setting, more than 1500 measurements were taken, and the predicted values for distance and

				received radar beat signal for identification purposes.	frequency of 5.8 GHz and a transmitter power of 25 mW PIRE when it is in operation. It makes use of 3D antennas that have a gain of 12 dBi and a receiver noise factor of 5 dB respectively. Sawtooth is the type of modulation that is used, and the frequency sweep that is applied is 60 MHz, and the ramp time that is applied is 80 microseconds. The system also includes a total	shift frequency, which were 15 m and 20.6 kHz, were the same as the real values. The angle of orientation that was recorded had a small range and a mean that was close to 1 degree, which is what it really was. Noise is what causes the angle estimate to change from time to time. They also showed the signal-to-noise ratio (SNR) values as a function of the number of readings, which showed a small drop in SNR as the transponder batteries ran out.

					of 1600 samples and functions at a sampling frequency of 20 MHz throughout its entirety. Collectively, these factors assist, in complex surroundings, to the accurate detection, localisation, and identification of cooperating targets.	
15	[22]	GNU Radio-Based FMCW Ground Penetrating	2022	The method used to build a frequency-modulated continuous-wave (FMCW) ground penetrating radar (GPR)	A set of parameters associated with the FMCW GPR system. The signal from the source has a	It is reported that the predicted depth is equal to 1.91m based on the beat frequency of 441.69 MHz.

		Radar for Range Detection		device is based on GNU Radio. The paper talks about how to make a software-defined radio (SDR) device that uses GNU Radio software to process signals. In the GPR system, the FMCW method is used to find out how far away something is. The paper also gives analytical and measurement results of the GPR system for uses in archaeology and detecting cylindrical tubes.	frequency of 259 kHz when it is sent. This particular system makes use of a VCO that has a sensitivity of 420.7 MHz. There is a mention of a sampling rate of 500 MHz for the system.	

From the table, it can be concluded that an FMCW signal is favored for target localization due to its robustness against weather and noise. There was various research utilizing 24 GHz which is a typical frequency band for radar applications in the industrial market. Several studies have applied MATLAB for their processing algorithms. Thus, this proposed project is a plan to utilize a 24 GHz FMCW signal for the water surface target data acquisition and MATLAB for post-processing detection algorithms development.

2.7 Radar Performance Analysis

Radar performance analysis plays a crucial role in evaluating the accuracy and reliability of target detection on water surfaces. In this project, the focus is on measuring the performance of the radar system in estimating the target range after post-processing the received signal. By comparing the estimated range to the actual target range, the percentage of error can be determined, providing valuable insights into the accuracy of the radar's range estimation capabilities. This analysis allows for an assessment of the radar's performance in detecting targets on water surfaces and helps identify any potential deviations or inaccuracies in the range estimation process. Additionally, by quantifying the percentage of error, the analysis enables a quantitative evaluation of the radar's ability to operate within the desired system tolerance. This information is crucial for optimizing radar system parameters, fine-tuning algorithms, and making informed decisions to enhance the overall performance and reliability of water surface target detection.

2.8 Summary

In the second chapter, a detailed literature analysis of radar systems is presented. This study covers important subjects including radar configurations, with a particular emphasis on the co-located monostatic radar configuration. The fundamental principles of the frequency-modulated continuous wave (FMCW) waveform and the usefulness of this waveform in radar applications are investigated here. This chapter also explores prior recent initiatives that have led to developments in radar technology and discusses the notion of range detection using FMCW. Additionally, the chapter provides an explanation of the concept of employing FMCW. In addition, an examination of the performance of radar systems is covered, with a focus on the primary metrics and assessment methods that are applied in order to determine the precision and efficiency of radar systems. Through an analysis and synthesis of the vast body of relevant literature, Chapter 2 lays a solid groundwork for the coming chapters, so strengthening the reader's comprehension of radar concepts and the practical implementations of those principle.

CHAPTER 3

METHODOLOGY

Chapter 3 begins with the project workflow and software specification. The workflow is a roadmap for the project, detailing the sequence of tasks. The software specification outlines the software's features and limitations. The Distance2Go radar module, a key component of the project, is then discussed. This module generates and transmits the radar signals. The chapter also covers the simulation process, which tests the system under controlled conditions.

The next part of the chapter focuses on the validation experiment conducted on a water surface target object. This real-world experiment verifies the system's performance and the accuracy of the data acquired. An experiment validation block diagram is provided for a visual understanding of the experiment setup. Lastly, the chapter discusses the MATLAB post-processing code used for experiment validation. This code analyzes the experiment data, extracts meaningful information, and validates the experiment results. This comprehensive methodology ensures the project's objectives are met effectively and efficiently.

3.0 Introduction

Radar system based on Frequency modulated continuous wave (FMCW) technology measures the range and speed of targets by continuously transmitting frequency-modulated signals. In FMCW radar, a frequency sweep pattern is produced by constantly modulating the transmitted signal's frequency. While transmitting this sweep pattern, the radar is also listening for echoes reflected from nearby targets. The range to a target can be calculated using FMCW radar based on the frequency shift of the received signal by comparing the transmitted and received signals. The Doppler effect, which is brought on by the relative motion of the target, changes the frequency of the received signal when the broadcast signal hits a target. The radar can determine the target's range and speed by analyzing this frequency shift.

Compared to other radar technologies, FMCW radar has several benefits. It first offers excellent range resolution, making accurate distance measurements possible. Accurate range estimation is possible thanks to the continuous frequency sweep's ability to identify even minute frequency alterations. The capability to assess range and velocity simultaneously is an additional benefit. The relative motion between the radar and the target, which causes the Doppler shift in the received signal, reveals information about the object's velocity. Applications like traffic monitoring, collision avoidance systems, and object tracking can all benefit greatly from this functionality. Additionally, FMCW radar features non-ambiguous range measurements, which means the distance to a target is always known. By doing this, the range ambiguities that might arise in pulse-based radar systems are resolved without the need for sophisticated processing algorithms. Additionally, FMCW radar has excellent sensitivity, making it possible to detect faint echo signals coming from far-off targets. The radar's capacity to identify and calculate the distance to targets with low reflectivity is improved by the continuous transmission and integration of the signals that are received throughout time.

3.1 Project Workflow

The project workflow is made up of five key steps that make sure there is a planned and efficient way to reach the goals. Planning is the first step. This is where the project's goals, scope, and timelines are set. This means setting clear goals, figuring out who is involved, and planning for the job. The next step is to do a literature study, which is an in-depth look at existing research and relevant resources to learn more about the project topic and get new ideas. This helps to understand the work that has already been done, find gaps, and build a strong basis for the project.

After the book review is done, the third step is simulation. This is where theoretical models and ideas are turned into real-world scenarios. This means using specialized software or tools to build simulated environments and test different hypotheses. Simulation lets you try things out in a controlled way and gives you important information about what might happen before you use them in the real world.

The fourth step is a field experiment. This is where the ideas and models made in the first three steps are tested in the real world. This means carrying out planned activities, getting data, and making observations to test the hypotheses and figure out how well the project worked in the real world. Field studies give you a chance to face problems in the real world and make the changes you need to make to make sure your project works.

The last step is analysis, where the facts and observations that have been collected are looked at to draw conclusions. This means measuring out what the results of the field experiment mean by using statistical methods, data visualization techniques, and other analysis tools. The analysis part helps find patterns, trends, and correlations. This gives a full picture of how the project turned out and helps with future decision-making.

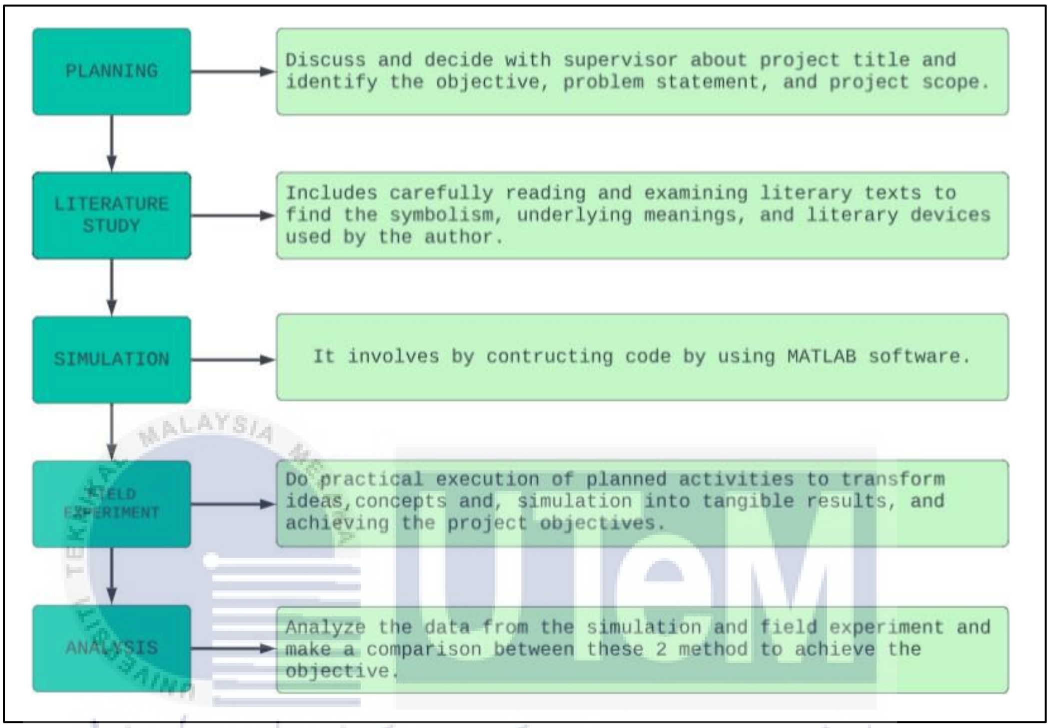


Figure 3.1: Process flow.

3.1.1 Project Planning and Flowchart

The project has been properly planned out to ensure that the deadline will be completed on time. The project flowchart, as shown in Figure 3.2, gives a visual depiction of the project's tasks' sequential sequence and interdependencies.

Table 5.1 and 5.2, which show the project Gantt Chart, have been produced in order to provide a more thorough breakdown of the project timeline. These tables provide brief summaries of the activities and the associated schedule. Gant chart have been stated at the appendices.

Project stakeholders may clearly comprehend the project's progress and important milestones by using the project flowchart and Gantt Chart. Throughout the course of the project, these visual aids support efficient coordination, resource allocation, and prompt decision-making.

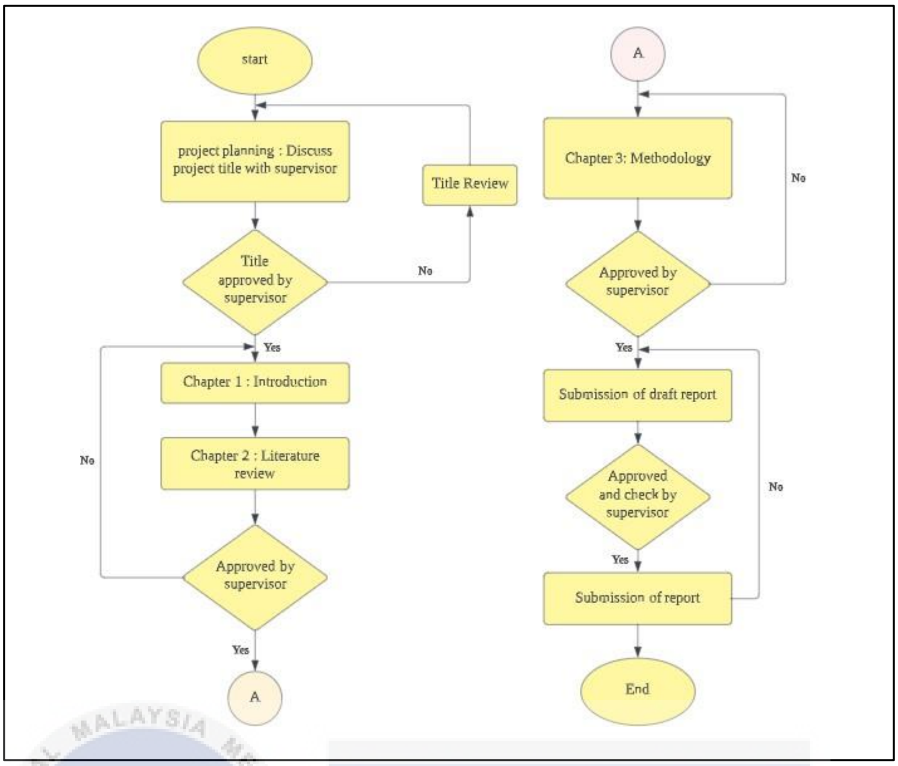


Figure 3.2: Project planning flowchar.

3.2 General Model & Process Flow of The Proposed Project

A high-frequency carrier signal modulates a frequency-modulated continuous wave (FMCW) baseband produced by the signal generator and emits by a transmitter antenna of a monostatic radar system. The transmit signal is reflected by a target and it is received by the receiver antenna. At the receiver, the received signal is demodulated, and it is mixed with the reference signal. Which is the FMCW original baseband signal. It resulted in a signal known as beat signal. Next only the required frequency range is allowed to pass through the band pass filter to eliminate unwanted signal such as ambience noise. The filtered signal is then applied with the Fast Fourier Transform (FFT) algorithm to convert a time-domain to a frequency-domain for signal analysis. After the frequency spectrum is obtained, the peak detection block detects the dominating frequencies corresponding to the target echoes. Finally, the range estimation is calculated based peak frequency obtained by the earlier block. In a monostatic radar system, these parts work together to produce and interpret radar signal, extract frequency data, and calculate the range of detected targets.

