MOBILITY OF AN AUTOMATED PESTICIDE SPRAYING ROBOT

This report is submitted in accordance with requirement of the University Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)

by

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2023/2024

DECLARATION

I hereby, declared this report entitled “Mobility of an Automated Pesticide Spraying Robot” is the result of my own research except as cited in references.

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Date : 21 June 2024

APPROVAL

This report is submitted to the Faculty of Industrial and Manufacturing Technology and Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

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ABSTRACT

The potential for mobile robots to improve crop management techniques has drawn a lot of attention to their usage in agriculture sector in recent years. The design, development, and testing of a mobile robot fitted with a pesticide spraying mechanism are presented in this study. Pesticide spraying robots also represent a groundbreaking technology poised to revolutionize farming practices, offering the potential to elevate agricultural efficiency, safeguard public health, and ensure the sustained profitability and viability of agriculture in regions such as Malaysia. The main objective for this project is to highlight the importance of mobile robot in agriculture. Other than that, this paper also aims to conduct a thorough examination of the performance of these robots in the context of palm oil plantations, characterized by uneven surfaces and challenging terrains. The primary focus will be on the design and development of the innovative robot, along with specific attention to the design features of the top cover for pesticide robot. This is because the mobile robot's development required the integration of mechanical, electrical, and software components to build a dependable and efficient system. These design elements are crucial not only for optimizing the robot's efficiency but also for securing the electrical circuit against leaks that could potentially lead to short circuits. Finally, the outcome from this project is to get a better robot performance in term of its mobility which is robot can go through a uneven ground, grass, possible obstacles like fallen branches or fruit bunches smoothly and the robot can climb up to 20-degree slope with or without pesticide load. Plus, the electrical component and circuit also will be secured to ensure adherence to our internal guidelines and procedures.

ABSTRAK

Potensi untuk robot mudah alih dalam meningkatkan pengurusan tanaman telah menarik minat pengguna di dalam sektor pertanian. Reka bentuk, pembuatan dan pegujian kepada robot tersebut yang dilengkapi alat penyembur racun perosak telah ditunjukkan di dalam laporan ini. robot penyembur racun perosak juga menunjukkan kemajuan teknologi yang boleh merevolusikan kerja-kerja pertanian, menawarkan potensi untuk meningkatkan keberkesanan dalam pertanian, menajaga kesihatan orang awam dan memastikan peningkatan keuntungan dan kemajuan dalam sektor pertanian di negara Malaysia. Tujuan utama kajian ini adalah untuk menunjukkan kepentingan penggunaan robot penyembur racun perosak dalam pertanian. Selain itu, kajian ini juga ingin melakukan ujian kepada prestasi robot dalam kawasan ladang kelapa sawit, karakter jalan yang tidak sekata dan curam yang tidak menentu. Perkara yang akan difokuskan adalah dalam reka bentuk dan pembuatan untuk robot yang berinovatif, seiring dengan perkara yang perlu dititik beratkan iaitu reka bentuk atap kepada robot tersebut. Hal ini adalah kerana, reka bentuk robot tersebut memerlukan kebolehan, peralatan elektrik dan juga perisian yang tepat untuk membina sebuah robot yang boleh berdiri dengan sendiri dan juga keberkesanan sistem yang memuaskan. Reka bentuk yang baik bukan sahaja untuk meningkatkan keberkesanan robot malah untuk menjaga litar elektrik daripada sebarang kebocoran yang boleh merosakkan litar tersebut. Akhir sekali, dapatan daripada kajian ini adalah prestasi robot akan meningkat terutamanya dalam pegerakannya iaitu boleh melalui jalan yang tidak rata, berumput, boleh mengatasi halangan-halangan seperti dahan dan buah-buahan yang jatuh dan juga boleh memanjat sehingga cerun yang setinggi 20 darjah sama ada dengan beban bahan peracun ataupun tidak. Tambahan, alat-alat elektronik dan litar juga akan ditingkatkan keselamatannya dengan ketetapan industry.

DEDICATION

I would be honoured to express my deepest gratitude to my loving family, who have played a vital role in shaping my personal and professional development journey. Their everlasting love, knowledge, and unbreakable belief in my potential have created in me an insatiable thirst for education and a burning desire to succeed. They made incalculable sacrifices to guarantee that I had access to the best educational possibilities from the start of my life, establishing the groundwork for my intellectual development and paving the road for a prosperous future. Furthermore, I give my deepest gratitude and admiration to my treasured circle of close friends, whose unwavering support has been a constant source of inspiration and strength throughout the gruelling years of my academic achievements. Their constant presence, support, and faith in my skills have served as guiding signs, illuminating my way and empowering me to overcome obstacles with dedication and determination.

ACKNOWLEDGEMENT

I would like to thank my supervisor, Prof Madya Dr. Hafidz Fazli bin Md Fauadi, for his support, guidance and encouragement through this project. Without his word of wisdoms, this project will never be done.

I would also like to thank our Final Year Project coordinator, Dr. Chang Siang Yee, for guiding us throughout the process of executing our project. I would also like to express my gratitude to all of my lectures and friends who have never stopped in encouraging and motivating me during conducting this project. I complete this dissertation on behalf of all those who have helped by mentioning the accomplishments that belong to all of us.

Lastly, I am very grateful to my family who are supporting me far from home.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

DC	-	Direct current
MOSFET	-	Metal-oxide-semiconductor field-effect transistor
AC	-	Alternative current
AI	-	Artificial intelligent
COM	-	Centre of mass
IMU	-	Inertial measuring unit
BDS	-	Beidou navigation satellite system
LIDAR	-	Light detection and ranging
ASLM	-	Aerial laser swath mapping
N	-	Newton
VRP	-	Vehicle routing problem
PET	-	Polyethylene terephthalate
PLA	-	Polylactic Acid
RPM	-	Rotation per minute

LIST OF SYMBOLS

v - Velocity
N - Newton
d - Displacement
t - Time taken
θ - Angle value
τ - torque
r - radius of wheel
m - mass of the robot

CHAPTER 1

INTRODUCTION

1.0 Introduction

This chapter provides a quick overview of the project. The project background of the industrial automated pesticide spraying robot will be covered initially. The project's issue statement will come next, and the objectives will come after that. The goals and problem description will be used to establish the work's scope. Lastly, it will outline this project's report format.

1.1 Project Background

The first automated pesticide spraying robot was created by a team of researchers at the University of Western England in Bristol, Philip J. Sammons and his team. He is a robotics researcher and engineer from Britain who has worked on several agricultural robots, including the first automated pesticide spraying robot also used in agriculture, which is for greenhouse applications (Sammons *et al*, 2005**).** By 2005, they had produced the first automated pesticide spraying robot, and their robot was able to satisfy the physical requirements specified by the National Greenhouse Horticulture Centre to function in their greenhouses.

It did this by using implanted hot pipes along the lanes for automated movement. Along with meeting the spray pattern accuracy requirements, the robot also fulfilled the time constraints for facing and spraying each plant. But it wasn't until 2016 that the first autonomous pesticide spraying robot for use in open fields was unveiled. A group of researchers at the University of California, Davis, created this robot, which had an accuracy of up to 90% when it came to identifying and spraying unhealthy plant sections. Additionally, compared to conventional spraying techniques, the robot utilised a great deal less pesticide, which might lessen agriculture's negative environmental effects. There are several different kinds of automated pesticide spraying robots on the market now, and farmers are using these robots more and more often (Chaitanya *et al*, 2020).

As we know, robotics is one of the fastest-growing engineering fields. Robots are also designed to remove human factors from intensive or dangerous work. This was also one of the reasons why an automated pesticide spraying robot was being developed at that time because to lessen the amount of pesticides personnel are exposed to. Long-term exposure to pesticides can cause a variety of health issues, such as cancer, respiratory issues, and neurological abnormalities. Pesticides can be detrimental to human health (World Health Organisation, 2022). By doing away with the necessity for human spraying, automated pesticide spraying robots can help lower the amount of pesticide exposure that employees experience. Next, applying pesticides with more precision is the next step. Pesticides can be sprayed more precisely by automated pesticide spraying robots than by hand. This helps guarantee that pesticides are not administered excessively and are only applied to areas where they are necessary. In doing so, you may lessen the damage that pesticide use does to the ecosystem. Other than that, it is to raise agricultural production and efficiency.

Robots that automatically apply pesticides can increase agricultural output and efficiency by doing a labor- and time-intensive operation (Singh *et al*, 2021). Farmers may then be able to concentrate on other duties, including managing their crops and harvesting them. Finally, in order to assist farmers in addressing the issues posed by climate change, automated pesticide spraying robots are also being created. For instance, several automated pesticide spraying robots are being designed with the capability to function in harsh weather scenarios, such as flooding and drought. All things considered, automated pesticide spraying robots are a promising new technology that might increase the efficiency, profitability, and sustainability of agriculture (Ashoka *et al*, 2018).

Agriculture is one of the important sectors in Malaysia, especially palm oil agriculture. This is because Malaysia is one of the world's largest palm oil exporters. In 2022, the export volume of palm oil from Malaysia totaled approximately 15.35 million metric tonnes, an increase from around 14.84 million metric tonnes in the previous year. In that year, the export value of palm oil was approximately 82 billion Malaysian ringgit. With Indonesia being the largest palm oil exporter worldwide, Malaysia now holds the second position in this regard (Ahmad, 2022).

Next, one of the biggest employers in Malaysia is the palm oil sector, which directly and indirectly employs approximately 1.2 million people (Kadir *et al,* 2022). Not only that, but palm oil also has a significant impact on food security (Tabe-Ojong *et al*, 2023). Cooking oils, margarines, and confections are just a few of the culinary items that employ palm oil, a versatile vegetable oil. Because Malaysia is a net exporter of palm oil, it contributes to the nation's access to reasonably priced and wholesome food. Apart from its economic and social advantages, palm oil serves as a significant revenue stream for the Malaysian government. Taxes on the production and export of palm oil are collected by the government, which is used to finance development and public services. Finally, Malaysian society and the economy rely heavily on palm cultivation. The sector gives the government money, employment, and income (Kadir *et al*, 2022).

In conclusion, autonomous pesticide spraying robots are a revolutionary technological advancement that might improve farming methods, protect public health, and support the long-term viability and profitability of agriculture in areas like Malaysia and beyond. These robots are anticipated to have a major impact on how agriculture develops in the future as technology develops.

1.2 Problem Statement

Manually spraying pesticides relies too much on human labour, especially for large-scale plantations like palm oil plantations. This issue did not just end there; the fact that the weather in Malaysia was so hot and sunny throughout the year also made it a big challenge for farmers to do the pesticide process. Other than that, this also creates a high risk of heat stress, particularly for elderly individuals who are working on farms. Farmers frequently have to bear bulky pesticide equipment on their backs, which can cause pain and discomfort in their bodies. It seems that using pesticides presents a number of difficulties for Malaysian farmers.

The uneven terrain of palm oil plantations makes it difficult for robots to move during the pesticide spraying process. This is due to the incapability of the motor used in operating the motion system. Plus, this is also because there are not enough motors being used to support the motion system. Additionally, using an incapable motor or amount of motor will only increase the load on the motor and finally increase the energy consumption of the battery.

The uncertain weather in Malaysia will be a big problem if the circuit is not fully secure. Plus, if the pesticide spraying process needs to be done in the rainy season, this can cause a short circuit due to the water leaking into the robot. Other than that, the uneven terrain of the ground surface can also cause the pesticide to leak and damage the circuit.

Finally, it is essential to determine and measure the improvement of the new robot against the existing robot. The challenge is to define and execute a comprehensive testing framework to measure and compare factors such as spraying accuracy, coverage, pesticide consumption, operational efficiency, environmental impact, and cost-effectiveness, with the goal of identifying the strengths and weaknesses of the new robot and informing decisions on its adoption or improvement.

1.3 Objective

The objectives are as follows:

a) To enhance robot mobility by adding new motors to ensure the smoother navigation in varied environment.

b) To increase the safety of the circuit by using a water resistant and lightweight rooftop of the robot. This is to ensure adherence to our internal guidelines and procedures.

c) To analyse the performance of the improved automated pesticide spraying robot.

1.4 Scope of Work

The Scopes of work are as follows:

a) Research on how the addition of a new motor can improve the mobility of the robot to work smoothly and properly in the palm oil plantation with an uneven surface and lots of terrain.

b) Study how to redesign the top cover and the pesticide tank of the robot to secure the circuit from any leaks that can cause a short circuit.

c) Analyze the navigation of the automated pesticide spraying robot on the uneven terrain of the ground surface. Analyze the security of the circuit for any leaks.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This section basically contains several articles, journals, and conferences, devoted in a brief summary and those related to the project to be undertaken. This study focuses on the automated pesticide spraying robot that being used in agriculture sector and what is the method used in this project.

2.1 Agriculture Robot

In this new modern era, everything is expected to be modish, and this also includes for agriculture sector. It is expected of modern farms to provide greater-quality, higher yields at lower costs in a sustainable manner that uses less work. Some potential solutions to this expectation include the use of digital farming and site-specific precision management. These solutions rely not just on sensor technology but also on the ongoing gathering of field data, which is only achievable with the effective use of agricultural robots. This is because, based on research Shamshiri, 2018 state that agricultural scientist, farmer, and growers are expected to produce more food from. This is because to meet the demands of the predicted 9.8 billion people population in coming 2050 (Shamshiri *et al*, 2018).

Precision agriculture and digital farming have evolved to rely heavily on agricultural field robots and manipulators. Applications of these robots in digital farming have demonstrated an increasing interest in automation due to advancements in controls theory, replacing conventional field workers with high-tech industrial jobs that are drawing businesses, investors, and professional engineers. Figure 2.1 below shows the examples of design pesticide spraying robot that being used in agriculture sectors. Plus, Shamshiri, 2018 did mention that an agricultural robot must have the least amount of effect while maximising efficiency because it operates in an exceedingly dynamic environment and is required to touch, feel, or control the crop and its surroundings precisely. In order to function effectively in real-world conditions, a field robot equipped with a manipulator and end-effector for spraying, de-leafing, and harvesting tasks in a dynamic, complex, and uncertain environment must consider the various arrangements of plant sizes and shapes, stems, branches, leaves, fruit colour, texture, obstacles, and weather influences (Shamshiri *et al*, 2018).

