ANALYSIS AND DEVELOPMENT OF FLOATING WASTE DETECTION USING A RADAR SENSOR

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This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honours

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DEDICATION

I dedicate this final year project report to all the individuals who have been instrumental in my academic journey and the successful completion of this endeavour – my beloved Father and Mother, dedicated lecturers, also, supportive friends.

ABSTRACT

The surge in global population has substantially contributed to insufficient waste management practices, leading to an escalation in the volume of waste discharged into rivers. In this era of globalization, modern communication protocols and smart detecting sensors are widely used in daily life. These implementations help in monitoring and analysing data to prevent and preserve environmental condition. A floating waste detector utilising radar sensor and low-powered LoRa technology in such to detect and locate floating waste in water bodies which is a major environmental problem including entanglement and ingestion of marine life, degradation of water quality, and destruction of habitats as well as flooding. The radar sensor is connected to a LoRa transceiver module that transmits data to a central server for processing and monitoring. This project aims to analyse the accuracy and reliability of radar sensor in floating waste detection. Results show that the radar sensor employed in the system has demonstrated a higher level of reliability in detecting larger and solid objects, making it a robust tool for monitoring and managing floating waste in water bodies.

ABSTRAK

Kenaikan jumlah penduduk global telah menyumbang kepada amalan pengurusan sisa yang tidak memuaskan dan menyebabkan peningkatan jumlah sisa yang dibuang ke dalam sungai. Dalam era globalisasi kini, protokol komunikasi moden dan pengesan pintar digunakan secara meluas dalam kehidupan seharian. Implementasi ini membantu dalam pemantauan dan analisis data bagi mencegah dan memelihara alam sekitar. Pengesan sisa terapung menggunakan teknologi LoRa berkuasa rendah dan pengesan radar bertujuan untuk mengesan dan menentukan lokasi sisa terapung di permukaan air yang merupakan masalah alam sekitar utama termasuk mengancam habitat laut, penurunan kualiti air, dan pemusnahan habitat serta banjir. Projek ini melibatkan pembangunan sistem prototaip yang terdiri daripada pengesan radar yang dihubungkan dengan modul LoRa yang menghantar maklumat ke perkhidmatan web untuk pemantauan. Projek ini bertujuan untuk menganalisis ketepatan pengesan radar dalam mengesan sisa terapung. Keputusan analisis menunjukkan bahawa pengesan radar yang digunakan dalam sistem lebih cenderung dalam mengesan sisa yang bersaiz besar dan padat. Hal ini membuktikan pengesan radar cekap untuk keperluan pemantauan serta pengurusan sisa terapung di badan air.

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LIST OF SYMBOLS AND ABBREVIATIONS

IT	:	Information Technology
IoT	:	Internet of Things
NGO	:	Non-governmental organization
mmWave	:	Millimetre-Wave
LoRa	:	Long Range
WHO	:	World Health Organization
uRAD	:	Universal Radar
LAN	:	Local Area Network
WAN	:	Wide Area Network
GSM	:	Global System for Mobile
SMS	:	Short Message Service
Wi-Fi	:	Wireless Fidelity
RF	:	Radio Frequency
DC	:	Direct Current
LPWAN	:	Low Power Wide Area Network
ISM	:	Medical Radio Frequency Bands
UNB	:	Ultra Narrow Band
DSSS	:	Direct Sequence Spread Spectrum

ED	:	End-devices
GW	:	Gateways
NS	:	Network Server
SF	:	Spreading Factor
CR	:	Code Rate
BW	:	Bandwidth
UL	:	Uplink
dBi	:	Decibels
GPS	:	Global Positioning System
App	:	Application
RGB	:	Red-Green-Blue
FMCW	:	Frequency Modulated Continuous Wave
MQTT	:	Message Queuing Telemetry Transport
PMW	:	Pulse Width Modulation
USB	:	Universal Serial Bus
FTDI	:	Future Technology Devices International Limited
SMD	:	Surface Mount Device
SMA	:	SubMiniature version A
SoC	:	System on Chip
BLE	:	Bluetooth Low Energy
PRF	:	Pulse Repetition Frequency
DSP	:	Digital Signal Processing
LNA	:	Low Noise Amplifier

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CHAPTER 1

INTRODUCTION

This chapter provides a concise introduction to the project, highlighting its significance and various research perspectives. It encompasses the problem statement, objectives, scopes, and overview of the project, all of which are comprehensively explained herein. Additionally, the chapter covers background studies and organizational aspects.

1.1 Background Studies

The problem of water pollution has emerged as a significant concern for all developing nations worldwide. The presence of floating waste in water bodies is a major environmental concern that poses a threat to aquatic ecosystems, deterioration of water quality as well as compromising the ecosystem and our environment [1]. Floating waste, also known as marine debris, is a significant environmental issue that has garnered global attention in recent years. The issue is particularly prevalent in coastal areas and it is the result of the improper disposal of waste products including plastic, paper and other types of waste, which then enter the marine environment. The most common type of floating waste is plastic which can persist in the environment for hundreds of years and can have a range of negative effects on marine life. According to a research article published in 2017, it is approximated that between 1.15 and 2.41 million tonnes of plastic find their way into the ocean annually through river systems [2]. Over 50% of this plastic has a lower density than water which indicates that it will remain afloat in the ocean. The worldwide calculation of plastic waste entering the ocean through rivers, which takes into account both the seasonal fluctuations and the spatial differences of local origins is depicted in the provided Figure 1.1. The calibration of the model is based on plastic concentration data collected from rivers across South America, Asia, Europe and North America.

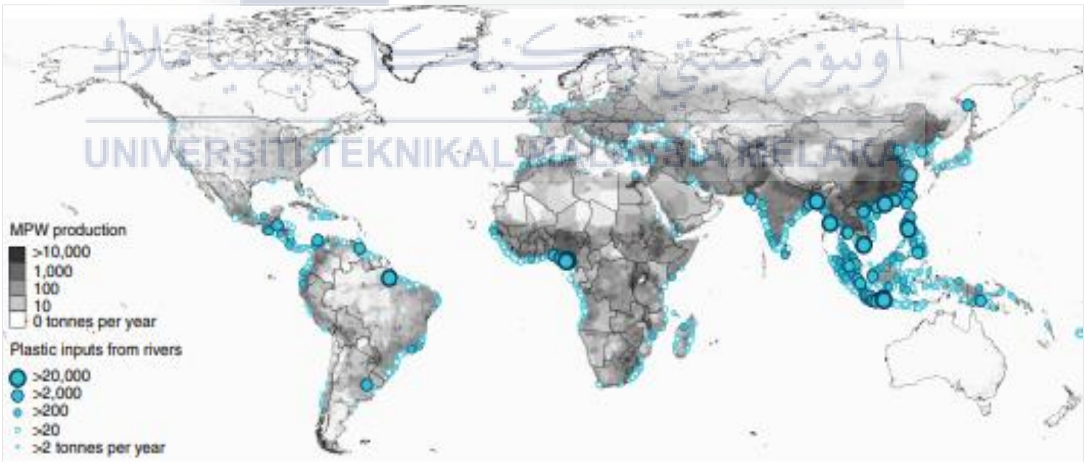


Figure 1.1: Quantity of plastic waste from rivers entering the oceans annually, measured in metric tons [2].

Conventional methods of detecting floating waste such as visual inspection and manual collection are time-consuming and labour-intensive. A Dutch NGO called The *Ocean Cleanup* invented a barge-like interceptor to concentrate plastic waste prior to extraction from rivers [1, 3, 4]. It consists of a floating structure extending 600 meters along the surface of the water along with a 3.5-meter-deep barrier designed to prevent the escape of micro plastics from below which us similar to the Kingston Harbour Project as shown in Figure 1.2 (a). In Malaysia, an Interceptor has been deployed in the *Klang River* known as one of the most polluted rivers in the Malaysia. The Interceptor in Malaysia is operated by the local waste management company, *Alam Flora* and is capable of capturing up to 100,000 kilograms of waste per day [1, 5]. The Interceptor is powered by solar panels and a conveyor belt system that separates the waste from the water that allows for easy removal and disposal depicted by Figure 1.2 (b).

(a) **(b)**

Figure 1.2: Interceptors deployed by Ocean Cleanup [1, 5]. (a) Interceptor in Kingston Harbour, Jamaica, at mouth of the gullies to collect the waste. (b) Interceptor 002 deployed at the Klang River that runs through Kuala Lumpur.

The solar energy powered system is capable of extracting 50 or more tonnes of plastic waste per day. However, the floating barrier has suffered setbacks with damage from wind and waves [6]. Similarly, Azure which is an invention designed by *Ichthion* uses a barrier to direct waste onto conveyor belt to intercept waste before it is carried out on ocean currents. The conveyer belt system is equipped with cameras that processes images of the waste which then uses algorithms to identify the types of waste [1, 7]. The collected materials are separated and processed to become flakes and distributed for recycling.

The efficient way to detect floating waste depends on the accuracy of the sensor, reliability and low-power operation in harsh weather conditions. Radar sensors are the new generation of scanners known for realibale and consistent detection which operates in higher frequency bands. Millimeter-wave, mmWave, radars show great potential as effective surveillance tools, particularly in situations with poor visibility. These radars emit electromagnetic signals towards objects in their vicinity which captures reflections that reveal information on the range, speed, and angle of detected objects. It can detect the speed, distance, and direction of moving objects with high accuracy [8]. This makes radars ideal for use in applications where accurate measurement is critical.

LoRa is considered one of the most reliable communication technologies available today. Its long-range, low-power capabilities and ability to operate in unlicensed frequency bands makes it an ideal choice for a wide range of applications [9]. LoRas use chirp spread spectrum (CSS) modulation which allow the transmission of data over long distances while consuming very little power which makes it ideal for use in remote or hard-to-reach locations [10, 11]. LoRa can be used for floating waste detection in water bodies such as rivers, lakes, and oceans. The LoRa low power consumption feature allows the sensors to operate on battery power for extended periods which results in feasible for continuous monitoring over long periods.

The combination of sensors, microcontrollers, and LoRa can be a powerful tool for developing a floating waste detection system. This system can provide a cost-effective, efficient, and sustainable solution to monitor water bodies and detect any floating waste. It can help prevent environmental damage caused by waste and contribute to a cleaner and healthier environment. Moreover, the use of LoRa allows for long-range communication, making it ideal for outdoor applications while the low power consumption of the system ensures it can operate for long periods with minimal maintenance.

1.2 Problem Statements

The increasing population worldwide has significantly contributed towards global warming and poor waste management, affecting water sources. The problem of floating waste arises due to human activities such as improper waste disposal, industrial activities and maritime transportations. The current estimation indicates that an annual influx of plastic waste into the ocean from rivers falls within the range of 1.15 to 2.41 million tonnes. Notably, more than 74% of these emissions were recorded between the months of May and October in 2017 [12]. The accumulation of floating waste has far-reaching consequences on the environment, including exacerbation of flood, pose human health risk and entanglement and ingestion of marine life.

1.2.1 Flooding

A significant proportion of the floating debris found in the ocean comes from rivers. Rivers act as a conduit, carrying waste and pollutants from inland areas to the ocean. The blockages of drains and rivers exacerbate the occurrence of floods. When water may not freely pass through the watercourses, it tends to overflow its banks during heavy rainfall or storm events. Various wastes are found in river and drains which leads to flood as shown in Figure 1.3. Immediate effects of a flood can include destruction of homes and businesses, loss of personal possessions, and displacement of individuals and families. In 2021, the cumulative financial damages resulting from floods in Malaysia amounted to RM6.1 billion which is equivalent to approximately 0.03% of the nominal Gross Domestic Product [13].

Figure 1.3: All sorts of waste found at the floating boom at Sungai Batu, Kuala Lumpur, near Taman Kolam Air.

Floods can damage public infrastructure such as roads, bridges, dams, and utilities. Repairing or replacing infrastructure systems is expensive and often requires significant time and resources. Agricultural areas can suffer significant losses due to flooding. Crops can be destroyed, leading to reduced yields and financial strain on farmers. Floodwaters can cause extensive damage to residential and commercial properties. Buildings can suffer structural damage, and the contents within them can be destroyed. Furthermore, floods can force people to evacuate their homes, leading to displacement and homelessness [14]. A statistic derived from evaluations of public assets and infrastructure, residential spaces, vehicles, manufacturing, commercial establishments, and agriculture is depicted in Figure 1.4.

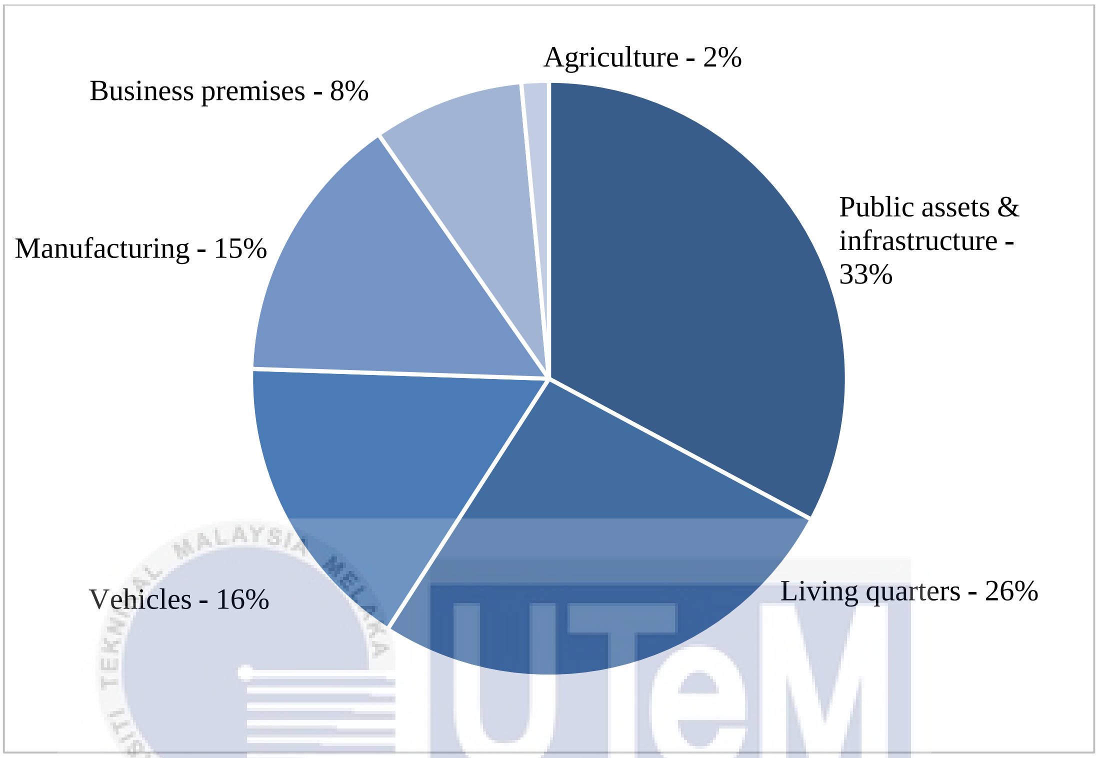


Figure 1.4: The distribution of losses due to the floods in December 2021 [14].

1.2.2 Human Health Risks

Floating waste can impact human health by causing the spread of diseases and the release of harmful chemicals. As per the World Health Organization (WHO), approximately 2 billion individuals across the globe consume water that has been polluted [15]. In areas where communities rely on the river for drinking water or irrigation, contamination can lead to serious health concerns. Contaminated drinking water with harmful microorganisms can lead to diseases like cholera and diarrhoea. Annually, such polluted water results in 485,000 deaths due to diarrhoea. Furthermore, direct contact with floating waste can cause injuries, infections, or exposure to hazardous materials.

1.2.3 Marine and Aquatic Life

Undissolved floating waste poses an increasing danger to living organisms. In 2019, hundreds of fish have been found dead in Melaka River due to pollution which the pollution is from industrial wastewater, rubbish, and sewage according to the authorities [16]. Plastic waste, for example, can break down into smaller particles that are ingested by fish and other aquatic organisms which leads to both physical and chemical damage. Ingesting plastics can lead to internal injuries, starvation, and even death. The accumulation of floating waste can also disrupt the habitats of marine organisms, affecting their reproduction and overall ecological balance.

Owing to the problem, a low-powered LoRa scalable system equipped with radar sensor is developed to detect floating waste in harsh weather conditions which allow water management agencies to evaluate and minimise the potential hazards of pollution and flooding along the riverbanks, enabling prompt intervention.

1.3 Objectives

This project focuses on a scalable system that employs radar sensor and low-powered LoRa to detect floating waste which can provide reliable waste on river status reports and minimise the risk of pollution and flooding through timely intervention. The objectives of the project are:

1. To investigate the feasibility of using radar sensor and low-powered LoRa for floating waste detection.
2. To design and develop a floating waste detection system using radar sensor and low-powered LoRa.

3. To analyse the accuracy and reliability of radar sensor to detect floating waste.

1.4 Scope of Work

The objective of the project is to design a floating waste detection system using a uRAD radar sensor and low-power LoRa technology which aims at delivering data on the number of floating waste on river surface. The system comprises two major components which includes the software development and hardware development for Transmitter (sender) and Gateway (receiver). The transmitter section of the system includes the radar sensor operated by Arduino UNO to measure frontal distance with reliable and comprehensive accuracy [17, 18]. In this system, the radar sensor detects the number of waste found on the surface of the river and the collected data from the sensor is transmitted through LoRa technology. The gateway part of the system includes a microcontroller of ESP32 which receives the data from transmitter part and connects it to a network through MQTT broker. The LoRa operates as medium of transmitting and receiving data. With the integration of IoT, it allows water management agencies to assess and mitigate the risk of riverside pollution and flooding for timely intervention with real-time information of river status reports.

1.5 Chapter Outline

The floating waste detection system using radar sensor is described based on the problems that have been subsequent throughout the years in relations of existing floating waste systems and technologies. The specifics of this project are outlined in each section, as depicted below.

Chapter 1: This chapter gives a concise overview and short description of the project. It describes the importance and different perspective of research on the project. It consists of background studies, problem statement, objectives, scopes and the project outline for the overall project.

Chapter 2: This chapter describes the literature review on the future trend of the project as well as the framework that shows the conceptual link towards the project researches. It describes the perspectives in researching as well as articles that relates to the project.

Chapter 3: This chapter discusses on the sequential tasks for project completion. The design process for the floating waste detection system involves several essential steps. This section provides the flowchart, the utilised methodology and an explanation of the components of the project.

Chapter 4: This chapter shows the attained results accomplished during the project completion within the semester. The outcome of the project through the perspectives of the objectives as well as problem statement is discussed throughout this chapter.

Chapter 5: This chapter explains the overall conclusion in line with the project objectives. This section includes project summary, project finding and further recommendation for the project in future reference on ways it can be improvised or manipulate.