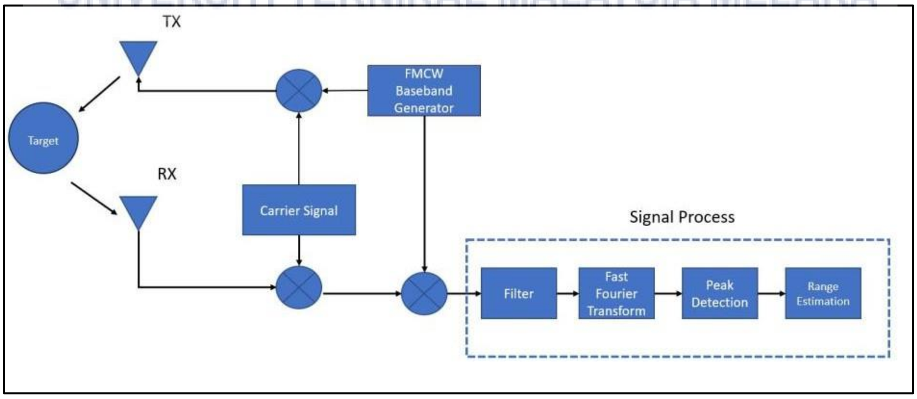


Figure 3.3: Block Diagram.

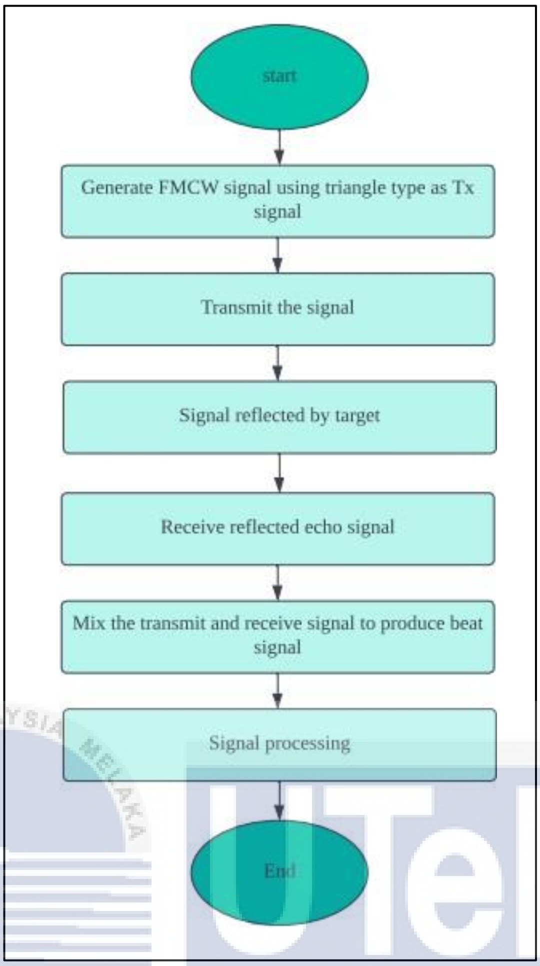


Figure 3.4: Flowchart of the process flow.

3.3 Software Specification

The MathWorks company developed the multi-paradigm programming language and environment known as MATLAB. Matrix manipulation, function and data visualization, algorithm implementation, user interface design, and interface with other language-written applications are all supported by MATLAB.

The FMCW waveform triangle's frequency domain and time domain were created using MATLAB MathWorks R2023a software simulations for all numerical simulations in this project. Additionally, this program was used for post-processing the raw signal that was recorded throughout the experiment.

Figure 3.5: MATLAB R2023a software for post-proessing.

3.4 Distance2Go Radar Module

Silicon-germanium is the foundation of Infineon's Distance2Go 24 GHz radar chipset. Due to its compact size, straightforward installation, and challenging configuration adjustment, D2G was chosen for this project. With careful configuration, D2G deployment takes little space for module installation. In addition, when compared to competing devices on the market, the D2G module was more expensive than the Blade RF software-defined radio (SDR) and other industrial radars. As a result, D2G became a sensible and economical option. The module also includes libraries, a user-friendly interface, and signal processing tools. The two parts of D2G are the main boards and the debugger boards. Its primary board is made up of four functioning parts: the radio frequency (RF), analogue amplifier, frequency control, and digital units[23].

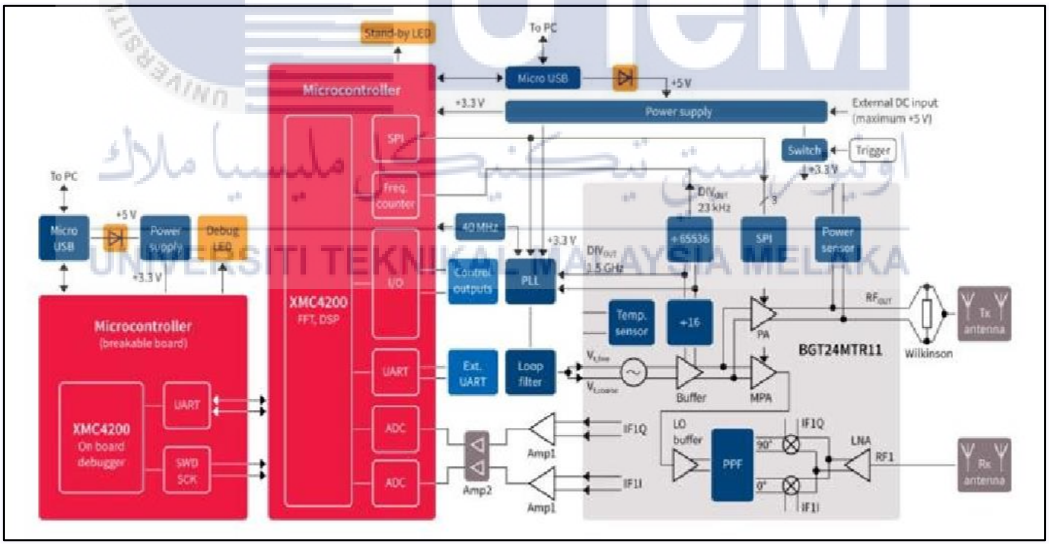


Figure 3.6: Block diagram of Distance2Go radar module.

At the back of the board, the radar module had 24 GHz microstrip patch antennas with an opening angle of 20° x 420° and a simulated gain of 12 dBi. Figure 3.6 shows the top view of the 45 mm x 50 mm radar module, and Figure 3.6 shows the bottom view of the module with an integrated antenna radiation pattern. This module was used to collect the raw beat signal for the experiment.

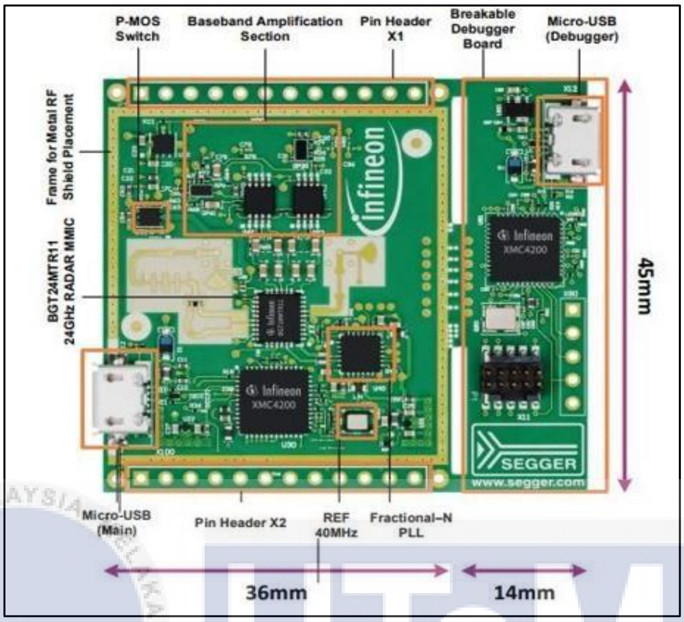


Figure 3.7: Top view of Distance2Go radar module.

Figure 3.8: Bottom view of Distance2Go radar module and antenna radiation pattern.

3.4.1 Interface of Radar GUI

The beat signals were acquired in the time domain through the utilization of the Infineon radar Graphical User Interface (GUI), as illustrated in Figure 3.9. Subsequently, the raw data underwent sophisticated processing in MATLAB, leveraging Fast Fourier Transform (FFT) techniques and a meticulously designed peak detection algorithm.

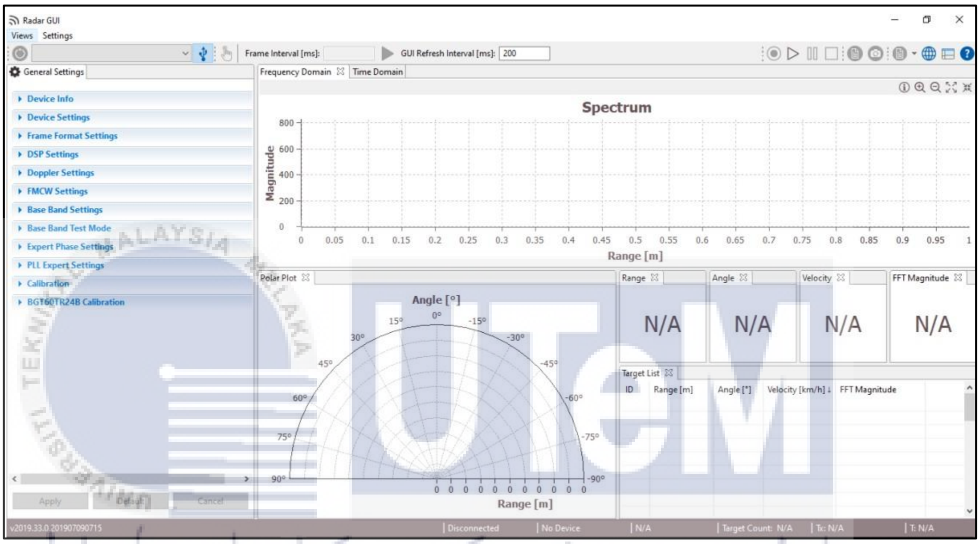


Figure 3.9: Example of Infineon radar GUI.

3.4.2 The Concept Diagram of the Proposed Model

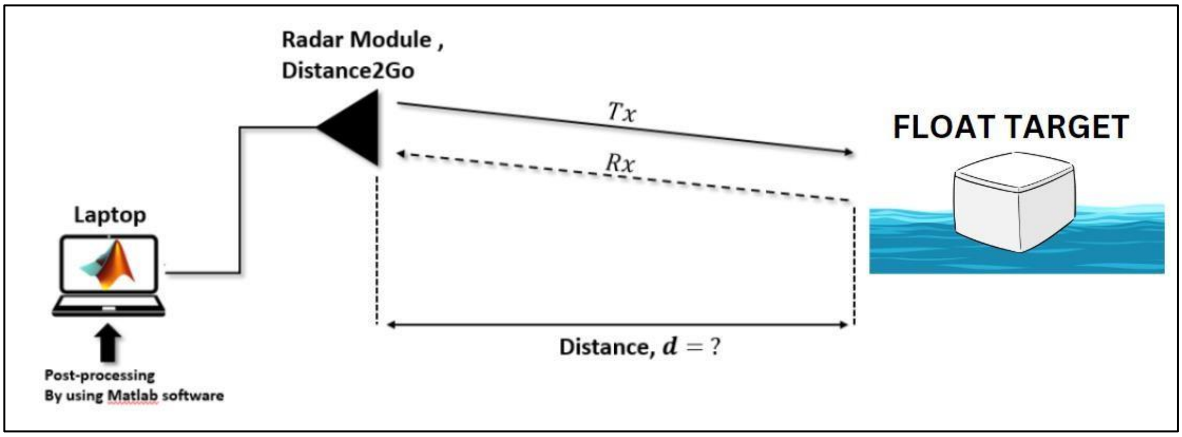


Figure 3.10: Conceptual diagram.

The development of an object software application for water surface detection using an FMCW (Frequency-Modulated Continuous Wave) radar involves a multi-phase approach. Initially, MATLAB is employed for simulation purposes, generating a sawtooth waveform and facilitating signal post-processing, including the conversion of time-domain signals to the frequency domain. Subsequently, practical experimentation is conducted using the Distance2go module to generate and acquire real FMCW signals and echoes. MATLAB is again utilized for post-processing these acquired signals. The resulting estimated ranges are then compared against the actual distances of the targets to assess the system's accuracy. The ultimate aim is to integrate these processes into a comprehensive software application, incorporating user interface elements and real-time data processing capabilities for effective water surface monitoring and analysis.

3.5 Simulation

The simulation phase was carried out using MATLAB software to develop the algorithm for detecting water surface targets. The detection algorithm processing is broken down into two primary steps. In the initial part, the beat signal received in the time domain is transformed into the frequency domain. Subsequently, a peak detection process is applied to the frequency spectrum. The frequency corresponding to the highest peak is then utilized to calculate the estimated range. Further details on the flow of the software are elucidated in the subsequent subsection.

3.5.1 Project Flowchart

The project flowchart acts like a roadmap, guiding us through the step-by-step workings of the monostatic FMCW radar experiment. In Figure 3.11, there's a simple illustration breaking down each part of the process, from sending signals to receiving them back. This visual guide helps us understand how the radar operates. Additionally, Figure 3.12 provides a block diagram, a visual representation of the radar system using Distance2Go. This diagram helps us see how Distance2Go fits into the entire radar setup. Together, these visuals make it easier for everyone to grasp the ins and outs of the monostatic FMCW radar experiment. Now, looking at the bigger picture, the procedural framework for these operations relies on insights from past projects and a thorough literature review. The knowledge gathered from these sources is set to be applied in the upcoming numerical simulation. The heart of the process involves a careful comparison and analysis of input and output data, ensuring a comprehensive understanding of the radar's functionality.