Figure 2.1: Examples of design pesticide spraying robot by (Shamshiri et al, 2018)

Chaitanya, 2020 in the research proposed that plant diseases have a huge after-effect since they can drastically lower the quantity and quality of agricultural goods. Crop planting is heavily impacted by the issue of early pest identification. Plants must be closely and regularly observed throughout the first phase. After that, the afflicted plants will be identified, and pictures of the damaged areas of the plants will be gathered using scanners or cameras. These pictures are then grouped, altered, and pre-processed. Following the transmission of these photos as input, the processor compares the images. An automatic pesticide sprayer will be utilised to apply the pesticide to the identified plant area if the image is impacted. If not, the computers will immediately reject it, and the robot will continue.

In conclusion, the modernization of agriculture in response to the demands of a growing global population involves the integration of cutting-edge technologies, such as digital farming and precision management, facilitated by agricultural robots. The automation of tasks like spraying and harvesting through advanced control systems is replacing traditional field workers. The efficient functioning of agricultural robots is crucial in dynamic environments, considering various factors like plant characteristics and weather conditions. Early detection and management of plant diseases and pests are addressed through automated systems employing scanners and cameras. This holistic approach aims to enhance the quality and quantity of agricultural goods while ensuring sustainability, meeting the challenges of the future.

2.2 Component of Agriculture Robot

The mechanism of modern pesticide spraying robot in application technique for crops such as state in the research by Dange*,* 2023 that spraying technology developed over the previous 15 years, including autonomous robots that use ARM7 microcontrollers, Robot for Automatic Seeding, Grass Cutting, and Pesticide Spraying with Bluetooth and Android App The robot that sprays pesticides uses an image processing system and a video processor. Automated Robot with Wireless Camera, Robot with GPS, Robot with Android Application to Spray Pesticides, Semi-autonomous X-Bot and Autonomous Robot with Microcontroller 89C52 (Dange *et al,* 2023).

Next, research by Terra, 2021 mention that an automated agricultural sprayer mechanism which is recognises and categorises weeds and crops using machine vision and deep learning. A four-wheeled robot with a movable base, a spraying mechanism, a wireless controller to manage the robot's movement, and a camera to track crop development and health as well as identify pests in the agricultural field are all part of the implemented system (Terra *et al*, 2021).

2.2.1 Motor

The pesticide spraying robot's primary goal is mobility. The robot is used to spray pesticides on agricultural fields and is intended for precision agriculture. Varied kinds of motors are used by the automated pesticide spraying robots on the market today for varied purposes. The following kinds of motors are utilised in automated pesticide spraying robots, according to the search results is firstly, direct current (DC) motor. These motors are electrically controlled with the aid of motor drivers by gadgets such as the Arduino UNO. Motor speed, torque, and accuracy are some of the considerations that go into choosing a DC motor for a robotic application, such a robot that sprays pesticide. In term of robotics applications, DC motors are often being use because of its wide speed range, high torque-to-speed ratio, and simplicity of control through embedded systems. The use of DC motors in pesticide spraying robots enables precise and reliable movement, which is necessary for precision spraying and navigation in challenging agricultural fields. Lastly, DC motor is popular for their reputation for energy efficiency, DC motors are a good fit for agricultural robots that run on batteries. This effectiveness supports precision agriculture's sustainability objectives by extending operation and consuming less energy (Dhagate and Kadam, 2017).

Secondly is Brushless DC Motor. Robots that spray pesticides commonly employ brushless DC motors as part of their movement mechanism. This kind of engine is frequently produced in tandem with the tyre that is normally used in hoverboards. The process involves using a brushless motor driver to link a brushless DC motor to a microcontroller, like an Arduino Uno, and receiving power from a 12V battery. The phase linked to the gate driver of a metal oxide semiconductor field-effect transistor (MOSFET) on its circuit allows the motor drivers to control the rotation of the motor. Because of its dependability, efficiency, and capacity to deliver significant torque at low speeds all of which are perfect for the exact motions needed in a pesticide spraying robot this kind of motor was selected. Compared to brushed motors, it also has the benefit of being quieter and requiring less maintenance. Lastly, a pesticide spraying robot with a brushless DC motor has fine motor control, which can result in a more effective and efficient application of pesticides. In the end, this may result in lower expenses and higher agricultural operations' production (Priya *et al*, 2022).

Thirdly, according to a paper titled "Using AC Motors in Robotics", particularly mobile robots, can make use of alternative current (AC) motors. The study compares the performance of two controllers built using the Mamdani and Takagi-Sugeno models with the traditional control scheme and addresses the construction of fuzzy controllers for an AC motor run mechanism. AC motors are inexpensive, strong, and resilient. High power solid-state switching devices that may be used in AC induction motors are a result of advancements in power electronics. For applications requiring just a slow change in speed, induction motors with solid state drive packages are preferable over DC motors for speed control. These drives, however, belong to the class of general-purpose AC drives, which have less precise speed regulation. These drives are suitable for systems where low-speed performance and transient responsiveness are not essential. Fan, pump, and compressors are example of application areas that need for a little amount of control flexibility. Asynchronous AC motors' angular speed may be adjusted by varying the AC power supply's frequency. The cost of the electronics needed for the solution is more than the cost of the motor itself. Generally speaking, AC motors come in a variety of constructions, some of which react slower than DC motors (Marzi, 2007).

Finally, Servo Motor. Because of their accuracy and controllability, servo motors are frequently seen in robots that spray pesticides. These motors are necessary for precise and reliable movement in agricultural environments, which improves the precision and efficacy of pesticide spraying operations. Servo motors provide agricultural robots exact control over their angular or linear location, velocity, and acceleration, resulting in precise and reliable movement (Priya *et al*, 2022). However, Servo Motor usually being used in spray mechanism because of the efficient speed control. For example, the robot can maintain the ideal spraying speed and pattern thanks to the good speed control provided by servo motors, which is essential for the successful application of pesticides. Finally, because servo motors are meant to use as little power as possible, they are a good fit for agricultural robots that run on batteries, including robots that spray pesticide (Priya *et al*, 2022).

Figure 2.2 below shows the example of motors that has been mentioned above. These motors are examples of motors that being used in mobile robot.

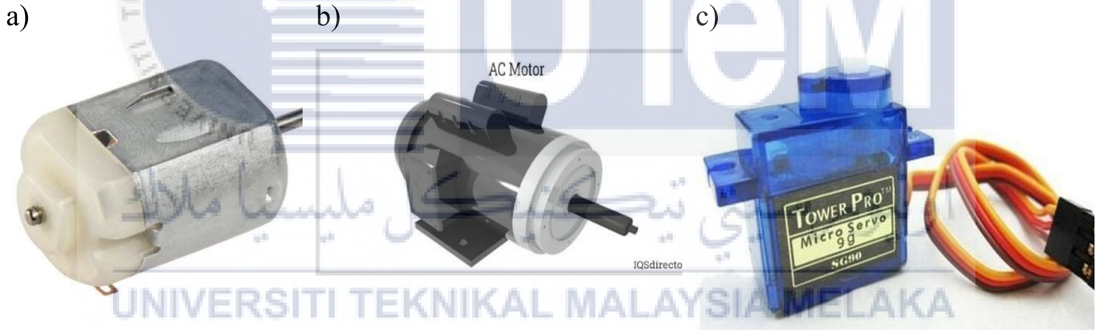


Figure 2.2: Motor (a) DC, (b) AC, (c) Servo (Liu et al, 2021)

For better understanding, table 2.1 below shows the differences between DC motor, Brushless DC motor, AC motor and Servo motor.

Table 2.1: Different between motors

Motor Type	**Power Source**	**Speed Control**	**Common Use in Pesticide Spraying Robots**
DC Motor	DC power source like batteries	Speed is directly proportional to the supply voltage, given a constant motor load	used in nearly every industry segment. Wide speed range, high torque-to-speed ratio, and ease of control via embedded systems make it the preferred option for robotics applications.
Brushless DC Motor	DC power source	Controlled by an inverter	frequently used in pesticide-spraying robots. It is well-known for its economy, durability, and ability to produce significant torque at low speeds.
AC Motor	AC power source	The frequency of the applied voltage and the quantity of magnetic poles in the motor determine speed.	Suitable for usage in mobile robots. Appropriate for systems where transient responsiveness and low-speed performance are not required.
Servo Motor	Can depend on either AC or DC power source	works in a closed-loop control system that makes use of encoder or resolver feedback.	Often seen in pesticide-spraying system because of their precision and controllability. Servo motors' excellent speed control is crucial to the effective application of insecticides.

2.2.2 Traction

The most often used traction system kinds are wheels and tracks. In addition to improving weight distribution on the soil, which lowers surface disturbance and compaction, the track system also improves traction, particularly in loose soils. Although the track system is widely used in big, high-performance equipment, it has a high maintenance cost. For the Agricultural Mobile Robot, cost-effectiveness, low power consumption, and direction precision are more important qualities. These are not necessary features. Wheeled systems fit the project's criteria better since they are less costly and can handle the project's restricted need for traction and load distribution. We used a four-wheel system in this investigation, and we added independent traction to each wheel to improve the vehicle's capacity to handle rough terrain. The system will be sized with complete traction.

2.2.3 Structure or Frame

The structure or frame of automated pesticide spraying robots in the current market can be described in terms of material, design, and size:

Material

- Based on journal, it states that robots handle dangerous chemicals and work in outdoor settings, it follows that the material needs to be strong and perhaps waterproof (Kassim *et al*, 2020).

Design

- The automated pesticide spraying robot's frame design is essential to its operation. Since the robots are meant to function independently, their frames must have room for a variety of parts, including sensors, spraying systems, and maybe solar panels for electricity. The sprayer boom should be controllable with flexibility in the design, and the robots may include artificial intelligent (AI) for autonomous operation and plant recognition based on the (Mustafid *et al*, 2021) research.

Size

- Kassim, 2020 also states that although there are many different sizes of automated pesticide spraying robots, one example from the search results shows a robot that is 1.22 meters (2 feet) long and 2 metres tall. The dimensions are set by the specifications needed to operate in greenhouses and agricultural areas. The robots' size is optimised for accurate and effective pesticide administration, and they are built to function independently without human assistance (Kassim *et al*, 2020).

In conclusion, the construction and frame of automated pesticide spraying robots are made to last, to fit a variety of parts, and to maximise independent functioning. The particular application determines the size of the robots, and the frame's material should be robust and maybe waterproof. It might be required to consult the technical specifications supplied by the robots' makers in order to obtain precise information about the composition and layout of the frames. The example of structure for pesticide robot are shown in figure 2.3.

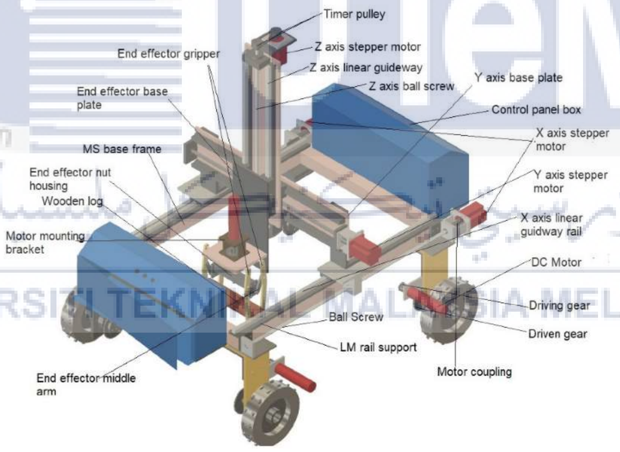


Figure 2.3: Structure of automated pesticide robot by (Kassim et al, 2020)

2.2.4 Power Supply or Circuit

Milan, 2018 in the journal states that an Automatic Pesticide Spraying Robot was designed and developed based on farming. The robot operates on a 33V (12+12+9) DC battery. Figure 2.4 below shows the circuit diagram for pesticide spraying robot. It uses a DC motor-pump set for spraying pesticide on the farm. The robot is designed on a four-wheel car base mechanism and is controlled through remote switches. The spray nozzle is arranged at variable distances as required between the crops. For controlling spreading, switches are arranged, and a pesticide level indicator is also put in place so the operator can easily see the level of pesticide in the tank (Milan *et al*, 2018)

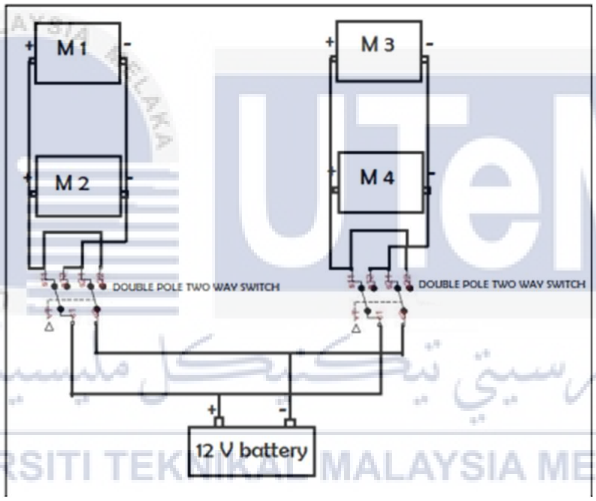


Figure 2.4: Circuit diagram of controlling a robot by (Milan et al, 2018)

Otherwise, based on the research, they mention that a comprehensive review on agriculture-based pesticide spraying robot discusses various technologies used for spraying pesticides on crops. The study considers the last 15 years of spraying technologies that are automated robots using ARM7 microcontrollers, automated seed sowing, grass cutting and pesticide sprayer robot using bluetooth or android app, pesticides spraying robot by using video processor, pesticides spraying robot by using image processing (Kanna and Ragunath, 2020).

Next, the agricultural pesticide spraying robot paper discusses the design and implementation of a semi-autonomous anti-pesticide spraying and insect repellent mobile robot for agricultural applications. The input pictures captured by a camera are what the robot uses to function. A machine learning approach is used to analyse these photos and identify any illnesses that may be present on the leaves, stems, or plants. Along with predicting the cure, the machine learning approach also identifies the disease's exposure region. An L293d motor driver controls the robot's mobility, while a Raspberry Pi 3 handles the embedded system or processing. The machine learning approach uses Python code to train the robot using pre-defined photos (Priya *et al*, 2022). Finally, Chavan, 2020 mention that the solar powered automatic grass cutter & pesticide spreading robot paper discusses the interfacing of a hybrid power system to the grid using STATCOM & power quality improvement (Chavan *et al*, 2020).