CHAPTER 2

BACKGROUND STUDY

This chapter discusses the relevant sources utilised to complete the project, encompassing thorough research and reference from various perspectives. This comprehensive approach ensures a deeper understanding of every detail and aspect of the project. Additionally, the chapter presents the literature review of previous works and conceptual framework pertaining to the project.

2.1 Network Structure Scheme

Network structure can be categorized based on the uniformity of nodes. In certain networks, nodes are evenly distributed and encompasses equal status, while in other networks, there are distinctions among nodes. These distinctions determine how information is routed within the network architecture. This classification encompasses two types of node deployments including uniform connectivity among nodes and hierarchical differences among nodes.

2.1.1 Flat networks Routing Protocols

In a flat network architecture, all nodes have equal roles and responsibilities [19]. Flat networks, also referred to as flat architectures or topologies, are network designs where all devices connect to a single layer or segment without hierarchical structures. Routing protocols play a vital role in determining data packet forwarding within these networks. Flat networks have become increasingly popular in modern architectures due to their simplicity and scalability. Robust routing protocols are crucial for efficient data packet forwarding in flat networks. These networks are established using homogeneous sensor nodes that possess identical capabilities and functionalities. These nodes have the versatility to perform various tasks such as image capturing, multimedia processing, and packet relaying as they communicate with the sink node in a multi-hop manner [20]. As the density of sensors increases, a flat architecture with a single-tier can lead to the sink node becoming overwhelmed. This overload can have detrimental effects on network performance which results in communication latency and delays in tracking events.

2.1.2 Hierarchical Networks Routing Protocols

Hierarchical models apply to both local area network (LAN) and WAN design. In cluster-based architecture, the network is divided into clusters where each containing diverse sensor nodes such as cameras, audio, and scalar sensors. These nodes transmit data to a cluster head for advanced data processing due to its additional resources. The cluster-based network architecture provides notable benefits compared to a flat network, especially in the domain of image processing and transmission [20]. The network architecture of flat and hierarchical network is shown in Figure 2.1. Hierarchical networks routing protocols are designed for networks that have a hierarchical structure where nodes are organized into different levels or tiers. These protocols aim to optimise communication and routing efficiency within the network by leveraging the hierarchical organization.

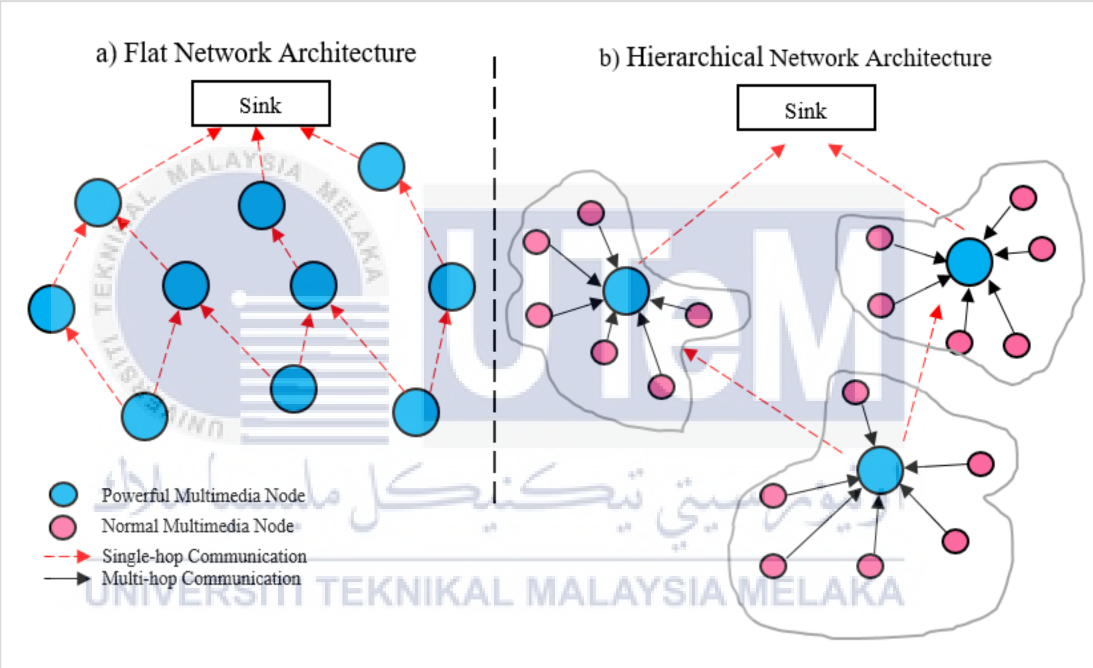


Figure 2.1: Flat vs. Hierarchical network architecture.

2.2 Wireless Networks

Wireless network is known as transmission medium without the need for cables as a physical connection [21]. This enables devices to communicate with each other without requiring physical cables.

2.2.1 Global System for Mobile (GSM)

The 2G network GSM, initially known as Groupe Spécial Mobile, defines the protocols for second-generation digital cellular communication networks, which are widely utilised by mobile phones worldwide [22, 23]. The GSM system operates using two frequency bands of 890 to 915MHz for the transmit band and 935 to 960MHz for the receive band in the mobile system.

In [24] authors introduced an intelligent waste monitoring system to gauge real-time waste levels within bins and, when necessary, notify the local authorities through SMS alerts. The system design incorporates an ultrasonic sensor for waste level measurement, a GSM module for SMS transmission, and an Arduino UNO to manage the complete configuration. The system has the objective to create and dispatch SMS warning messages to the municipality once the waste bin reaches full or nearly full capacity, thereby ensuring timely garbage collection.

2.2.2 Wireless Fidelity (Wi-Fi)

Wi-Fi is a prevalent wireless networking infrastructure providing high-speed data transmission over a LAN and is commonly used in home and office environments. Wi-Fi is extensively utilised for mobile connectivity in home and small office networks due to its inherent flexibility and mobility. Wi-Fi, denoted as a trademarked term representing the IEEE 802.11x standard, eliminates the requirement for physical wired connections between sender and receiver. Instead, Wi-Fi relies on radio frequency (RF) technology to establish wireless connections [25]. The basic principle of Wi-Fi involves the transmission of data through radio waves. Wi-Fi operates in the unlicensed radio frequency bands.

Narendiran et al [26], 2023, designed a versatile, efficient, cost-effective, and compact prototype to address issues on challenges to water bodies by effectively removing floating waste and restore unpolluted water bodies. Equipped with DC geared motors and propellers, controlled by the Motor Driver L293D, it utilises efficient propulsion. The central control unit is the microcontroller NodeMCU and Arduino UNO which receives input signals from a custom-designed mobile application. With its integrated Wi-Fi module, the NodeMCU accepts and executes operational tasks based on input signals from the mobile application. The controller receives Wi-Fi commands for propeller and conveyor belt control. The Ultrasonic sensor detects overload on the conveyor belt, triggering an automatic shutdown to prevent further trash collection. The microcontroller promptly measures the bin level upon trash deposition and provide data for the development of the mobile application.

2.2.3 Sigfox

Sigfox employs the utilisation of Ultra Narrow Band (UNB) technology within unlicensed frequency bands. This approach of utilising a highly restricted bandwidth provides SigFox with distinct benefits, including reduced power consumption, enhanced receiver sensitivity, and lower costs for low-end devices [27, 28].

The authors in [29] proposed a waste monitoring system that utilises Arduino UNO-based sensor to oversee city-wide waste management. The system employs Sigfox technology which automatically forwards events using callback services. The Sigfox network comprises objects, base stations, and a cloud platform. The Sigfox Access Station Micro, also called the Sigfox Gateway, solves network coverage gaps in areas with limited coverage. It can be mounted indoors or outdoors for flexible placement, ensuring reliable network coverage. It automates device management and enables efficient knowledge integration through data integration. The instrumentation configuration of the automated waste management system is depicted in Figure 2.2. This method offers municipalities better insights into waste status, particularly when bins are full.

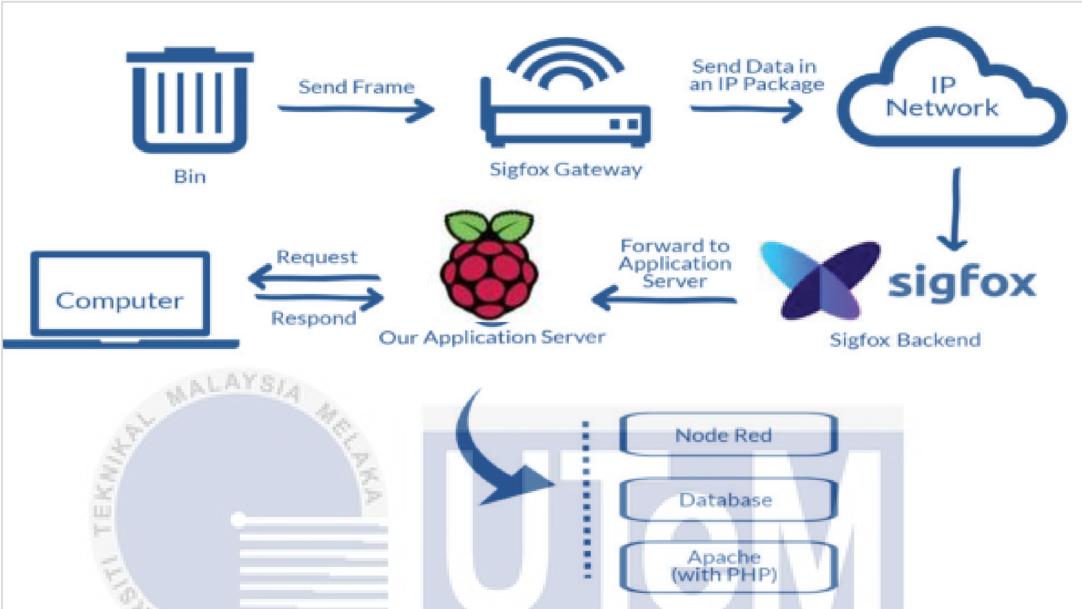


Figure 2.2: The hardware for the Sigfox-enabled smart dust bin system [29].

2.2.4 Long Range (LoRa)

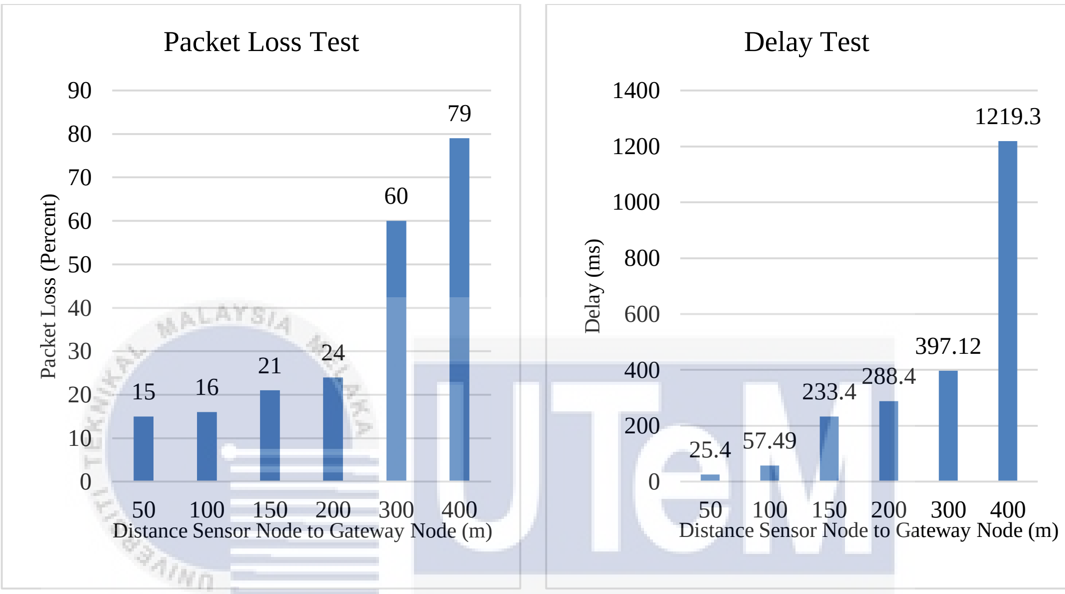
LoRa, developed by *Semtech*, enables long-range communication, capable of spanning distances of up to five kilometres in urban environments and reaching up to 15 kilometres in rural regions. LoRa networks can span a broad area and typically use a larger bandwidth of 125 kHz to transmit signals. Nodes can last up to ten years in operation which makes LoRa a very efficient and sustainable solution [30].

LoRas uses CSS modulation which allows it to transmit data over long distances while consuming very little power, making it ideal for use in remote or hard-to-reach locations [10, 11]. CSS is a substitute for the usual Direct Sequence Spread Spectrum (DSSS) method. In DSSS, a code is multiplied with data and then multiplied again with the same code at the receiver to recover the original data. This multiplication of sequences allows for extended-range communication [31]. The chirp signal provides enhanced immunity to factors such as the Doppler effect, interference, and malicious attacks. LoRa modulation technology employs the unlicensed ISM band, with frequencies varying across different regions globally [32, 33]. The most up-to-date frequency plans and the commonly used names are provided in Table 2.1.

Table 2.1: Frequency Spectrum [32, 33].

Frequency Spectrum	Name
863 – 870 MHz	EU868
902 – 928 MHz	US915
779 – 787 MHz	CN779
433 MHz	EU433
915 – 928 MHz	RU864
470 – 510 MHz	CN470
923 MHz	AS923
920 – 923 MHz	KR920
865 – 867 MHz	IN865
864 – 870 MHz	RU864

In [34] designed a real-time river pollution monitoring system that can promptly detect changes in water parameters and enable immediate response by relevant stakeholders using Raspberry Pi and Arduino Nano. Due to its remote location, the river lacks access to sufficient electrical power resources which pose a challenge in establishing a comprehensive river water monitoring system. WebSocket is used for real-time data transmission from the system to the server. The setup has sensors to gather water turbidity, acidity and temperature data. This information gets passed to a gateway using LoRa communication in JSON format. To assess the system, 120 data points are sent at varying distances of 50m, 100m, 150m, 200m, 300m, and 400m between the sensor and gateway nodes which is subsequently presented to the client. The analysis results are graphically illustrated in Figure 2.3 (a). Similarly, the system delay is assessed by repeating data transmission three times for each distance parameter as shown in Figure 2.3 (b).



(a) **(b)**

Figure 2.3: Perfomance results [32]. (a) Packet loss test. (b) Delay test.

The authors in [35] proposed a smart bin system integrated with ultrasonic transducer and LoRa transmission module based on evaluating the practicality of waterproof ultrasonic sensors for gauging waste levels within a garbage bin. The MOSFETs deactivate the sensor and trigger the LoRa module which allows data transmission to a distant of LoRa gateway. The proposed sensing platform, in conjunction with the customised ultrasonic sensor, successfully underwent laboratory testing that validates its operational efficiency. The trash layer measurement accuracy within the bin ranges between 2 to 3 cm. Subsequently, data are transmitted on an hourly basis with each transmission containing four values.

In 2021, Sallang et al. [36] developed a smart waste management incorporating a deep learning model to optimise waste segregation and streamline bin status monitoring in an IoT setting. The system employs a LoRa module to transmit the status of the bin to a receiver with an ultrasonic sensor overseeing the waste fill percentage and a GPS module for acquiring the location of the bin. The integrated camera module identifies waste utilising TensorFlow Lite and Raspberry Pi 4 while the servo motor sorts the waste into designated compartments. The machine learning system, utilising SSD MobileNetV2 Quantized is trained with a dataset containing paper, cardboard, glass, metal, and plastic for the classification and categorisation of waste.

2.2.5 LoRaWAN

LoRaWAN is a wide area network protocol developed for low powered, long ranged communication using the LoRa technology. LoRa operates on physical layer, while LoRaWAN facilitates secure two-way communication between an end-device and an end-user [31]. The LoRaWAN hardware is implemented using a star-of-stars topology comprises of four primary elements which are Gateways (GW), End-devices (ED), a Network Server (NS) as well as application servers, as depicted in Figure 2.4.

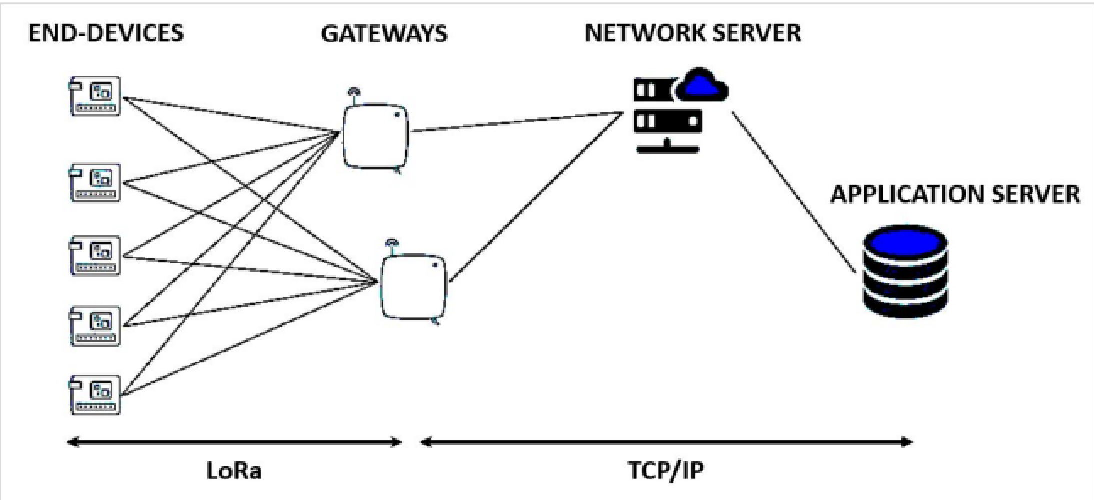


Figure 2.4: A typical LoRaWAN implementation [31].

2.3 Comparison of Wireless Networks

Users of today have a diverse set of demands when it comes to wireless networks to meet their specific needs, preferences, and budgetary constraints while delivering an optimized and satisfactory user experience. Table 2.2 shows the comparison between the wireless networks introduced.

Table 2.2: Comparison of wireless networks technologies [57].

Parameters	GSM	Wi-Fi	Sigfox	LoRa
IEEE standard	802.11	802.11	-	802.15.4
Operational frequency	900 MHz to 1800 MHz	2.4GHz to 5GHz	900 MHz	868MHz, 915 MHz, 923MHz
Range	30 km	100 meters – 300 meters	15 km	10 km
Data rate	100 kbps - 14.4 Mbps	11 M bps	100 bps – 1 kbps	300 bps - 50 kbps
Battery Life/Cost	Days Medium	Days to Weeks Medium	>10 years Low	>10 years Low

2.4 LoRa Perfomance

This section discusses the parameters that can significantly affect LoRa performance and signal propagation which include spreading factor (SF), bandwidth (BW), and antenna gain.