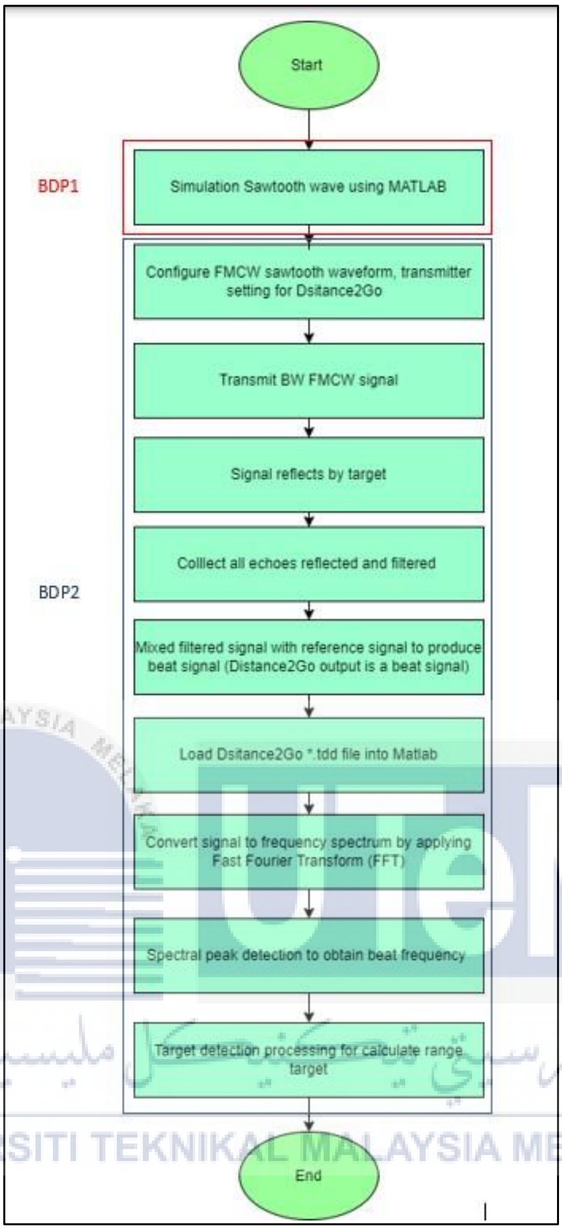


Figure 3.11: Experiment process flow of a monostatic FMCW radar.

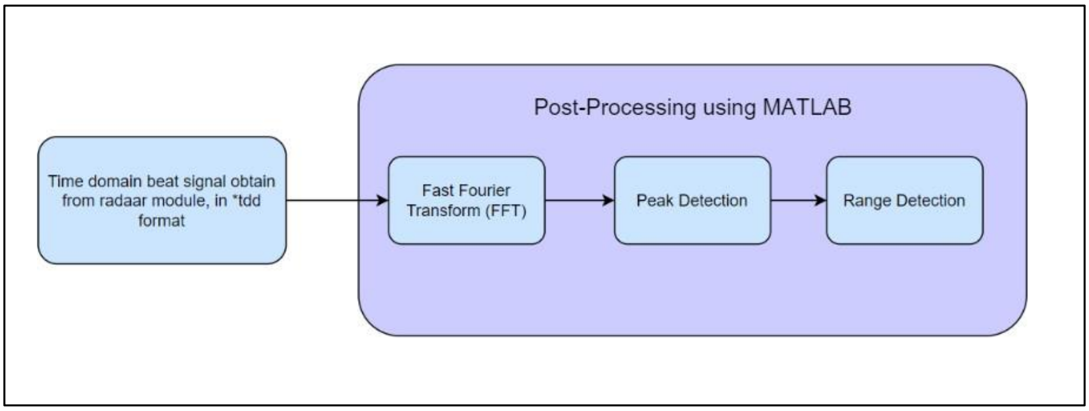


Figure 3.12 A monostatic FMCW block diagram utilised a Distance2Go.

3.5.2 Simulation Block Diagram

In the initial design phase, crucial system parameters were established based on literature insights. MATLAB simulations were then performed to set the stage for upcoming detection algorithms, vital for processing experimental data.

The simulation generated a sawtooth FMCW transmitter signal and a delayed receiver signal simulating target reflection. Combining received signals with a reference signal produced a beat signal, transformed to the frequency domain using FFT for further processing.

The FFT spectrum identified the highest peak, determining range based on peak magnitude. This post-processing step, crucial for sample data, lays the foundation for actual data collection, enhancing experiment efficiency, and ensuring robustness and accuracy in real-world signal processing.

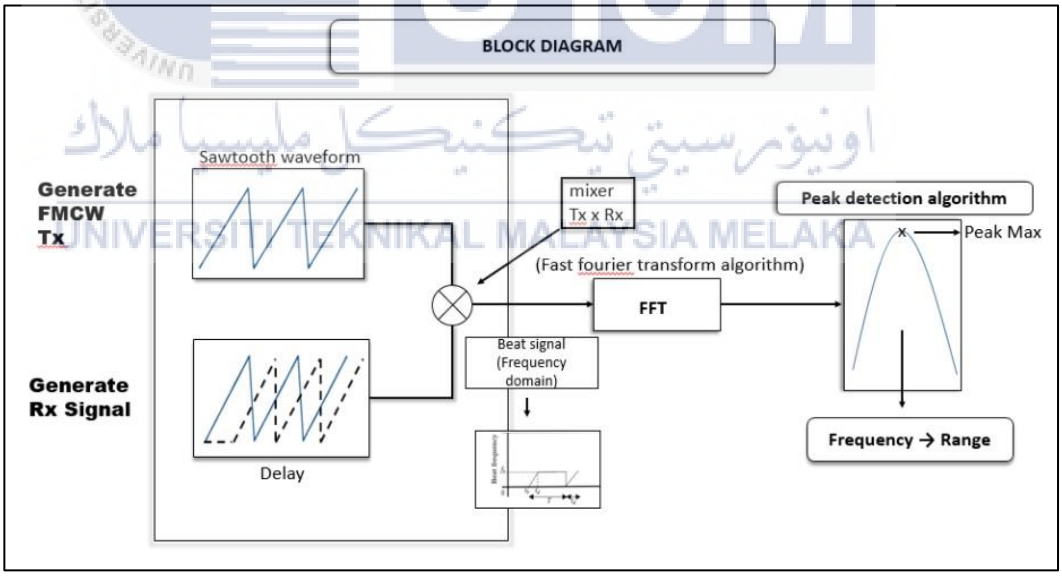


Figure 3.13: Simulation Block Diagram.

3.6 Validation Experiment on Water Surface Target Object

During the outdoor testing phase, we conducted experiments using a Radar Under Test (RUT) equipped with a Distance2Go (D2G) module. The D2G module was affixed to a 2-meter high pole and connected to a laptop for data collection purposes. The experiment focused on a floating target positioned at a distance of 3 meters from the radar.

The radar module, with an antenna height of 1 meters and an opening angle of 20° (as depicted in Figure 3.12), was employed to gather data. To provide a comprehensive view of the outdoor experiment setup, as per figures 3.14, 3.15 and 3.16 illustrate the utilization of Distance2Go (D2G) and the arrangement of the radar module.

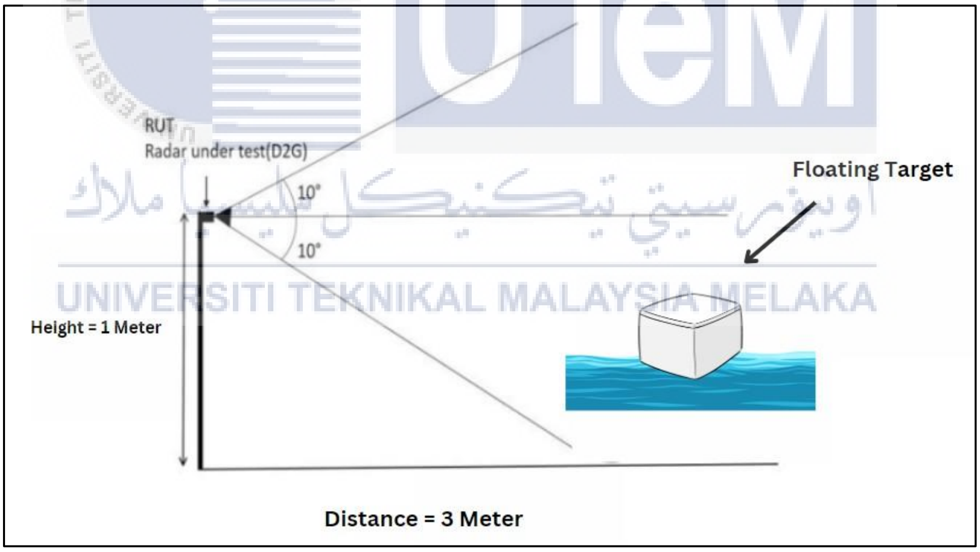


Figure 3.14 Illustration of experiment setup for range detection within object and RUT.

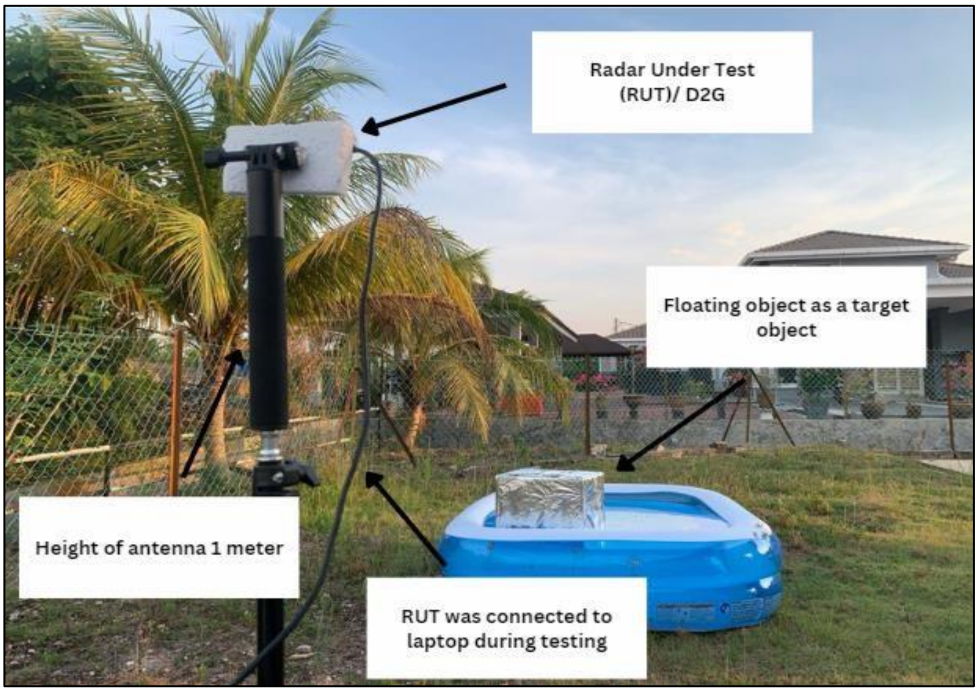


Figure 3.15: View outdoor experiment setup for target detection using Distance2Go module with distance 3 meter.

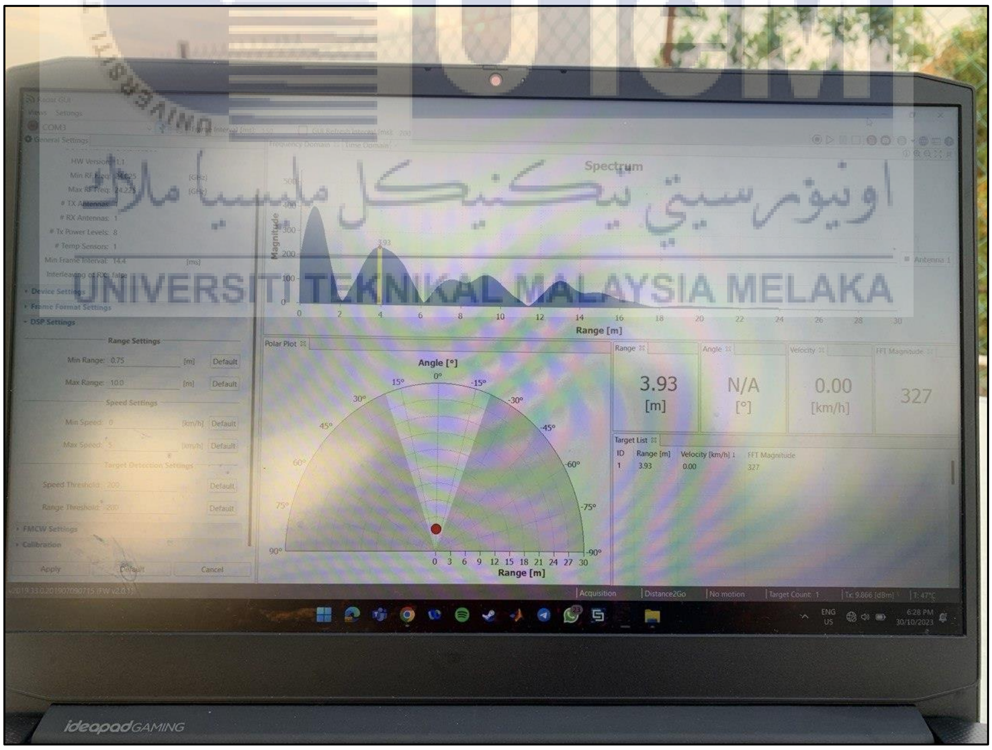


Figure 3.16: Setup outdoor radar module to detect the floating target.

The experimental setup involved utilizing a 200 MHz sweep bandwidth for testing. The Distance2Go (D2G) module captured and generated data stored in a *.tdd file, representing a beat signal in the time domain. This beat signal was then employed to estimate range measurements. Throughout all tests, the 200 MHz sweep bandwidth served as the reference point for the intended range.

The simulation in this experiment employed a chirp time of 1500 microseconds. Additionally, the radar module was configured with a maximum frequency of 24.225 GHz and a minimum frequency of 24.025 GHz, as outlined in Table 3.1. This comprehensive parameter setup ensures accurate and consistent testing conditions for the radar module's performance evaluation.

Table 3.1: Parameter in Distance2Go for target detection object.

PARAMETER	VALUE
Max Frequency	24.225 Ghz
Min Frequency	24.025 Ghz
Bandwidth	200 Mhz
Chirp Time	1500 us

3.6.1 Experiment Validation Block Diagram

To begin, the radar module's parameters were configured with a 200 MHz bandwidth, a chirp time of 1500 microseconds, a maximum frequency of 24.225 GHz, and a minimum frequency of 24.025 GHz. Subsequently, the Distance2Go (D2G) module was enabled to capture data, which manifested as beat signals.

Once the data from D2G was gathered, post-processing procedures were applied. The time domain representation of the beat signal underwent transformation into the frequency domain, accomplished through the Fast Fourier Transform (FFT) method. This conversion allowed us to analyze the signal in terms of its frequency components.