2.2.5 Steering System

The kinematic model is the mathematical description of a mobile robot with skid steering. The robot is assumed to travel on a flat surface in the formulation. Four wheels make up the robot's construction; for instance, there are two wheels on the right and two more on the left. The differential drive system, which arranges the left and right wheels separately, is what allows the robot to move (Abdullah *et al*, 2016).

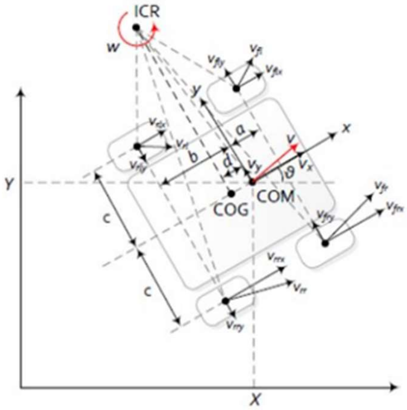


Figure 2.5: Kinematic diagram of robot by (Abdullah et al, 2017)

Figure 2.4 above shows the illustration of 4 wheeled mobile robot kinematic. The robot's motion may be appropriately identified and expressed in the local frame connected, with its centre of mass (COM) serving as the origin. The vector configuration in global coordinate is,

$$q = (x\ y\ \theta)^T \epsilon\ R^T$$

Where:

X, Y and θ are the position and orientation of robot’s structure. Then, the coordinate of attached frames on robot’s COM and velocity generalized is shown below.

$$\begin{matrix} x \\ y \\ \theta \end{matrix} = \begin{matrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{matrix} = \begin{matrix} V_x \\ V_y \\ W \end{matrix}$$

Then the nonholonomic operational constraint that limit lateral skid will be defined in equation below.

$$V_y - dw = 0$$

$$[-\sin\theta\ \cos\theta\ -d][\dot{X}\dot{Y}\dot{\theta}]^T = A(q)\dot{q} = 0$$

Then the control input vector at kinetic level will be defined as shown below.

$$\dot{q} = S(q)\eta$$

$$S(q) = \begin{matrix} \cos\theta & -d\sin\theta \\ \sin\theta & d\cos\theta \\ 0 & 1 \end{matrix}, \eta = [V_x\ W]^T$$

The equation's broad range of applications in several scientific and industrial domains makes it a vital tool in linear algebra, according to the conclusion. One of the most important functions in a lot of algorithms and systems is the ability to rotate in a two-dimensional environment.

2.3 NAVIGATION SYSTEM

Kanse, 2021 in the journal, titled “Smart Pesticide Spraying Robot”, states that some robots have integrated multi-sensor module obstacle avoidance, driving control, spraying mechanism, system building, and complete route planning and navigation systems. Obstacle avoidance, spraying, and sensor integration simulations and analyses are all included into these robots. Next, it also mentions that route planning and navigation algorithms are essential for a pesticide spraying robot's smooth and productive functioning. By directing the robot along a predefined route, these systems make sure that the entire crop or field is covered. The robot is typically equipped with various sensors and algorithms that allow it to navigate autonomously. This includes the ability to avoid obstacles, which aids the robot in navigating through any that it may come across in the field. Making a map of the field or crop area and figuring out the best course for the robot to take is the process of the route planning system. The goal of this approach is to guarantee that the robot traverses the whole space without going over or underestimating any areas. The robot's actual travel along the predetermined path is handled by the navigation system, on the other hand. Numerous technologies may be used for this, such as computer vision and other sensor-based systems for indoor or greenhouse applications, or GPS for outdoor applications. Finally, route planning and navigation algorithms are essential to the autonomous and effective operation of pesticide spraying robots. They allow the robots to cover the full target area without missing any locations or needlessly repeating any areas (Kanse *et al*, 2021).

Next, Zhang, 2022 mentions that a navigation system called the beidou navigation satellite system (BDS) or inertial measuring unit (IMU) Integrated Auto-Navigation System was created to increase the precision and dependability of orchard spraying robots. IMU, a navigation controller, servo motors, and a real-time kinematic positioning-Beidou satellite navigation system (BDS) receiver make up this system. While the IMU offers real-time information about the robot's orientation and velocity, the BDS receiver delivers high-precision, real-time positioning data. The servo motors carry out the motions that the navigation controller commands the robot to perform. The system also incorporates a path-tracking control algorithm that combines the spraying robot's kinematics and pure pursuit models. This algorithm makes sure the robot moves steadily and smoothly along the predetermined path. Route planning is done based on the features of the orchard landscape. This guarantees that the robot, on any surface, can navigate the orchard efficiently. To sum up, the BDS or IMU Integrated Auto-Navigation System is an advanced navigation system that combines a number of technologies to guarantee precise and dependable navigation for robots that spray orchards (Zhang *et al*, 2022).

Otherwise, Tiwari, 2020 mention in their research paper that when discussing a robot that sprays pesticides, autonomous navigation refers to the robot's capacity to move around and function on its own in a certain setting. Usually, this entails the robot using a variety of sensors and algorithms to sense its surroundings, form judgements based on those judgements, and then take appropriate action. A robot may, for instance, identify crops and pests using cameras and machine vision algorithms, figure out the best route across a field, and then follow this route while applying pesticides. Such as one system that has been discussed in the research, with the use of a visual servo system, this method incorporates artificial intelligence into agriculture and allows the robot to navigate autonomously1. The robot recognises the location of the plant and applies a spray on the target, minimising the damage that pesticides due to the applicators and significantly lowering labour costs while boosting productivity. Other system that been discuss in research paper, Terra*,* 2021 state that optimises the use of pesticides by automating sprayers with a robotic system that uses computer vision and individual nozzle on/off control2. Low-cost components used in the system include Raspberry Pi, Arduino boards, solenoid valves, pressure and flow sensors, smartphones, and webcams (Terra *et al,* 2021). To sum up, in order for pesticide spraying robots to navigate autonomously and effectively within their surroundings, a variety of sensors and algorithms are used (Tiwari *et al*, 2020).

Finally, in research paper titled "LIDAR-based Navigation Rover for Fields with Smart Pest Sprayer using Machine Vision", it mentions that light detection and ranging (LIDAR) can allow autonomous navigation in the context of a pesticide spraying robot. The robot senses its surroundings and chooses its path based on LIDAR data. This may entail spotting crops, pests, and other items in the surroundings, figuring out the best route across a field, and then following this route while applying pesticides. Light detection and ranging, or LIDAR for short, is a remote sensing technique that measures distances using light in the form of a pulsed laser. With applications in geodesy, geomatics, archaeology, geography, geology, geomorphology, seismology, forestry, atmospheric physics, laser navigation, aerial laser swath mapping (ALSM), and LiDAR contour mapping, it can be used to produce high-resolution maps. One system that being discussed in the research paper is the system using LIDAR data, the system creates a robust and wide-ranging strategy that allows autonomous robots to navigate around a cereal field. Lines are extracted from 2D point clouds using the approach that is described. The retractable sprayer boom can be used in an outdoor environment, such an open-air farm, or in a greenhouse (Thamaraiselvan *et al*, 2023). Another system, discussed in the paper, Abanay, 2019, mention it enables precise steering between strawberry crop rows, detects the end of the row and automatically switches to the next, all while spraying pesticides. Robot Operating System (ROS) was used to construct the primary control system, which was based on a 2D LIDAR sensor. To determine the robot's heading and lateral offset with respect to the crop rows, the collected 2D point cloud data is processed. In conclusion, LIDAR data is used in LIDAR-based autonomous navigation in pesticide spraying robots to allow the robot to sense its surroundings and manoeuvre on its own. As a result, the robot can cover the full target area more effectively and efficiently, without missing any locations or repeating any areas needlessly (Abanay *et al*, 2019).

2.4 Structure Analysis for Mobile Robot

Based on the journal titled "Mobile robot structure design, modelling and simulation for confined space application", it shows the simulated design using embedded analysis programme from SolidWorks software. The mobile robot dimension is 15-inch length, 15 inch wide and 4.4 inch height, the example of robot is shown in figure 2.6 below.

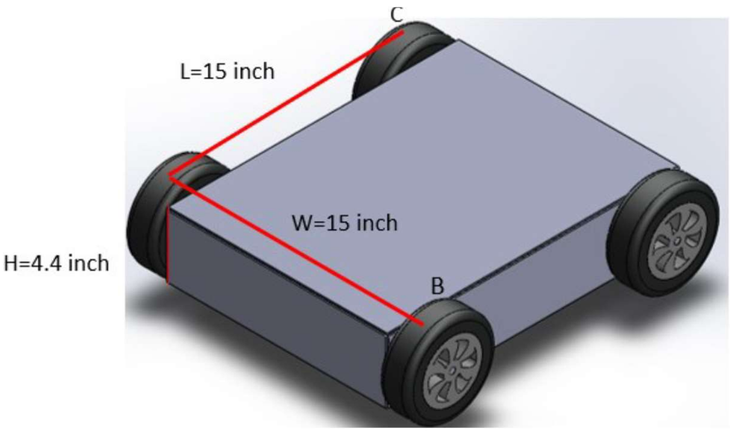


Figure 2.6: Design of mobile robot (Abdullah et al, 2017)

The main reason to run this analysis test is to analyse the structure endurance and displacement to the pressure. The parameters used for the study will determine the result of the simulation. The fixture was positioned at the motor's shaft, and the input force was adjusted at 300 Newton (N). According to the study, the construction of the design robot is appropriate for operation in a limited location. The visualization is shown in figure 2.7 below. For the structure, the mixed mesh is chosen based on the displacement and stress analysis. The mixed mesh has the ability to equally distribute force to each node, with a maximum total load of 300N that can be applied to the structure a load that is more than the 20N that an e-nose can handle. The example of mixed mesh is shown in figure 2.8 below.

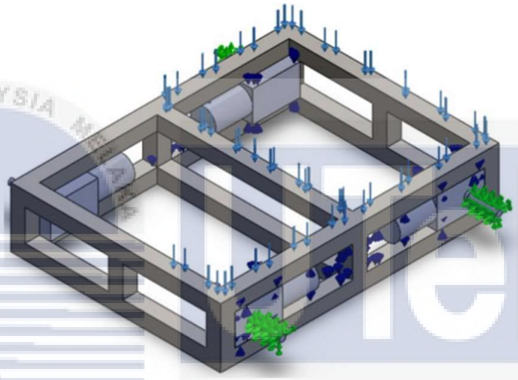


Figure 2.7: The full assembly structure by (Abdullah et al, 2016)

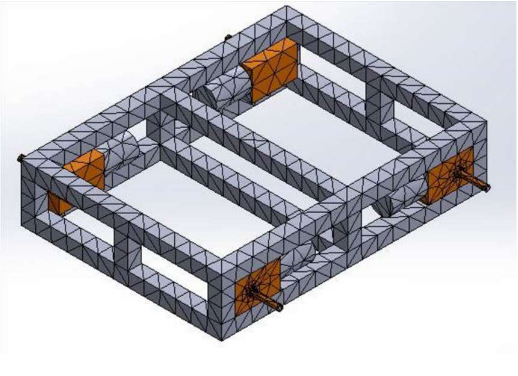


Figure 2.8: Mixed mesh of mobile robot structure by (Abdullah et al, 2016)

Software mention above is then used to examine the mobile robot's body structure by using Von Mises Stress test. The test is as a gauge that will detect and determine if the structure begun to yield for certain or specific point. The result from Von Mises Stress is shown in figure 2.9 below. Finally, the analysis's objective is to locate the structure's yield point so that the strength of the mobile robot body structure under load may be assessed (Abdullah *et al*, 2016).

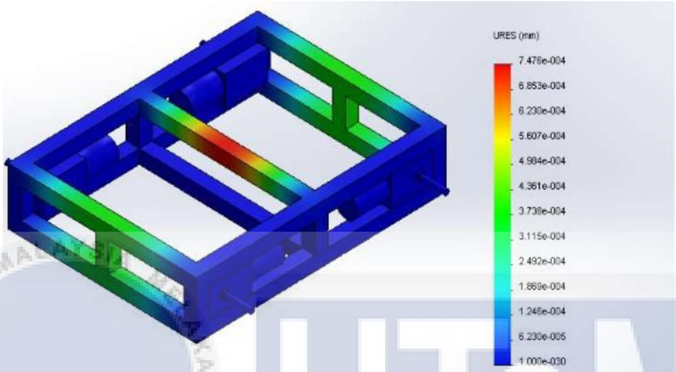


Figure 2.9: The example of Von Mises Stress test by (Abdullah et al, 2016)

2.5 Industry Standard for Electronic Component

For electrical goods to be reliable and safe, industry standards for electronic components are essential. These standards address a wide range of subjects, such as electronic component design, production, testing, usage, and end-of-life processes. It is required of businesses who produce or import electrical and electronic equipment to adhere to these requirements. There are a lot of standards in term of electronic standards such as IEC 61508. For the management of Functional Safety in relation to Electrical, Electronic, and Programmable Electronic Safety Related Systems (E/E/PES), IEC 61508 is an international standard. It offers a general framework for utilising a risk reduction technique to achieve functional safety. The standard addresses the stages to achieve functional safety in a methodical and auditable way by using the idea of the "safety lifecycle" as a framework (Jackson *et al*, 2008). After being in circulation for more than a decade, IEC 61508 has become a vital global standard for the secure use of programmable electronic systems in safety-related contexts. Setting aside aerospace and military uses, this standard is most pertinent to industrial applications (Bell, 2010). The overall safety of the Equipment Under Control (EUC) and the EUC control system is defined by IEC 61508 as functional safety. This safety is dependent upon the proper operation of the E/E/PE safety-related systems, other technological safety-related systems, and external risk reduction facilities.

Next is ISO 10218. An international standard called ISO 10218 specifies safety standards for industrial robot and robot system design and integration. ISO 10218 can be divided into two parts. Firstly, ISO 10218-1 which is focused on the robot. An international standard called ISO 10218-1 lays out the safety specifications for industrial robots. As a component of the ISO 10218 series, it addresses safety in the development and incorporation of industrial robots and robot systems. Numerous nations, including Europe (represented as EN ISO 10218-1), the United States (ANSI/RIA R15.06), Canada (CAN/CSA Z434), Japan (JIS B 8433-1), and the Republic of Korea (KS B ISO 10218-1) have all adopted ISO 10218-1 as a critical safety standard for industrial robots (Universal Robots). The standard is always changing to stay up with the latest developments in technology. In the context of collaborative robotics, where people and robots share a workplace, it is especially pertinent. The ISO/TS 15066 technical specification was developed to enhance and govern the safety standards for robots, collaborating systems, and their work environments (Universal Robots).

