ASHESI UNIVERSITY

SEMI-AUTONOMOUS AGRICULTURAL CROP SPRAYER FOR MEDIUM-SCALE FARMS IN GHANA

GROUP CAPSTONE PROJECT

BSc. Mechanical Engineering

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2022

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Capstone Project submitted to the Department of Engineering, Ashesi University, in partial fulfilment of the requirements for the award of a Bachelor of Science degree in Mechanical Engineering.

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2022

DECLARATION

We hereby declare that this capstone is the result of our original work and that no part of it has been presented for another degree at this university or elsewhere.

Candidate 1's Signature:

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Candidate 1's Name:

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Candidate 2's Signature:

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Candidate 2's Name:

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Date:

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We hereby declare that the preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University.

Supervisor's Signature:

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Supervisor's Name:

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Date:

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Abstract

Most small-scale farmers in Ghana that have transitioned into medium-scale farming are currently using lever-operated Knapsacks for fertilizer/pesticide application. For farm sizes above five hectares, it becomes inefficient and labour intensive, resulting in health issues. Efficient methods like drones and tractors are expensive. Hence, the need to design and fabricate a cost-effective, semi-autonomous sprayer with low labour intensity. This project designs and fabricates a mechanical system equipped with a nozzle and navigation control system. The nozzle system turns the nozzles on and off and directs the crop sprayer via Bluetooth. The nozzle control system also has flow sensors that measure the flow rate from each nozzle. Results obtained from testing the system show that the on and off control of one nozzle increases the flow rate in the other nozzle, which can be attributed to an increase in pressure. Also, the cost of automating the system is cost-effective for medium-scale farmers. The system was able to control the nozzles for potential savings for farmers while reducing manual labour.

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Chapter 1: Introduction

1.1 Background

Agriculture in Africa is an essential economic activity, employing about two-thirds of the continent's working population [1]. Ghana's economy is heavily reliant on agriculture, which employs about 42% of the workforce, contributing about 19.7% of the country's gross domestic product (GDP). Although Ghanaian agriculture has traditionally been dominated by small farms with less than 2 ha of farmland, the predominance of small farms in the country's agriculture is abating [2]. Although small farmers constitute a considerable share of the Ghanaian farming population, their number declined between 1999 and 2012. On the other hand, the number of medium-scale farmers rose considerably during the same time and is still growing. This growth in medium-scale farms has called for attention to farming practices like crop spraying best suited for medium-scale farms.

Pesticide use among farmers in Ghana has reached its peak in recent years, especially for controlling weeds, pests and preservation of harvested crops. Farmers have depended on pesticides to attain acceptable levels of crop production. Knapsack sprayers have offered many advantages to small farms. However, aside from problems with pressure and flow control, it is highly inefficient and has a large labour intensity, making it unsuitable for medium-scale farming. Technologies like drone spraying, diesel pumping systems, and tractors are efficient for crop spraying, but the cost remains unattractive to medium-scale farmers, especially those transitioning from small-scale farming. This calls for a cost-effective method that significantly reduces human efforts during crop spraying.

1.2 Motivation

Knapsack sprayers are cheap, reliable, efficient, and durable when used for fertilizer/pesticide application in subsistent and small-scale farms; however, their dependable performance is limited for relatively large-scale operations. It becomes labour intensive leading to low efficiency. Farmers who use conventional backpack sprayers experience many problems, including fatigue and back pain due to their heavyweight. Given that some small-scale farmers are shifting to medium-scale farming, a cost-effective, efficient, and less labour-intensive crop spraying approach is required for these larger-scale operations.

1.3 Problem Definition

Most small-scale farmers in Ghana that have transitioned into medium-scale farming are currently using lever-operated Knapsacks for fertilizer/pesticide application. For farm sizes above five hectares, it becomes inefficient and labour intensive, resulting in health issues. Efficient methods like drones and tractors are expensive. Hence, the need to design and fabricate a cost-effective semi-autonomous sprayer with low labour intensity.

1.4 Objectives

This project aims to design and fabricate an efficient and cost-effective autonomous pesticide/fertilizer sprayer that can be used for wide-row medium-scale farming. It also aims to reduce/eliminate human efforts to reduce the fatigue load acting on the body that poses health risks to farmers, reducing efficiency. The key deliverables to accomplish this task are presented below.