Within the frequency spectrum, the highest peak was identified, serving as a crucial indicator. By pinpointing this peak, the range to the target object was estimated. In essence, this post-processing methodology, involving the conversion from time to frequency domain and the identification of frequency peaks, facilitated a clear and precise estimation of the target's range based on the captured beat signals.

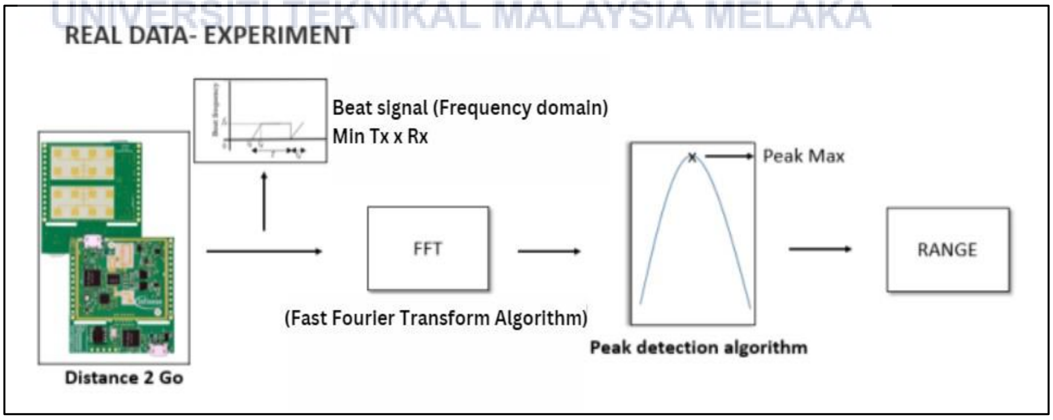


Figure 3.17: Flow diagram for real data-experiment.

3.6.2 MATLAB Post-Processing Code for Experiment Validation

Matlab post-processing encompasses four crucial stages to analyze and extract valuable insights from data. The first stage involves data extraction, where relevant information is isolated and organized for further analysis. Subsequently, the Fast Fourier Transform (FFT) is applied to the extracted data, enabling the transformation of time-domain signals into frequency-domain representations. This step unveils underlying frequency components and patterns within the dataset. Following FFT, the third stage incorporates peak detection algorithms to identify prominent features or spikes in the transformed data, aiding in pinpointing significant events or characteristics. Finally, the last stage involves range estimation, where the identified peaks are utilized to infer the range or distance associated with specific phenomena, providing a comprehensive understanding of the spatial aspects embedded in the dataset. Through these four stages, Matlab post-processing ensures a systematic and comprehensive exploration of data, enabling researchers and engineers to extract meaningful insights and make informed decisions based on the analyzed information.

3.6.2.1 Data Extraction

A programming code using Matlab software has been developed for actual data postprocessing, resembling the numerical simulation method. In this experiment, real data collected from D2G was subjected to post-processing to estimate the target of the object. A total of 50 samples were obtained by D2G for this post-processing analysis. Specifically, the code, as illustrated in Figure 3.18, focuses on loading and reading signals captured from D2G at distances of 9 meters. Within this context, the provided MATLAB code segment is instrumental in handling the signal data extracted from D2G for subsequent analysis and target estimation.

```
n = 1;                    % Define 1st signal in the file.
iii = 50;                 % Define number of signal to process
m = 1;                    % Define start of stored value
for ii = 1:1:iii;
%% Load and read signal from D2G capture
files = Peisal9M; % CHANGE FILE NAME TO TEST THE TARGET RANGE     % Call beat signal file to read
A = files(n,:);                                                    % Define signal for processing
B = files(n+1,:);
%signal1 = A+(1i*B);
signal1 = A;
```

Figure 3.18: Load and read signal from D2G radar module.

Next, parameters crucial for radar signal processing are defined. The Signal-to-Noise Ratio (SNR) is set to 50 dB, and white Gaussian noise is introduced to the signal using the awgn function, simulating varying noise levels for realistic scenarios base on figure 3.19. FFT parameters are specified with NFFT set to 64, determining the frequency resolution. System bandwidth (BW) is established at 200 MHz, and the pulse duration (tau) is set to 1500000e-9 seconds. Constants such as the speed of light (c) are defined, and time and range parameters, including the time duration of each sample (tsample), a time axis for plotting (ts_plot), maximum range (R_max), and distance per range bin (DistPerBin), are calculated. These parameters collectively form the foundation for radar signal analysis, aiding in the estimation of target range under varying conditions.


```
%% Define parameters
SNR = 50;                                          % Define Signal-to-noise ratio
signal1 = awgn(signal1,SNR); %CHANGE THIS TO TEST ON SNR   % Simulate signal with white noise

NFFT = 64;                                         % Define no of sample (As per D2G)
BW = 200e6;                                        % Define bandwidth (As per D2G)
tau = 1500000e-9;                                  % Define chirp time (As per D2G)

c = 3e8;                                           % Define speed of light
tsample = tau/NFFT;                                % Calculate sampling time
ts_plot = (0:tsample:tsample*(255));               % Create sampling time for plotting
ts_plot = transpose(ts_plot);                      % Transpose matrix to suit for plotting

R_max = NFFT*c/(2*BW); % NTS*c/(2*BW);             % Calculate Maximum Distance (As per D2G)
DistPerBin  = R_max/(NFFT);                        % Calculate Distance per bin/ 1 scale
```

Figure 3.19: Define parameter as per D2G.

3.6.2.2 Fast Fourier Transform

Following, Figure 3.20 code code helps figure out where a target is by processing the radar signal. It uses a technique called Fast Fourier Transform (FFT) to change the signal from telling us about time to telling us about different frequencies. The code then calculates the strength of each frequency and puts it on a scale that's easier to understand, like turning the volume up or down. The length of this information helps us know how many different frequencies are there. This step is important for getting useful details about the target's location from the radar signal.

```
%% Signal processing to estimate target range

% FFT beat signal to transform from time domain to frequency domain

zm1a = fftshift(fft((signal1),NFFT));
z2m1a = abs(zm1a);
z3m1a = 20*log10(z2m1a);
len_z3m1a = length (z3m1a);
```

Figure 3.20: Signal processing to estimate target range.

With the reference to block diagram in figure 3.12, in the earlier chapter, this code represent the Fast Fourier Transform (FFT) as per figure 3.20.

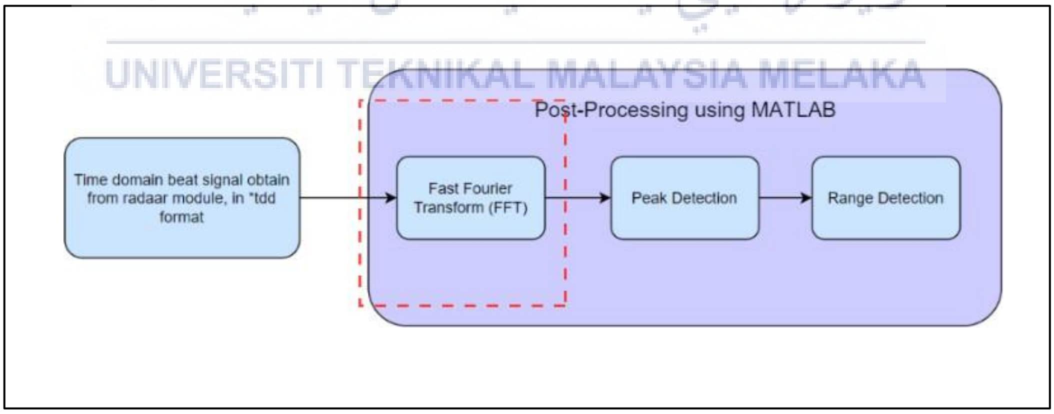


Figure 3.21:Block diagram of system (FFT).

3.6.2.3 Peak Detection

This segment focuses on the detection of the maximum peaks in specific frequency components of a radar signal for beat frequency determination, crucial in estimating target range. With a defined sampling frequency (Fs) and frequency vector (f), the code calculates corresponding range values. It then selects and processes specific frequency components (fm1_1a, f1_1a, fm2_1a, and f2_1a). Figure 3.21 show Utilizing the findpeaks function, the code identifies and sorts the peaks in these components in descending order (psor1_1a, lsor1_1a, psor2_1a, lsor2_1a). Subsequently, it determines the beat frequencies (fb1_1a and fb2_1a) corresponding to the peak positions, providing crucial information for accurate target range estimation in radar signal processing.

```
% Maximum peak detection to detect fbeat for range estimation

Fs = 42666;                                          % Define sampling frequency (As per D2G)
f = -Fs/2:Fs/(NFFT-1):Fs/2;
ran = f.*(((tau)*c)/(2*BW));
fm1_1a= z3m1a(17:len_z3m1a/2);
f1_1a=f(17:len_z3m1a/2);
fm2_1a= z3m1a((len_z3m1a/2)+1:48);
fm2_1a(2)=0;
f2_1a=f((len_z3m1a/2)+1:48);

[psor1_1a,lsor1_1a] = findpeaks(fm1_1a,'SortStr','descend');
[psor2_1a,lsor2_1a] = findpeaks(fm2_1a,'SortStr','descend');

tsort = isempty (lsor2_1a);
if (tsort == 1);
fbAS1a = 0;
else
fb1_1a = abs(f2_1a(lsor2_1a(1)));
fb2_1a = abs(f1_1a(lsor1_1a(1)));
end
```


Figure 3.22: Maximum peak to detect frequency beat.

With the reference to block diagram in figure 3.12, in the earlier chapter, this code represent the peak detection as per figure 3.22.

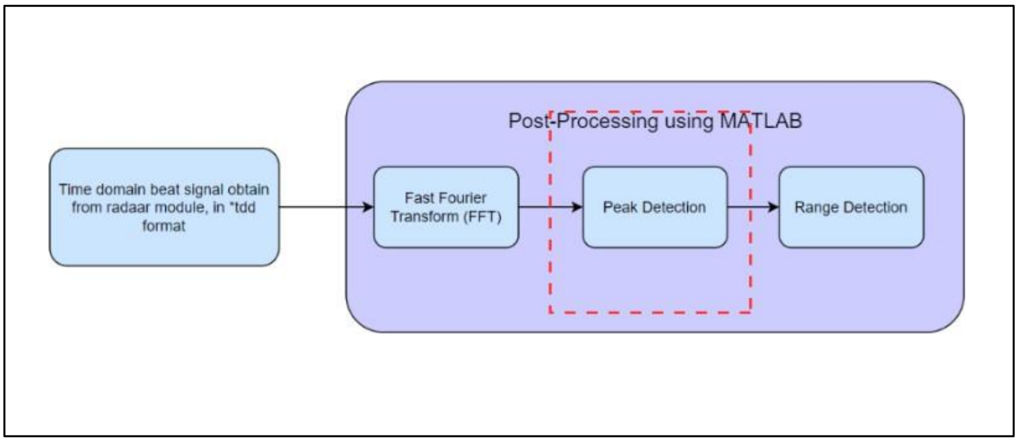


Figure 3.23: Block diagram of the system (Peak Detection).

3.6.2.4 Range Estimation

Finally the figure 3.22 show the averaged beat frequency (fbAS1a) is computed by taking the average of two beat frequencies (fb2_1a and fb1_1a). Subsequently, the code employs this averaged beat frequency to estimate the range of the target (range_est), factoring in essential radar system parameters such as pulse duration (tau), speed of light (c), and system bandwidth (BW). The incrementing indices (n and m) suggest that this process may be part of a loop structure, likely designed for continuous or batch processing over different sets of data. This iterative approach aligns with the numerical simulation for range estimation, providing range estimates for multiple data points within a radar signal sequence. Additionally, Figure 4.8 illustrates an example of the beat signal in the time domain, offering a visual representation of the signal characteristics in the simulation.

```
% Range & velocity Estimation
fbAS1a = (fb2_1a+fb1_1a)/2;                    % for range estimation
range_est (m) = (fbAS1a)*(((tau)*c)/(2*BW))

n = n + 2;
m = m +1;
```

Figure 3.24: Range estimation.

With the reference to block diagram in figure 3.12, in the earlier chapter, this code represent the Range detection as per figure 3.24.

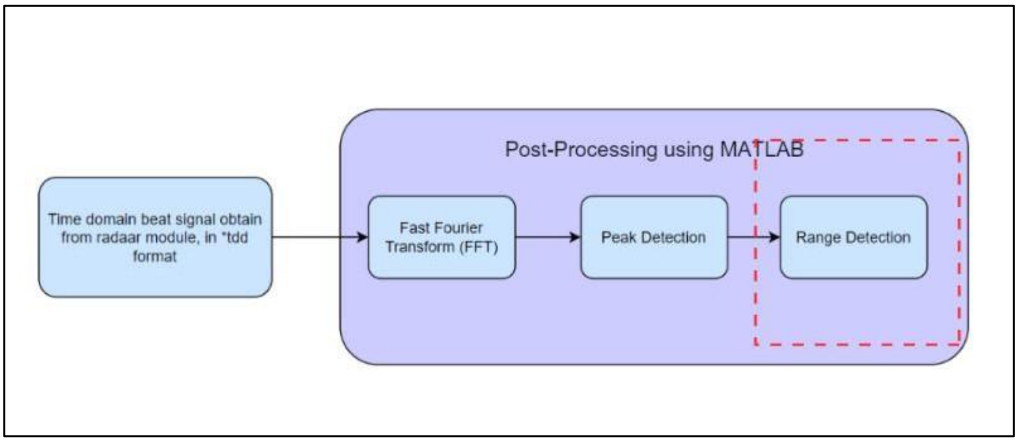


Figure 3.25: Block diagram of the system (Range Detection).

3.7 Summary

In summary, Chapter 3, focusing on methodology, outlines the project's systematic approach. It details the project workflow and software specifications, and discusses the Distance2Go radar module used. The chapter also covers the simulation process and a validation experiment on a water surface target. A proses flow and block diagram is provided for visual understanding of the experiment setup. Lastly, MATLAB is used for post-processing code to analyze and validate the experiment data. This chapter serves as a comprehensive guide to the project's execution.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

Chapter 4 talks about the study project's results, giving a look at what has been found and what has happened. This part is a big step in the study because it gives an overview of observations gathered during the research. This chapter is an important step towards the end results and conclusions because it gives an early look at the project in progress and what it might mean. The results talked about in Chapter 4 set the stage for the rest of the analysis and conversation.