A number of robotics and automation standards have been produced by the IEEE (Institute of Electrical and Electronics Engineers). The IEEE 1872TM-2015, or IEEE Standard Ontologies for Robotics and Automation, is one of the important standards. The Core Ontology for Robotics and Automation (CORA), which represents the basic ideas from which additional specialised ontologies may be constructed, is included in this standard. Furthermore, the Ontological Standard for Ethically Driven Robotics and Automation Systems, IEEE 7007TM-2021, can serve as a roadmap or point of reference for the creation of robotics and automation systems. Because they offer a common framework and criteria for the development and use of related technologies, these standards are essential to the advancement of the robotics and automation fields, these statements are taken from (IEEE SA Working Groups, 2022).

Furthermore, is Electronic Industries Alliance (EIA). The industry group EIA creates standards for the electronics manufacturing industry. It gives specialists in the field a place to collaborate on standards and publications in key technological areas including internet security, telecommunications, consumer electronics, electronic information, and electronic components. EIA standards are created in compliance with the American National Standards Institute (ANSI) and are intended to serve the public interest by removing miscommunications between buyers and sellers, promoting product improvement and interchangeability, and helping buyers choose and acquire the right product for their specific needs. Many firms in the electronics sector have embraced and applied EIA standards, which are used worldwide. Connector test protocols, EIA standards projects, EIA weekly date codes, component bulletins, soldering techniques, and EIA source codes are just a few of the many subjects they address. In conclusion, the EIA is essential to the electronics manufacturing sector because it offers a forum for the creation of guidelines and publications that guarantee the calibre and uniformity of electronic component production and use (EIA Standard, 2016).

2.6 Related Research

In “Robotic in-row weed control in vegetables” research paper, it explains a cutting-edge robotic device intended for vegetable crop in-row weed management. The robot applies pesticide droplets directly to weeds without harming crops, greatly lowering the need for herbicides. It does this by using machine vision to distinguish between crops and weeds. The three-wheeled robot's design is sturdy, affordable, and manageable. While reducing weight and expense, an atypical design with a single off-center rear castor wheel promotes stability and manoeuvrability in row crops. With a hybrid power system that combines a generator and battery bank, the robot can run almost constantly and meet peak demand for electricity. Both in lab and field experiments, the Drop-on-Demand (DoD) system efficiently targets weeds with little herbicide use by controlling individual chemical droplets. The robot is powered by two HBL5000 brushless motors, producing a maximum driving power of 10 kW. This is more than enough to move the robot's 500 kg weight plus the tool across rough terrain. The robot offers growers a useful tool while signalling a change in the direction of lowering the dangers to the environment and human health connected with weed eradication (Utstumo *et al*, 2018).

Next is journal titled “An intelligent spraying robot based on plant bulk volume” explore the creation of an automated spraying system to save personnel costs and minimise harmful impacts on human health. In order to achieve uniform coverage and effective pesticide application, the robot function uses a Kinect camera to calculate the bulk volume of the plants and then sprays in accordance with that calculation. Additionally, the robot maintains spraying quality at high plant levels with a 19% detection error, guaranteeing that the full height of the plant is treated consistently. The robot can navigate across farmland and greenhouse conditions with ease because of its lightweight and small mechanical build. The wheels and the DC motor used for the spraying mechanism are driven by an electric motor within the robot. The essay highlights how automation and clever volume prediction may enhance agricultural spraying operations using robots. The robot is a viable answer for agriculture in the future because of its small size, effective application of pesticides, and even coverage (Hejazipoor *et al*, 2021).

Other than that, paper titled “Agricultural rout planning with variable rate pesticide application in a greenhouse environment” presents the construction and operation of a mobile agricultural robot used for the application of pesticides. The robot weighs 8.6 kg, has a 0.28 m height, and a circular base with a radius of 0.22 m. It has two primary wheels that are propelled by a DC motor with an incremental encoder and supported by a castor wheel. An Arduino Mega drives the motors using an IC driver MD10C 10A, which controls the robot's movements. The components of the pesticide spray activity, the technique for carrying out the spraying procedure, and the duration of travel computation are also included in this study. The robot moves in two parts: first, it corrects its angle and targets the next node, then it moves as quickly as possible to reach the desired node. The overall trip time and the rotation angle for each visit sequence or route are obtained using the time functions for linear and rotational motions. The robot issue for the greenhouse is further formulated in the study as a vehicle routing problem (VRP), with deterministic changing demand, a single depot, and a single vehicle. The VRP aims to reduce the overall trip time, total rotational angle, and total travel distance. The formulation of the issue, the geometry of the greenhouse, and the discrete model of the vacant area on the greenhouse plan are also covered in this work. The paper's primary innovation is how the path-planning problem for an autonomous robot operating in a greenhouse setting is solved by using a variable spray operation (Zangina *et al,* 2021).

The paper "Development and Performance Test of a Height-Adaptive Pesticide Spraying System" provides a height-adaptable pesticide spraying system for plants. A depth sensor and a spraying system with several nozzles at various heights are part of the system that is mounted on an autonomous guided vehicle. The application of a Kinect sensor for precise spraying and plant height detection is the main topic of this article. The sensor is used to gather visual data, and to optimise the spraying system's open or closed condition for various plants of varying heights, the depth and colour data of the figure are extracted and examined. The working concept of the system, sensor introduction and calibration, depth data gathering, processing of colour and depth data, and plant height measurement are all covered in detail in this article. The Kinect sensor, which gathers visual data and transmits it to a controller for processing and subsequently controlling the spraying system, is the foundation of the system's operation. The analysis of colour data to identify green plants for precision spraying and the translation of depth data into real distance are also covered in the study. The suggested technique adjusts to the plant's height in order to accomplish the goal of precisely applying pesticides (Chen and Meng, 2018).

In “multi-objective path planner for an agricultural mobile robot in a virtual greenhouse environment” paper explains the significance of bringing modern agricultural methods to India, especially when it comes to pesticide use, in order to protect farmers' safety and maintain crop health and output. It presents the idea of an AGROBOT, a remote-controlled agricultural robot created to solve the problems with conventional pesticide application techniques. The paper emphasises the need for better agricultural practices while highlighting the possible advantages of deploying remotely operated or piloted robots to spray pesticides. A summary of current developments in digital farming is also given, including the creation of robots to do a range of agricultural duties including weed control, crop scouting, off-season cultivation, seed planting, and soil preparation. The construction of an electric pesticide-spraying vehicle with live streaming capabilities for improved observability and remote-control operation via an RC transmitter is the novel idea put forward in the publication. The report also notes that a number of academic institutions and researchers contributed to the creation of the AGROBOT and discussed how it would lessen the need for human intervention in agriculture (Gupta *et al*, 2022).

Plus, paper from Martin *et al* discussed the creation of a precision agriculture-related control architecture for pest detection and treatment. It highlights the necessity of adding more features to the navigation stack in order to guarantee localization quality and recovery behaviours in the event that navigation becomes inaccurate, or localization quality is lost. By utilising the ROS pluginlib method, the architecture enables the construction of new robotic jobs and supports various global, relative, and precise navigation modules. The capabilities layer, which contains ROS nodes controlling sensor and actuator components and offering robot functions like autonomous navigation, manipulation, and inspection, is also highlighted in the document. Modern robotic algorithms are mentioned, including “MoveIt!” for creating and executing collision-free manipulation trajectories, GMapping for creating maps, the Navigation Stack for planning global and local pathways, and URDF for creating a united robot description. It also talks about creating more nodes to meet system needs and allow free movement about the greenhouse by using the European Global Navigation Satellite System for localization (Martin *et al*, 2021).

Finally, the paper "Identification of Fruit Tree Pests with Deep Learning on Embedded Drone to Achieve Accurate Pesticide Spraying" provides research on the establishment of an intelligent pest recognition system using edge intelligence and deep learning. The goal of the research is to control the Tessaratoma papillosa (Drury) pest issue, which seriously harms Taiwanese longan crops. The research applies a Tiny-YOLOv3 neural network model based on an embedded system NVIDIA Jetson TX2 to identify Tessaratoma papillosa in the orchard in real-time. A detecting drone is used to take pictures of the pest. The best path for the agricultural drone to spray pesticides is then determined by considering the locations of the pests. The training of the YOLOv3 model for object recognition, the use of unmanned aerial vehicles (UAVs) for precision agriculture, and the application of deep learning to agricultural inspection are all covered in this work. The YOLOv3 model's training, labelling, augmentation, and acquisition of data are all covered by the authors. The average number of training sets for every recognition category will increase recognition accuracy, according to the study's findings. The study approach, including the hardware environment, implementation techniques, and experimental outcomes, is thoroughly described in the publication (Chen *et al*, 2020).

Table 2.2 below shows the different between each research paper about agriculture application, the country that robot being used or develop, microcontroller used, whether the system is fully or semi-automatic, motor type, agriculture environment, machine category, tank capacity and finally nozzle type that being used in each pesticide robot.

Table 2.2: Different between each research paper

Authors and year	Agriculture applications	Country	Microcontroller	Automatic or Semi-automatic	Motor Type	Environment	Machine category	Tank Capacity
Utstumo et al (2018)	Vegetable Crops	Norway	CAN-bus Module	Fully automatic	Brushless DC motor	Open field garden	3-Wheeled mobile robot	1.5 liters
Hejazipoor et al (2021)	Bulk Plant	Iran	Arduino Mega	Fully automatic	DC motor	Greenhouse	Mobile robot	2.5 liters
Zangina et al (2021)	General Plant	Egypt	Arduino Mega	Semi-automatic	DC motor	Greenhouse	Mobile robot	1 liter
Chen and Meng (2018)	Height Plant	China	Arduino	Semi-automatic	DC motor	Greenhouse	Mobile robot	Not stated
Gupta et al (2022)	Vegetable Crops	India	60A Cytron Board	Semi-automatic	Dual DC motor	Open field garden	Mobile robot	15 liters
Mahmud et al (2019)	General Plant	Malaysia	Arduino Mega 2560	Fully automatic	DC motor	Greenhouse	Mobile robot	1 liter
Mustafid et al (2019)	Cabbage Cultivation	Thailand	Arduino Mega	Semi-automatic	Not a mobile robot	Open field garden	Backpack	Not stated
Raja et al (2023)	Lettuce	United State	CompactRio-9045	Semi-automatic	DC motor (solenoid)	Polybag of sapling	Stick robot system	2 liters
Hafeez et al (2023)	Vegetable Crops	Asia	Arduino UNO and Raspberry Pi	Semi-automatic	8 Brushless DC motor	Open field garden	Drone	6 liters
Martin et al (2021)	Vegetable Crops	Europe	ROS	Fully automatic	Not stated	Greenhouse	Mobile robot	Not stated
Chen et al (2020)	Vegetable Crops	Taiwan	Raspberry Pi 3	Semi-automatic	Not stated	Open field garden	Drone	4 liters
Tufail et al (2020)	Tobacco	Pakistan	Raspberry Pi 4	Semi-automatic	Servo motor (spray system)	Open field garden	Boom spray	320 liters
Shahrooz et al (2020)	General Plant	Iran	Not stated	Semi-automatic	Not stated	Open field garden	Drone	10 liters
Terra et al (2020)	General Plant	Brazil	Arduino UNO	Semi-automatic	DC motor (solenoid)	Open field garden	Boom spray	320 liters
Ozlüoymak et al (2022)	Vegetable Crops	Turkey	NI myRIO 1900	Fully automatic	GAMAK and AGM714b motors	Greenhouse	Conveyor spraying system	Not stated
Utstumo et al (2018)	Vegetable Crops	Norway	CAN-bus Module	Fully automatic	Brushless DC motor	Open field garden	3-Wheeled mobile robot	1.5 liters

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter outlines the research's suggested methodology, which consists of the general procedures that will be followed to finish the study. The chapter will begin with planning and progressing through the improvement of the robot's mobility by adding a new motor and safety of the circuit by using a waterproof and lightweight rooftop. This research will use the flow chart as shown in figure 3.1. The specification and specifics of earlier study will be carefully consulted before the material selection, designing, processing, and testing are provided. The primary tenet of methodology is offering appropriate approaches, suggested instruments, and strategies to finish this study. The paragraph summarises the contents of a chapter or section that will go over the methodology, process, and data analysis of a research study.

Figures 3.1 and 3.2 below show the flowchart for the methodology part in this project. This flowchart will be used to finish this report.