2.4.1 Spreading Factor

LoRa employs a proprietary spread-spectrum modulation method that expands upon currently available spread-spectrum technologies. It employs an orthogonal spreading factor and incorporates a constant channel width of 125/500 kHz [37]. SF is a code applied towards the data signal. LoRa offers six factors, SF7 to SF12. SF corresponds to the encoded bits per symbol. Higher SF results in lower bit rates. Table 2.3 illustrates that lower spreading factors provide greater data rates but shorter distances, whereas higher spreading factors yield lower data rates yet longer distances for uplink (UL) messages within a 125 KHz channel.

Table 2.3: Spreading factor effect on distance [30, 31].

Data Rate	SF (125kHz)	Bit Rate (bps)	Range (km)
5	7	5470	2
4	8	3125	4
3	9	1760	6
2	10	980	8
1	11	440	11
0	12	290	15

2.4.2 Bandwidth

LoRa offers three scalable bandwidth settings options of 125kHz, 250kHz, and 500kHz, as depicted in Figure 2.5. The system bandwidth corresponds to the spread data at a chip rate in chips per second per Hertz [38].

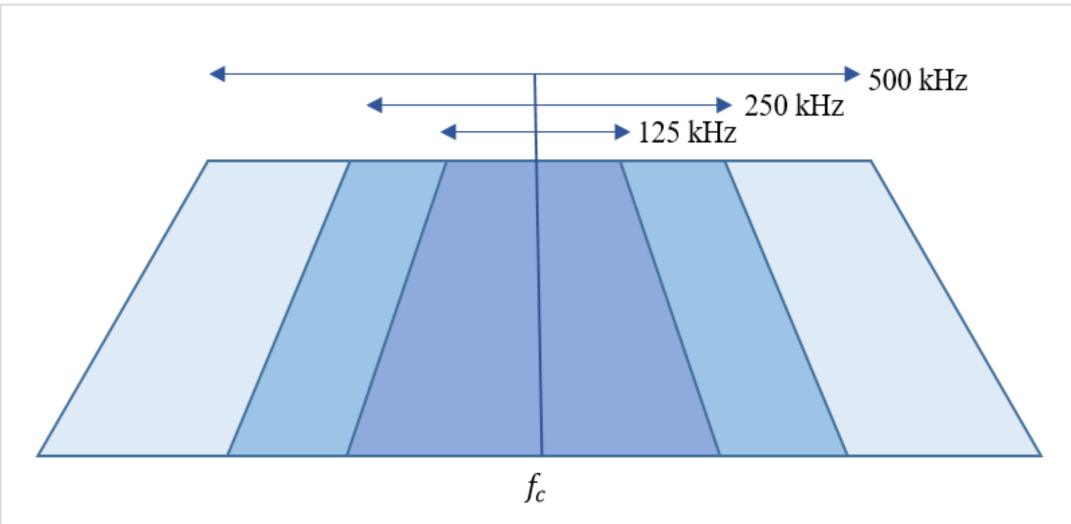


Figure 2.5: LoRa Bandwidth with double-sided transmit spectrum.

2.4.3 Antenna Gain

Antenna gain refers to the ability of an antenna to concentrate its radiation pattern in a specific direction [39]. Antenna gain is commonly represented in decibels (dBi), a logarithmic unit used to compare the performance of antenna relative to a reference antenna. The dBi value of an antenna indicates its directional characteristics and beam width as illustrated in Figure 2.6. Higher gain values correspond to narrower beam widths which indicates a more directional nature of the antenna.

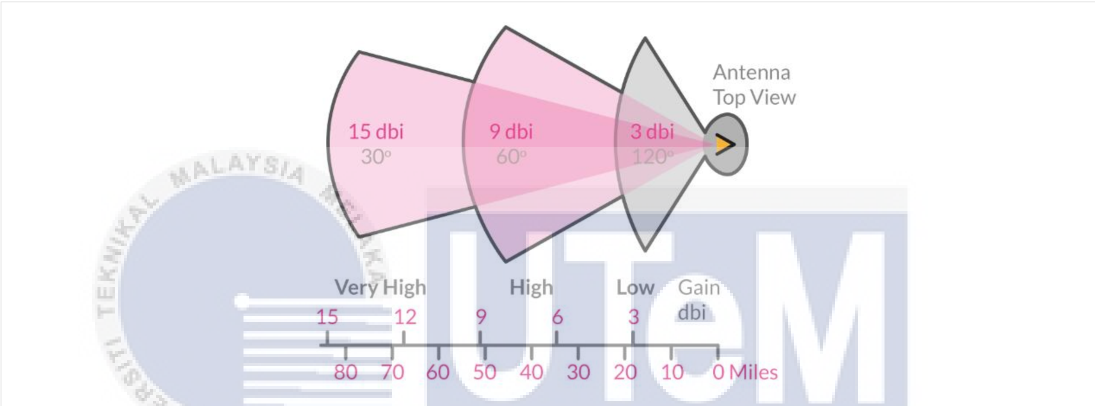


Figure 2.6: Antenna gain coverage.

2.5 Sensor Technologies

The advancement of sensor technologies has revolutionised various industries, including environmental monitoring and waste management. In the context of floating waste detection, sensors play a crucial role in identifying and tracking waste objects present in water bodies.

2.5.1 Infrared Sensors

In [40] the authors purposed an efficient and automated system for identifying and removing floating debris from water surfaces which utilises cameras and sensors to detect and classify different types of floating wastes which enable effective waste management strategies. The information of every action taken are sent to the corresponding authority through GSM. By employing IR sensors and flow sensors controlled by Renesas 64 pin, the system is capable of identifying floating waste on water bodies and assessing the pollution level which results from improper disposal of toxic materials as depicted in Figure 2.7.

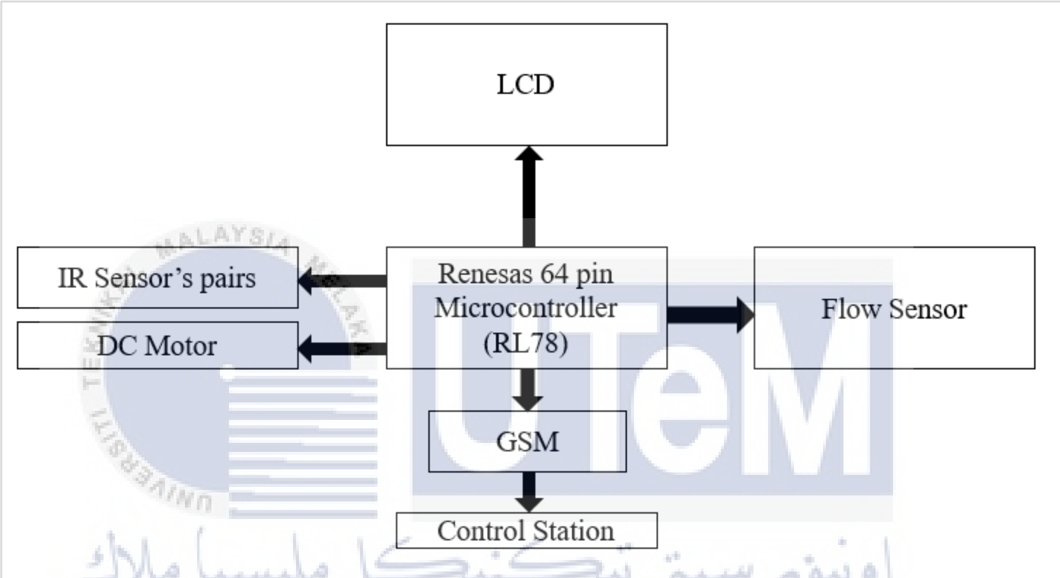


Figure 2.7: The removal of floating wastes system architecture [48].

The floating barricades then come into action and remove the wastes present. The data captured by these sensors is then processed, enabling the GSM module to transmit notifications to the appropriate authority regarding the waste collection status within the bag positioned near the barricades.

2.5.2 Ultrasonic Sensors

The paper [41] in 2023 introduced a remote-controlled aquatic waste collector featuring an IoT-based water pollution monitoring and tracking system. This implementation incorporates GPS and a GSM-based notification system to alert relevant authorities through SMS, with ESP32 serving as the primary controller. An ultrasonic sensor is installed on a buoyant platform to identify the presence and pinpoint the location of floating debris in water bodies. The sensors function by radiating high frequency waves and then calculates time taken for these waves to reflect back from an object as shown in Figure 2.8. The sensor accurately measure the distance of the object and determine its precise location by analysing the delay between emitting and receiving the sound waves.

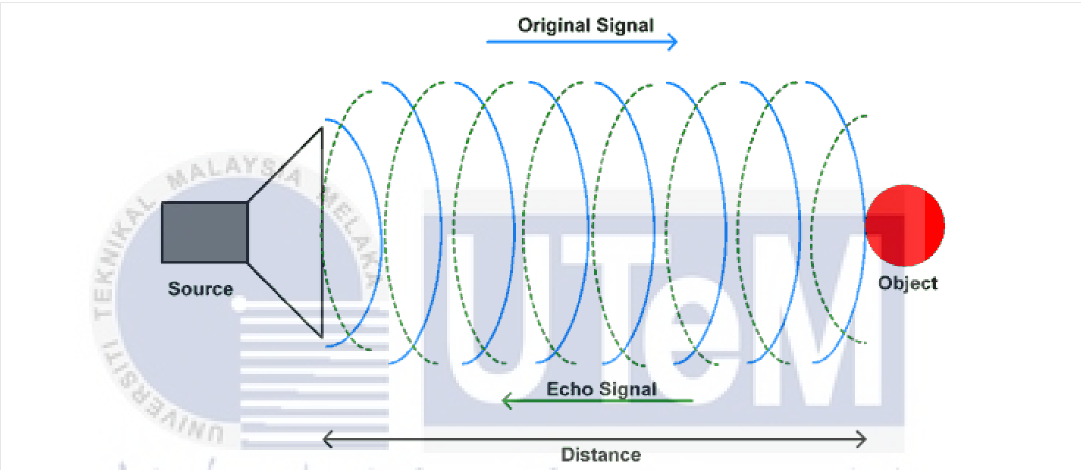


Figure 2.8: Overview of ultrasonic sensor working principle.

In [42] authors designed a robot equipped with ultrasonic sensors, programmed to identify and eliminate larger waste particles found in water bodies. Upon detecting an obstruction, the sensor triggers the robot to cease propulsion and redirect itself towards the path with the least obstruction. The arm of the robot is controlled by a servo motor to gather waste within a net-enclosed area. IR sensors are also employed to spot waste and transmit a signal to the Arduino UNO microcontroller. This method offers significant advantages by reducing labour and manpower requirements as well as minimizing the time needed for water treatment. The efficiency of the system makes it a viable option despite its minimal cost. However, it may not be feasible to install this system everywhere.

2.5.3 Optical Sensor

Optical sensors, such as cameras or imaging systems, use visual detection techniques by capturing images or video footage and employ image processing algorithms to analyse and detect objects based on their visual characteristics. The authors in [43] designed a model utilised a fixed camera in order to quantify floating waste on a river surface based on images and utilises pre-trained Mask R-CNN model with the MATLAB software to obtain the calibration parameters of the camera. The model is tested for its reliability to recognise floating waste with initial visual assessment shown in the contaminated area in Figure 2.9.

Figure 2.9: A close-up perspective of the waste detection results [43].

In 2022, Li et al. [44] proposed a technique for detecting floating debris which employs the PC-NET algorithm to produce feature maps characterized by enhanced resolution and more distinguishable features with field photography analysis. A method for pyramid anchor generation is proposed which aims for a centralised generation of anchors in close proximity to the target. This improves the feature information for small targets and increases the classification accuracy. The results of the analysis reveal that the average detection accuracy achieved by the proposed approach is 86.4% and compared with existing detection approaches.

2.5.4 Lidar Sensor

Sumroengrit and Ruangpayoongsak [45], 2018, designed a method of laser-based floating waste detection system using autonomous surface cleaning robots to remove waste on water surface. The proposed laser-based technique utilises principles of ray refraction and reflection to detect floating waste. The system is accessed in a tranquil pond revealing the cost-effective to accurately detect plastic containers on the fluid boundary within a five-meter range. The system was attached to a fixed camera positioned at different heights, ranging between 80 to 160 cm over the water surface level. The incident angle adjusted between 50 to 85 degrees. With a water level of 160 cm and an incident angle of 80 degrees, waste can be detected at a distance of approximately ten meters while the vastest range of incident angle, from 55 to 80 degrees is obtained at 140 cm. Experiments have shown that the sun brightness on the water surface can prompt errors in laser measurements. The digital distance meter is not able to return a value when the sunlight is overly luminous, such as at noon, or excessively dim, such as at night.

2.5.5 Radar Sensors

Radar (Radio Detection and Ranging) sensor technology has evolved into a fundamental tool across numerous industries due to its ability to provide precise and real-time information on the surrounding environment. The sensor employs wireless detection technology to identify motion by analysing the form of the object, location, path of movement, and motion attributes. Radar sensors employ electromagnetic waves, typically in the microwave frequency range, to interact with objects in their vicinity. The operational concept of a radar sensor involves calculating both the velocity and direction of an object by sensing the alteration in the frequency of a wave, a phenomenon referred to as the Doppler Effect [46]. The Doppler effect enables radar systems to detect moving targets by analysing the frequency shift from the transmitted and received signals.

The architecture of the radar sensor is illustrated in Figure 2.10. The device includes PRF (pulse repetition frequency), VCO, DSP (digital signal processing), two antennas and LNA (low noise amplifier). The VCO generates a signal with changing frequency, the power splitter divides single RF into one line and mixer generates frequencies sum and difference. The transmitter generates electromagnetic waves, which are then radiated into the environment using specialized antennas. Modern radar systems often employ frequency modulation or continuous wave techniques to enhance detection accuracy. The receiver captures and processes the reflected signals. Antennas play a pivotal role in radar performance. Various antenna configurations, such as parabolic, phased-array, and planar antennas, cater to specific applications, offering directional control and beamforming capabilities.

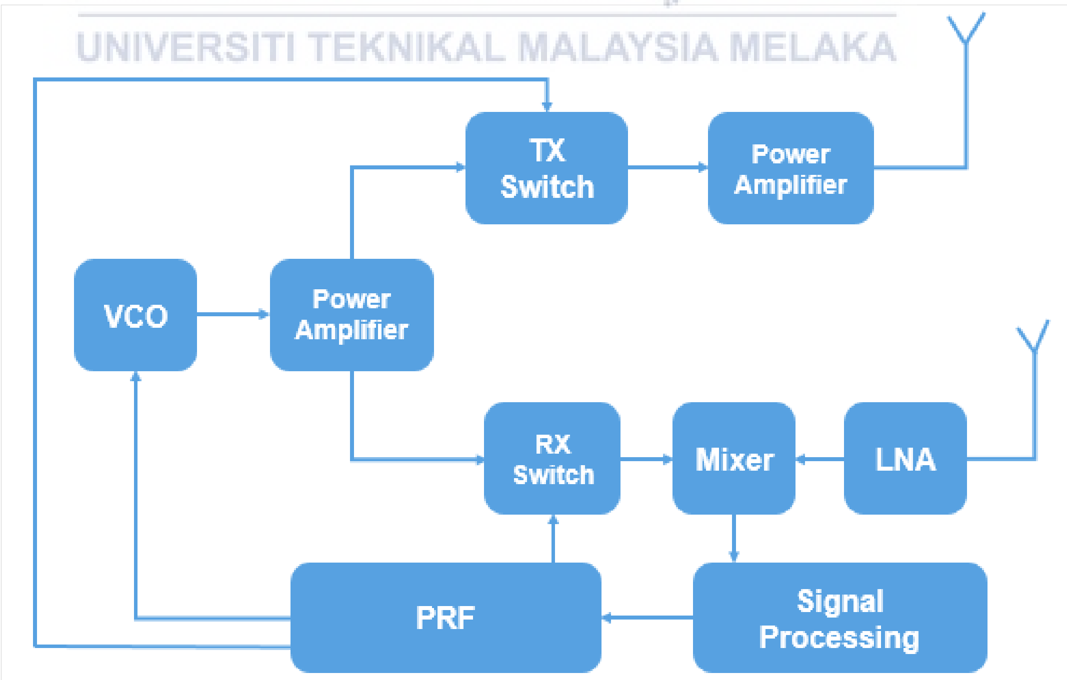


Figure 2.10: Architecture of automotive radar sensor [46].

Morris and Hari [47], 2021, designed a system utilising millimetre-wave automotive radar sensors to detect and localize unmanned aircraft systems. The sensor detected and located UASs within a 40-meter range, constrained by the radar transmission power and elevation coverage. Radar sensors are highly accurate, providing reliable and precise data. It can detect the speed, distance, and direction of moving objects with high accuracy [8]. This makes them ideal for use in applications where accurate measurement is critical such as in automotive safety systems.

The authors in [48] proposed a novel radar-vision fusion technique aimed at robustly detecting small objects on water surfaces. This approach involves utilizing an innovative millimetre-wave radar and integrating deep learning techniques to combine radar and vision data. The system is tested on a real-world dataset of floating bottles, utilizing multi-scale fusion of RGB images and multi-frame radar data. Results showed significantly improved detection accuracy in comparison to vision-based methods. To confirm the enhancement in detection accuracy through modal fusion, the techniques are evaluated by comparing single-modality performance on a real-world dataset. The MMW radar employs frequency-modulated continuous wave (FMCW) for transmission and captures the resultant reflections. The results of the test are depicted in Table 2.4.

Table 2.4: Results on the real-world dataset [48].

Modality	Method	AP^{35}	AP^{50}
Image	FCSO	68.71%	58.56%
	YOLOv4	78.46%	57.04%
Radar	VoteNet	36.98%	20.06%
Image & Radar	RISFNet (purposed system)	90.05%	75.09%

In 2020, Jang et al. [49] proposed for distance measurement and enhanced accuracy, relying on data gathered from both a radar sensor and a vision sensor. The coordinate for an object is received when motion is detected by the sensor through calculation of the distance from the coordinate. Upon detecting any motion of an object, the distance to its initial value in the corresponding section is computed. Results indicate radar sensor has a good accuracy when dealing with a single object within range. However, it does not detect objects in the presence of multiple objects at the same distance or nearby.

Ali and Daim [50] proposed a study on fine human detection using IR-UWB radar sensor. The experiment involved the movement of the right hand and fingers, to accurately discriminate movements within a distance of 5cm to 10cm, with minimal instances of noise. However, notable errors occurred at specific measurement points due to the presence of noise, causing radical behaviour in the amplitudes of certain radar frames.