4.2 Simulation for FMCW Sawtooth Signal Generation

During the first phase of the project, known as BPD 1, The task of simulating and generating a sawtooth signal. This was accomplished using MATLAB, a high-level language and interactive environment that is widely used for numerical computation, visualization, and programming. The successful simulation of the sawtooth signal laid the groundwork for the subsequent phases of the project.

In the second phase, BPD 2, we leveraged a tool known as D2G to generate and transmit the sawtooth signal. This tool was instrumental in facilitating the data acquisition process. The transmission of the sawtooth signal was carried out using Time Division Duplexing (TDD), a scheme used in advanced networks for the transmission of data. TDD operates in the time domain signal and is known for its efficiency and reliability, making it an ideal choice for our project.

The data acquisition process also involved the use of Fast Fourier Transform (FFT), a method used to compute the discrete Fourier Transform and its inverse. FFT is a critical component in signal processing and data analysis, as it transforms a signal from its original domain (often time or space) to a representation in the frequency domain and vice versa.

Following the FFT, we conducted peak detection and range detection. Peak detection is a technique used to identify the points in a signal where the amplitude reaches a maximum, and range detection is used to determine the distance between the radar system and the target object. These techniques further enhance the accuracy and reliability of our data acquisition process.

In summary, the project involved a series of complex and interconnected steps, from the simulation of the sawtooth signal using MATLAB to the transmission of the signal using D2G and TDD, and finally, the application of FFT, peak detection, and range detection. Each of these steps played a crucial role in enhancing the efficiency and reliability of our data acquisition process, thereby contributing to the overall success of the project.

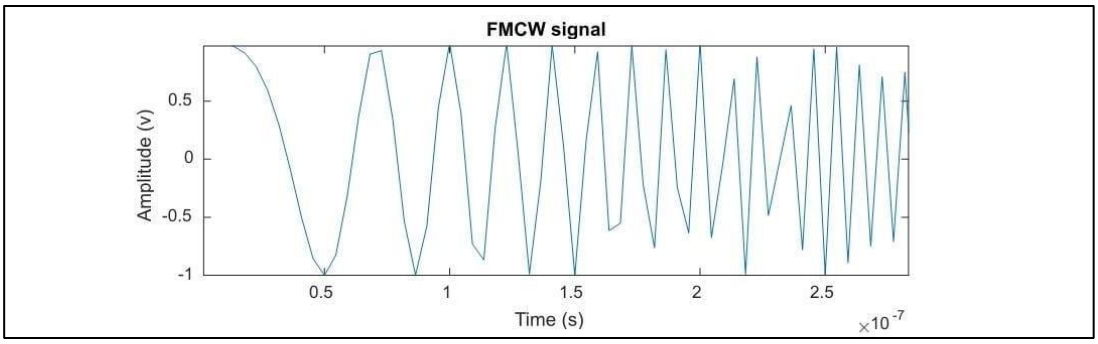


Figure 4.1: FMCW baseband signal in time domain.

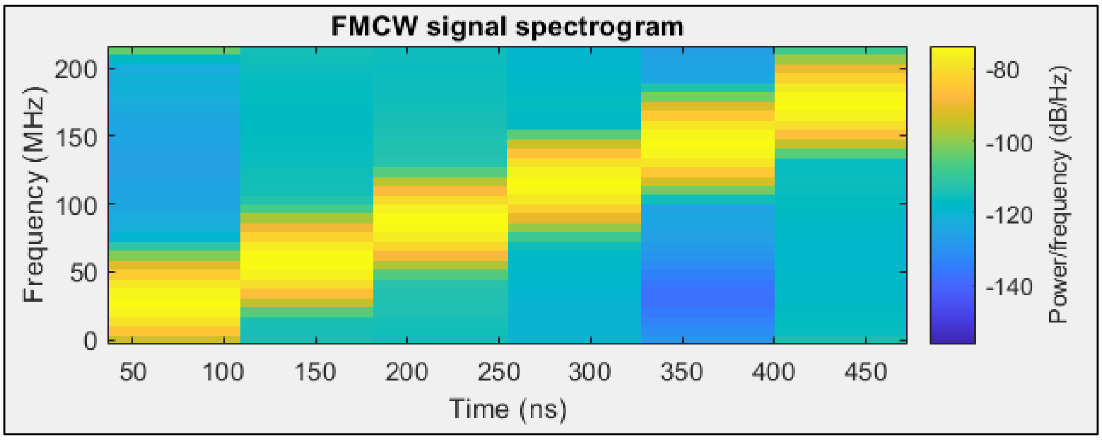


Figure 4.2: FMCW baseband signal in frequency domain.

4.3 Analysis of Range Estimation

Table 4.1 presents the range compared to the actual range simulated. The simulation of produced the analysis of data obtained from experimental simulations is a critical phase in post-processing, involving a comprehensive examination of key parameters within the collected dataset. In particular, the table generated from the experiment simulation encompasses crucial metrics such as range resolution, actual target range, average measurement target range, and the corresponding differences between them. Range resolution is pivotal for assessing the system's ability to distinguish between closely spaced targets, providing insights into the precision of the measurements.

The Actual target range represents the true distance to the targets, serving as a baseline for evaluating the accuracy of the measurement system. Average measurement target range provides an overview of the central tendency of the measured distances. The analysis of differences between these values is essential for identifying potential discrepancies and evaluating the overall performance of the experimental setup.

This comprehensive examination of the simulation data table contributes valuable insights into the effectiveness and reliability of the measurement system, guiding further refinement and optimization of the experimental design. The difference is actual target range – averaged measured target range.

Table 4.1: Analysis from experiment data.

Range Resolution (m)	2	3	4	5	6	7	8	9
Actual target range (m)	**2.10**	**3.10**	**4.10**	**5.10**	**6.10**	**7.10**	**8.10**	**9.10**
Average estimation measured target range (m)	**2.52**	**3.04**	**4.57**	**5.33**	**6.09**	**7.54**	**8.38**	**9.14**
Difference	**-0.42**	**0.06**	**-0.47**	**-0.23**	**0.01**	**-0.44**	**-0.28**	**-0.04**

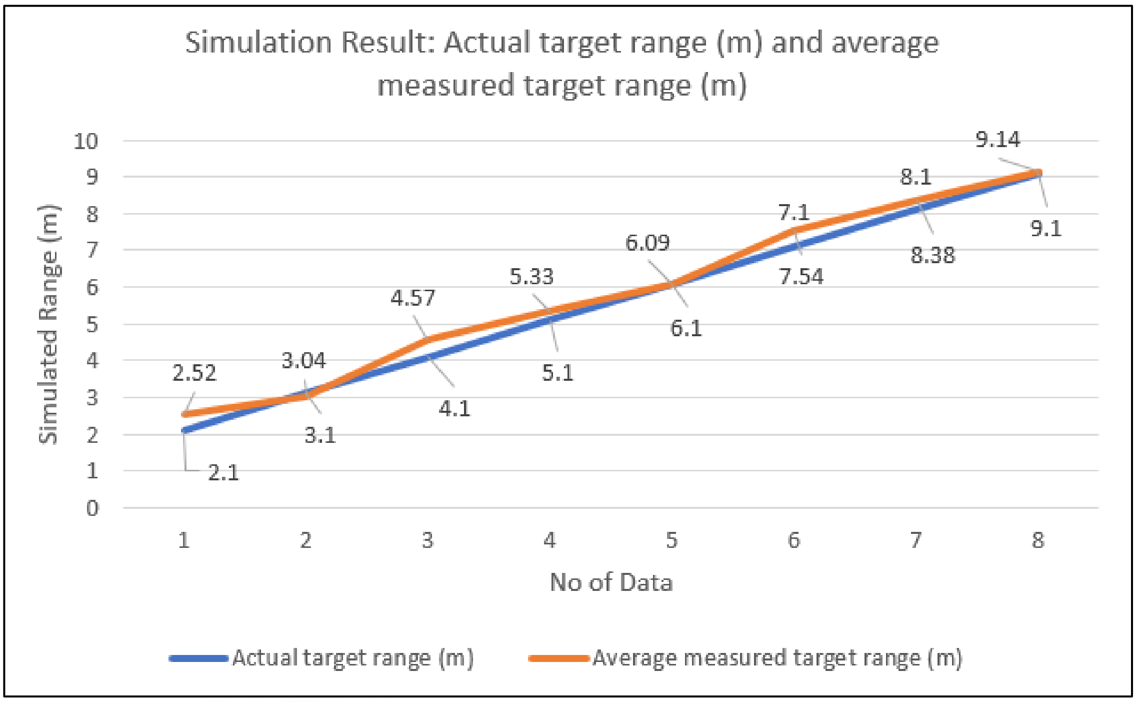
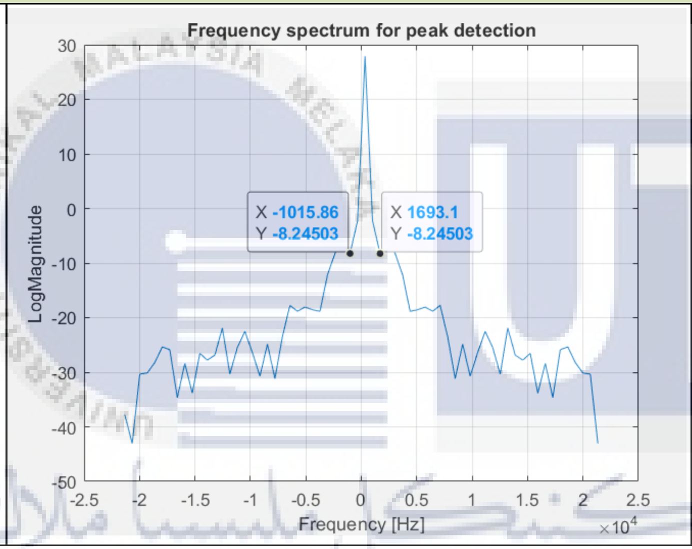


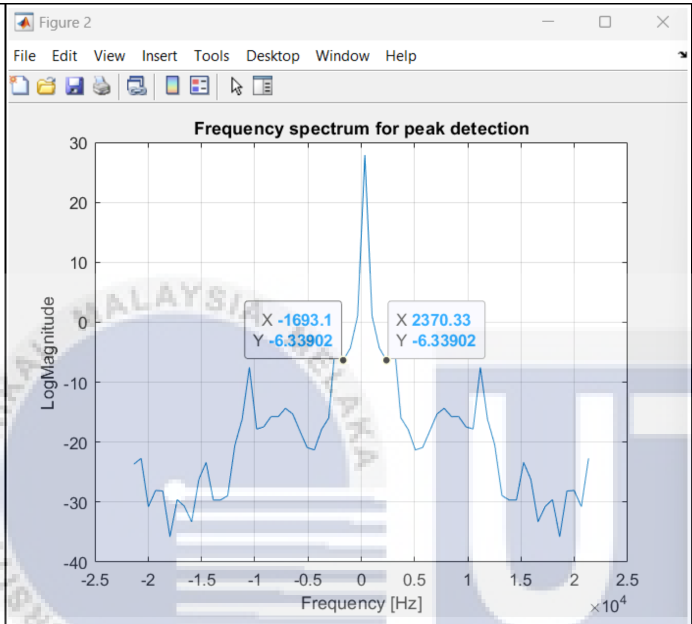
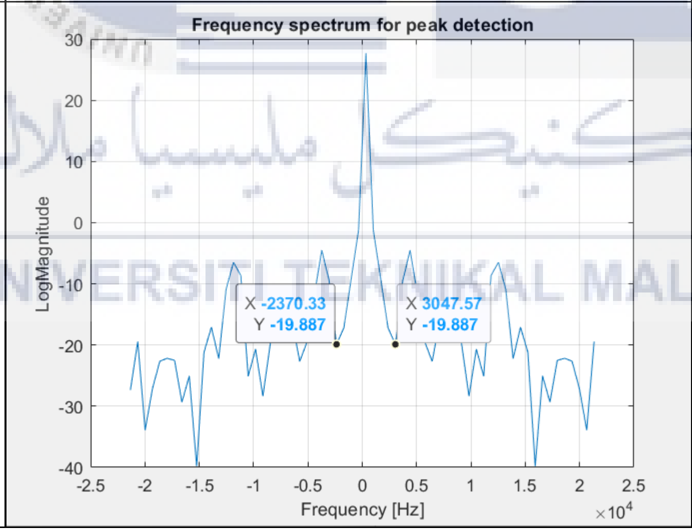
Figure 4.3: Simulation Result of estimated Actual, Average of target range.