3.2 Flow Chart

3.2.1 Flow chart for PSM 1

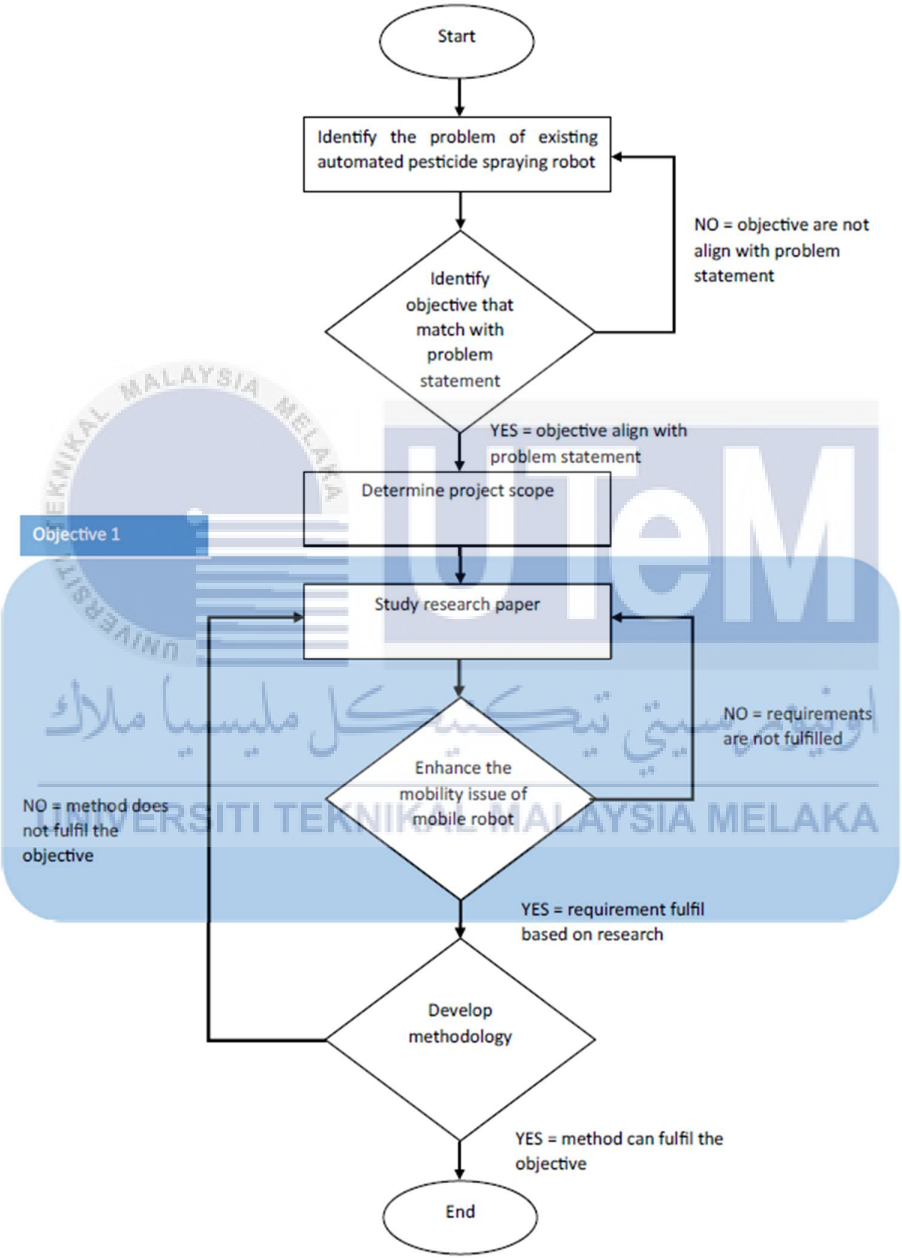


Figure 3.1: Flow chart PSM 1

3.2.2 Flow chart for PSM 2

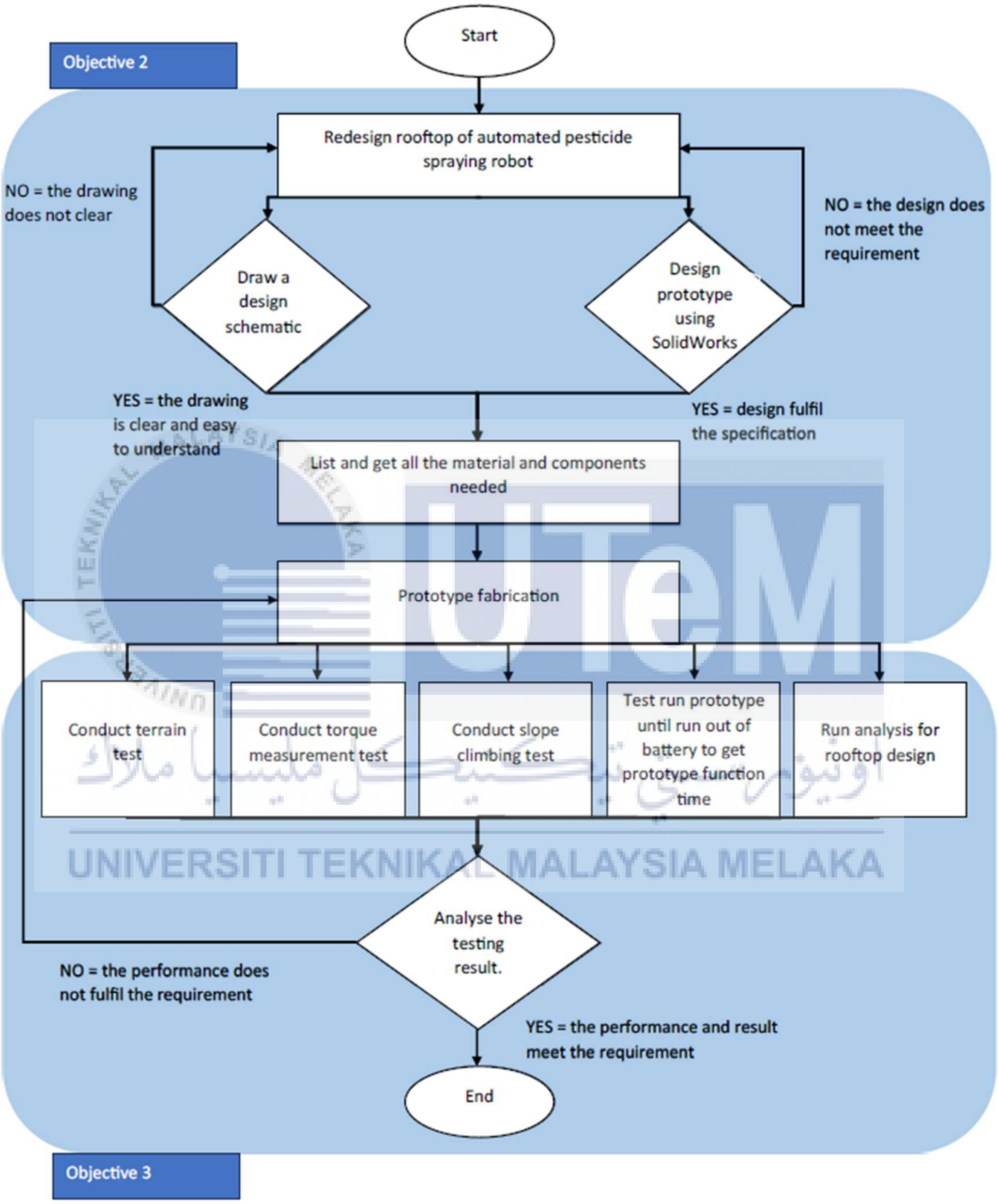


Figure 3.2: Flow chart PSM 2

3.3 Study Research Paper

As shown in figure 3.1, the project starts by doing research on engineering journal and research paper about existing pesticide spraying robot in current market. The aim of this study is to collect data on new and current pesticide spraying robot developments and technologies in market, with a particular emphasis on mobility. This is important because by extracting all of the information, we can contribute to improve the mobility of current pesticide spraying robot. Finally, by studying on research paper we can get a fully understanding on the goal of this project. The goal is crucial to make this project successful.

3.3.1 Motor choosing

The selection of type of motor needs to do carefully. This is because, the selection involves by considering several factors and its suitability. In addition, each motor has their own function, and the selection must fulfil the requirements. For example, the requirement is enhancing the mobility of robot, so that the motor that need to choose is motor that can give wide speed range and high torque-to-speed ratio. Based on study, the most suitable motor is DC motor. Other than that, most mobile robot uses DC motor because of its power output, efficiency, simple control system, wide speed range and high torque at low speed. Plus, the current robot uses direct current power source and DC motor. So thar, there will be a challenge by using a different motor than DC motor. The specification of motor that being choose is as shows in table 3.1 below.

Table 3.1: Motor specifications

Model	A58-555
Operating Voltage	12 Volts
Motor Weight	400g +- 20g
Rated Current	1.6 Ampere
Stall Current	5 Ampere
RPM	80 rpm

3.3.2 Concept design

The important parameter for robot's rooftop must be identified first to avoid the error design. If the error occurred, then the objective cannot be achieved. Other than that, the good result also cannot be obtained. The first thing that need to be considered in designing the rooftop is complexity. This is because, the less complexity the easier to fabricate the rooftop. However, the main objective of designing the rooftop need to put number one. The design of rooftop must be solid and did not have any gap with the robot's body to make sure that the circuit is fully secure. Finally, the material of rooftop must be waterproof which is the material that being used in this fabricate is Polylactic Acid (PLA) that have high-modulus thermoplastic with high, density, stiffness and resistance to water. However, in the analysis using SOLIDWORK there is no PLA material so that in this report the material will be used to analysis is the material that have similar properties such as Polyethylene Terephthalate (PET). So that. it is appropriate for applications where water resistance is crucial due to its molecular structure and characteristics, which prevent it from absorbing water. Lastly, PET is widely used in many different applications since it is a lightweight material.

3.3.3 Design brief

One step in the methodological process is designing the product, which comes before building the rooftop robot for automated pesticide spraying. The research and studies that are stated in Chapter 2, the literature review, are what led to the creation of this project's design. The concept design will be designed in smart designing software such as SolidWorks. By using this kind of design software, we can state the dimension clear and accurately to avoid any technical issues for fabricating process using 3D printing. Plus, SolidWorks provides designers with a wide range of tools that enable them to conduct in-depth engineering analyses of proposed designs. This results in significantly decreased errors and higher accuracy when designing products, leading to better designs.

3 designs were proposed in this project, each design has their own advantages and disadvantages however it still fulfils the main purpose of the project aim. All of the design concept that has been shown in figure 3.3 are dimension 660mm×360mm.

The first design as shown in figure 3.3 (a) and (b) is design that divided into 12 parts that need to be assembly by whether using screw, glue or bolt and nuts. This is due to the design did not have feature like snap fit that make the 3D printed part easy to be assembly. However, this bond is strong and rigid for heavy duty use like usage of automated pesticide spraying robot.

Next, second design concept as shown in figure 3.3 (c) and (d) is design that consist of 12 parts that need to be assembly. However, this design concept has snap fit feature that can make the printed part easy to be assembly. Nevertheless, the snap fit design only can be used for big sized of part due to the shape of snap fit design that cannot be fit at the small part. The snap fit shape is in square and designed at the bottom of the rooftop design. This kind of snap fit shape is easy to be design and fabricated though the tie between part not too rigid.

The last design concept as shown in figure 3.3 (e) and (f) also consist of 12 parts using the snap fit feature. This design is using a complex shape of snap fit that can make the connection between one and another part to be tough and rugged than design concept two. This snap fit design can connect the big parts and also the side part of the rooftop as shown in figure 3.3 (e) and (f).

(a) (b)

(c) (d)

(e) (f)

Figure 3.3: Designs concept for rooftop of automated pesticide spraying robot

3.4 Analysis and Evaluation

Various analyses and evaluations can be conducted to determine the ultimate design. It is necessary to do this analysis and assessment as evidence, taking the evaluator's viewpoint into account that might have an impact on the final design. Since we are now operating as salespeople and want to know what clients think before they buy our goods, it will be very difficult to move the research process forward without any analysis and review. The product will then be improved with the help of this feedback. One of the most efficient methods to get the feedback is to conduct a Google Form survey.

3.4.1 Google form characteristics

The Google Form survey is intended to serve as a tool or component to assist clients in assessing design concept ideas. Additionally, this form will provide them a general understanding of what they are reviewing and why they are evaluating the design concept. Without this Google Form, opinions cannot be spoken, and it will be difficult for us to decide which design concept is best. 8 questions that are relevant to the new, simplified redesign product's conclusions have been generated for this reason. The question characteristic is as below:

1. Prefer design.
2. Simple design.
3. Functionality of the design.
4. Flexibility.
5. Easy to be assembly.
6. Easy to be disassembly.
7. Efficient connections between parts.
8. Strong and rigid connection between parts.

3.4.2 Grading scheme

In order to assess the Google Form, the indications or markings that attest to the design's selection and qualification must be provided based on the preferences of the clients. Table 3.2 below shown the planned grading structure for each given indicator.

Table 3.2: shows the indicator for grading structure

Indication	Description	Marks
✷	Excellent	+2
☆	Good	+1
○	Fair	0
★	Bad	-1
✹	Worst	-2

After the indicator is clearly being stated by evaluator, the marks count can be calculated according to the above grading system. This will include inside the final decision making.

3.4.3 Final decision

The result obtained from the calculation can be compile into tabular form so that it is easier to make a comparison. Comparison will be made according to the total highest mark as shown in table 3.3 Referring to the analysis table, it can be see clearly that design number 3 is the preferable one. As a result, the modelling work will emphasise on the design idea. But this will not be final decision to take in account the modelling work. Logically, me must also concern on the best way to structure to be by considering simplification and number of parts involved.

If referring to the design concept number 3, it has the most rigid and strong connection between parts due to the solid design of snap fit it got.

Table 3.3: Grading analysis

Question number	Design concept		
	1	2	3
1	2	9	17
2	14	4	2
3	1	4	25
4	-1	10	20
5	2	9	21
6	0	10	17
7	3	2	24
8	2	2	25
Total marks	23	50	151

The table 3.3 above presents scores for 8 different design criteria evaluated across three design concepts. Design concept 1 scores highest for simplicity (14) and design concept 2 ease of disassembly (10 tied), while concept 3 excels in functionality (25), flexibility (20), ease of assembly (21), ease of disassembly (17), efficient connections (24), and strong connections (25). Concept 1 has relatively lower scores across most criteria. In terms of total marks, concept 3 leads with 151, followed by concept 2 with 50 and concept 1 with 23. This suggests that while concept 2 is simple and easy to disassemble, concept 3 may be the most well-rounded design, balancing functionality, flexibility, assembly or disassembly, and connection efficiency and strength.

3.4.4 Fabrication of rooftop design

The rooftop design then being fabricated using 3D Printing method. Firstly, because it offers design flexibility. 3D printing allows for the creation of complex geometries that would be difficult such as the application of snap fit feature into the design. By having the snap fit feature the method need to be used must do not have any of the design limitations such as draft angles, separation lines, wall thickness, and undercuts. This allows for greater flexibility and innovation in design. Other than that, snap fit designs can be easily altered and optimized in the 3D model, making them ideal for rapid prototyping where clearance and fit are critical. Next, 3D printing being chosen because of its cost efficiency. The 3D printing process only adds material where needed, contrasting sharply with processes like CNC machining, injection moulding, or other manufacturing technologies, which remove material, leading to potential waste.