Sohail et al. [51], 2023, proposed a method for radar-based relative vehicle positioning estimation utilising the dynamic range and azimuth of a FCMW. In the process of position estimation, the speed of the vehicle equipped with the radar sensor, represent the change in the speed of vehicle. The relative speed and distance between the reference vehicle and an adjacent vehicle are used in the context of relative position estimation. The accuracy and intersection Over Union (IOU) values are then computed using the data that the radar sensor recorded. YOLO4, a deep learning algorithm, is used to compute the precision, reaching 80.0% accuracy in location estimate.

2.5.6 Comparison of Sensor Technologies

Table 2.5 shows the comparison between the sensors discussed in previous section. This comparison highlights aspects including Range Detection, Detection Accuracy, Detection Resolution, Speed, Measurements, Robustness vs. Environmental Condition, Dark/light Independent, Size and Cost. It serves as a valuable reference for understanding the relative strengths and weaknesses of each sensor type.

Table 2.5: Comparison between sensors [33, 42, 49].

	Radar Sensor	Optical Sensor	Ultrasonic Sensor	Lidar Sensor
Range Detection	Short/Med/Long	Short	Short	Short/Med
Detection Accuracy	High	Medium	High	High
Detection Resolution	Medium	High	Medium	High
Speed Measurements	Good	No	No	No
Robustness vs. Environmental Condition	Good	Poor	Medium	Medium
Dark/light Independent	Good	Poor	Good	Good
Size	Small	Small to Med	Small	Large
Cost	Low	Low/Medium	Low	High

2.6 Conclusion

The majority of past studies related to floating waste detection and waste management systems have prominently employed machine learning-based models as summarised in Table 2.6. The systems commonly utilise ultrasonic sensors which is one of the most leading devices in the IoT platform for its reliability and intelligence. Notably, radar sensors, although extensively used in automotive applications, have not been as prevalent in floating waste systems. Radar finds particular suitability in automotive applications due to vehicles serving as effective reflectors for electromagnetic waves which enables precise determination of their distance, position, and velocity. However, the integration of radar sensors into floating waste detection brings a unique perspective to the field. Additionally, researchers have explored diverse communication protocols which showcase a broad spectrum of technological integration. The incorporation of these technologies enables a more efficient and comprehensive floating waste management system.

Table 2.6: Summary and comparison of past studies in microcontroller used, object detection model, communication protocol and sensor used.

Journal/Article	Micro-controller	Object Detection Model	Comm. protocol	Sensor
Narendiran et al. 2023 [26]	NodeMCU Arduino UNO	-	Wi-Fi	Ultrasonic sensor, PH level sensor
Verma et al. 2021 [29]	Arduino UNO	-	Sigfox	Level sensor, Temperature sensor
Nurwarsito et al. 2021 [34]	Raspberry Pi, Arduino Nano	-	RFM95 LoRa, WebSocket	Turbidity Sensor
Addabbo et al. 2021 [35]	Atmel ATMega328P	-	Libelium SX1272 LoRa, GSM	RFID sensor, Ultrasonic sensor, Level sensor

Table 2.6 continued.

Journal/Article	Micro-controller	Object Detection Model	Comm. protocol	Sensor
Sallang et al. 2021 [36]	Raspberry Pi 4, Arduino UNO R3	Tensorflow Lite-CNN	LoRa-GPS shield	Ultrasonic sensor, Vision sensor
Aishwarya et al 2018 [40]	Renesas 64 pin (RL78)	-	GSM	Infrared sensor, Ultrasonic sensor
Patil et al 2023 [41]	ESP32	-	GSM	Ultrasonic sensor, Turbidity sensor
Gauri et al 2021 [42]	Arduino UNO	-	-	Infrared sensor, Ultrasonic sensor
Minh et al. 2022 [43]	-	Mask R-CNN	-	Optical sensor
Huang et al. 2022 [44]	-	PC-Net	-	Optical sensor
Sumroengri & Ruangpayoongsak 2018 [45]	Arduino Mega 2560	-	-	Lidar sensor, Ultrasonic sensor
Morris & Hari 2021 [47]	-	CFAR	-	Radar sensor
Cheng et al. 2021 [48]	-	RISFNet	-	Radar sensor, Optical sensor
Jang & Jung 2020 [49]	-	GMM	-	Radar sensor, Optical sensor
Ali & Daim 2020 [50]	-	-	-	Radar sensor
Sohail et al. 2022 [51]	-	PCA-CNN		Radar sensor

CHAPTER 3

METHODOLOGY

This chapter provides a comprehensive overview of the project implementation, outlining the processes and steps taken to achieve the objectives. A clear flowchart with detailed explanations illustrates the project implementation. Furthermore, the chapter thoroughly explains the hardware and software utilised in the project.

3.1 Overview of Project Implementation

The flow of the project outline is illustrated in Figure 3.1. The initial phase of the project begins with the activities of gathering the information related to the project title, including the background study of other projects done similar to the title. This step is vital as it is done throughout the whole duration of the project progress for a better understanding on the theory and project implementation. This stage would involve conducting a thorough analysis of the current sources and types of waste in water bodies, and the available technologies for detecting and managing waste in water bodies. This analysis would help to identify the gaps in the current systems and the opportunities for developing a floating waste detection system using a radar sensor and LoRA technology to determine the best options for the project. A project outline or planning must be produced where it is the blueprint of the project.

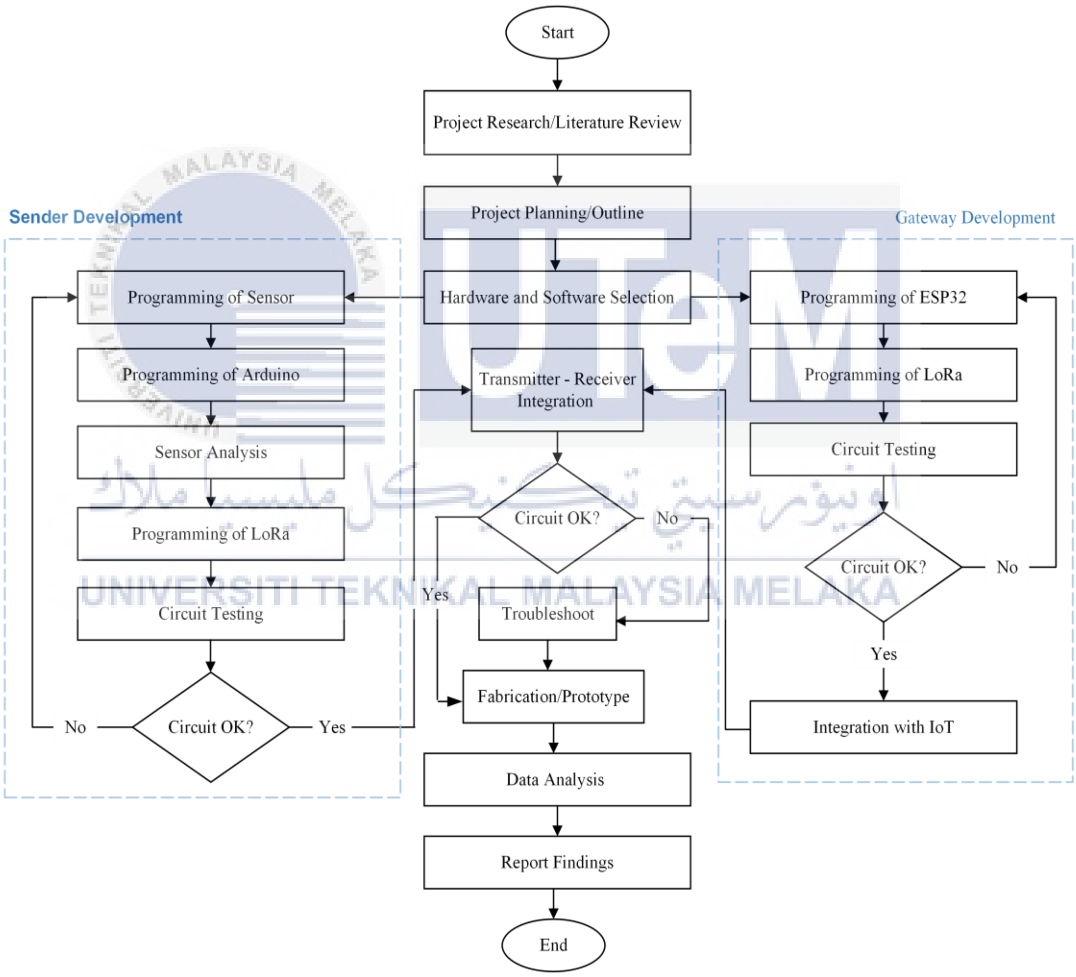


Figure 3.1: Flowchart of the project.

The hardware part is designed and developed which includes the transmitter (sender) section and gateway (receiver) section. The LoRa and Arduino UNO is programmed to satisfy the objectives of the project to make able of data processing and analysis. A cloud/server is integrated as a network to receive the data on the number of waste through the LoRa controlled by the ESP32 microcontroller. If the circuit is not well functioning or having problems, troubleshooting is necessary to solve for the raise issues.

The recorded data of the system will be analysed and reported based on the findings. The data collected by the floating waste detection system would be processed and analysed to provide meaningful insights. This would involve developing algorithms to process the data generated by the system and to provide insights into trends and patterns in the waste detected as well as the feasibility of the system in detecting floating waste. The prototype designing and fabrication is proceeded only when the functionality is confirmed. Lastly, the findings are reported and documented.

3.2 Project Planning

The workflow of the project implementation is depicted in Table 3.1. The Gantt chart illustrates the planned schedule for carrying out the project. While certain activities have been successfully executed as planned, others have experienced delays due to various constraints.

Table 3.1: Gantt chart for project planning.

PROJECT PLANNING (GANTT CHART)

List of all relevant activities of the proposed project and the period of time that is needed for each of the activities.

	SEM I																		SEM BREAK					SEM II															
Project Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Literature Review, Data Collection and Journal Study											SEMINAR PSM I																										X	SEMINAR PSM II		
Proposal Defence			X																																					
Writing of Chapter 1 & Chapter 2										X																														
Seminar of PSM1																																								
Transmitter Circuit Development																								X																
Receiver Circuit Development																											X													
Software Development (Dashboard)																											X													
Transmitter – Receiver Integration																													X											
Testing and Troubleshooting circuit																														X										
Writing of Chapter 3: Methodology																																					X			
Development and troubleshooting transmitter and receiver																											X													
Prototype Fabrication																																	X							
Data Analysis																																		X						
Writing of Chapter 4: Results																																					X			
Writing of Chapter 5: Conclusion																																					X			
Seminar PSM 2																																	X							
Other Related Documents (Logbook)																																					X			

3.3 Design

The main structure of the project design is divided into two significant parts which are the Transmitter (sender) and Gateway (receiver) section as shown in Figure 3.2. The sender includes the radar sensor which is the primary component responsible for detecting the presence of floating waste on the water surface. The receiver circuit receives the transmitted data on the number of the waste. The Message Queuing Telemetry Transport (MQTT) broker acts as a central communication hub in the system. It receives the processed data from the signal processing stage and publishes it to subscribed devices or applications. The MQTT protocol ensures efficient and reliable transmission of data. The MQTT or mobile/web based platform provides a user-friendly interface for visualizing and analysing the data collected from the system. It receives the published data from the MQTT broker and presents it in a graphical representation format, allowing users to monitor the floating waste levels in real-time using smartphones, tablets, or web browsers.

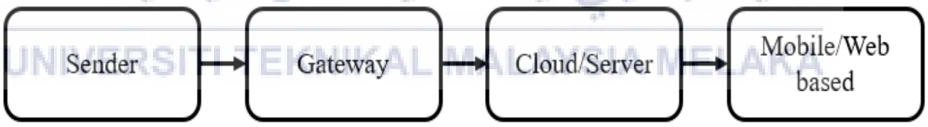


Figure 3.2: Block diagram of system.

3.4 Transmitter Circuit (Sender)

The sender prototype in the floating waste detection system, referred in APPENDIX A, consists of various components to transmit data from the radar sensor using LoRa technology as well as to ensure proper operation and compatibility with the overall system. The architecture of the sender is depicted in Figure 3.3.

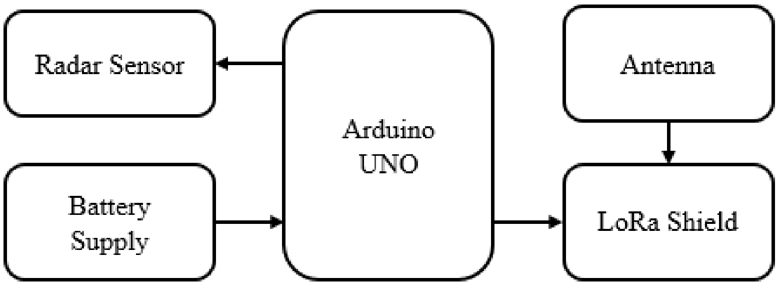


Figure 3.3: Transmitter (sender) block diagram.

3.4.1 1D Radar Sensor for Arduino

The uRAD Radar Sensor Arduino v1.2 solution is a radar sensor that operates on millimetre wave technology operated in Frequency Modulated Continuous Waves (FMCW) and Doppler as shown in Figure 3.4. By analysing the time delay and characteristics of the reflected signals, the radar sensor can determine the distance, velocity, angle and SNR with exceptional precision [52].

Figure 3.4: 1D Radar sensor for Arduino.

The 53.3×74.8×18 mm sensor operates in the free emission 24.005 to 24.245 GHz ISM frequency with different operation modes that are ease programmed with Arduino IDE. The detection range varies from 0.45 to 100.00 m supplied with 3.5 to 10.0 V and current of 170 mA powered by Arduino UNO [52]. The sensor is able to detect up to five different elements with a range of velocity up to ±75 m/s that are in its field of view of 30 by 30 degree as shown in Figure 3.5.

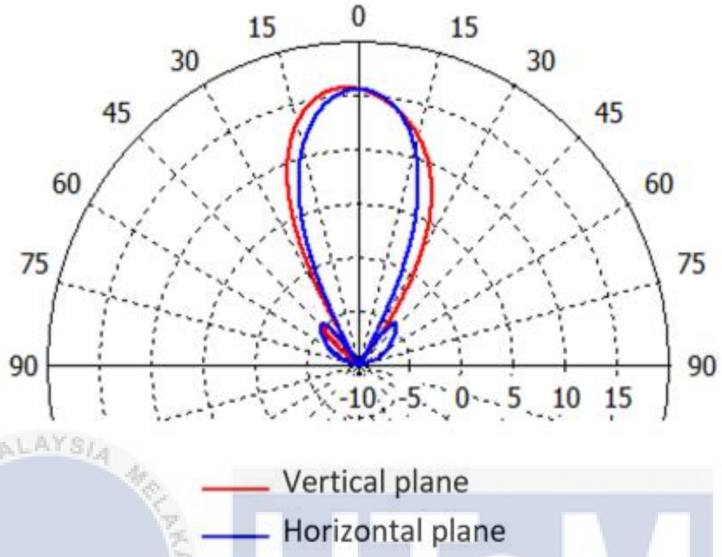


Figure 3.5: Antenna radiation pattern.

3.4.2 Arduino UNO

The Arduino UNO is a microcontroller board that utilises the ATmega328P microchip as its core component [53]. The microcontroller is equipped with 14 digital input/output pins where six can be employed as PWM (Pulse Width Modulation) outputs as shown in Figure 3.6. Additionally, it includes an on-board resonator for clock synchronisation, six analog input pins, reset button for easy board reset, as well as mounting holes for attaching pin headers. Arduino send commands to the radar sensor through analog and digital inputs in sending and receiving serial data. The Arduino sends commands to the radar sensor to start measurements and configure settings. The radar sensor then responds with data, which the Arduino read and process.

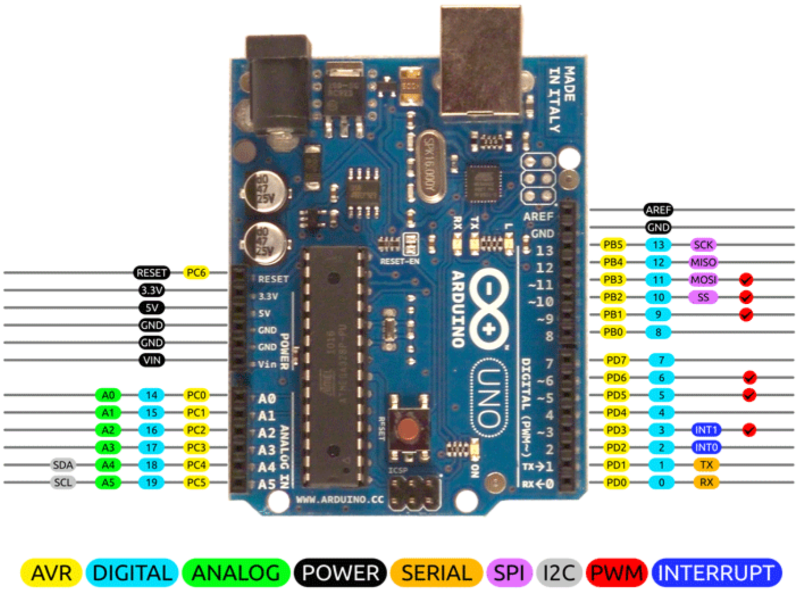


Figure 3.6: Architecture of Arduino UNO.

3.4.3 Dragino LoRa Shield 915MHz

The sender circuit utilises Dragino LoRa shield shown in Figure 3.7 which is compatible with the voltage of Arduino UNO, Mega and DUE with 915MHz frequency. The Dragino LoRa Shield is designed to be compatible with Arduino UNO and other similar Arduino boards where it can be easily connected to the microcontrollers platforms without extensive hardware modifications. It is also used with an external antenna corresponding to its frequency.

Figure 3.7: Dragino LoRa Shield with the frequency of 915MHz.

3.5 Gateway Circuit (Receiver)

The gateway circuit in the floating waste detection system referred in APPENDIX A consists of main components including ESP32 WeMos LOLIN32 microcontroller and LoRa. The receiver circuit plays a crucial role in the floating waste detection system, as it receives and interprets signals from the sender circuit.

3.5.1 ESP32 WeMos LOLIN32

The ESP32 WeMos LOLIN32 board is a cost-effective and energy-efficient system-on-chip (SoC) that includes dual-mode Bluetooth functionality and built-in Wi-Fi. It is specifically designed for applications in the IoT and battery-powered devices [54]. Figure 3.8 illustrates the ESP32 WeMos LOLIN32 board along with its pinout configuration. The microcontroller board is implemented in the system to transmit the data of floating waste to broker.