- Design and fabricate compact hardware to minimize cost
- Developing a semi-autonomous system for the sprayer to navigate without much human effort
- Developing an autonomous multi-nozzle system that is controlled via Bluetooth

1.5 Proposed Solution

At the end of this project, the expectation is to have a semi-autonomous crop sprayer used on small and medium-scale farms. The sprayer will be able to navigate through the farm using Bluetooth navigation controlled by the worker. The system will also have an automatic boom sprayer with an on and off control. This will allow the worker to turn the nozzles on and off to prevent the wastage of chemicals. The flow rates and pressure values will also be collected to keep track and adjust when necessary. The sprayer boom will also be height adjustable to accommodate for different stages in the crop's growth.

1.6 Scope of Work

This project's scope spans research, analysis of information gathered, incorporation of the research findings into a design solution, implementation of design, testing, and evaluation of the solution. The proposed solution is limited to medium-scale wide-row farming in Ghana. The solution will be an application of Mechanical engineering concepts, including but not limited to circuits and electronics and programming. All these concepts, when applied, would hopefully result in a practical, cost-effective semi-autonomous agricultural spraying machine.

Chapter 2: Literature Review and Related Work

This chapter reviews literature that significantly influences the design of the crop sprayer. These include pesticide application methods, boom sprayers, wheeled robots, and DC motors for wheeled robots. Related works are also reviewed, and insight is drawn from the existing autonomous spraying methods.

2.1 Literature Review

2.1.1 Pesticide Application

Pesticide application varies from crop to crop and depends on factors such as the nature of the pesticide (solid or liquid), specific pests and weeds to be managed, formulation, the availability of water, and site of application, among others. Different pesticides are also applied at different times, varying from morning to evening [6]. Examples of pesticide applications include Dusting, Spraying, Granular Applications such as Broadcasting, Ring Application, side dressing, Stem Injection, Padding, Swabbing, Soil drenching, Baiting, and fumigation [7]. For simplicity and consistency in designing the crop sprayer, one crop is selected for the project.

Maize is one of the major crops cultivated in Ghana as it grows well in almost all parts of the country. Maize ranks first as Ghana's most important cereal produced and consumed [8, 9, 10]. It can be found in the country's northern savannah, forest, transitional, and coastal savannah zones [11]. The Eastern, Ashanti, and Brong Ahafo regions of Ghana produce most of the country's maize, accounting for more than 80% of total maize production. The rest is supplied by the Northern, Upper East, and Upper West Regions [11]. Also, considering the location where the crop sprayer will be tested, maize was selected as the specific crop that was designed.

In maize farming, the first application of pesticides is performed within the first 2 to 3 weeks; at this point, the height of the maize plant is approximately 10 – 14 cm. The second application is performed, if necessary, within the 6th to 7th week after planting with an approximate height of 32 – 41 cm [11]. In Ghana, the main pests that maize farmers deal with include fall armyworms, leafhoppers, locusts, aphids, stem borers, ash weevils, ear head bugs, and shoot bugs [12]. Weeds are also a major problem leading to low crop yield in maize farms as 73% of maize farms in Ghana apply herbicides [13]. Different pesticides and herbicides are used in different quantities depending on the specific pest being dealt with.

2.1.2 Boom Sprayers

A boom sprayer is a type of hydraulic sprayer used in agriculture to apply pesticides and increase crop protection [3]. It comprises a tank, a pump, a boom, and numerous nozzles. The pesticide mixture is converted into droplets by a sprayer. This conversion is performed by putting the spray mixture under pressure through a spray nozzle. The size of the droplets is determined by both the nozzle type and the system pressure. Boom sprayers can be trailer-mounted or tractor-mounted (attached to a tractor's 3-point hitch).

This paper focuses on the tractor-mounted boom sprayer, as shown in Figure 2.1; however, tractors are expensive, so a low-cost mobile robot will be designed for the boom sprayer to be mounted.