In conclusion, 3D printing is a powerful tool for fabricating models, particularly those with complex geometries and features such as snap fit connections. It offers unparalleled design freedom, allowing for the creation of structures that would be difficult, if not impossible, to produce with traditional manufacturing methods. The ability to rapidly prototype designs, test them, and iterate on the design based on the results is a significant advantage of 3D printing. This can lead to substantial cost savings and efficiency improvements in the product development process. Finally, the increasing accessibility and affordability of 3D printers are making this technology more available to individuals and small businesses, further expanding its potential applications. Therefore, for these reasons and more, 3D printing is an excellent choice for fabricating models. However, as with any technology, it’s important to consider the specific requirements of the project to determine if the 3D printing is the most suitable method.

The table 3.4 below shows the specific setting that being set up in the 3D printing in the fabricated method. The setting is in Ultimaker Cura app for Ultimaker S5 Machine. Finally, figure 3.4 below shows the 3D printing machine that being used which is Ultimake S5.

Figure 3.4: Shows the Ultimaker S5 printer

Table 3.4: Shows the setting detail for Ultimaker S5

Setting		**Value**
Quality	Layer height	0.2 mm
Walls	Walls thickness	0.8 mm
	Wall line count	2
	Horizontal expansion	-0.02 mm
Top/Bottom	Top/bottom thickness	1.0 mm
	Top thickness	1.0 mm
	Top layers	5
	Bottom thickness	1.0 mm
	Bottom layers	5
Infill	Infill density	5.0%
	Infill pattern	Octet
Material	Printing temperature	205.0˚C
	Build plate temperature	60˚C
Speed	Print speed	100.0 mm/s
Travel	Enable retraction	Yes
	Z hop when retracted	Yes
Cooling	Enable print cooling	Yes
	Fan speed	100.0%
Support	Generate support	Yes
	Support structure	Tree
	Support placement	Everywhere
	Support overhang angle	60.0˚

3.5 Test the Automated Pesticide Spraying Robot

Validating a prototype is crucial, involving testing it with diverse inputs like nominal, boundary, invalid, and stress cases to assess performance under various scenarios. The resulting outputs are examined against physical rules, scientific principles, and domain expertise to identify potential flaws, inefficiencies, or areas for improvement. This iterative process combines subjecting the prototype to a range of inputs, analyzing the observed results based on fundamental laws and intuitive understanding from subject matter experts, addressing identified issues through design modifications, and repeating the validation cycle until satisfactory outcomes are achieved. By rigorously validating the prototype, developers can ensure the final product meets desired specifications, handles real-world conditions effectively, and adheres to established principles and best practices.

3.5.1 Speed test of the robot on different terrain

In order to assess the robot's mobility, the experiment involves putting it through its paces on four distinct terrains which is flat road, uneven road, grass, and obstacles like fallen branch and fruit brunches. Two distinct speed tests will be conducting such one for the robot carrying a pesticide load and another without carrying the pesticide load will be carried out for each terrain test. After that, the data was examined to confirm the design and get a deeper comprehension of the kinematic and dynamic characteristics of navigating uneven ground. The robot's finishing time will be measured, and a distance of 20 metres will be used for the test for each terrain.

To start the test, firstly, the start and end point will be marked first. The distance between the point will be measured using measuring tape. Figure 3.5 shows the distance of 20 meters is measured for the speed test.

Figure 3.5: The distance is measured before running the test

Next, the robot will be placed at the starting point, and it will be sure that operator is ready with the timer before beginning the test. This is to make sure that there will be no error for this test. Then, when the timer started, the speed channel on controller will be push in maximum capacity simultaneously while following the robot until it reaches the finish line to get the perfect stop time for the test. This test will be repeated for three times to get average reading and accurate result. For the test with pesticide load, again robot will be place at the starting point, then operator will be ready with the timer. Once the test is started, the timer will be start while operator push the maximum capacity for speed channel to make the robot move in maximum power output. Time will be stop only when the robot is fully across the finish line. The time taken for the robot to complete the test for 20 meters will be recorded. This test also will be repeated for three times to get average reading and accurate result. For this both tests, the speed of the robot can be calculated by taking the distance of 20 meters and divide by average time taken to complete the run. Figure 3.6 shows the robot that being tested with and without pesticide load on the flat road.

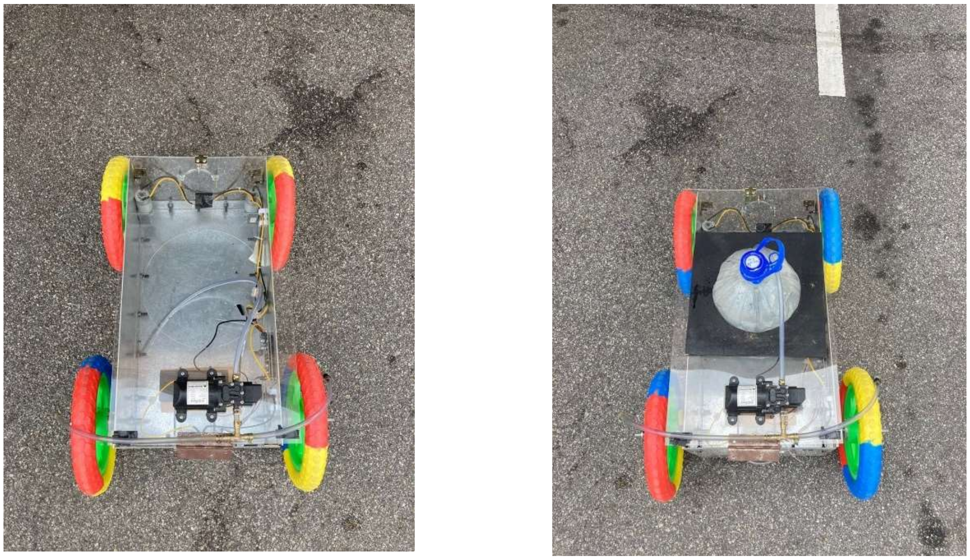

(a) (b)

Figure 3.6: The robot being tested for flat road

The test procedures are repeated to test the speed and amount of time taken on the different terrain. The robot is tested with and without pesticide load on uneven, grass and obstacle with wood and fruit branch road. Figure 3.7 (a and b) shows the robot is tested with and without pesticide load on the grass road. While figure 3.7 (c and d) shows the robot is tested with and without pesticide load on uneven road. And figure 3.7 (e and f) shows the robot is tested with and without pesticide load on obstacle road. Finally, the aim of this test is to measure the velocity of robot. If the time taken of improved robot is lower, then its velocity of power output is bigger than previous robot. This statement will be support by the formula below which is it explain that velocity is equal to the total displacement divided by the time taken. This is a key concept in kinematics, the study of motion.

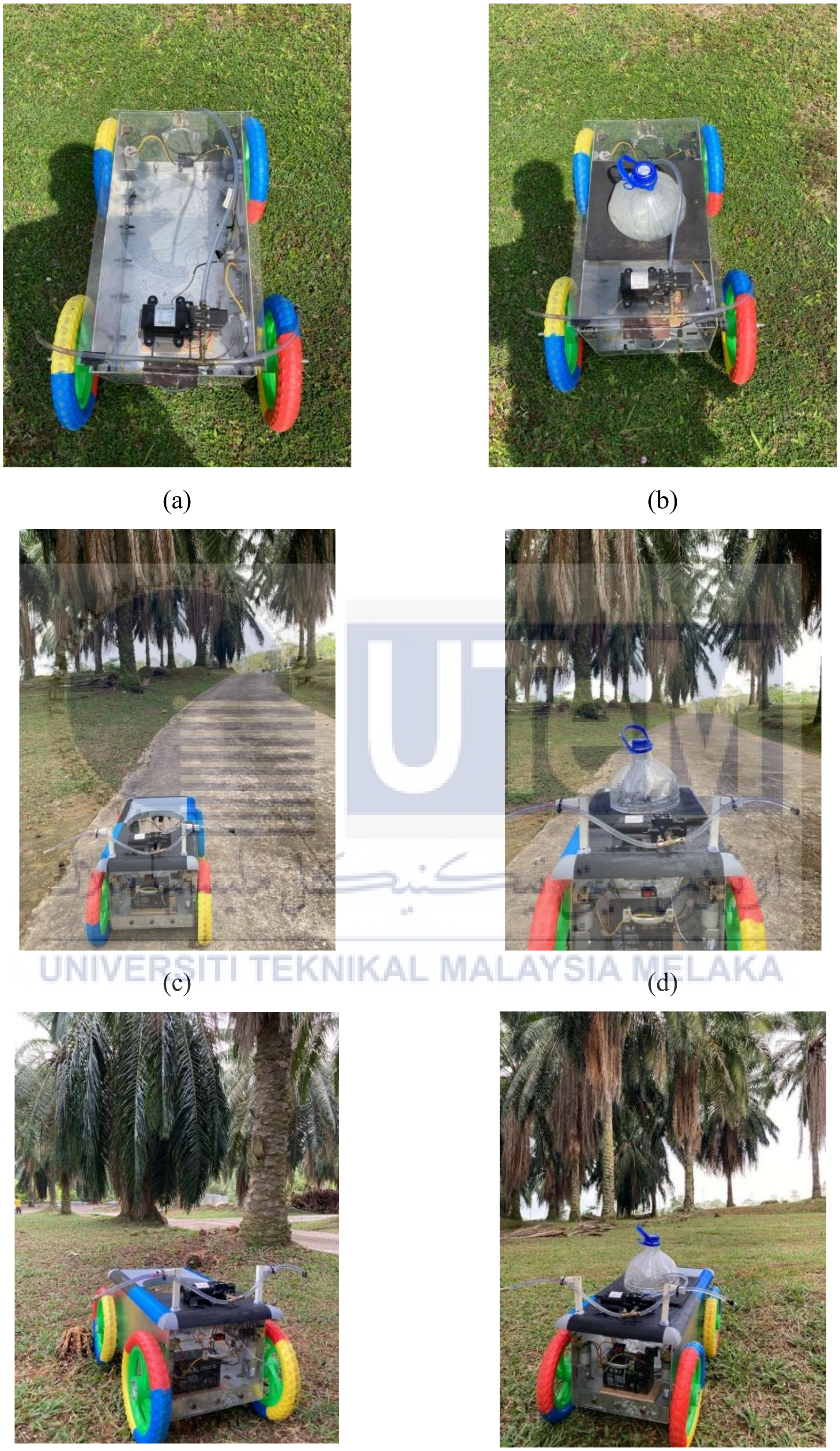
$$v = \frac{d}{t}$$

where:

v = velocity (ms^{-1})

d = displacement (m)

t = time taken (s)



(a) (b)

(c) (d)

(e) (f)

Figure 3.7: The robot being test in different kind of environment and challenge

3.5.2 Torque measurement test

The output torque of robot is required to justify the improvement of robot's mobility. It also important to have a bigger torque output. The reason is bigger torque is better for robot to move in uneven terrain or slope. When the robot undergoes through those challenges, the motor will support the weight of the robot. It will maintain the contact of each wheel with the ground. The torque measurement will be calculated for robot before it being improved and after it being improved. The torque will be calculate based on the motor specification. The formula that will be use in this test is as shown below.

$$\tau = \frac{P}{\omega}$$

Where:

τ = torque (Nm^{-1})

P = power (Watts)

ω = angular speed (rad/s)

$$P = V \times I$$

Where:

P = power (Watts)

V = voltage (Volts)

I = current (Amperes)

$$\omega = 2\pi f$$

Where:

ω = angular speed (rad/s)

f = frequency (Hz)

3.5.3 Slope climbing on fixed terrain test

In this test, the slop climbing ability need to be measure. The test will be conduct by operating at four different gradients which is 5˚, 10˚, 15˚ and 20˚. The test will be conducting two times which is with pesticide load and without pesticide load. All of the tests will be conduct on fixed terrain. This is because the data that we got must be precise. The test will be conducted by testing the robot whether it is pass which can climb the terrain or not. Plus. the gradient will be measured by angle measuring tool, Slope Angle Meter. This tool generally applicable to civil engineering, construction engineering, interior decoration engineering and other projects that must involve slope and inclination angle specification. Figure 3.8 below shows the angle measuring tool that being use in this test.

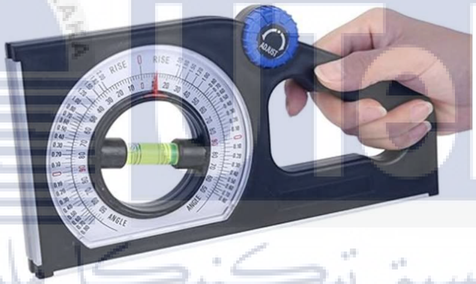


Figure 3.8: Slope Angle Meter

To start the test, firstly the terrain angle will be measured first to know whether it is appropriate for the test or not. Figure 3.9 below shows the procedure of measure the terrain angle. The road angle must be included in range of 5˚, 10˚, 15˚ and 20˚. After the angle of terrain being defined, the robot then will be run on those terrain. While testing, the robot will be using the same power output for each terrain, which is the speed channel on controller will be pushed to maximum capacity for each test. This is due to get the accurate result from the test. Plus, by using the same power output, we ensure a fair comparison between the robot’s performance in various terrains, and this can give a clear result on robot mobility’s performance improvement. However, before the robot being improved in its mobility, for the test with pesticide load, the robot cannot climb the 15˚ slope due to the incapability of the motor. Nevertheless, after upgrading the mobility of the robot which is by adding a new motor and make it 4-wheel drive, the robot can climb the slope smoothly. Finally, the data will be recorded whether the robot pass which is the robot able to climb the terrain or not. Figure 3.10 shows the robot that cannot climb the 15˚slope due to power incapability.

Figure 3.9: Shows the using of Slope Angle Meter

Figure 3.10: Shows the robot stuck at angle 15˚ slope

3.5.4 Function time test

This test's main objective is to determine how long the prototype gadget can run on a single battery charge. Grasp the device's usefulness and user experience in actual situations requires a grasp of this information. Firstly, must be ensured that the robot is fully charged before initiating the test. Then, activate the robot and run it continuously by simulating the typical usage patterns. Through the testing session, the data about robot’s performance will be measured over time. Finally, the test will be concluded when the robot’s battery is fully depleted.

3.5.5 Rooftop test

The rooftop test will be conducted using engineering simulations software (Ansys). The goal from the test is to measure the durability of material that being used before it will be fabricated. The method that will be used is Von Mises Stress test. By doing this, we can figure out the rooftop design’s yield point, so that we can evaluate the strength of the rooftop. The benefit is the errors in the design can be detected and ensuring the final product meets the specification. Other than that, the most appropriate material also can be identified that meet the project requirements. During the selection of materials, the waterproof material like PET will be prioritized to get the desired results which is waterproof rooftop.