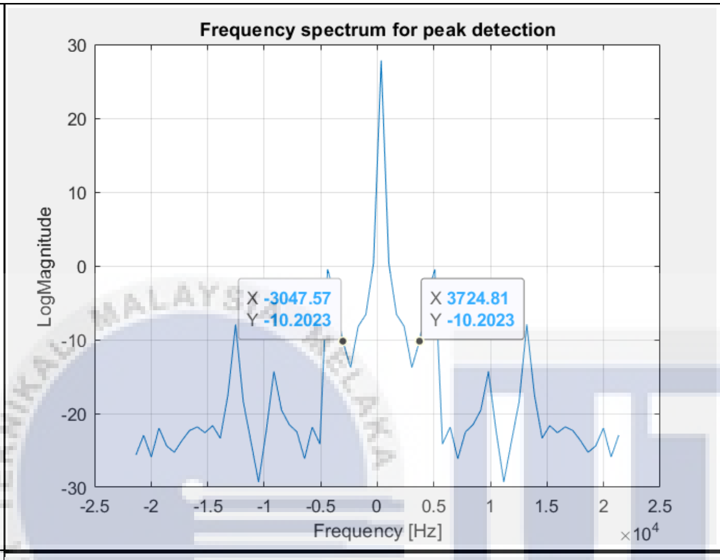
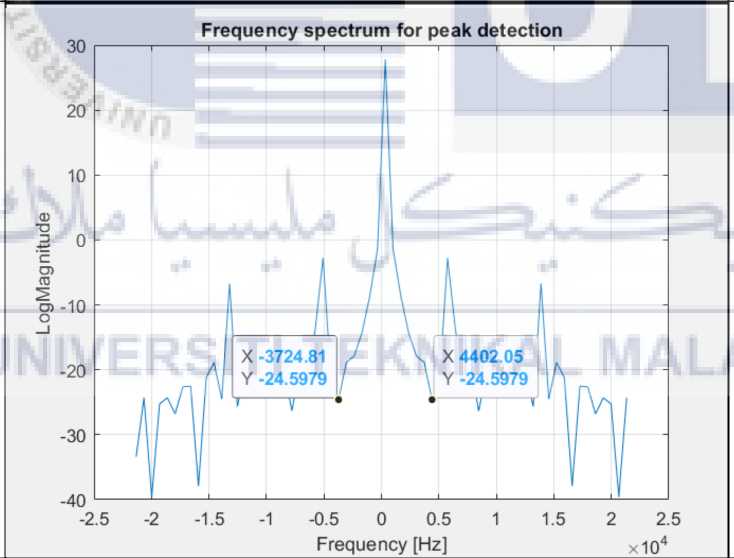
Table 4.3 presents a summary of the simulation results obtained from the object detection simulation, specifically focusing on the estimation of range using the beat frequency derived from local maximum peaks in positive and negative regions. The beat frequency (fb) is determined by applying the equation $\boldsymbol{fb1}+\boldsymbol{fb2}/\boldsymbol{2}$, representing the frequency difference between up-ramp and down-ramp signals. It is important to note that, theoretically, a static target generates a $fb(f)$ due to both up-ramp and down-ramp, resulting in an identical frequency difference.

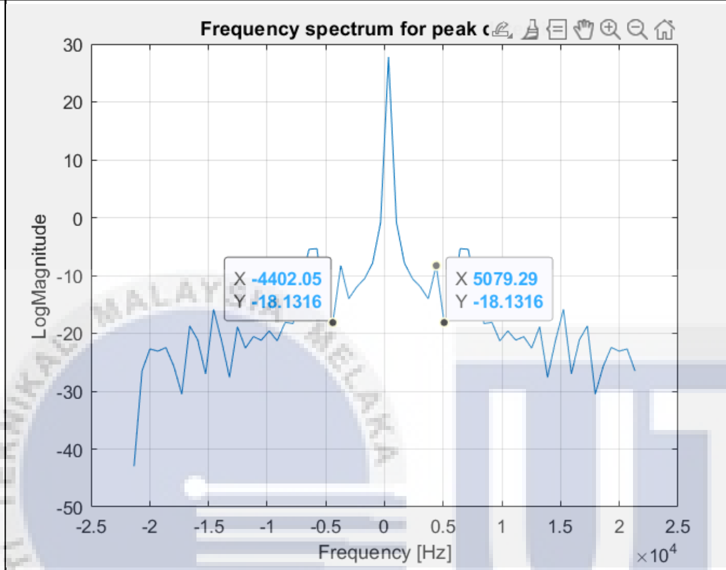
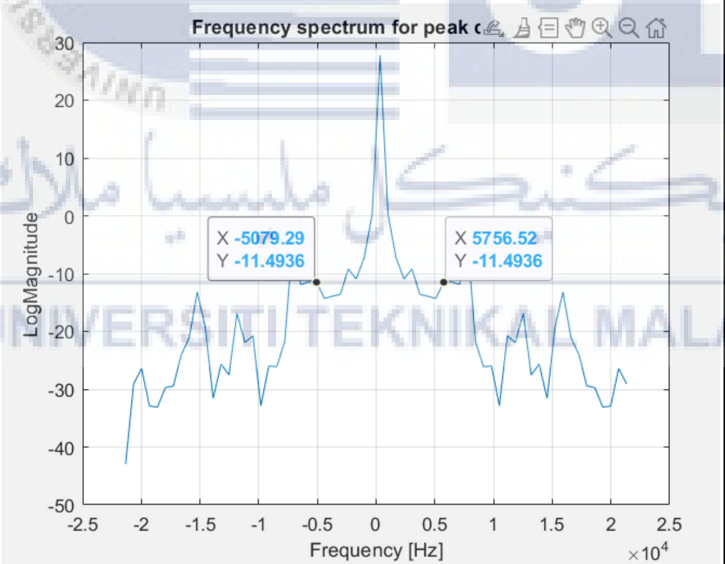
Conventionally, target range calculations rely on utilizing only the local maximum peak in either the positive or negative region. The $fb(f)$ values obtained from the beat frequency equation are then employed in the range calculation formula, $Rest = fbeat(c)(\tau)/2BW$, where c is the speed of light, and τ equals 0.002, consistent with the D2G setup. Notably, the FFT frequency spectrum analysis highlights that a 200 MHz bandwidth configuration yields a finer resolution.

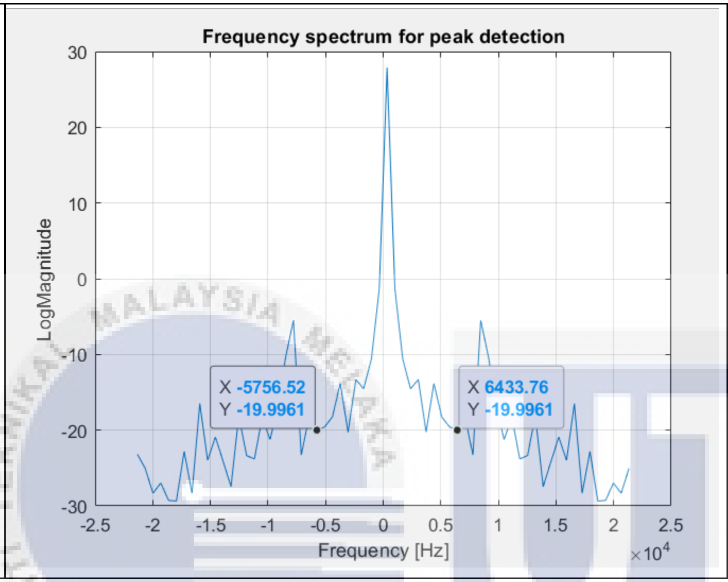
Table 4.2 Simulation post processing.

Range resolution (m)	Actual Range (m)	GRAPH	$\lvert fb\ 1 \rvert$	$\lvert fb\ 2 \rvert$	$fb(f)$	$Rest$
2	2.10		**1014.86**	**1693.1**	$fb1+fb2/2$ =1353.98	$fbeat(c)(\tau)/2BW$ **=2.03**

3	3.10				**1693.1**	**2370.33**	$\boldsymbol{fb1+fb2/2}$ =2031.715	$fbeat(c)(\tau)/2BW$ **=3.04**
4	4.10				**2370.33**	**3047.57**	$\boldsymbol{fb1+fb2/2}$ =2708.95	$fbeat(c)(\tau)/2BW$ **=4.06**

5	5.10				**3047.57**	**3724.81**	$\boldsymbol{fb1+fb2/2}$ =3386.19	$fbeat(c)(\tau)/2BW$ **=5.08**
6	6.10				**3724.81**	**4402.05**	$\boldsymbol{fb1+fb2/2}$ =4063.43	$fbeat(c)(\tau)/2BW$ **=6.09**

7	7.10				**4402.05**	**5079.29**	$\boldsymbol{fb1+fb2/2}$ =4740.67	$fbeat(c)(\tau)/2BW$ **=7.11**
8	8.10				**5079.29**	**5756.52**	$\boldsymbol{fb1+fb2/2}$ =5417.905	$fbeat(c)(\tau)/2BW$ **=8.13**

9	9.10				**5756.52**	**6433.76**	$\boldsymbol{fb1+fb2/2}$ =6095.14	$fbeat(c)(\tau)/2BW$ **=9.14**

4.4 Analysis of Signal to Noise Ratio (SNR) for Experimental Data

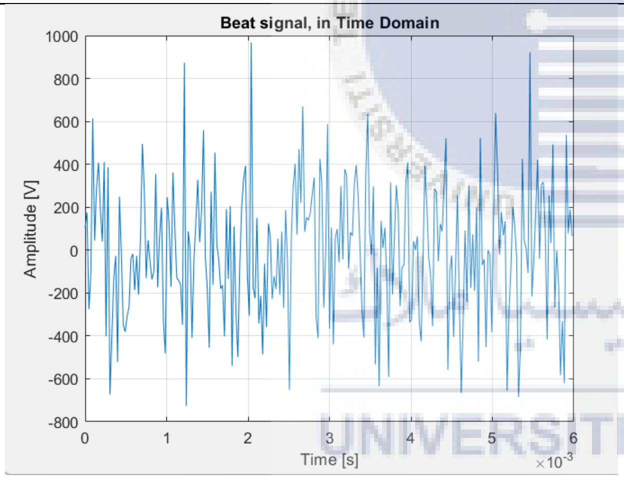
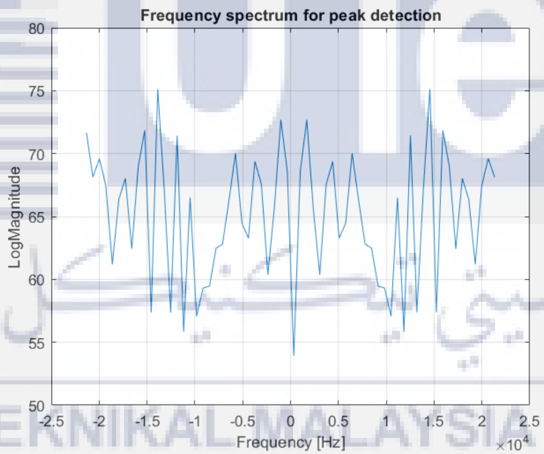
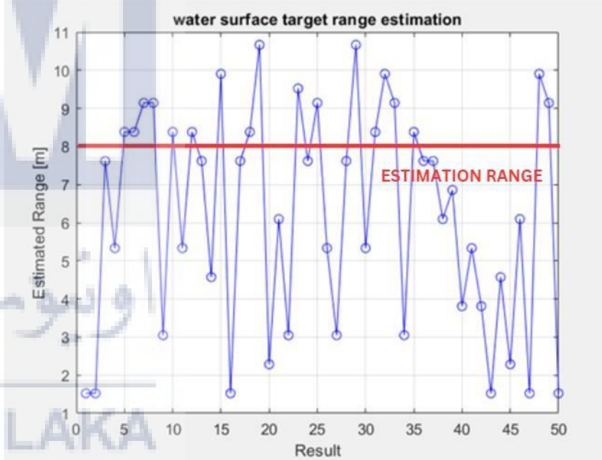
The validation of the target detection code using actual data captured by D2G was a crucial step in assessing its reliability. The results, presented in Tables 4.3 and 4.4, offer a detailed breakdown of the signal, frequency, and estimated range at distances of 8 and 9 meters. To evaluate the code's performance under different conditions, we introduced Additive White Gaussian Noise (AWGN) at varying Signal-to-Noise Ratio (SNR) levels, ranging from -50 dB to 50 db. For this analysis, we tested over 1 signal for all 3 SNR level.

In instances where the SNR was at its lowest, such as -50 dB, the noise overwhelmed the signal, causing distortion in the beat signal. Consequently, the algorithm struggled to identify the actual peak in the frequency spectrum, resulting in inaccurate range estimations. At an SNR of 0 dB, where noise levels equaled the signal, the code exhibited intermittent success in detecting the target. Despite an observable peak in the frequency domain, consistency was a challenge, impacting the reliability of range estimations.

Conversely, at an SNR of 50 dB, where the signal dominated the noise, the code performed optimally. The beat signal was clearly discernible, leading to a well-defined peak in the frequency spectrum and accurate estimations of the target range.

In summary, the Signal-to-Noise Ratio significantly influences the code's ability to accurately estimate target ranges. Higher noise levels relative to the signal pose challenges, while lower noise levels enhance the precision of the range estimations. This underscores the importance of managing SNR levels to optimize the effectiveness of the target detection code in real-world scenarios

Table 4.3: If the SNR for target range at 8 meter.