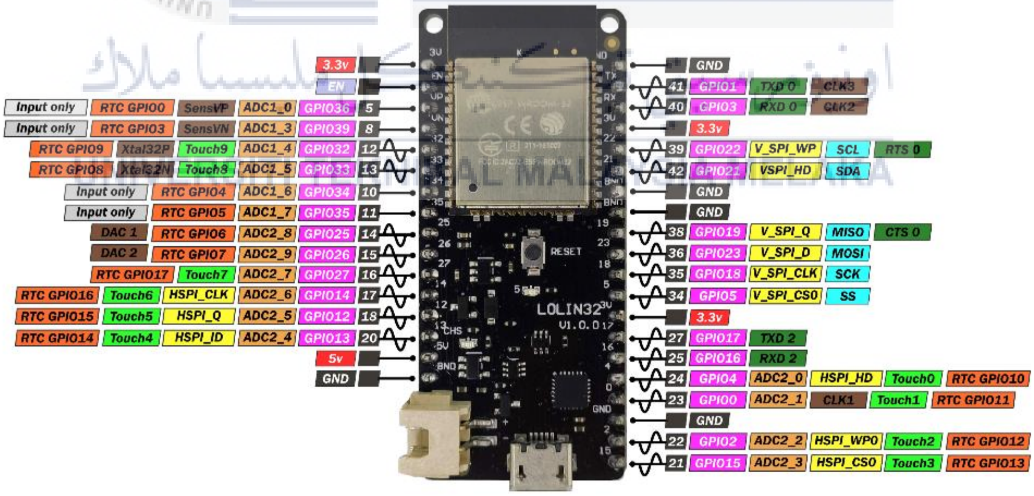


Figure 3.8: ESP32 WeMos LOLIN32 and its pinout [54].

3.5.2 RFM95 915MHz LoRa Module

The RFM95 module is a commonly available LoRa device found in the market. It utilises the LoRa SX1276 chip and operates at a frequency of 915 MHz. The 16×16 mm module is depicted in Figure 3.9. LoRa modules operating at 915MHz employ the industrial, scientific, and medical radio bands, which are regulated and require the appropriate licensing for operation [55, 56]. The RFM95 module provides long-range communication capabilities, enabling reliable wireless communication over extended distances and designed for low power consumption.

Figure 3.9: LoRa module.

3.5.3 Buck Boost Converter

A buck-boost converter shown in Figure 3.10 is a type of DC-DC power converter that can both step up and step down the voltage of a direct current power source while maintaining a relatively constant output voltage. It is utilised to control and regulate the power supply to an ESP32 microcontroller.

Figure 3.10: Buck Boost converter.

3.5.4 Voltage Regulator

A voltage regulator is an electronic circuit responsible for generating and maintaining a consistent output voltage, unaffected by changes in input voltage or load conditions. The LM117GS shown in Figure 3.11 is used in the transmitter circuit as it is designed with short-circuit protection to safeguard against accidental short circuits in the load or output. This protection helps prevent damage to the connected components in the event of a fault.

Figure 3.11: LM117GS voltage regulator.

3.5.5 Surface-Mount Fast Switching Rectifier Diode

The RS1G diode shown in Figure 3.12 is a versatile component that provides efficient rectification, fast switching, and reliable performance in various electronic applications. The primary function of the RS1G diode in the sender is rectification where it allows current to flow in one direction while blocking it in the opposite direction.

Figure 3.12: Surface-mount fast switching rectifier.

3.5.6 SMD Capacitor

A surface mount resistor is a small rectangular ceramic component with conductive silver edges located on both ends as shown in Figure 3.13. Surface mount capacitors can provide overvoltage protection in circuits.

Figure 3.13: Surface mount capacitor.

3.5.7 SMD Resistor

A surface mount resistor in Figure 3.14 offers similar functionality to conventional axially leaded resistors, but with a lower power dissipation capacity and often reduced stray inductance and capacitance. The resistors are employed to control the flow of electric current within a circuit. Resistors play a crucial role in regulating and controlling the flow of current within a specific section of a circuit by introducing resistance. This is essential for safeguarding sensitive components from excessive current and mitigating the risk of circuit damage.

Figure 3.14: SMD resistor.

3.5.8 SMA Port

The sender and gateway uses an external antenna corresponding to its frequency to capture and transmit signals more efficiently. The SMA (SubMiniature version A) port is a common type of coaxial connector designed to provide a secure and reliable connection for transmitting high-frequency signals as shown in Figure 3.15.

Figure 3.15: SMA connector.

3.6 Program Coding

In order for the controllers of both sender and gateway to operate, program code development is a critical component that ensures seamless communication between the sender that is equipped with radar sensors, and the gateway. The software used for program development is Arduino IDE 1.8.7 which is an open source platform hosted on GitHub with a wide range of microcontrollers and its extensive support for necessary libraries.

3.6.1 Programming of Transmitter

The program code development for the sender is depicted in Figure 3.16, where the algorithm commences by initializing various parameters essential for radar operation.

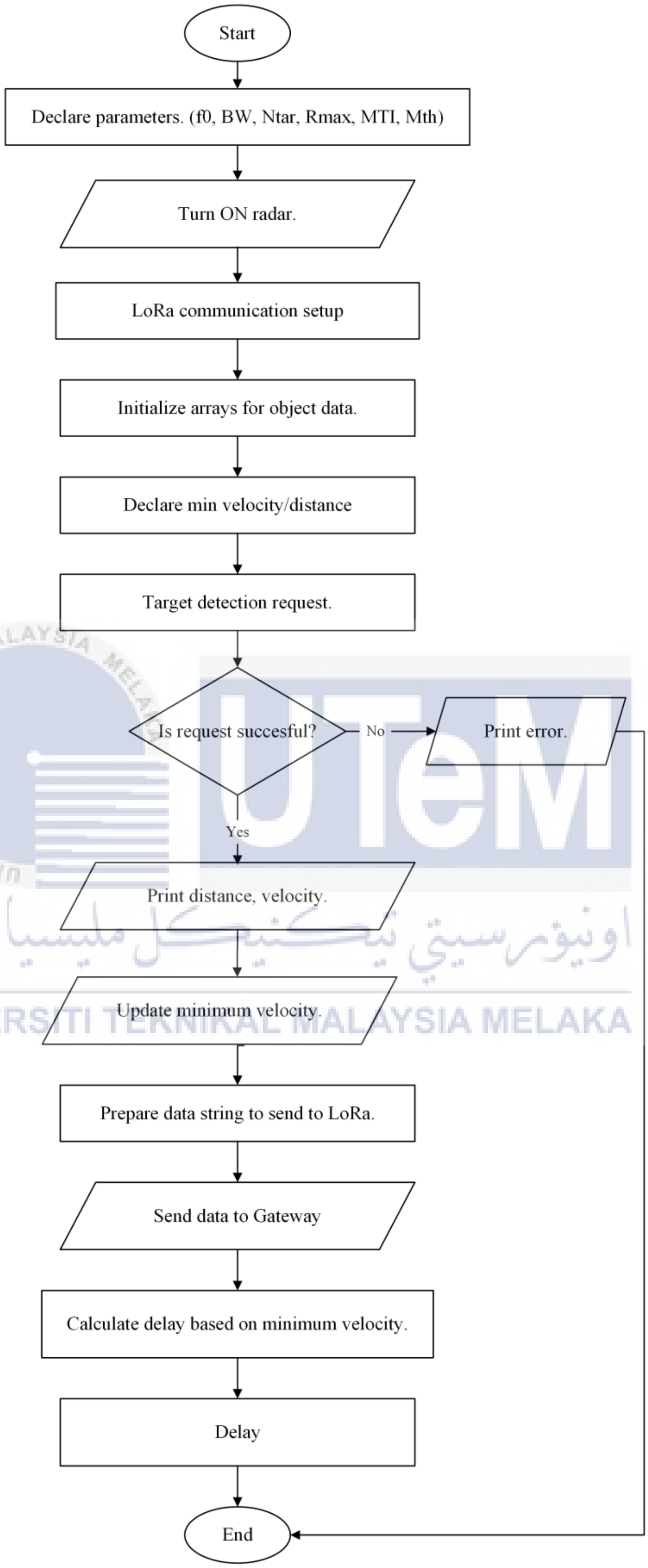


Figure 3.16: Flowchart of program code for sender circuit.

The declaration includes 'f0', which signifies the operating frequency in Continuous Wave (CW) mode, ranging between 5 to 245. 'BW' represents the operating bandwidth in ramp modes, with a minimum threshold of 50 MHz. 'Ns' determines the number of samples the uRAD captures of the reflected wave to calculate distance and velocity, within a range of 50 to 200. 'Ntar' sets the maximum number of detectable targets. 'MTI' toggles the Moving Target Indication mode, wherein the system disregards static objects, focusing exclusively on targets that exhibit movement relative to the sensor. The 'Mth' establishes the sensitivity of the sensor when functioning as a movement detector.

The LoRa communication is set up with 915 MHz frequencies and awaits the Serial interface to be available. The algorithm of the code maintains arrays to track multiple objects and averages measurements for the same object detected in multiple samples. The program checks if the data matches any previously detected objects based on their distances within a specified tolerance. If a match is found, the average values is calculated for distance, velocity, and SNR for that object as shown in Figure 3.17.

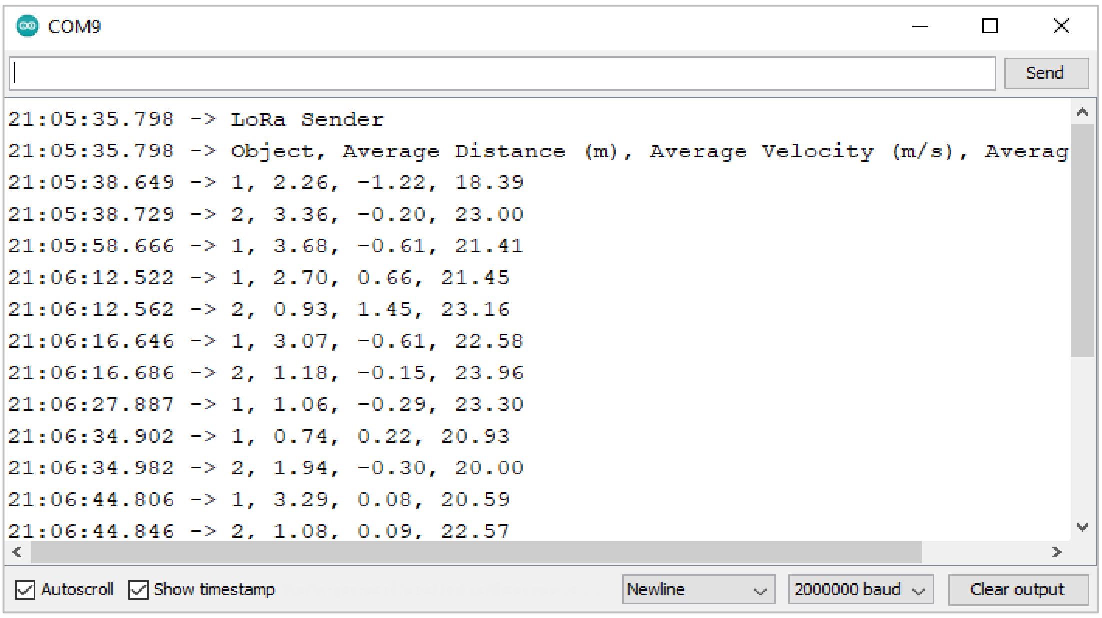


Figure 3.17: Serial monitor for sender.

For each detected object, it sends data of object number, distance, velocity and SNR over LoRa communication which is formatted as a comma-separated string and sent to the specified gateway. The program calculates a delay time based on the minimum detected velocity of objects. This delay is intended to account for the time it takes for an object to move a certain distance away, ensuring that data is not sent too frequently and duplicated for the same object. The minimum velocity is initially set to a small value and it is updated if a detected target has a velocity greater than the current. For each detected object, the program prepares a data string that includes object number, distance, velocity, and SNR to be transmitted through LoRa. A delay time is calculated based on the minimum detected velocity and minimum detected distance. This delay controls the rate at which the loop iterates.

3.6.2 Programming of Gateway

The program code development for the gateway is depicted in Figure 3.18 which is designed to act as a receiver for a LoRa-based communication system. It receives data from sender, processes the received data and publishes it to an MQTT broker through Wi-Fi. It initiates serial communication for debugging purposes and configures LoRa communication by specifying pins and frequency. The LoRa spreading factor is set, influencing the trade-off between communication range and data rate.

The Wi-Fi credentials and MQTT broker details are defined to enable the gateway to connect to the internet and communicate with an MQTT broker. The program code ensures of internet access for forwarding data to the MQTT broker with ‘WiFiClient’ and ‘PubSubClient’ to configure the MQTT client in establishing a connection to the broker. One of the primary responsibilities of the gateway is to receive data sent by the sender through LoRa. The program code processes the received data, extracts sender and recipient information, and parses the payload. The payload is separated into individual pieces of information to interpret the received data accurately.

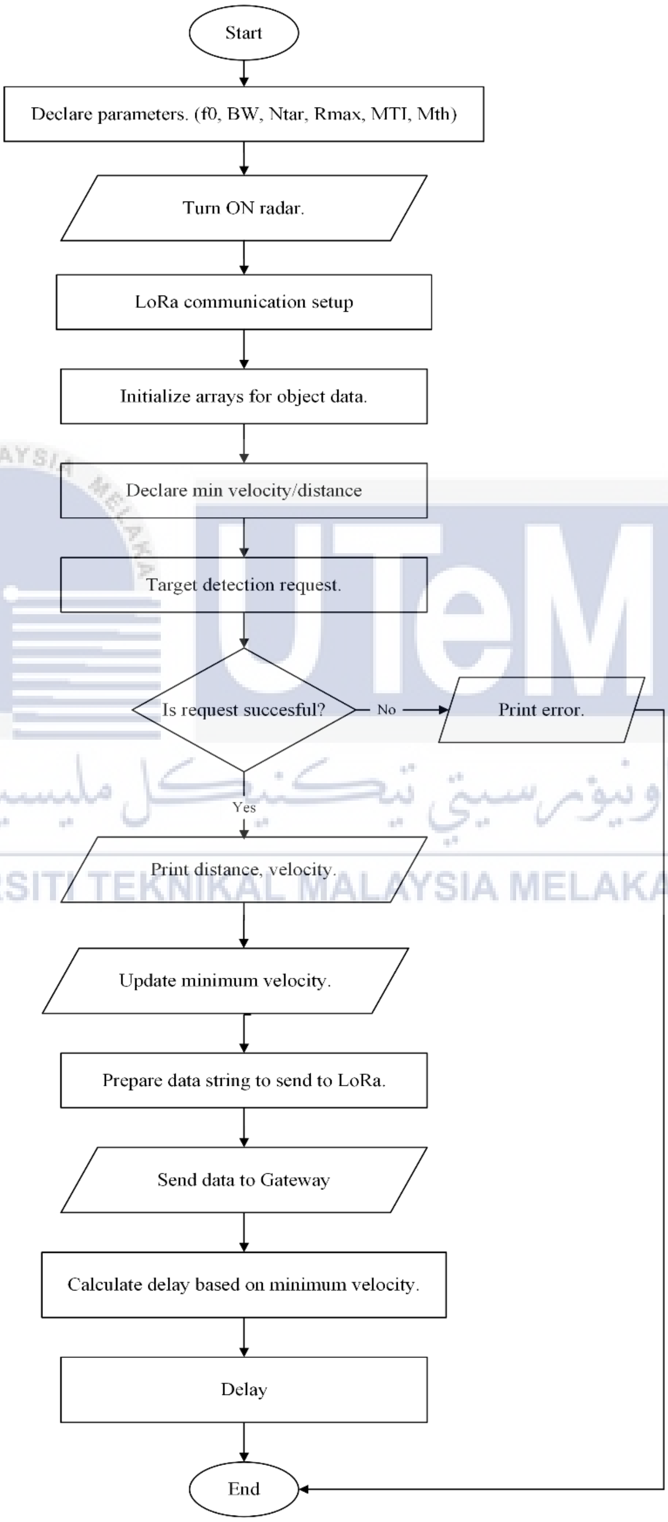


Figure 3.18: Flowchart of program code for gateway circuit.

The separated data, including sender and recipient addresses, message ID, object number, distance, velocity, and Signal-to-Noise Ratio (SNR), is then printed to the serial monitor as depicted in Figure 3.19. The gateway maintains a count variable with increments for each received packet. This indicates the number of waste detected. Subsequently, the code publishes this count to a specified MQTT topic that enables remote monitoring and tracking of data collection. The code includes a mechanism to ensure continuous Wi-Fi connectivity to the MQTT broker. This ensures that data transmission to the MQTT broker remains uninterrupted.

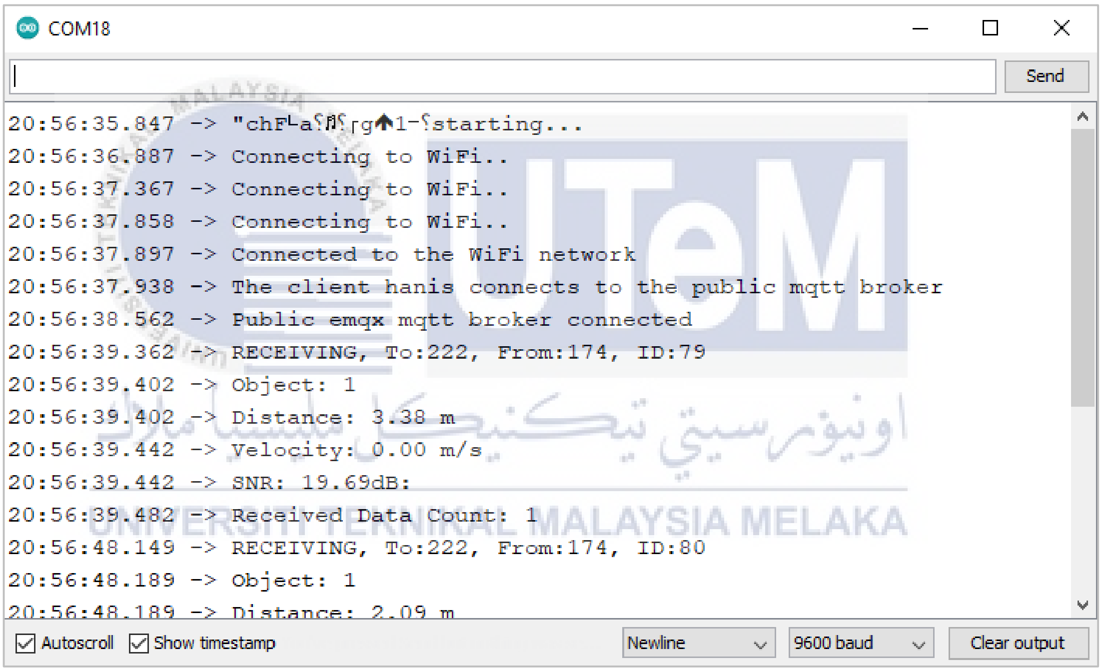


Figure 3.19: Serial monitor of Gateway.