3.6 Conclusion

Chapter 3 will cover the methodology strategy for this project. The strategy also includes in defining the procedures that will be used to get the desired results. Everything that need to be done need to plan first because a goal without plan is just a wish. Every process concept had been condensed from the outset in the literature review and marginally modified to align with the project's objectives. The events form this chapter will have it aftereffect next in PSM 2 and regarded as a whole.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this section, we present the results obtained from our study and provide a detailed discussion of their implications. The primary objective of this final year project was to analyse the performance of the improved automated pesticide spraying robot in terms of it mobility and evaluate the effectiveness of tests that being done to achieve the objective. The results are organized to address the research questions and hypotheses outlined in the earlier sections of this report. We will also compare our findings with existing literature to highlight the contributions and limitations of our work. Finally, by systematically presenting and discussing the results, this section aims to provide a comprehensive understanding of the study's outcomes and their relevance to the broader research context.

4.2 Effect of robot’s mobility in varied environments

The first approach of this study is to boost the performance of robot in term of its mobility through upgrading the power output of the robot. The influence effect of robot mobility was carried out by adding new motors. An additional motor can enhance the robot’s agility and manoeuvrability. It allows for more precise control over movements, especially in complex environments. Plus, extra motors can distribute the load more evenly, allowing the robot to carry heavier payloads. In summary, adding a new motor can enhance a robot’s capabilities but also introduces complexities, so that the decision making must be carefully evaluated to optimize mobility while considering practical constraints.

4.2.1 Speed test of the robot on different terrain

The robot will be test on 4 different types of terrains which is flat roads, uneven road, grass, and obstacles like fallen branch and fruit brunches to test the mobility of robot. There will be two different test that will be conducted which is robot with the pesticide load and without the pesticide load. This data was then analysed to validate the design and better understand kinematic and dynamic properties of traversing rough terrain. For the test, the road will be set to 20 meters and the time taken for robot to finish the task will be measure. Table 4.1 and 4.2 below shows the data that being record during the test which is before and after the robot being improvise. Meanwhile figure 4.1 and 4.2 below shows the result data in graph.

The aim of this test is to measure the velocity of robot. If the time taken of improved robot is lower, then its velocity of power output is bigger than previous robot.

Table 4.1: Result data before the robot being improvise

Type of road	Time taken robot with pesticide load (s)	Time taken robot without pesticide load (s)	Velocity robot with pesticide load (ms^{-1})	Velocity robot without pesticide load (ms^{-1})
Flat	20.51	18.05	0.9751	1.1080
Uneven	27.84	23.73	0.7184	0.8428
Grass	20.95	19.88	0.9547	1.0060
Obstacles	42.25	27.56	0.4734	0.7257

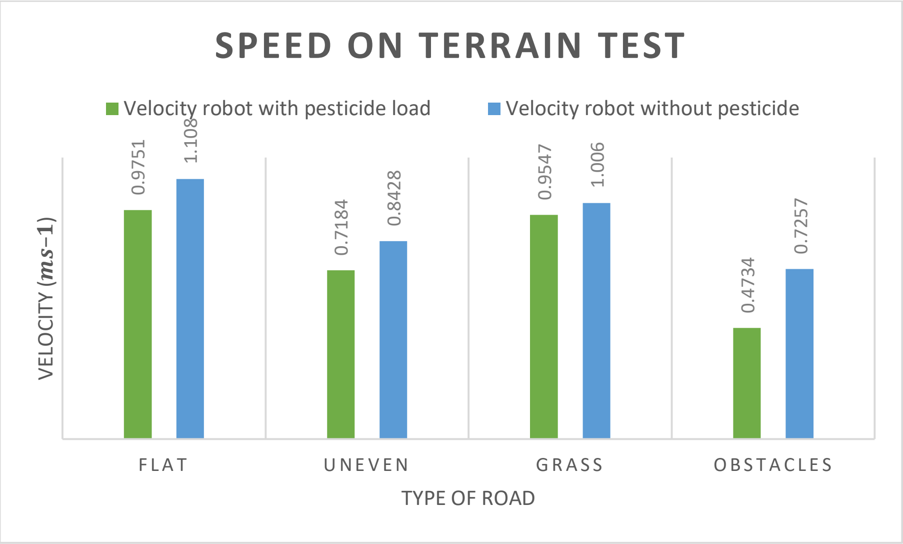


Figure 4.1: Graph for result from terrain test based on table 4.1

The table offers insights into how a robot's performance is affected by carrying a pesticide load across different types of terrain. Firstly, time taken. The time taken by the robot to traverse various terrains is crucial for assessing its efficiency. On flat road, the robot performs slightly faster without the pesticide load, taking approximately 18.05 seconds compared to 20.51 seconds with the load. Uneven terrain raod shows a more significant impact. The robot takes around 27.84 seconds with the pesticide load, whereas it completes the same route in approximately 23.73 seconds without the load. Grass road exhibits a similar trend. The robot takes about 20.95 seconds with the pesticide load and approximately 19.88 seconds without it. The most substantial difference occurs on obstacle-filled road, where the robot takes approximately 27.56 seconds without the pesticide load but significantly longer which is around 42.25 seconds with it.

Next, by viewing the graph in figure … the data suggests that the velocity of the robot with pesticide load is generally lower than that of the robot without a pesticide load. The compares the velocity of a robot with and without a pesticide load across different terrain types: flat, uneven, grass, and obstacles. The green bars represent the velocity of the robot with the pesticide load, while the blue bars represent the velocity of the robot without the load. On flat terrain, the robot with the pesticide load achieved a velocity of 0.9751 ms^{-1}, compared to 1.108 m/s without the load. On uneven terrain, the velocities were 0.7184 ms^{-1} with the load and 0.8428 ms^{-1} without the load. On grass terrain, the robot's velocity was 0.9547 ms^{-1} with the load and 1.006 ms^{-1} without the load. When navigating obstacles, the robot's velocity was 0.4734 ms^{-1} with the load and 0.7257 ms^{-1} without the load. The graph illustrates that the robot's velocity is consistently slower when carrying the pesticide load, with the difference being more pronounced on more challenging terrains.

Table 4.2: Result data from test after the robot being improvise

Type of road	**Time taken robot with pesticide load (s)**	**Time taken robot without pesticide load (s)**	**Velocity robot with pesticide load (ms^{-1})**	**Velocity robot without pesticide load (ms^{-1})**
Flat	19.34	17.56	1.0341	1.1390
Uneven	25.68	22.13	0.7788	0.9038
Grass	20.14	17.87	0.9930	1.1192
Obstacles	35.46	25.87	0.5640	0.7731

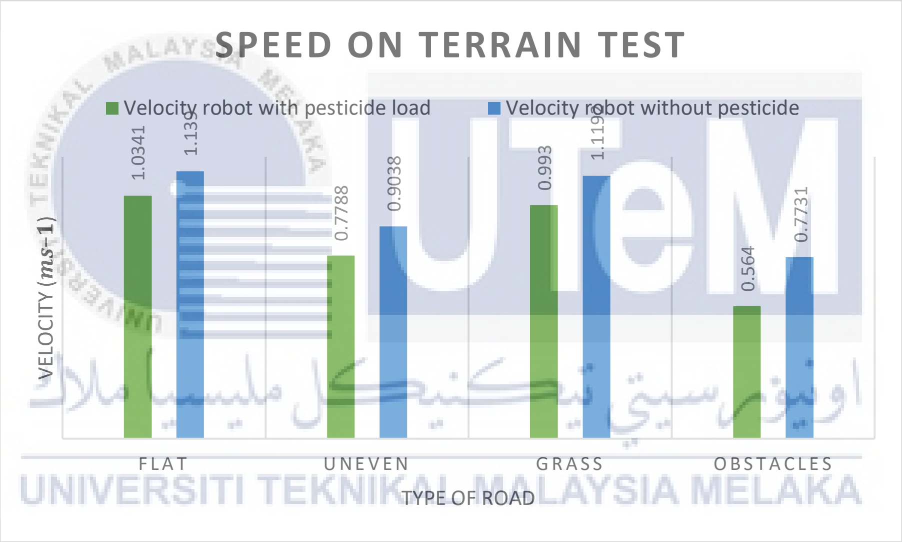


Figure 4.2: Graph for result from terrain test based on table 4.2

The bar graph above compares the velocity of a robot with and without a pesticide load across four types of terrain: flat, uneven, grass, and obstacles. The green bars represent the robot's speed with a pesticide load, while the blue bars represent its speed without the load. On flat terrain, the robot's speed is 1.0934 ms^{-1} with the load and 1.1315 ms^{-1} without it. On uneven terrain, the speeds are 0.7708 ms^{-1} with the load and 0.9038 ms^{-1} without it. On grass terrain, the robot moves at 0.9593 ms^{-1} with the load and 1.1156 ms^{-1} without it. On terrain with obstacles, the speeds are 0.5564 ms^{-1} with the load and 0.7731 ms^{-1} without it. The graph clearly shows that the robot consistently moves faster without the pesticide load across all types of terrain, with the most significant speed reduction observed on obstacle-laden terrain.

In conclusion, both graphs result as shown in figures 4.1 and 4.2 prof that improved robot has a higher speed while moving on any type of terrain as stated. The increasing of robot velocity is due to the adding of DC motor that make the robot to move in 4-wheel drive mode. This would likely increase the robot's power and traction, allowing it to maintain higher speeds even while carrying the pesticide load while doing the task. For example, the new motor seems to provide a more significant performance boost on more challenging terrains which is uneven road, grass road, obstacles road. For instance, on obstacles road, the velocity with the pesticide load increased from 0.4734 m/s to 0.564 m/s, and without the pesticide load from 0.7257 m/s to 0.7731 m/s. In conclusion, the addition of a DC motor, enabling 4-wheel drive mode, significantly enhances the robot's speed and traction across various terrains. This improvement is evident in the increased velocities observed in both loaded and unloaded conditions, as shown in Figures 4.1 and 4.2. The enhanced performance, particularly on challenging terrains, underscores the effectiveness of the motor upgrade in boosting the robot's operational efficiency.

4.2.2 Torque measurement test

The output torque of robot is required to justify the improvement of robot’s mobility. It also important to have a bigger torque output. The reason of this because of the bigger torque is better for robot to move in uneven terrain or slope. When the robot undergoes through those challenges, the motor will support the weight of the robot. It will maintain the contact of each wheel with the ground. The torque test measure will be divided into two which is the torque for 2-wheel drive which is the robot before it being improvised and the torque for 4-wheel drive which is the robot after being improvised its mobility. Figure 4.3 below shows the graph that being constructed from the calculation data that stated in table 4.3.

Table 4.3: Torque measurements test

Torque robot for 2-wheel drive	**Torque robot for 4-wheel drive**
4.5836 Nm^{-1}	9.1672 Nm^{-1}

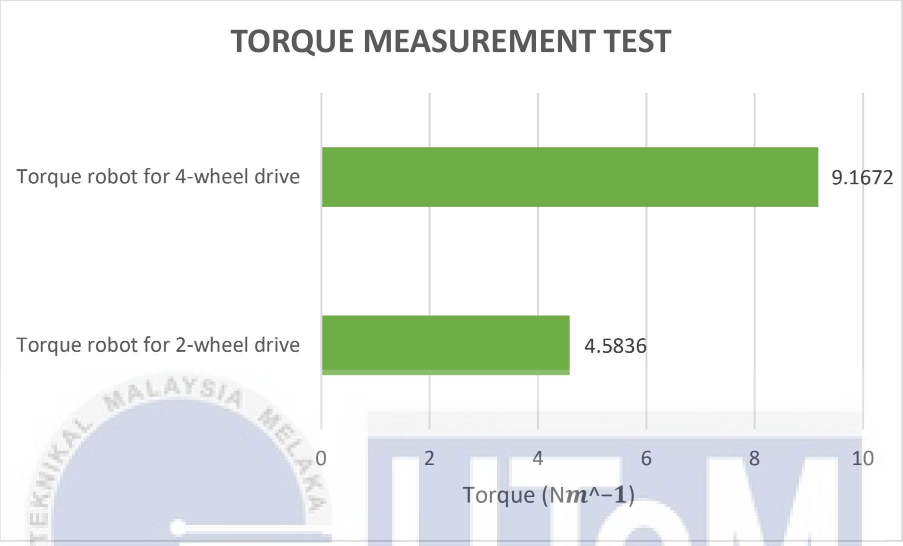


Figure 4.3: Graph that generated from the calculation data.

In figure 4.3 graph above, presents the torque values measured for a robot configured in two different drive modes, 4-wheel drive and 2-wheel drive. The horizontal axis represents the torque in Newton-meters (Nm), while the vertical axis lists the two configurations tested. The results indicate that the torque for the 4-wheel drive configuration is significantly higher, measuring 9.1672 Nm, compared to the 2-wheel drive configuration, which measures 4.5836 Nm. This suggests that the 4-wheel drive configuration provides more than double the torque of the 2-wheel drive configuration. This is because of the 4-wheel drive system is running by using four DC 12V 80RPM motor compared to 2-wheel drive system that only use two. So that, it can produce higher torque. The increased torque in the 4-wheel drive mode likely enhances the robot's ability to handle more demanding tasks, such as navigating rough terrain or carrying heavier loads. In summary, the 4-wheel drive robot's higher torque compared to the 2-wheel drive robot provides significant advantages in terms of traction, stability, manoeuvrability, load-bearing capacity, and overall reliability, making it better suited for challenging environments with uneven terrain.

4.3.3 Slope climbing on fixed terrain test

In this test, the slop climbing ability need to be measure. The test will be conduct by operating at four different gradients which is 5˚, 10˚, 15˚ and 20˚. The test will be conducting two times which is with pesticide load and without pesticide load. Next, the data from this test been recorded as shown in table 4.4 and table 4.5 below while the graph in figure 4.4 and 4.5 shows the result from data obtained and 100% means the robot pass the test. This data was then analysed to validate the design and better understand kinematic and dynamic properties of traversing various of gradient terrain.