SNR (Signal Noise Ratio)	Beat Signal in time Domain	Frequency Spectrum for Peak Detection	Water Surface target range estimation
-50			

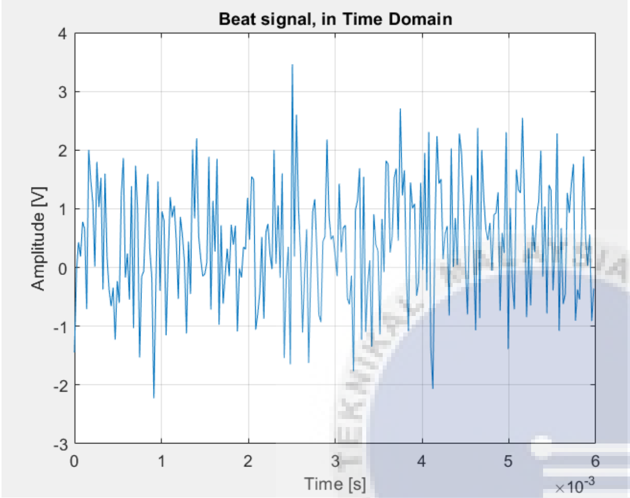
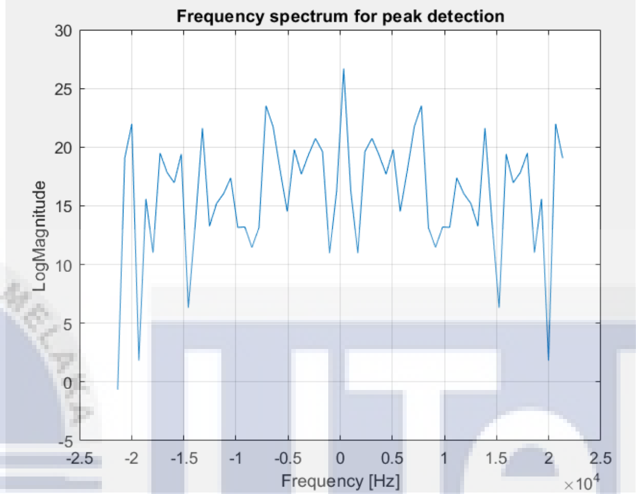
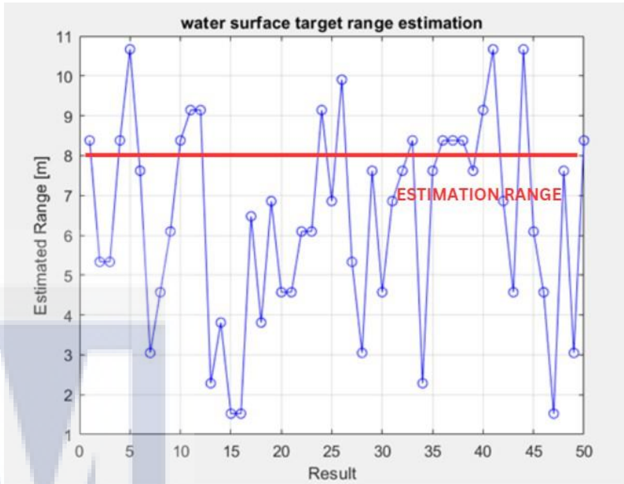
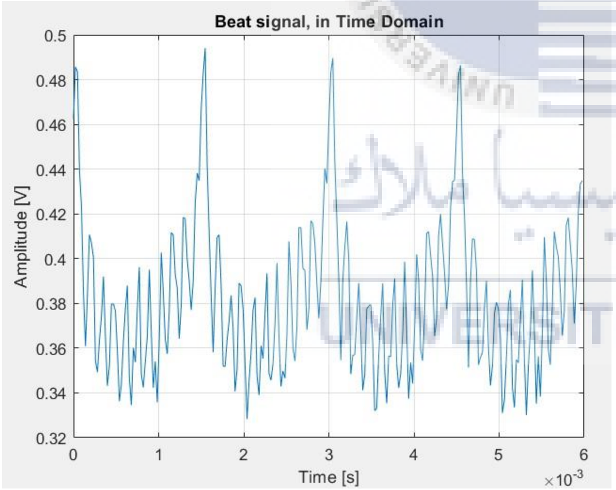
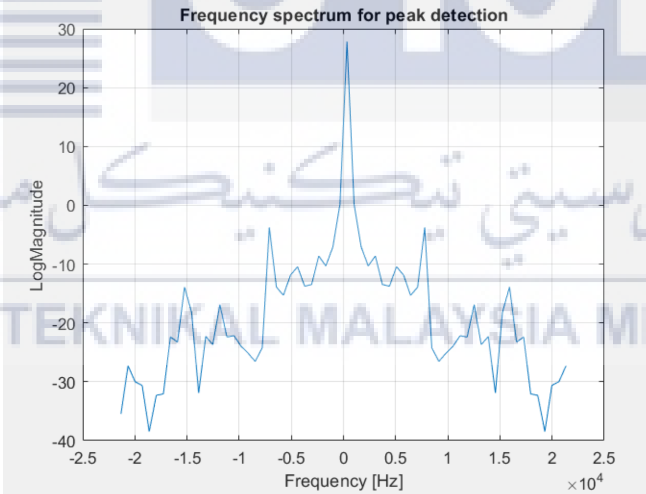
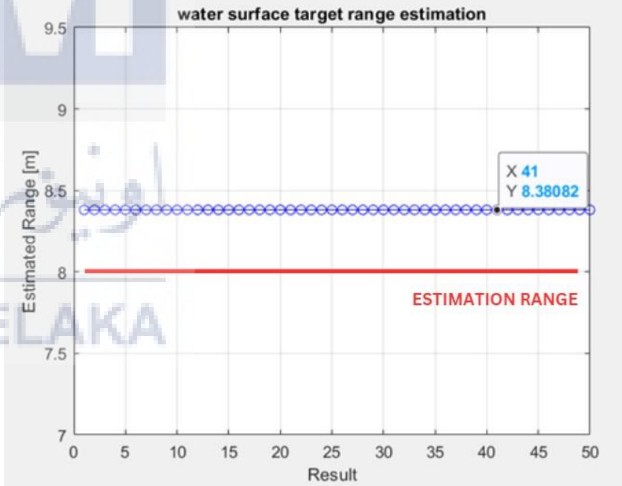
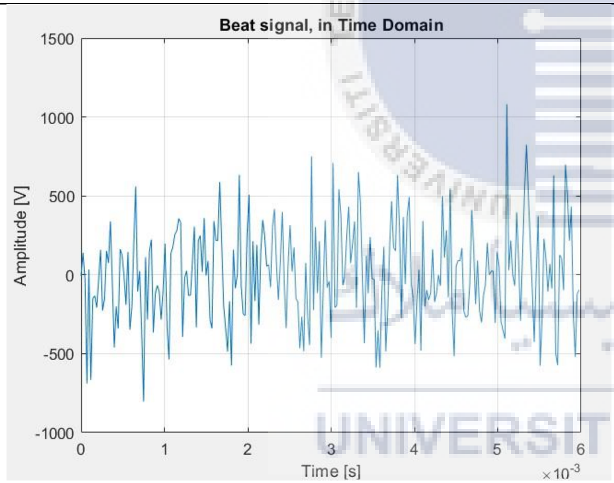
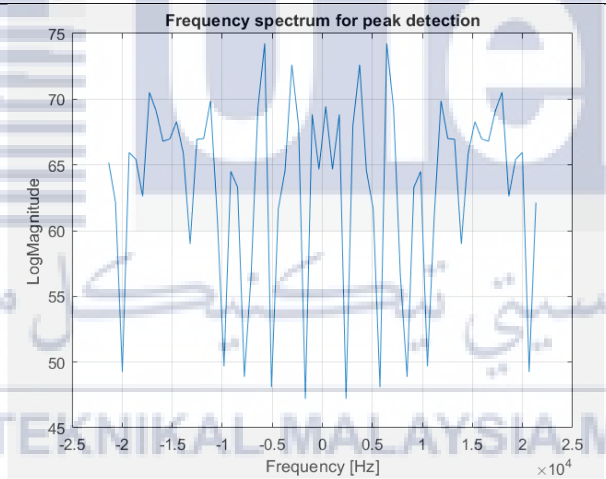
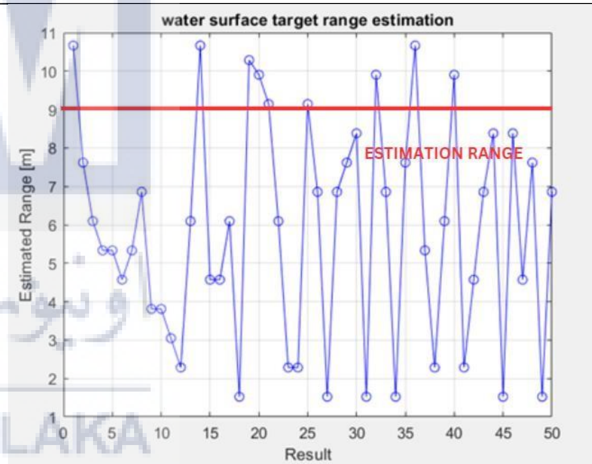
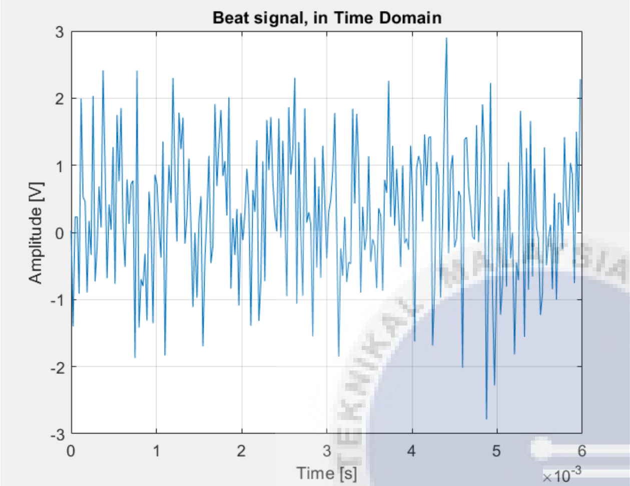
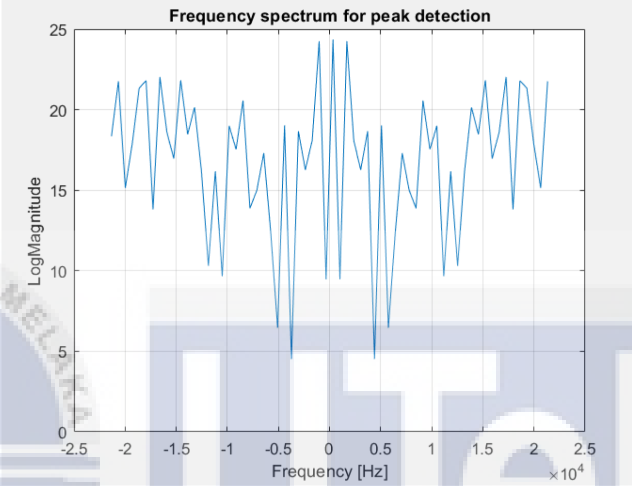
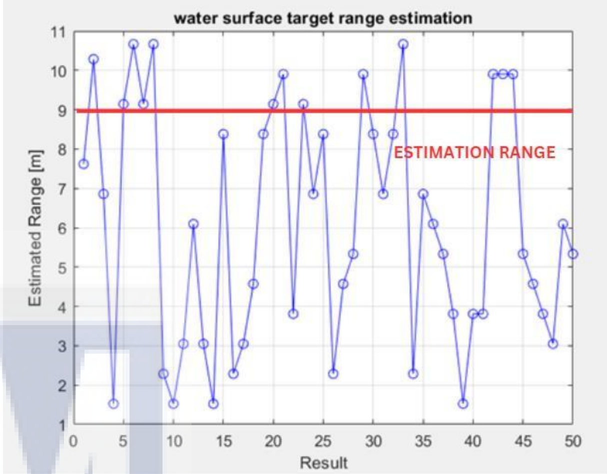
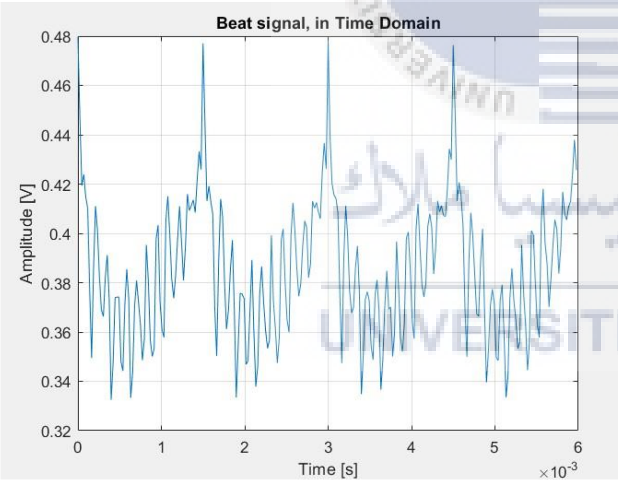
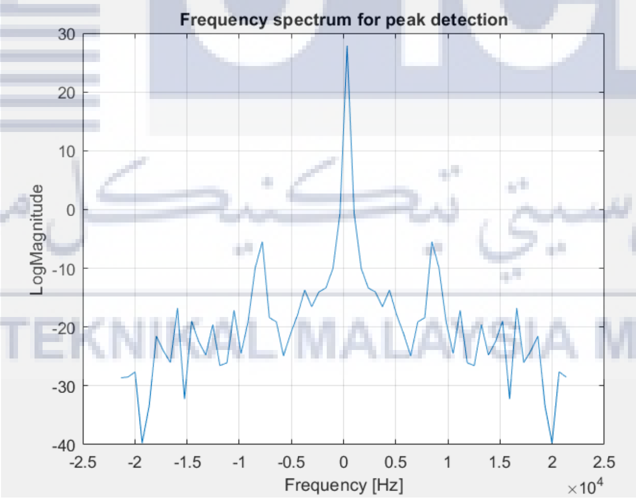
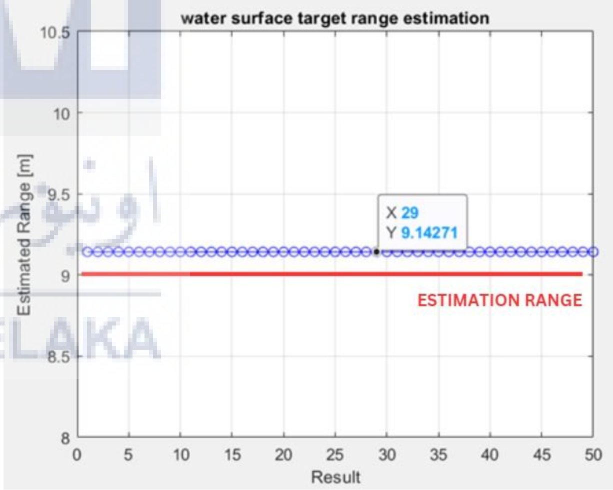
<table>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
</table>

Table 4.4: If the SNR for target range at 9 meter.

SNR (Signal Noise Ratio)	Beat Signal in time Domain	Frequency Spectrum for Peak Detection	Water Surface target range estimation
-50			

<table>
<tr>
<td>0</td>
<td>
</td>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>50</td>
<td>
</td>
<td>
</td>
<td>
</td>
</tr>
</table>

4.5 Summary

In this chapter, Chapter 4 delves into the methodology involving the simulation for Frequency Modulated Continuous Wave (FMCW) sawtooth signal generation. It discusses the process of creating this signal and how it is used in the project. The chapter also includes an analysis of range estimation, which is crucial for determining the distance between the radar system and the target object. Additionally, it provides an analysis of the Signal to Noise Ratio (SNR) for the experiment data, a key factor in assessing the quality and reliability of the data collected.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the comprehensive analysis of both simulation data and Signal-to-Noise Ratio (SNR) experiments has provided valuable insights into the performance of the target detection code. The identified minor discrepancies in range resolution underscore the significance of refining calibration procedures and incorporating noise reduction strategies for improved accuracy. Simultaneously, the conclusion provides a segue into the stated objectives. The SNR experiment highlights the pivotal role of managing noise levels in ensuring the code's optimal performance, aligning with the objective of developing a water surface detection algorithm for FMCW radar signal processing using MATLAB. Moving forward, the findings offer a roadmap for further refinement and optimization of the experimental design, which corresponds to the objective of validating the range detection algorithm through experimental data. This holistic approach emphasizes the importance of addressing calibration issues, exploring advanced noise reduction techniques, and maintaining a favorable SNR, aligning with the objective of analyzing the software developed in terms of its functionality and accuracy. In essence, the combined analysis and objectives provide a comprehensive framework for ongoing improvements, ensuring that the water surface detection algorithm is not only robust in simulated environments but also reliable and effective in real-world scenarios.