Figure 2.1: Example of a tractor-mounted boom sprayer

2.1.3 Wheeled Robots

Wheeled mobile robots can be equipped with a variety of wheels. The ideal wheel for a robot is determined by its design and specifications. One of the parameters to be determined when selecting wheels for a robot is the wheel size. The size of the wheel will determine the speed of the robot and its ground clearance. Wheel width determines the amount of traction it has and the maximum load it can support. Another parameter is the wheel thread, and it determines the surface(s) that the robot can travel on, while the wheel type will determine the degree of movement. Standard/fixed wheels, orientable wheels, ball wheels, and Omni wheels are some of the various types of wheeled robots. Orientable wheels are often used to balance a robot and are rarely used to drive a robot. Primarily used for indoor designs, ball wheels, like orientable wheels, are used to balance robots. They are not suitable for uneven, dirty, or greasy surfaces. Omni wheels are helpful for both driving and steering, but they have some drawbacks. They are costly and inefficient since not all wheels rotate in the robot's direction. They are also ineffective for positioning control due to wheel slippage.

Standard/fixed wheels are utilized for this project since they are ideal for simply connecting wheels to a motor and driving or steering. They have two degrees of freedom and can move the robot forward and backward. They come in a wide range of sizes with several different mounting arrangements. They also have a wide selection of tire threads for several different surfaces. These are also used on four-wheel-drive robots.

Figure 2.2: Standard/Fixed Wheel

2.1.4 DC Motors for Mobile Robot

Selecting a drive motor for your mobile robot is one of the most critical decisions. A DC motor consists of magnets, a rotor coil, and a commutator [5]. When electricity is applied to the rotor coil, it transforms into an electromagnet and repels the magnets. As the rotor coil rotates, the commutator causes its current to switch polarity [5]. The rotor coil repels the magnets and generates continuous torque because of this polarity switch.

It is essential to note that power produced by the motor is proportional to the voltage multiplied by current. This tells us that the voltage rating or current can be increased for the motor's output power to be increased. Using higher voltages like 24 volts if the robot is extremely heavy is advised. Higher voltages can be used, but that is often traded for safety. The speed of a DC motor is controlled by changing the voltage. When sizing, the rated voltage is used, which is the maximum voltage the motor is designed to handle.

The four major types of dc motors are Series DC Motor, Shunt/Parallel DC Motor, Compound DC Motors, and Permanent Magnet DC Motor. For this study, the Permanent Magnet DC motor was utilized as it is cost-effective, has no field circuit copper losses, does not require field winding, and has an overall increased efficiency [12].

The key specifications when selecting the motor include the nominal voltage, no-load RPM, stall torque and current, size and shaft specifications, and gear down ratio. Nominal voltage is the voltage for the highest motor efficiency. This is, however, not the same as the operating voltage range. It is the voltage that is used to measure other specifications. The no-load RPM is the angular velocity with no connection. It is the speed of the shaft and not that of the motor, and it is measured at the nominal voltage.

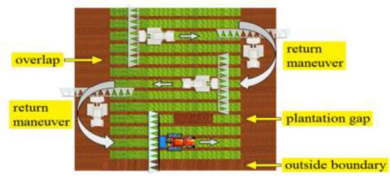
The stall torque is the maximum torque when the motor shaft can no longer move. The stall current is the current drawn at the stall torque. It is vital to design a robot to use 30% of the motor's stall torque. The spacing and thread specifications for the mounting holes should be considered for motor size and specifications and the shaft diameter and length. In many gear motors, the shaft is not at the centre of the motor hence the need to know the shaft position and offset. The internal gear of a gear motor increases torque and reduces RPM. The internal motor speed/gear down = RPM. This equation is essential because if the motors have encoders, they will spin at the motor speed and not the shaft speed. An essential accessory in motors is a rotary encoder, and it can be built-in or added as an attachment—these help control speeds and the direction of movement.