Table 4.4: Data from the test before robot being improved

Slope angle	**Robot with pesticide load (s)**	**Robot without pesticide load (s)**
5˚	Pass	Pass
10˚	Pass	Pass
15˚	Not pass	Pass
20˚	Not pass	Pass

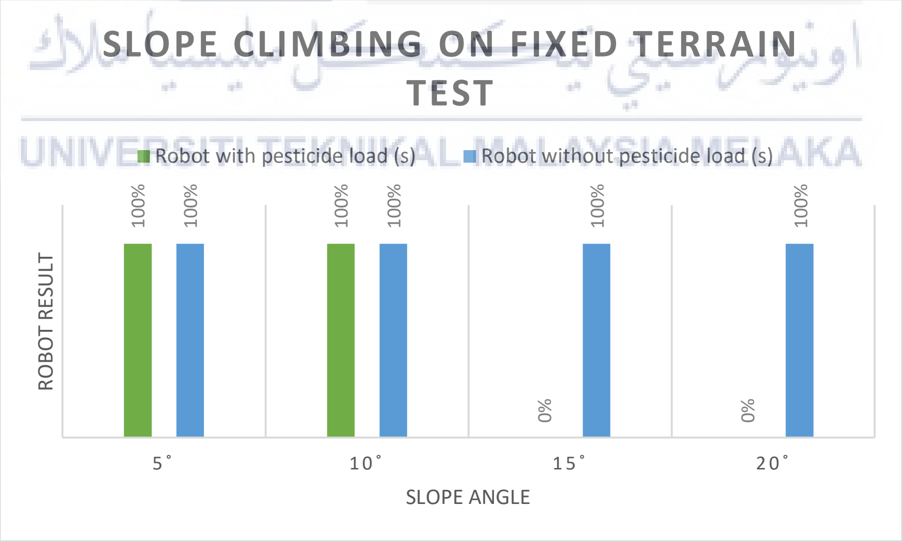


Figure 4.4: Graph for the test before robot being improvised

Based on the table and graph above, it can be concluded that the robot cannot climb on terrain that above 15˚ if the robot is carrying the pesticide load. This is due to the insufficient power and torque output from the motor to manage the large weight of pesticide load while climbing a high angle of terrain. This can be proof by looking at the torque measurement test for robot that is run by 2-wheel drive system which is got small torque and power output.

Table 4.5: Data from the test after robot being improved

Slope angle	Time taken robot with pesticide load (s)	Time taken robot without pesticide load (s)
5˚	Pass	Pass
10˚	Pass	Pass
15˚	Pass	Pass
20˚	Pass	Pass

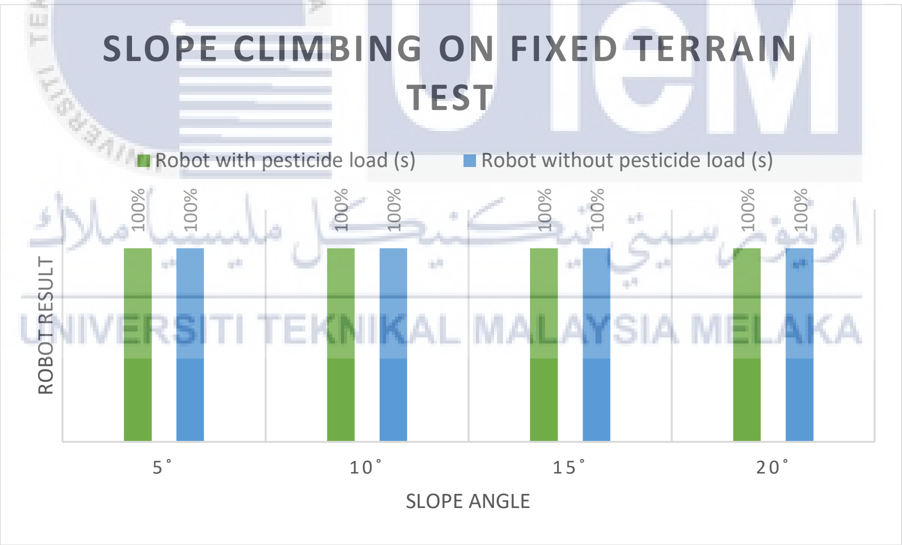
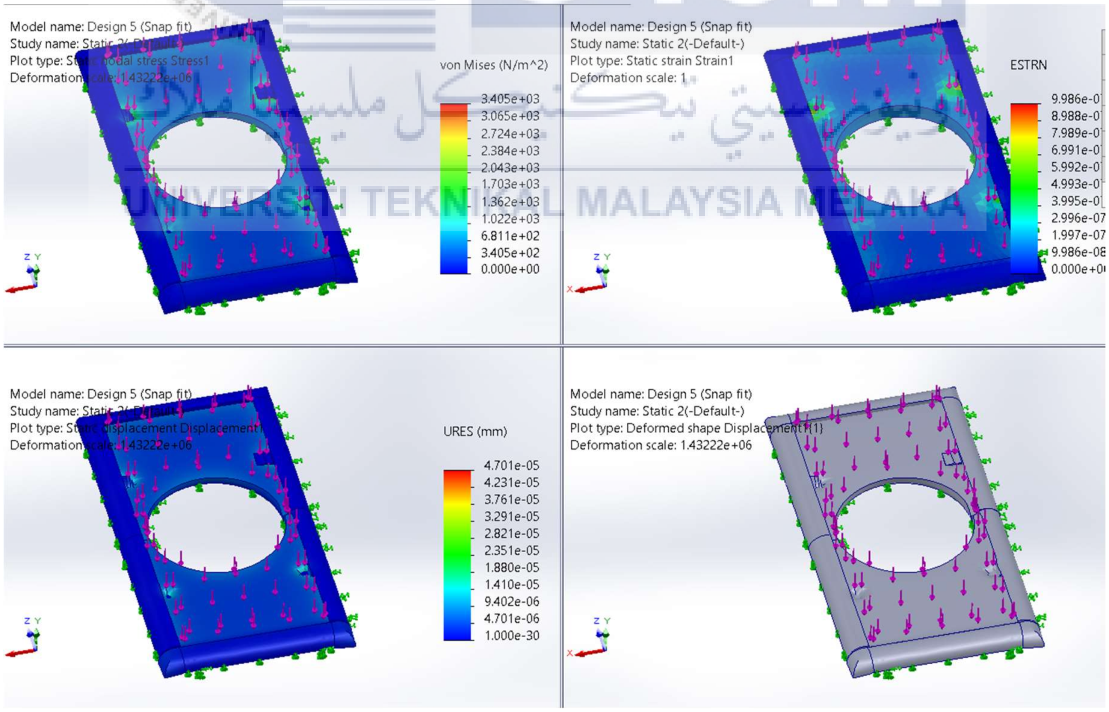


Figure 4.5: Graph for the test after robot being improvised

The table and graph above summarize the performance of a robot under different slope angles (5°, 10°, 15°, and 20°) with and without a pesticide load. It shows that the robot successfully passed the test in all conditions, indicating that it completed the task within an acceptable time frame regardless of the slope angle or the presence of the pesticide load. This suggests that the robot's motors, possibly enhanced by the addition of a new motor, are capable of generating sufficient torque to handle the increased load without compromising performance.

In conclusion, it can be concluded that the robot, even while carrying a pesticide load, is capable of climbing slopes up to 20 degrees without any issues, as evidenced by the successful completion of tasks on all tested slope angles (5°, 10°, 15°, and 20°) within an acceptable time frame. This improved performance can be attributed to the addition of a new motor, which has increased the robot's overall torque output, and the transition from a 2-wheel drive system to a 4-wheel drive system, significantly enhancing its traction and stability on various terrain types, including slopes above 15 degrees; the combination of these upgrades has enabled the robot to generate sufficient torque to overcome the challenges posed by the pesticide load and the steep slopes, making it suitable for a wide range of terrain conditions.

4.3.4 Rooftop design test


Model name: Design 5 (Snap fit)
Study name: Static 2(-Default-)
Plot type: Static nodal stress Stress1
Deformation scale: 1.43222e+06

Model name: Design 5 (Snap fit)
Study name: Static 2(-Default-)
Plot type: Static strain Strain1
Deformation scale: 1

Model name: Design 5 (Snap fit)
Study name: Static 2(-Default-)
Plot type: Static displacement Displacement1
Deformation scale: 1.43222e+06

Model name: Design 5 (Snap fit)
Study name: Static 2(-Default-)
Plot type: Deformed shape Displacement1{1}
Deformation scale: 1.43222e+06

Figure 4.6: Result from analysis material

Based on the finite element analysis (FEA) results shown in figure … above, the stress distribution, The von Mises stress distribution indicates that the highest stress regions are concentrated around specific areas of the component, likely near the edges of the circular opening. This suggests that these areas are critical points that need to be carefully designed to avoid failure under load. Next is deformation patterns, the deformation patterns under displacement-controlled loading conditions show that the component is designed to undergo significant deformation, characteristic of a snap-fit or interference-fit connection. The largest displacements are indicated in red, while the smallest are in blue. Other than that, structural integrity. The analysis helps in evaluating the structural integrity and reliability of the component under static loading conditions. By understanding where the highest stresses and largest deformations occur, designers can make informed decisions to optimize the component's design, ensuring it can withstand the intended loads without failure. Finally, design optimization, the results provide valuable insights for optimizing the design of the component. Areas with high stress concentrations may need to be reinforced or redesigned to distribute the stress more evenly. Similarly, the deformation patterns can guide adjustments to ensure the component fits and functions as intended in its assembly. Overall, the FEA results are crucial for validating the design and making necessary improvements to ensure the component's performance and durability in its application.

In conclusion, based on the FEA results, the design appears to be structurally sound and capable of withstanding the applied loads without significant deformation or stress concentrations that could lead to failure. Therefore, the design can be considered as good as in terms of its structural performance.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study on the "Mobility of an Automated Pesticide Spraying Robot" aimed to enhance the efficiency and reliability of pesticide application in agricultural settings, particularly in palm oil plantations characterized by uneven terrains. The research focused on improving the robot's mobility, ensuring the safety of its electrical components, and analyzing its overall performance.

The key findings of the study include significant improvements in the robot's mobility due to the addition of new motors. The 4-wheel drive system provided better traction and stability, allowing the robot to navigate various terrains more effectively. Speed tests on different terrains (flat, uneven, grass, and obstacles) showed that the improved robot had higher velocities compared to the previous version, indicating a substantial enhancement in its operational efficiency. The torque measurement tests revealed that the 4-wheel drive system produced more than double the torque of the 2-wheel drive system. This increased torque is crucial for the robot to handle challenging terrains and slopes, ensuring consistent performance even with a pesticide load. The improved robot successfully climbed slopes up to 20 degrees with and without a pesticide load, demonstrating its enhanced capability to operate in hilly and uneven agricultural fields, which is essential for palm oil plantations. Additionally, the new rooftop design, fabricated using 3D printing, provided effective protection for the robot's electrical components. The finite element analysis (FEA) confirmed the structural integrity and durability of the design, ensuring it can withstand environmental challenges and prevent water ingress.

The improvements made to the automated pesticide spraying robot have significant implications for the agricultural sector. The enhanced mobility and reliability of the robot can lead to more efficient pesticide application, reducing the labor and time required for this task. Additionally, the improved design ensures the safety and longevity of the robot, making it a viable solution for large-scale agricultural operations.

In conclusion, the study successfully demonstrated the potential of an improved automated pesticide spraying robot to revolutionize agricultural practices. The enhancements in mobility, torque, and design ensure that the robot can operate efficiently in challenging environments, thereby contributing to the sustainability and profitability of agriculture in regions like Malaysia.

5.2 Recommendation

Based on the conclusion from the final year project report, the recommendations that would be suggested for further enhancement and future research are for example using a heavy-duty tire. Heavy-duty tires are engineered to withstand higher pressures and loads, making them ideal for demanding applications. These tires possess an elevated load capacity, which is advantageous for transporting substantial loads in industrial and agricultural settings. The reinforced construction of heavy-duty tires enhances their durability and wear resistance, rendering them suitable for extended and arduous road journeys. Additionally, heavy-duty tires offer superior road handling, stability, and improved power transfer, which is particularly beneficial for vehicles operating in challenging terrains.

Secondly, by implementing a camera system to the robot. The integration of a camera system on a mobile robot represents a significant advancement, providing essential visual feedback to remote operators. The inclusion of a high-resolution camera capable of transmitting video data over extended distances—up to 500 meters—enables operators to obtain a real-time, comprehensive view of the robot's surroundings. This enhanced visual perspective facilitates the robot's navigation within its environment, allowing operators to identify potential obstacles and hazards, thereby ensuring a more accurate and effective pesticide spraying operation. The camera system's augmented vision not only enables remote control of the robot but also substantially enhances the overall safety, precision, and efficiency of its activities in agricultural settings.

Finally, by using a solar powered robot. Using a solar-powered robot for automated pesticide spraying in palm oil plantations offers numerous advantages, including environmental sustainability by reducing reliance on fossil fuels and minimizing the carbon footprint. It significantly lowers operational costs by utilizing free and abundant solar energy, reducing expenses related to fuel and electricity. The automation of labour-intensive tasks decreases the need for manual labour, addressing labour shortages and high labour costs. Equipped with advanced sensors, these robots ensure precise pesticide application, minimizing wastage and environmental impact while enhancing pest control effectiveness. They also improve safety by reducing human exposure to harmful chemicals. Designed to navigate rough terrains, solar-powered robots provide reliable, continuous operation during daylight hours, leading to higher productivity. Additionally, their multifunctional capabilities, such as crop health monitoring and irrigation, make them versatile tools for comprehensive farm management.

In conclusion, the implementation of heavy-duty tires, a high-resolution camera system, and solar power in automated pesticide spraying robots for palm oil plantations offers substantial benefits. Heavy-duty tires enhance the robot's load capacity, durability, and stability, making them suitable for demanding agricultural applications and challenging terrains. The integration of a camera system provides real-time visual feedback, enabling remote operators to navigate the robot accurately and identify obstacles, thereby improving the precision and safety of pesticide application. Utilizing solar power ensures environmental sustainability by reducing reliance on fossil fuels and lowering operational costs. Solar-powered robots also automate labor-intensive tasks, addressing labor shortages and high costs, while advanced sensors ensure precise pesticide application, minimizing wastage and environmental impact. These enhancements collectively improve the efficiency, safety, and productivity of agricultural operations, making the robots versatile tools for comprehensive farm management

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