3.7 IoT Platform Development

The data will be received from the sender to the gateway and it will be sent to the MQTT which is integrated with the MQTT broker, HiveMQ. MQTT in simple term is a messaging protocol for the machine to talk with other machine. The connection of these two is established through Wi-Fi. The gateway is configured to register to the MQTT topic and receive data from the connected sensor. The data of number of waste will be flushed through the MQTT broker that can be extracted to a suitable hosting environment that can serve mobile and web applications for monitoring as depicted in Figure 3.20.

Figure 3.20: Data flows from gateway to mobile/web based application.

HiveMQ is a high-performance MQTT broker designed specifically for IoT and machine-to-machine communication which stands as the central hub in the data flow architecture of the system. The number of waste is accessible on the IoT MQTT Panel app available on IOS and Android platform as depicted in Figure 3.21. This platform also allows various ways of data interpretation including graphical representation.

Figure 3.21: Number of waste data on IoT MQTT Panel.

3.8 Analysis of LoRa Parameter

To evaluate the performance of LoRa sender and gateway, it is essential to analyse the LoRa parameters. This analysis helps determine the suitability of these devices for the intended location and identifies the parameters that need to be adjusted to align with the environmental conditions. In this analysis, the spreading factors is configured specifically ranging from SF7 to SF12, for three different antenna gains of 2dBi, 3.5dBi, and 5dBi as depicted in Figure 3.22.

(a) **(b)** **(c)**

Figure 3.22: Antenna Gains for LoRa Parameter testing. (a) 2 dBi antenna gain. (b) 3.5 dBi antenna gain. (c) 5 dBi antenna gain.

The analysis covers a range of 100 meters to 1 kilometre. Several key factors are considered during this analysis, including the Signal-to-Noise Ratio (SNR), Received Signal Strength Indication (RSSI), and detection of missing sequences. These factors provide insights into the quality and reliability of the LoRa communication. The analysis test is conducted at a line-of-sight road *Persiaran Bukit Tambun Perdana* in Durian Tunggal, Melaka with the range up to 700 metres distance depicted in Figure 3.23. The analysis test location is finalised in accordance of safety concerns.

Figure 3.23: Map of Persiaran Bukit Tambun Perdana.

The setup of the test is shown in Figure 3.24. Power is supplied to the transmitter module using a 3.5V battery, while the receiver module is powered through a USB connection, utilising the power source of a car radio.

(a) (b) (c)

Figure 3.24: Antenna setup. (a) 2dBi antenna gain. (b) 3.5dBi antenna gain. (c) 5dBi antenna gain.

The experiment commences by setting the initial distance between the transmitter and receiver to 0 meters. To monitor the measurement values, the Arduino of the receiver module is connected to a laptop, enabling real-time monitoring through the serial monitor interface. The spreading factor is configured on both the transmitter and receiver, optimising the data transmission efficiency. The receiver is configured with identical LoRa settings as the transmitter, ensuring compatibility and synchronization between the devices. The receiver is then set up to listen for incoming LoRa packets of 1 to 50, while the transmitter and receiver modules are placed outside to simulate real-world conditions. The receiver is activated, waiting for the transmission packet to be received. During this process, the RSSI and SNR values are collected.

The collected measurement values are continuously monitored through the serial monitor, providing insights into the strength and quality of the received signals. In order to assess the impact of different antenna gains, the 2dBi antenna is interchanged with antennas of 2dBi, 3.5dBi, and 5dBi. To evaluate the influence of distance on LoRa performance, the distance between the transmitter and receiver is increased by intervals of 100 meters. The speedometer of the car is utilised to ensure precise distance measurements as shown in Figure 3.25.

Figure 3.25: Indication of distance on speedometer.

The procedures, including hardware configuration, data transmission, and measurement collection, are repeated until the maximum distance of 1,000 meter is reached. By assessing SNR and RSSI, the strength and clarity of the received signals can be evaluated. Additionally, analysing missing sequences helps identify potential data loss or transmission issues within the LoRa system. The flow of the test analysis is shown in Figure 3.26.

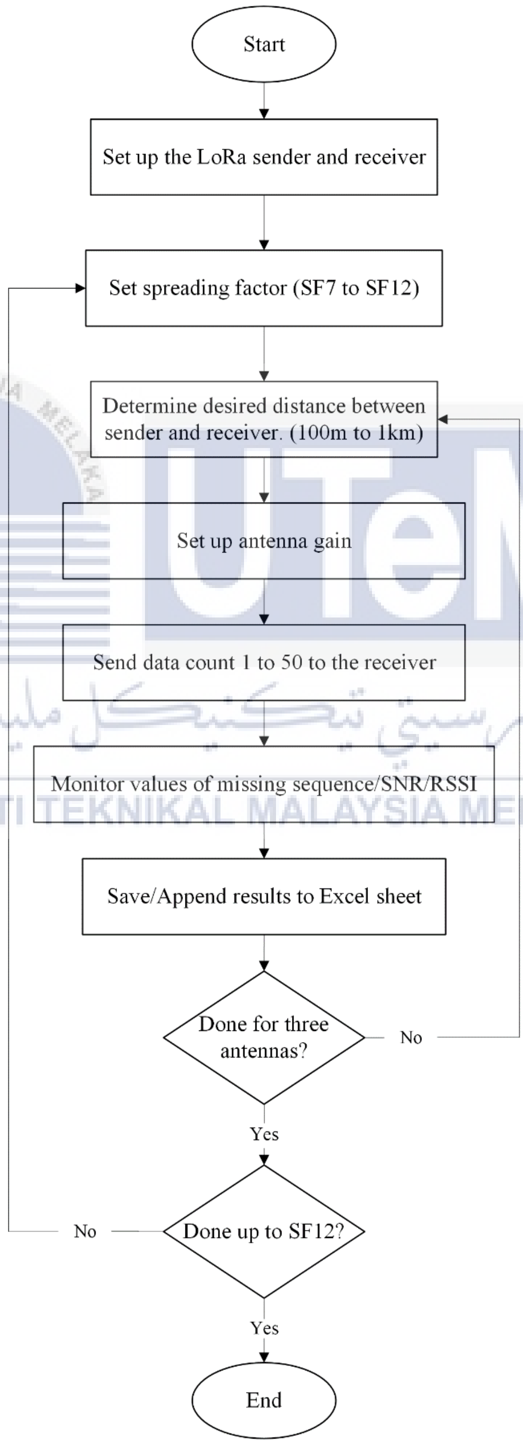


Figure 3.26: Flowchart of LoRa parameter testing.

3.9 Analysis of Radar Sensor

The radar sensor is tested for sensitivity in detection and accuracy as a fundamental step in designing an effective and reliable floating waste detection system. It ensures that the system can adapt to real-world conditions and provides the necessary data for optimising its performance and making informed decisions. Analysis of the sensor determines its capabilities, including its range, sensitivity, and limitations. The waste in water bodies can vary in size and composition. By assessing the performance of the sensor across a range of objects and materials, the sensor can be ensured to remain effective in diverse environmental scenarios. In this analysis, six objects varying in sizes and materials as summarised in Table 3.2 is tested over a range distance of 1 to 5 metres. By subjecting the sensor to these diverse objects and materials, the analysis aims to ascertain how well it performs in detecting and distinguishing between various waste items.

Table 3.2: Specifications of tested objects.

Object	Size (cm^2)	Material	Remark
Drinking Can	80.754	Metal	Solid
500ml Bottle	128.305	Plastic	Transparent
1L Bottle	346.505	Plastic	Transparent
Wood	257.090	Organic	Solid
5L Bottle	540.00	Plastic	Frosted/Coloured
6L Bottle	640.970	Plastic	Transparent

The analysis test is conducted at Tasik UTeM, Universiti Teknikal Malaysia Melaka in Durian Tunggal with the range up to 5 metres distance depicted in Figure 3.27. By conducting the analysis at the university lake, the complexities and administrative processes associated with testing in a public river can be bypassed.

Additionally, public rivers can have unpredictable and dynamic conditions. Water flow, currents, and water levels can change rapidly, especially in response to weather events such as heavy rainfall.

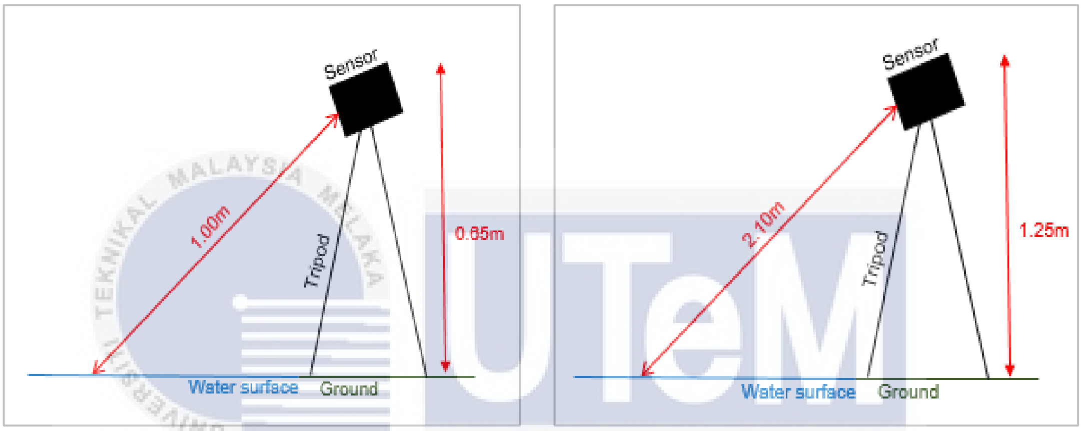
Figure 3.27: Map of Tasik UTeM in Durian Tunggal, Melaka.

The setup of the test is shown in Figure 3.28. The radar sensor is initialised at a height 1.2 and 0.6 metres, above the water surface to simulate actual operational conditions. The dual height setting is a response to a range limitation encountered at the higher elevation. This is due to the sensor is incapable of detecting objects within less than 2-metre distance due to the boundaries of its detection area at 1.2 metres. Consequently, for objects positioned closer than 2 metres, the sensor is adjusted to a height of 0.6 metres to enable detection.

(a) (b)

Figure 3.28: Radar sensor setup. (a) 1.2 m height setup. (b) 0.6 m height setup.

The sensor is placed onto a tripod with aluminium foil covering the sides in order to minimise interference. Following the setup, the distance between the sensor and the water surface is measured with a measuring tape as shown in Figure 3.29. This measurement is pivotal to calibrate the sensor and establish a baseline for the subsequent detection tasks. Once the distance is established, the size of various objects intended for detection is measured and the type of material are determined as summarised in Table 3.2.



(a) (b)

Figure 3.29: Distance measurement between sensor and water surface. (a) Distance at 0.6 metres. (b) Distance at 1.2 metres.

The sensor is configured with the necessary program code compiled on Arduino IDE sketch. For convenience, the sensor is powered by the computer and data monitoring is done through the serial monitor in the Arduino IDE. The actual testing commences with the objects being thrown 5 metres away from the sensor with the objects tied to a rope. This action sets the stage for the sensor to demonstrate its detection range and accuracy. After the initial placement, each object is gradually pulled towards the sensor. The procedure is applied to all different sized objects as depicted in Figure 3.30.

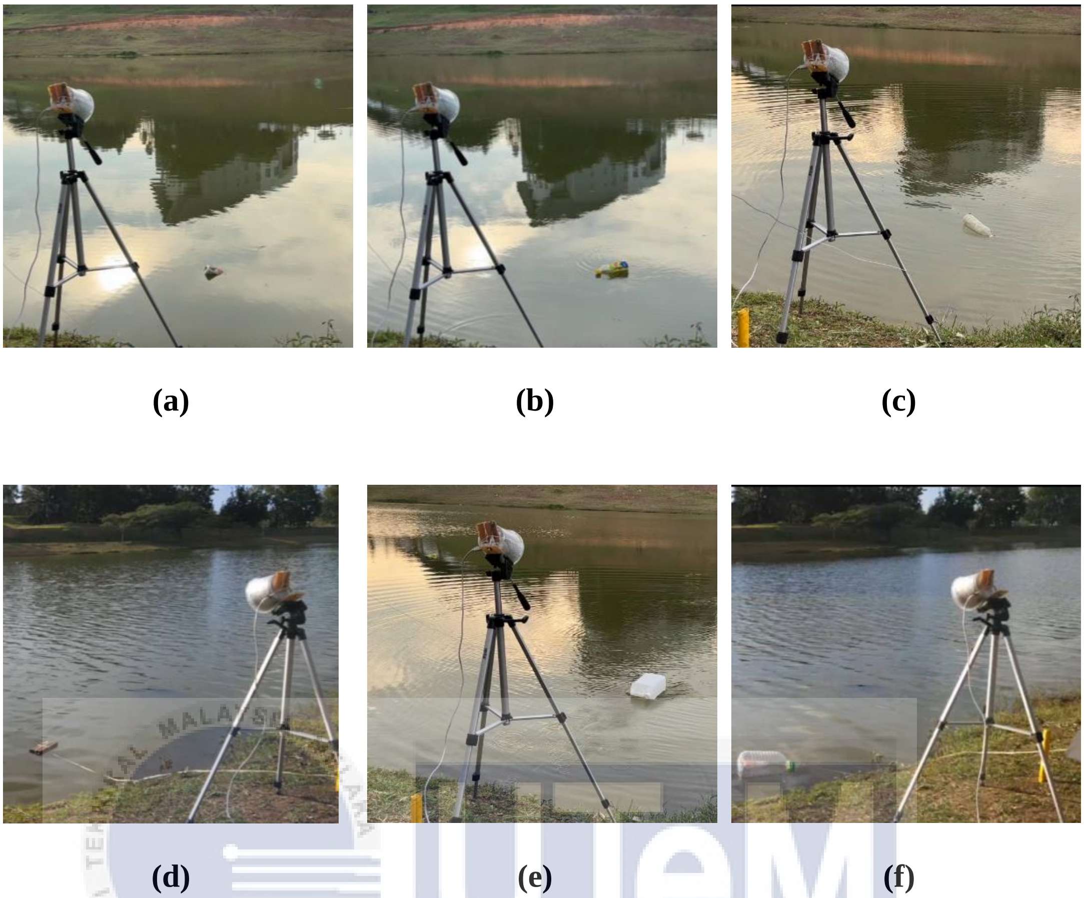


Figure 3.30: Radar analysis testing. (a) Drinking can. (b) 500-ml bottle. (c) 1-litre bottle. (d) Wood. (e) Detergent Bottle. (f) 6-litre bottle.

Throughout this process, the readings from the sensor are monitored on a serial monitor. Subsequently, the captured data is systematically recorded on Excel sheet through Arduino IDE platform. The steps are repeated for three iterations to obtain a more accurate data collection. The steps are repeated for all different sized objects. The flow of the radar sensor testing is depicted in Figure 3.31.

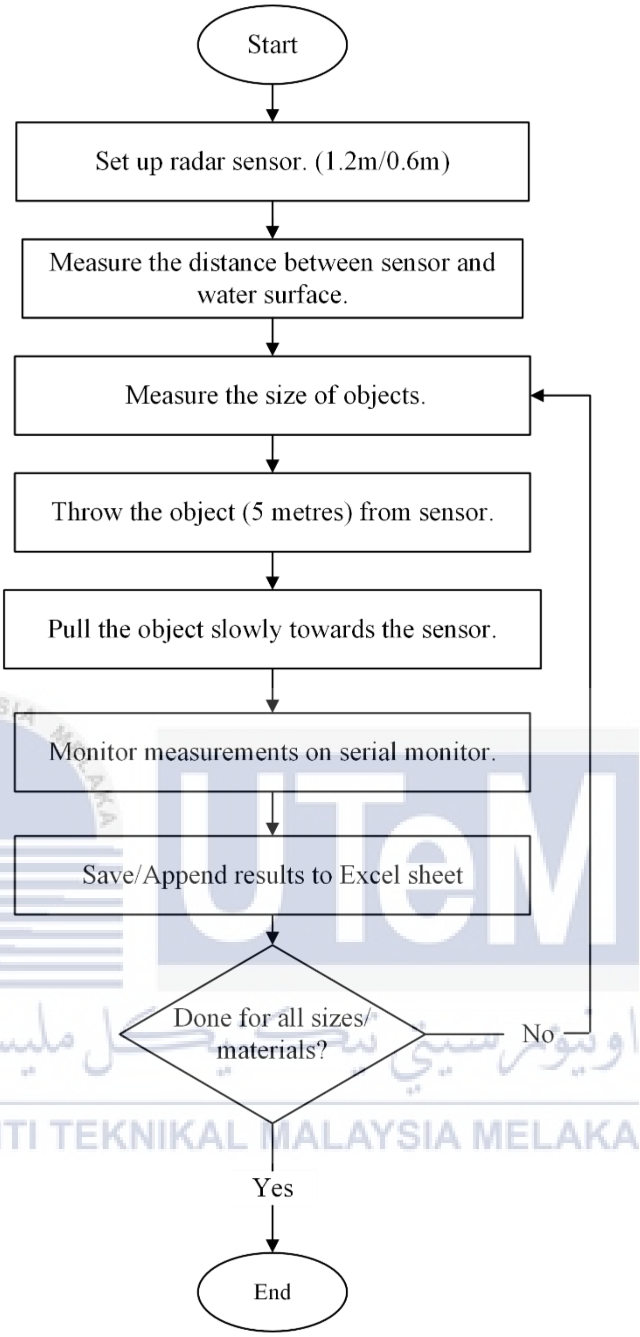


Figure 3.31: Flowchart of radar sensor testing.

3.10 Conclusion

The project includes hardware and software development for transmitter and gateway section. The transmitter includes a radar sensor controlled by Arduino UNO for detecting floating waste, while the receiver circuit processes and receives data on waste numbers communicated with LoRa module. The MQTT broker acts as a central communication hub, receiving processed data and publishing it to user-friendly platforms for visualization and analysis. Program code development is essential for ensuring seamless communication between the sender and gateway. The system includes features of MTI which focuses on moving targets while ignoring static objects. The gateway counts each received packet to indicate the number of waste detected. This data is then published to a specified MQTT topic for remote monitoring and tracking of data collection. Continuous Wi-Fi connectivity to the MQTT broker ensures uninterrupted data transmission. The procedures of the LoRa parameters and radar sensor is outlined. The next chapter builds upon the groundwork of this chapter which focus on results obtained from the implementation of the system including analysing the data collected to access the feasibility and accuracy.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents the findings derived from the conducted analysis, incorporating insights from previous studies and other relevant sources. It encompasses the analysis, output data, and specifications of the project. The results obtained hold significant importance to demonstrate the effectiveness of integrating radar sensor and LoRa technology for floating waste detection system.

4.1 The Result of LoRa Parameter Analysis

The result of the parameter test is conducted in the residential area of Persiaran Bukit Tambun Perdana, Durian Tunggal, Melaka with the range between the sender and gateway reaching up to 700 metres. The results are obtained using the serial monitor provided by Arduino IDE which saves the data directly to Excel Sheet.