5.2 Recommendation

The future work on the water surface detection project could greatly benefit from the employment of advanced signal processing techniques. Techniques such as adaptive filtering, clutter suppression, and target tracking can significantly improve the accuracy and reliability of the detection algorithm. Adaptive filtering involves adjusting the filter's characteristics based on the signal's statistical properties, which can help reduce noise and improve signal quality. Clutter suppression techniques can help eliminate unwanted reflections that might interfere with the target signal. Target tracking involves following the movement of a target over time, which can help in predicting the target's future position.

Another area of focus should be the optimization of the FMCW radar system. This can be achieved by exploring different waveform designs like linear, nonlinear, or stepped frequency modulation. Each of these designs has its own advantages and disadvantages for water surface detection. For instance, linear frequency modulation provides good range resolution and is relatively simple to implement, while nonlinear or stepped frequency modulation can offer better performance under certain conditions.

Conducting comprehensive field experiments is also crucial. These experiments should encompass diverse water surface conditions and target types to validate and refine the range detection algorithm in varied scenarios. This could involve testing the system in different weather conditions, with different types of water surfaces (e.g., calm, choppy), and with different types of targets (e.g., small boats, large ships).

Lastly, the integration of the FMCW radar system with complementary sensors such as optical, infrared, or sonar can enhance detection capabilities. This multi-sensor approach can provide more comprehensive information and improve the algorithm's applicability.

Furthermore, establishing a continuous evaluation and optimization framework will ensure ongoing refinement based on feedback from field experiments and sensor integration. This will help maintain the project's effectiveness and adaptability over time, ensuring that the water surface detection algorithm remains robust and reliable in the face of changing conditions and requirements.

5.3 Project Potential

The project, which focuses on the development and implementation of the Frequency Modulated Continuous Wave (FMCW) radar system, has immense potential in various domains. Its primary application in water surface monitoring provides a powerful tool for collecting critical data on parameters such as water level, wave height, and surface roughness. This data is crucial for effective water resource management, flood prediction and prevention, and comprehensive environmental assessments.

In maritime surveillance, the system's ability to detect and track targets on water surfaces enhances maritime security, navigation, and safety. This capability extends to monitoring maritime traffic, aiding navigation in busy waterways, and ensuring the safety of sea-based activities.

Lastly, the high range resolution and accuracy of the FMCW radar system can be utilized in diverse radar applications, including automotive radar systems, air traffic control, and obstacle detection. By enhancing the performance and reliability of these applications, the project has the potential to introduce new functionalities and significantly contribute to advancements in these fields.

In summary, the project's potential impact is broad reaching, spanning water resource management, maritime security, and various radar applications, thereby promising substantial contributions across multiple domains.

REFERENCES

[1] "The Different Types of LiDAR Systems – LiDAR and RADAR Information," pp. 1–8.

[2] R.Resolution, "Frequency-Modulated Continuous-Wave Radar FMCW radar is a special type of radar sensor which radiates," pp. 1–8, 2018.

[3] W. Butler, P. Poitevin, and J. Bjomholt, "Benefits of Wide Area Intrusion Detection Systems using FMCW Radar," in *2007 41st Annual IEEE International Carnahan Conference on Security Technology*, IEEE, Oct. 2007, pp. 176–182. doi: 10.1109/CCST.2007.4373486.

[4] D. Overview, "Monostatic Radar," pp. 1–11, 2001.

[5] C. Wolff, "Bistatic Radar Sets," available: https://www.radartutorial.eu/05.bistatic/bs04.en.html.

[6] C. Detection, R. Classification, and R. Further, "Multistatic radar," pp. 21–24.

[7] Storr Wayne, "Electrical Waveforms," Basic Electron. Site.

[8] Z. SURAYA, "IMPROVEMENT OF ERROR PARAMETERS IN MARITIME FMCW RADAR USING MIMO," vol. 2507, pp. 1–9, 2020.

[9] C. Will, P. Vaishnav, A. Chakraborty, and A. Santra, "Human Target Detection, Tracking, and Classification Using 24-GHz FMCW Radar," *IEEE Sens J*, vol. 19, no. 17, pp. 7283–7299, Sep. 2019, doi: 10.1109/JSEN.2019.2914365.

[10] M. Detection, "M . Sc . Thesis Multi-target Detection and Tracking with 8 GHz FMCW Radar System," 2020.

[11] A. Vijayaraghavan, A. G. C. Koppelaar, and F. Laghezza, "Short Range Height Classification in FMCW Radar," in *2020 17th European Radar Conference (EuRAD)*, IEEE, Jan. 2021, pp. 116–119. doi: 10.1109/EuRAD48048.2021.00040.

[12] E. Hyun, Y.-S. Jin, and J.-H. Lee, "Moving and stationary target detection scheme using coherent integration and subtraction for automotive FMCW radar systems," in *2017 IEEE Radar Conference (RadarConf)*, IEEE, May 2017, pp. 0476–0481. doi: 10.1109/RADAR.2017.7944250.

[13] E. Hyun, Y.-S. Jin, Y. Ju, and J.-H. Lee, "Development of short-range ground surveillance radar for moving target detection," in *2015 IEEE 5th Asia-Pacific Conference on Synthetic Aperture Radar (APSAR)*, IEEE, Sep. 2015, pp. 692–695. doi: 10.1109/APSAR.2015.7306300.

[14] M. A. Mutschler, P. A. Scharf, P. Rippl, T. Gessler, T. Walter, and C. Waldschmidt, "River Surface Analysis and Characterization Using FMCW Radar," *IEEE J Sel Top Appl Earth Obs Remote Sens*, vol. 15, pp. 2493–2502, 2022, doi: 10.1109/JSTARS.2022.3157469.

[15] "Frequency Modulated Continuous Wave Radar Design and Simulation".

[16] H. Jeong and S. Kim, "Educational low-cost c-band fmcw radar system comprising commercial off-the-shelf components for indoor through-wall object detection," *Electronics (Switzerland)*, vol. 10, no. 22, Nov. 2021, doi: 10.3390/electronics10222758.

[17] P. D. Hilario Re *et al.*, "FMCW Radar With Enhanced Resolution and Processing Time by Beam Switching," *IEEE Open Journal of Antennas and Propagation*, vol. 2, pp. 882–896, Aug. 2021, doi: 10.1109/ojap.2021.3097820.

[18] T. Y. Lim, S. A. Markowitz, and M. N. Do, "RaDICaL: A Synchronized FMCW Radar, Depth, IMU and RGB Camera Data Dataset with Low-Level FMCW Radar

Signals," *IEEE Journal on Selected Topics in Signal Processing*, vol. 15, no. 4, pp. 941–953, Jun. 2021, doi: 10.1109/JSTSP.2021.3061270.
[19] Y. Zhang, X. Li, G. Ma, J. Ma, M. Man, and S. Liu, "A New Model for Human Running Micro-Doppler FMCW Radar Features," *Applied Sciences*, vol. 13, no. 12, p. 7190, Jun. 2023, doi: 10.3390/app13127190.
[20] H. Park, M. Kim, Y. Jung, and S. Lee, "Method for Improving Range Resolution of Indoor FMCW Radar Systems Using DNN," *Sensors*, vol. 22, no. 21, Nov. 2022, doi: 10.3390/s22218461.
[21] N. Bouhlel, S. Méric, C. Moullec, and C. Brousseau, "FMCW Radar System for Transponder Identification," 2018.
[22] N. Ben Abid, R. Ghozzi, S. Lahouar, and C. Souani, "GNU Radio-Based FMCW Ground Penetrating Radar for Range Detection," in *Advances in Science, Technology and Innovation*, Springer Nature, 2022, pp. 255–258. doi: 10.1007/978-3-030-72896-0_57.
[23] U. M. and A. N. D. Environment, "24 G Hz tr ans ceive r - BGT24 MT R11," pp. 1–43.
[24] K. Czaplewski, "Determining The Accuracy of Ship Position as a Function of Radar Bearing," in *2015 International Association of Institutes of Navigation World Congress (IAIN)*, 2015.

APPENDICES

Appendix A Coding in MATLAB PSM 1 & 2

```
clear all
close all;

fc = 24e9;
c = 3e8;
lambda = c/fc;
range_max = 15;
tm = 5.5*range2time(range_max,c); %1500000e-9; %5.5*range2time(range_max,c);
range_res =1;
bw = 220e6;%rangeres2bw(range_res,c);%200e6; %rangeres2bw(range_res,c);
sweep_slope = bw/tm;
fr_max = range2beat(range_max,sweep_slope,c);
v_max = 230*1000/3600;
fd_max = speed2dop(2*v_max,lambda);
fb_max = fr_max+fd_max;
fs = max(2*fb_max,bw); %42666; %max(2*fb_max,bw);
waveform = phased.FMCWWaveform('SweepTime',tm,'SweepBandwidth',bw, ...
    'SampleRate',fs);

sig = waveform();
subplot(211); plot(0:1/fs:tm-1/fs,real(sig));
xlabel('Time (s)'); ylabel('Amplitude (v)');
title('FMCW signal'); axis tight;
subplot(212); spectrogram(sig,32,16,32,fs,'yaxis');
title('FMCW signal spectrogram');
```

```
close all
n = 1;                                                                    %
Define 1st signal in the file.
iii = 1;                                                                 %
Define number of signal to process
m = 10;                                                                    %
Define start of stored value
for ii = 1:1:iii;
%% Load and read signal from D2G capture
files = Peisal9M; % CHANGE FILE NAME TO TEST THE TARGET RANGE             %
Call beat signal file to read
A = files(n,:);                                                           %
Define signal for processing
B = files(n+1,:);
%signal1 = A+(1i*B);
signal1 = A;

%% Define parameters
SNR = 50;                                                                 %
Define Signal-to-noise ratio
signal1 = awgn(signal1,SNR); %CHANGE THIS TO TEST ON SNR                  %
Simulate signal with white noise

NFFT = 64;                                                                 %
Define no of sample (As per D2G)
BW = 200e6;                                                               %
Define bandwidth (As per D2G)
tau = 1500000e-9;                                                         %
Define chirp time (As per D2G)

c = 3e8;                                                                  %
Define speed of light
tsample = tau/NFFT;                                                       %
Calculate sampling time
ts_plot = (0:tsample:tsample*(255));                                      %
Create sampling time for plotting
ts_plot = transpose(ts_plot);                                             %
Transpose matrix to suit for plotting

R_max = NFFT*c/(2*BW); % NTS*c/(2*BW);                                    %
Calculate Maximum Distance (As per D2G)
DistPerBin  = R_max/(NFFT);                                               %
Calculate Distance per bin/ 1 scale

%% Signal processing to estimate target range

% FFT beat signal to transform from time domain to frequency domain

zm1a = fftshift(fft((signal1),NFFT));
z2m1a  =  abs(zm1a);
z3m1a = 20*log10(z2m1a);
len_z3m1a = length (z3m1a);
```

```
% Maximum peak detection to detect fbeat for range estimation

Fs = 42666;                                                             %
Define sampling frequency (As per D2G)
f = -Fs/2:Fs/(NFFT-1):Fs/2;
ran = f.*(((tau)*c)/(2*BW));
fm1_1a= z3m1a(17:len_z3m1a/2);
f1_1a=f(17:len_z3m1a/2);
fm2_1a= z3m1a((len_z3m1a/2)+1:48);
fm2_1a(2)=0;
f2_1a=f((len_z3m1a/2)+1:48);

[psor1_1a,lsor1_1a] = findpeaks(fm1_1a,'SortStr','descend');
[psor2_1a,lsor2_1a] = findpeaks(fm2_1a,'SortStr','descend');

tsort = isempty (lsor2_1a);
if (tsort == 1);
fbAS1a = 0;
else
fb1_1a = abs(f2_1a(lsor2_1a(1)));
fb2_1a = abs(f1_1a(lsor1_1a(1)));
end

% Range & velocity Estimation
fbAS1a = (fb2_1a+fb1_1a)/2;                                     % for
range estimation
range_est (m) = (fbAS1a)*(((tau)*c)/(2*BW))

n = n + 2;
m = m +1;
end

%% Plotting Figures

% Plot Figure 1: Beat signal in Time Domain
figure();
plot(ts_plot,(signal1));
grid on
title('Beat signal, in Time Domain');
xlabel('Time [s]')
ylabel('Amplitude [V]')
```

Table 5.1: Project Gantt Chart PSM 1

PROJECT ACTIVITIES	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8	WEEK 9	WEEK 10	WEEK 11	WEEK 12	WEEK 13	WEEK 14	WEEK 15	WEEK 16
BDP Briefing						M										S
Meeting with Supervisor						I										T
Distribution of project titles						D										U
PSM 1 Rubrics Explanation						S										D
Project Planning						E										Y
Proposal Preparation						M										
Abtract						B										W
Literature Review						R										E
Design Project						E										E
Flowchart						A										K
Design Software						K										
Contruct The Application																

Table 5.2: Project Gantt Chart PSM 2

Project Gantt Chart	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16
INTRODUCTION																
Subject briefing by lecturer								M								S
Project briefing by supervisor								I								T
DEVELOPEMENT								D								U
Brainstroming Ideas																D
Literature review								S								Y
A POST-PROCESSING SIMULATION								E								
Programming Matlab Coding Writing								M								
Finish the simulation																W
Collect data from D2G								B								E
EXPERIMENT FOR ACTUAL DATA								R								E
Complete the simulation for actual data								E								K
Comments and Improvements								A								
REGIONAL EVALUATION								K								
Evaluation																
Final poster																
Presentation project																