4.1.1 Received Signal Strength Indicator (RSSI)

The graph of the RSSI measurement using the spreading factor of 7 for antenna gains of 2 dBi, 3.5 dBi and 5dBi is shown in Figure 4.1. It is observed that RSSI decreases as the distance between the transmitter and receiver increases. This inverse proportionality is primarily due to the spreading of the signal over a larger area as it propagates through space. The signal power diminishes as it is dispersed, resulting in a weaker received signal at greater distances. However, antennas with higher gain can concentrate the transmitted energy more effectively in the desired direction, thus, the 3.5dBi and 5dBi antenna has a larger RSSI value compared to 2 dBi antenna. Antennas manufactured by different companies or in different regions can have variations in quality and performance. Factors such as the consistency of manufacturing processes, quality control standards, and choice of materials can influence the overall performance of the antenna.

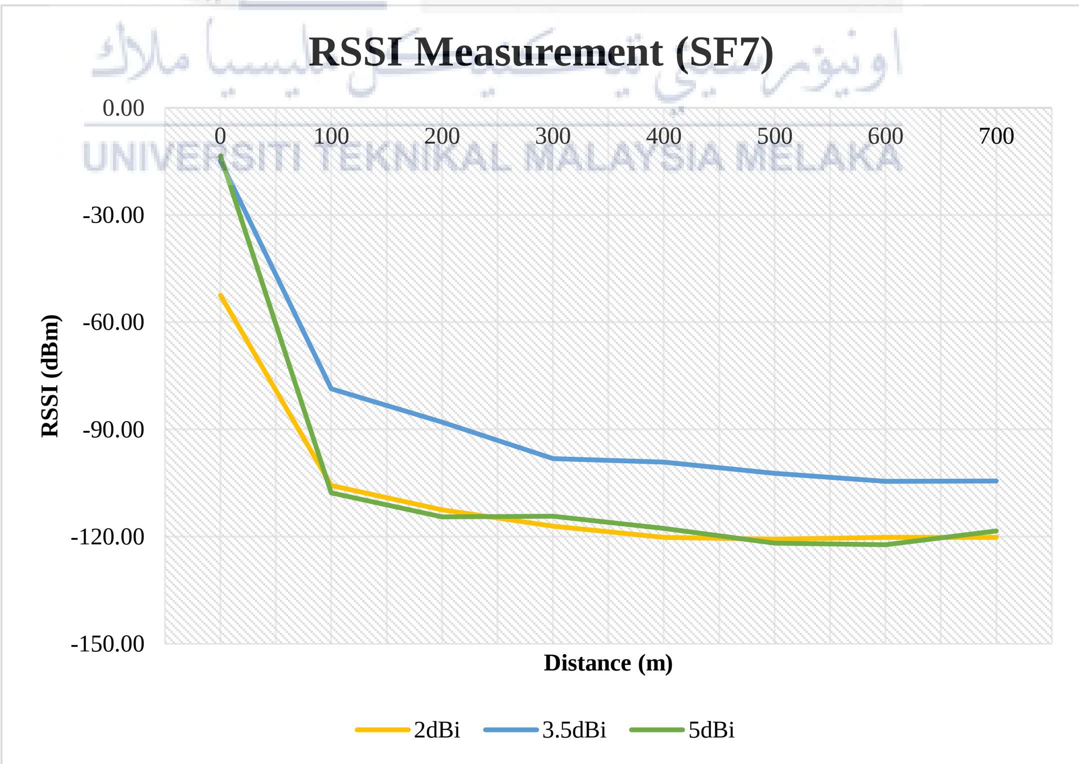


Figure 4.1: RSSI measurement graph for SF 7.

4.1.2 Signal-to-Noise Ratio (SNR)

Signal-to-Noise Ratio known as SNR represents the ratio of the signal power to the noise power. A higher SNR value indicates a stronger signal relative to the noise. Figure 4.2 shows the graph of the SNR measurement using the spreading factor of 7 for antenna gains of 2 dBi, 3.5 dBi and 5dBi. It is observed that with an increasing separation between the transmitter and receiver, there is a decline in the SNR which is primarily influenced by signal attenuation, which the decrease in signal potency as the signal travels through a distance. The 3.5dBi and 5dBi had a larger value of SNR compared to 2 dBi. A higher gain antenna captures and concentrate more of the desired signal, resulting in a stronger received signal at the receiver. However other factors such as interference, and receiver sensitivity influence the values at 700 metre, the SNR values rises.

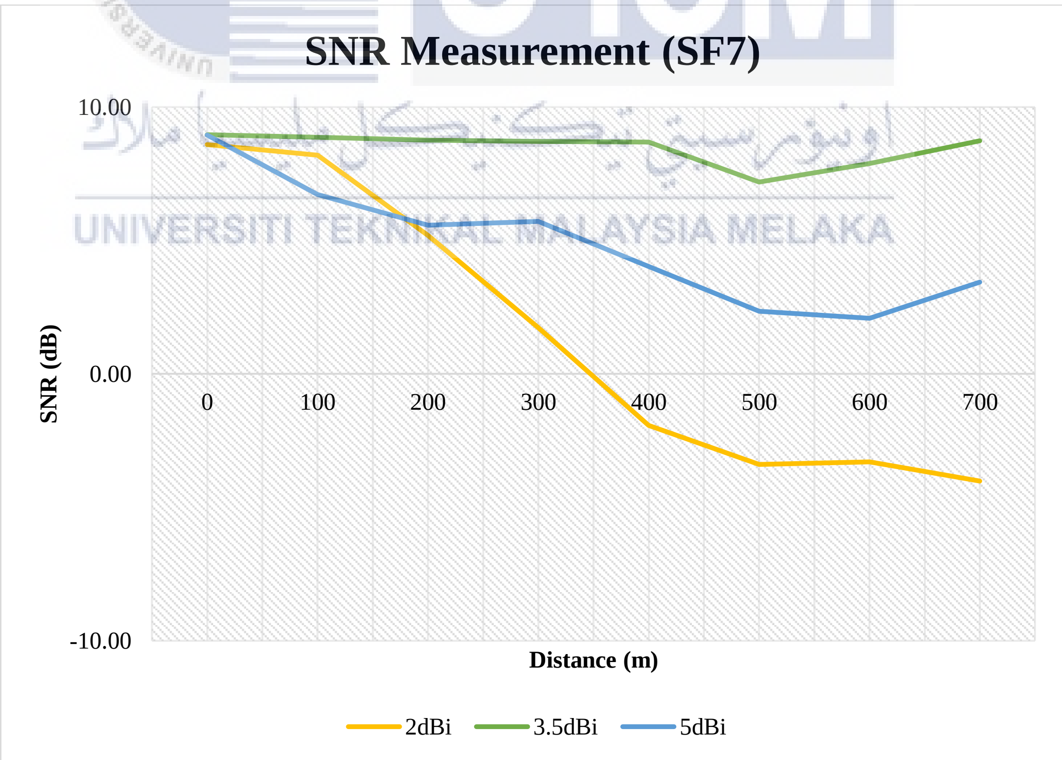


Figure 4.2: SNR measurement for SF7.

4.1.3 Missing Sequence

The missing sequence measurement of SF 7 is shown in Figure 4.3. It is observed that the 2 dBi antenna experience missing sequences as the distance increases. Increasing distance introduces higher path loss and weaker received signals, which can lead to missing sequence due to reduced signal strength. As the distance increases, the received signal weakens, and the SNR may deteriorate, increasing the likelihood of missing sequence.

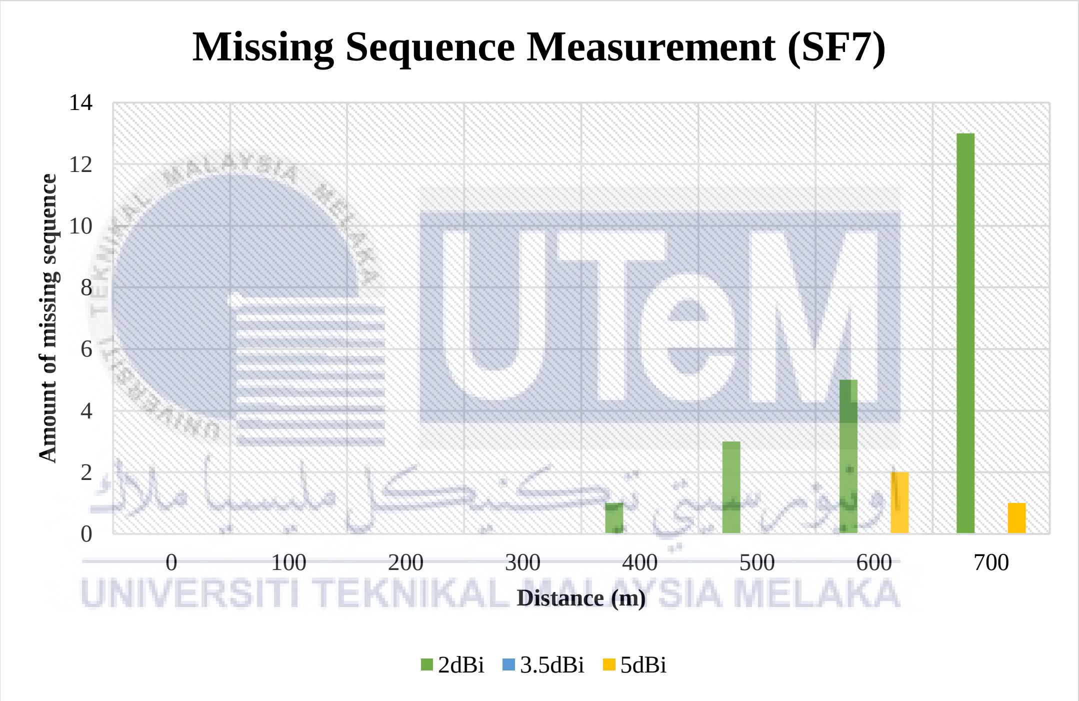
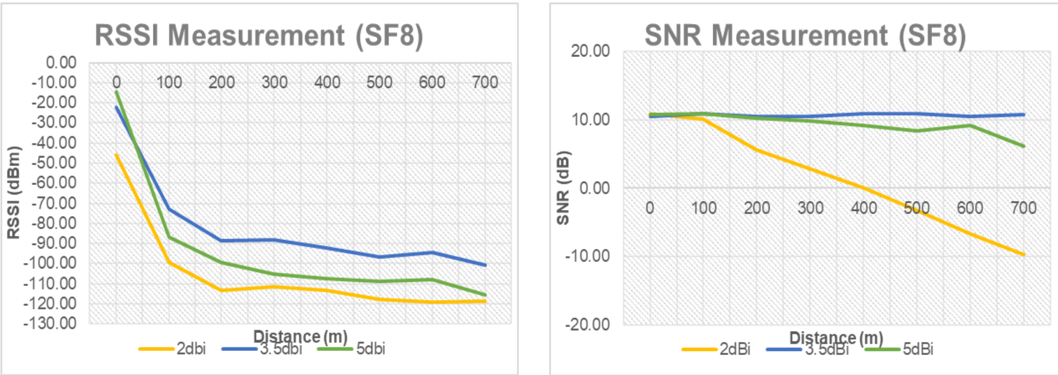


Figure 4.3: Missing sequence measurement for SF7.

4.1.4 Varying of Spreading Factor

The measurement of RSSI and SNR for SF8 is depicted in Figure 4.4. It is observed that the RSSI values are larger compared to values in SF7 test. Increasing the spreading factor can lead to a decrease in RSSI because the transmitted signal is spread over a wider frequency bandwidth. As the spreading factor increases, the transmitted signal is spread over a wider bandwidth, resulting in a lower power density.

Consequently, the RSSI value tends to decrease because the energy of the signal is distributed across a larger frequency range.



(a) **(b)**

Figure 4.4: Results of Spreading Factor 8. (a) RSSI measurement for SF8. (b) SNR measurement for SF10.

Similarly, it is observed that the SNR values are larger compared to the values obtained in SF7 test. With a higher spreading factor, the received signal is less susceptible to noise and interference. The signal is spread out, allowing for better discrimination between the desired signal and background noise. Consequently, the SNR typically improves as the spreading factor increases. This is also because the spreading factor effectively increases the processing gain, enabling better discrimination between the desired signal and unwanted signals or noise sources. However, the interference might affect the signal quality but not necessarily result in missing sequence.

4.2 The Result of Radar Sensor Analysis

The result of the radar sensor analysis is conducted in the private area of Tasik UTeM, Universiti Teknikal Malaysia Melaka with the range up to 5 metres between the sensor and object. The results are obtained using the serial monitor provided by Arduino IDE which saves the data directly to Excel Sheet.

4.2.1 Sensor Detection Reliability at 1.2-metre Height

The results for the radar sensor test for different size objects and materials over distance is depicted in the graph in Figure 4.5 for three iterations of each test at a height of 1.2 metres. The result shows that the 6-litre bottle with the largest surface area of 640.97 cm^2 provides more data points indicating that the radar sensor is able to detect it more consistently than smaller surface area objects. Similarly, wood which is solid organic material has a more consistent larger number of data points whereby solid material has a higher reflectivity for radar waves where it produces strong radar reflections and are easily detected. However, the range of detection is less consistent compared to the 6-litre bottle due to its smaller surface area of 257.09 cm^2.

The smaller surface area of the drinking can (80.764 cm^2) results in even fewer data points, with an increased spread of detection range. This implies less consistent detection, particularly at longer distances. Metal surfaces exhibit a notable propensity for reflecting electromagnetic waves, including those of the radar spectrum. Upon interaction with a metal object, radar waves undergo a robust and distinctive reflection. Based on Figure 4.5, the results show that the transparent plastic-material 1-litre bottle (346.5 cm^2) and 500-mililitre bottle (128.905 cm^2) have the least consistency and range spread of detection. This is primarily attributed to its composition of a plastic material with extremely low conductivity, resulting in a material with minimal reflective properties. Radar waves tend to pass through transparent materials without significant reflection.

The coloured detergent bottle (540 cm^2) has a more consistent data point compared to the transparent plastics. Opaque coloured plastic contains pigments or dyes that can scatter and reflect radar waves to some degree. This scattering and reflection of radar waves results in plastic to be more visible to radar sensors. Transparent plastic, on the other hand, absorbs radar waves which allows radar to pass through with minimal reflection. Nevertheless, size considerations are integral to assessing the overall radar sensing.

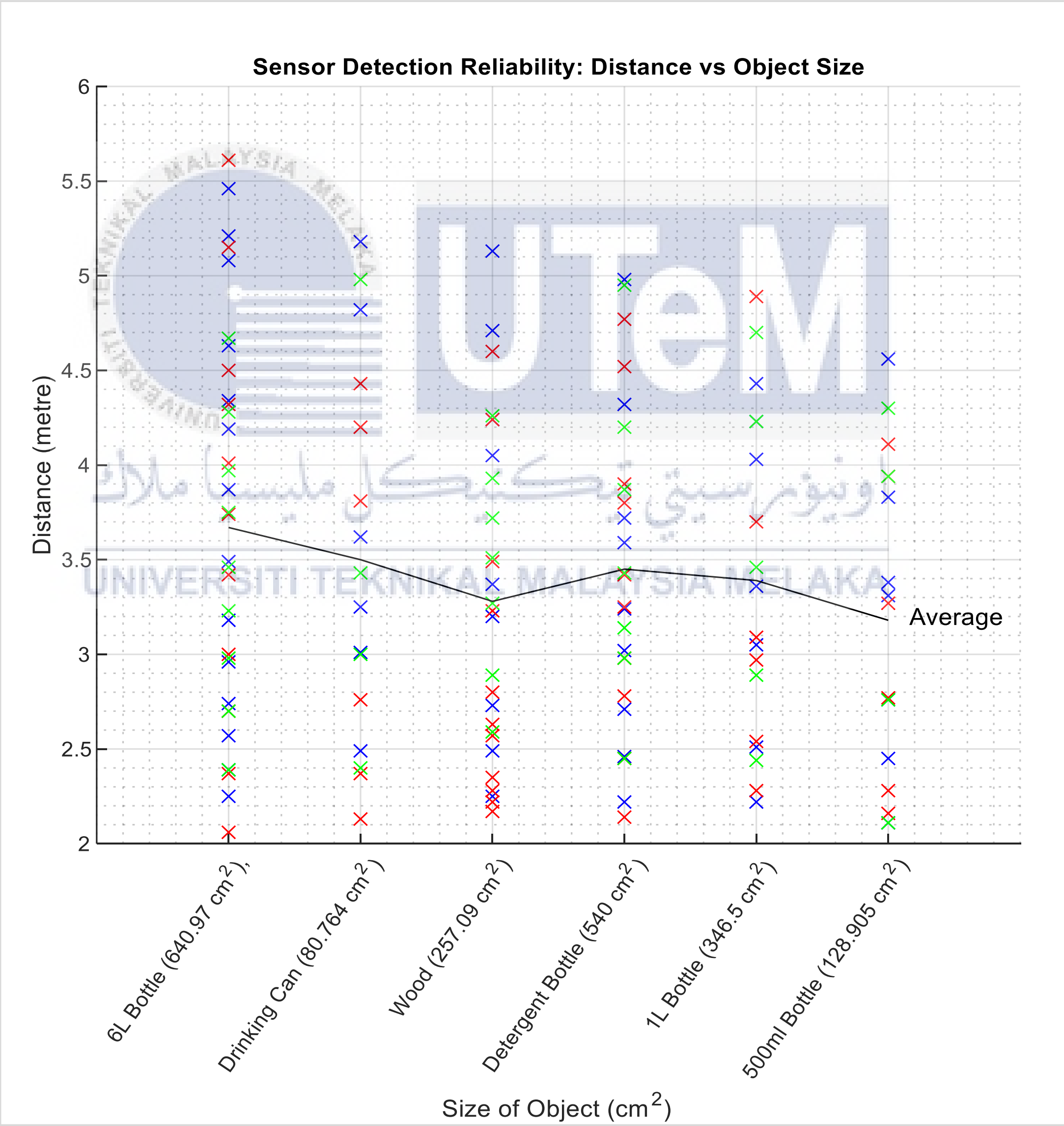


Figure 4.5: Graph of sensor detection reliability for distance over object size at 1.2 metre of height.

4.2.2 Sensor Detection Reliability at 0.6-metre Height

The test is conducted for the range of 0 to 5 metres. When the radar sensor is placed at a height of 1.20 metres, it has a broader field of view because it is positioned higher above the ground. The field of view (FOV) of a sensor describes the angular range within which it can detect objects where the utilised 1D radar sensor has a FOV of 30 by 30 degree. Thus, it can detect objects within its conical FOV at various distances.

At this height with a 45-degree angle placement of the sensor, its FOV extended farther into the distance but had a minimum detection range limitation of 2 metres. Objects within the FOV but closer than 2 metres were not reliably detected due to this limitation. Thus, the sensor is placed at a lower height of 0.6 metres. This change in height narrows the FOV and ensures that the radar sensor can now detect objects at shorter distances, including those within the 2-metre range. Lowering the sensor height also eliminates the need to manipulate the angle at which the sensor is placed. The result of the lowered height tis depicted in Figure 4.6.

The detection points for the 6-litre bottle are spread across a shorter distance range than at 1.2-metre height. However, the consistency of detection across iterations remains strong. There is noticeable reduction in the spread of data points for the drinking can, which has fewer data points than at 1.2-metre height. The black line labelled "Average" indicates the average detection distance for all objects across the three iterations. The average line is lower than at 1.2-metre-height, indicating a general reduction in the average detection distance across all objects. Nevertheless, it shows a similar trend as to when the sensor placement is at 1.2-metre-height. Across all objects, there is a general trend that larger objects are detected more consistently at greater distances. Smaller objects are harder to detect at greater distances due to the weaker return signal. At a lower height, the RCS needed for detection may increase, disadvantaging smaller objects. However, the water ripples are detected as objects as the sensor is lowered. Lowering the sensor height brings it closer to the water surface, increasing its sensitivity.

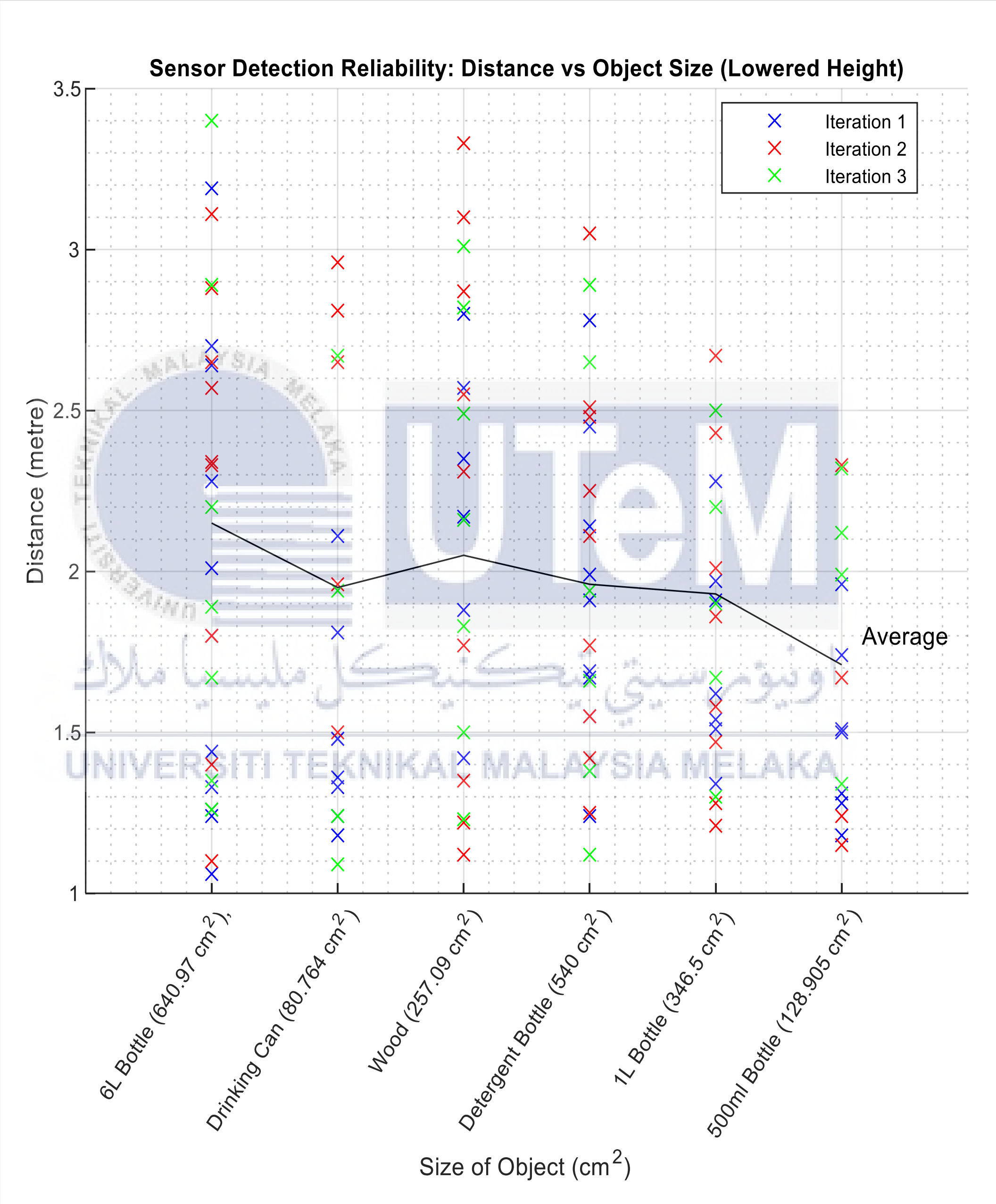


Figure 4.6: Graph of sensor detection reliability for distance over object size at 0.6 metre of height.

4.2.3 Sensor Trailing Detection at 1.2-metre Height

The result of sensor trailing detection for distance over different material is depicted in Figure 4.7. Red circles in the graph appear to denote instances where the object was not detected by the sensor, referred to as trailing holes. There are several trailing holes for plastic objects, suggesting that these materials may have varied radar cross-sections or reflectivity characteristics that can result in inconsistent detection, especially at larger distances depending on the size of the objects (S/M/B).

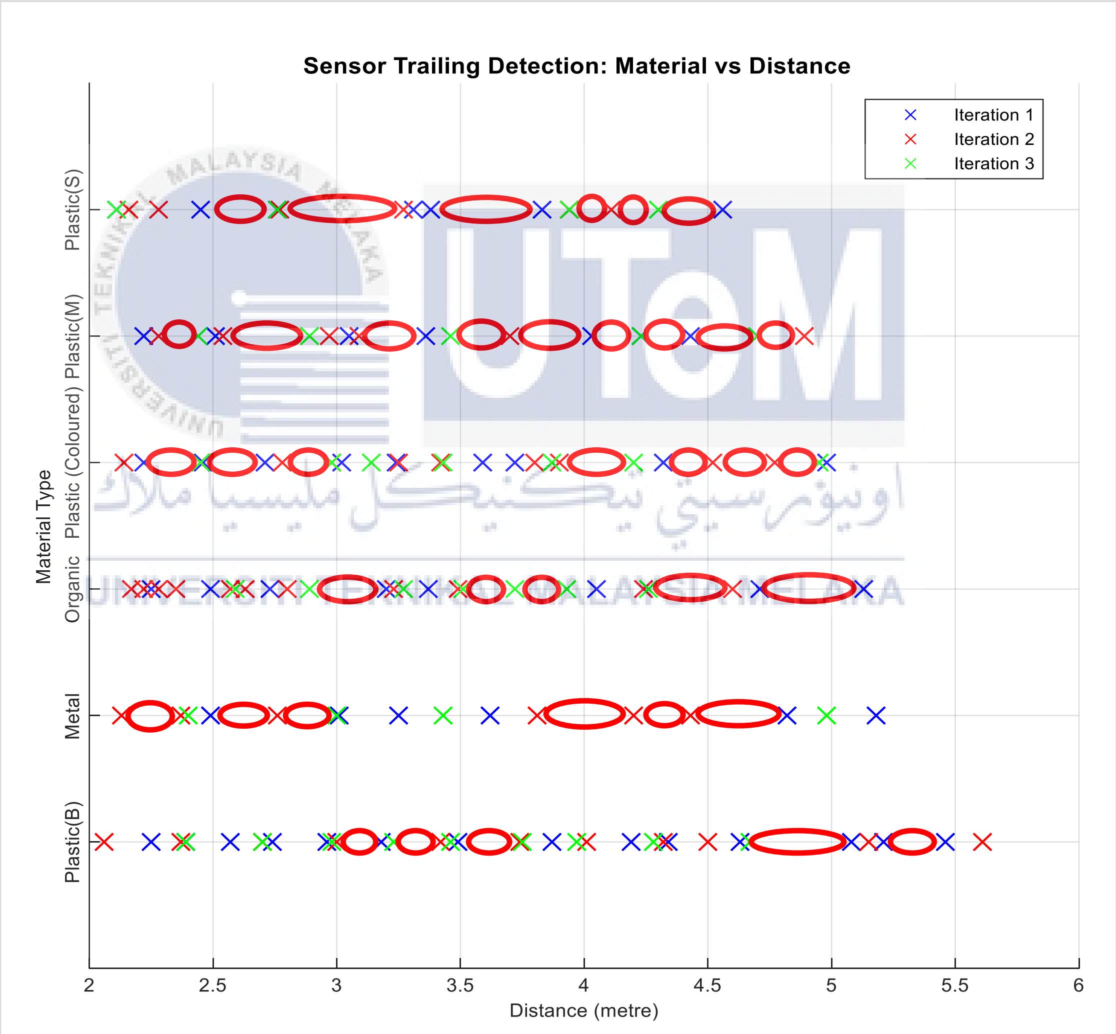


Figure 4.7: Graph of sensor trailing detection for material over distance at 1.2 metre of height.

Metal object appear to have fewer trailing holes, which is consistent with the expectation that metal typically has a higher radar reflectivity due to its conductive properties. It shows that as the distance increases, the number of trailing holes also increases, which indicates the ability of the sensor to detect objects on water surface decreases with distance. Materials with lower dielectric constants might not reflect radar waves as effectively as those with higher constants.

Larger objects present a more significant RCS, providing a larger surface area for radar waves to interact with. This results in a stronger return signal to the radar sensor. Solid objects, especially those with smooth and dense surfaces, tend to reflect radar waves more effectively. Smooth surfaces reduce scattering, directing more energy back towards the radar sensor. Metals, for instance, are particularly reflective due to their conductivity.

4.2.4 Factors and Limitations Effecting Radar Detection

Environmental factors such as humidity, temperature, and surface conditions of the water could influence the detection of different materials, particularly those with absorbent properties. The state of the water surface can significantly affect radar performance. Rough conditions with waves and ripples can scatter the radar signals which results in difficulty for the sensor to differentiate between the water surface and the target object. Radar signals can bounce off multiple surfaces before returning to the sensor, causing confusion and inaccurate readings. This is particularly problematic on water, where the signal can reflect off the water surface multiple times. Additionally, adverse weather conditions such as heavy rain, fog, or extreme temperatures can affect the performance of radar sensors. These surface disturbances can interfere with radar signals, leading to inaccuracies in detecting and locating floating waste.

Furthermore, it is more challenging for the sensor to maintain a lock on the target and provide accurate readings when an object is moving with the water currents or tides. The mobility of water can introduce challenges to the detection process which includes the water ripples, waves, and currents can affect the ability of radar to accurately detect objects. The movement of the water can create false returns or obscure the detection of actual floating objects. When the sensor is positioned too close to the water surface, it becomes susceptible to interference from waves and ripples. Radar signals can bounce off the water waves, leading to false returns and potential misinterpretation of data.

The 5 metre range provide a controlled environment with a more accurate data on the analysis. The radar sensor is theoretically capable of detecting objects at distances of up to 100 metres. The results suggest that the radar sensor exhibits reliability in detecting objects beyond the 5-metre range. This indicates that the specified range of 100 metres may indeed be achievable under appropriate conditions. In the test results indicated that, on average, only one object per scan was accurately detected. This suggests that the default settings or algorithms of the sensor may not fully utilise its capability to detect multiple objects simultaneously.

4.3 Conclusion

The LoRa parameter analysis demonstrates the influence of antenna characteristics and spreading factors on signal strength and reliability. Table 4.1 shows a summary of the impact of antenna gain, spreading factor, and distance on RSSI, SNR, and missing sequence in the LoRa communication system. The results suggest that higher gain antennas and increased spreading factors contribute to better signal reception and discrimination against noise, crucial for optimizing the performance of LoRa communication. The 3.5 dBi shows superior performance in terms of RSSI and SNR, indicating better signal strength and quality compared other antennas. The choice of antenna gain significantly influences the communication reliability in the LoRa system.

Table 4.1: Summary of LoRa parameter testing.

Measurement	Observation/Comparison	Implication
RSSI	RSSI decreases with increasing distance.	Inverse proportionality due to signal dispersion.
	3.5dBi and 5dBi antennas have larger RSSI values than 2dBi antenna.	Higher gain antennas concentrate transmitted energy.
	RSSI values decrease with higher spreading factor (SF8).	Higher spreading factor spreads signal over wider frequency.
SNR	SNR declines with increased separation between transmitter and receiver.	Influenced by signal attenuation and interference.
	3.5dBi and 5dBi antennas have larger SNR values than 2dBi antenna.	Higher gain antennas capture more desired signal.
	SNR values increase with higher spreading factor.	Higher spreading factor improves SNR due to less susceptibility to noise.
Missing Sequence	2dBi antenna experiences missing sequences as distance increases.	Increased distance leads to higher path loss.

The radar analysis is crucial to provide valuable insights in accuracy and capabilities of radar sensor in detecting floating waste. Table 4.2 summarises key insights regarding sensor height, object size and material influence from the radar sensor analysis.

Table 4.2: Summary of radar sensor testing.

Aspect	Observation and Analysis
Sensor Height (0.6-metre and 1.2-metre)	By lowering the height of the sensor at 0.6-metre, the FOV is narrowed. This improves detection at shorter distances. However, water ripples are detected as objects. Average detection distances decrease with the lower sensor height, although, obtains a similar trend at a higher height.
Object Size Influence	Objects with larger surface area consistently obtain more data points, indicating more reliable detection at greater distances. Smaller objects exhibit less consistent detection, especially at longer distances.
Material Influence	Different materials exhibit varied detection characteristics. Metals show fewer trailing holes and larger spread of detection range. Transparent materials show less consistency in detection. Coloured detergent bottles exhibit better consistency. Trailing holes appear for plastic objects, indicating inconsistent detection, especially at larger distances.

The system demonstrates reliability beyond the tested 5-meter range, indicating the potential for long-range detection with limitations for further refinement to achieve consistent and accurate detection. Overall, the study provides insights into the strengths and limitations of both LoRa and radar technologies for waste detection in water bodies. In the next chapter, the conclusion will assess whether the set objectives have been met based on the observed results and their implications.

CHAPTER 5

CONCLUSION AND FUTURE WORKS

This chapter concludes the project based on the objectives of the project. It includes future recommendations that can be done to improvise the floating waste system. This section includes project summary, project findings and further recommendation to improve the project.

5.1 Justification of Objectives

The primary goal of the project is to design a prototype of floating waste detection using a radar sensor and low-powered LoRa to analyse the accuracy of the radar sensor in detecting floating waste. A prototype is developed to provide real-time feedback on the presence of floating waste detected in river water bodies with integration of IoT. It can be concluded from the analysis results that the objectives of this project has been successfully met. The radar sensor demonstrated a high level of reliability in detecting larger and solid objects, indicating its effectiveness in monitoring and managing floating waste in water bodies. The prototype developed delivers data on the number of floating wastes on river surfaces through MQTT broker that can be monitored through various IoT platforms.

According to the LoRa parameter testing, the distance between the sender and gateway is 700 metre. By using this distance, the results indicate that the higher spreading factor will have higher SNR and RSSI values as well as the least missing sequence. However, the higher spreading factor implies to a higher time on air. According to the radar sensor testing, the analysis indicates that larger objects, with a greater cross-section and solid composition objects are more reliable to be detected by the sensor at the range up to 5 metres. Nonetheless, while radar is effective in detecting larger and solid objects, its performance can be influenced by various factors such as the material properties, environmental conditions, and the specific radar system parameters. The analysis demonstrates reliability beyond the tested 5-meter range, indicating the potential for long-range detection.

Despite the acknowledged limitations, the compatibility and reliability of both the radar sensor and LoRa technology in floating waste detection are evident. This synergy between LoRa and radar technologies enhances the overall efficiency and reliability of the system and well-suited for environmental monitoring applications. The modern tools provide valuable data, enhance detection reliability, and offer a technological foundation for efficient waste monitoring. The advantages afforded by these tools, including long-range communication capabilities with LoRa and reliable object detection with radar sensors, outweigh the identified limitations.

5.2 Research Impacts

The project introduces a new methodology that combines radar sensor technology with LoRa communication for environmental monitoring. This approach aligns with sustainable development goals by offering a sustainable, efficient solution to a pressing environmental issue Its capacity for early detection of floating waste positions it as a crucial asset in preventing environmental degradation, minimizing economic losses, and addressing health concerns associated with water pollution. This initiative is in close alignment with Sustainable Development Goal (SDG) 6 and SDG 14, contributing to global efforts in ensuring clean water and sanitation and life below water respectively.

The technology has the potential to be commercialised in a wide range of industries and settings including disaster management where this system is able to provide critical information for decision-makers and emergency responders, allowing proactive measures to prevent flood damage and ensure public safety. The system may also be used by waste management authorities to monitor and manage waste in water bodies, allowing for more effective and efficient waste management practices. Environmental organizations can use the system to monitor the impact of waste on water bodies, and to advocate for policies and practices that promote a cleaner and more sustainable environment. This can help to reduce the amount of waste that is generated and prevent waste from ending up in water bodies in the first place. The data generated by floating waste detection technologies can be used to inform policies and decisions related to waste management and environmental protection. The project contributes significantly to environmental protection by providing a means to detect and manage floating waste effectively.

5.3 Future Recommendation

The system has the potential for improvement by incorporating a 3D radar sensor. This enhancement aims to create a more efficient system and overcome the current limitations. A 3D sensor is able to provide an additional data on the position of the object in three-dimensional space of x, y, and z coordinates which allows for more accurate and precise localisation of detected objects. An improvement in object recognition can aid in distinguishing between different types of waste materials based on their shapes and sizes. 3D sensors have the capability to detect multiple objects simultaneously within their field of view of up to 20 objects. This is particularly advantageous for scenarios where there might be several pieces of floating waste in close proximity. The system can identify and track multiple objects concurrently, improving the overall efficiency of waste detection.

With more detailed data about the shape and dimensions of detected objects, a 3D sensor can potentially reduce false positives by distinguishing between waste items and natural features such as waves or ripples. This contributes to a more accurate and reliable waste detection system, minimising the chances of misinterpretation and improving the overall system performance. The additional dimensions provided by a 3D sensor enable more sophisticated data analysis, allowing for insights into the spatial distribution and movement patterns of floating waste. This future development could further enhance the capabilities and effectiveness of the system in detecting and monitoring floating waste.

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APPENDIX A

System Prototype

Note: Sender Prototype.

Note: Gateway Prototype.