2.2 Related Works

2.2.1 Autonomous Agricultural Sprayer Using Machine Vision and Nozzle Control

Pedrotti et al. [3] employ a precision agriculture modular system to automate sprayers, optimizing pesticide delivery via a robotic system based on computer vision and individual nozzle on/off control. The system uses low-cost components such as Arduino boards, solenoid valves, pressure and flow sensors, a smartphone, a webcam, and a Raspberry Pi to achieve this functionality. The system can be utilized in any row crop, including onion, soybean, corn, beans, and rice. The on/off control was created to solve issues that may occur in spraying (see Figure 2.6), such as double coverage caused by the overlap of adjacent lanes, the application outside the field boundary during return manoeuvres and on the last pass, and the application in areas with plantation gaps [3]. The authors achieved this by using two approaches. The first approach involved connecting solenoid valves to each nozzle and communicating through Bluetooth with an android application which allows the operator to send commands to open or close the solenoid valves. The second approach involved acquiring crop data by capturing an image and processing that image using algorithms to detect crops in a particular row. A detection of crop meant the nozzles would open. If there were no crops, a command is sent to close the nozzles. By doing this, the system should reduce the number of pesticides used in crops, not just for possible savings for farmers but also for environmental and food safety concerns. This showed that their system could detect lines in plantations and can be used to retrofit conventional boom sprayers.

(a)



(b)

Figure 2.3: (a) Individual nozzle on/off control (b) Issues in conventional boom spraying

2.2.2 A Versatile Electric Robot for Autonomous Spraying in Agriculture

Cantelli et al. [4] developed an agile autonomous robotic vehicle capable of moving in conditions where traditional agricultural machines (automated or autonomous) cannot operate: greenhouses, mountainous places, and heroic cultivations. The robot comprises four major subsystems: a mobile tracked robot, localization and navigation system, a smart spraying system, and a human-machine interface. The mobile tracked robot is a vehicle with rubber tracks and electric traction. It can manoeuvre between narrow passages due to its compact external dimensions. It is also outfitted with several sensors for autonomous navigation in harsh outside situations. Data from these sensors are gathered to communicate with the mobile tracked vehicle and perform high-level control functions such as terrain reconstruction and drivable-surface detection. The localization and navigation subsystems are in charge of high-level control. It uses sensor data to properly assess the vehicle's position and attitude, allowing it to perform specified trajectories and avoid obstacles. The smart spraying system is based on a regular machine with automatic control add-on technology. A hydraulic subsystem and an electronic control unit comprise the sprayer unit. The hydraulic components can be operated by the electronic control unit using the appropriate commands that have been programmed (i.e., valves, flow regulator, pump). The proposed human-machine interface also enables inexperienced operators to plan spraying treatments, supervise the mission from a safe distance, and generate a treatment report at the end of the operations.

Figure 2.4: The versatile spraying robot.

2.3 Insights from the Related Works

The more technical add-ons, the more the cost one is likely to incur. Both papers have incredible systems and ways of automating the spraying process to reduce human effort. The use of Bluetooth to control the nozzles is quite simple and easy to replicate in a cost-effective project. Even though the worker must operate it, it is still an effective way of controlling the nozzles while the sprayer is automated.

Chapter 3: Methodology

This chapter highlights the requirements and design process of the project. The requirements include both functional and design requirements. A detail of the system architecture, conceptualized designs, design decisions, and final project design are discussed.

3.1 Requirements

3.1.1 Functional Requirements

The functional requirements comprise the functions of the sprayer robot. These indicate clearly what the device is supposed to do. The functional requirements of the project are as follows:

1. Spraying should be controlled (on/off control)
2. The sprayer should be easy to operate
3. The robot should require very minimal human effort to operate

3.1.2 Design Requirements

The design requirements indicate the expected technical characteristics regarding the device's performance. The design is in three sub-systems, hence the need for each subsystem's requirements.

3.1.2.1 Mechanical design requirements

The requirements of the mechanical sub-system are as follows:

1. The width of the chassis should be less than 75 cm
2. The chassis should be at least 17 cm above the ground to accommodate uneven grounds.
3. The boom height should be adjustable, with the minimum height at 32 cm and the maximum at 102 cm.

3.1.2.2 Nozzle system requirements

1. The distance between nozzles should be approximately 76 cm

3.1.2.3 Navigation control requirements

1. The system should have an operation time of at least 1 hour
2. The device should operate at a minimum of 1 m/s, which is within the optimum window suggested when applying a broadcast herbicide

3.2 Design

Here the breakdown of the entire system is shown in Figure 3.1.

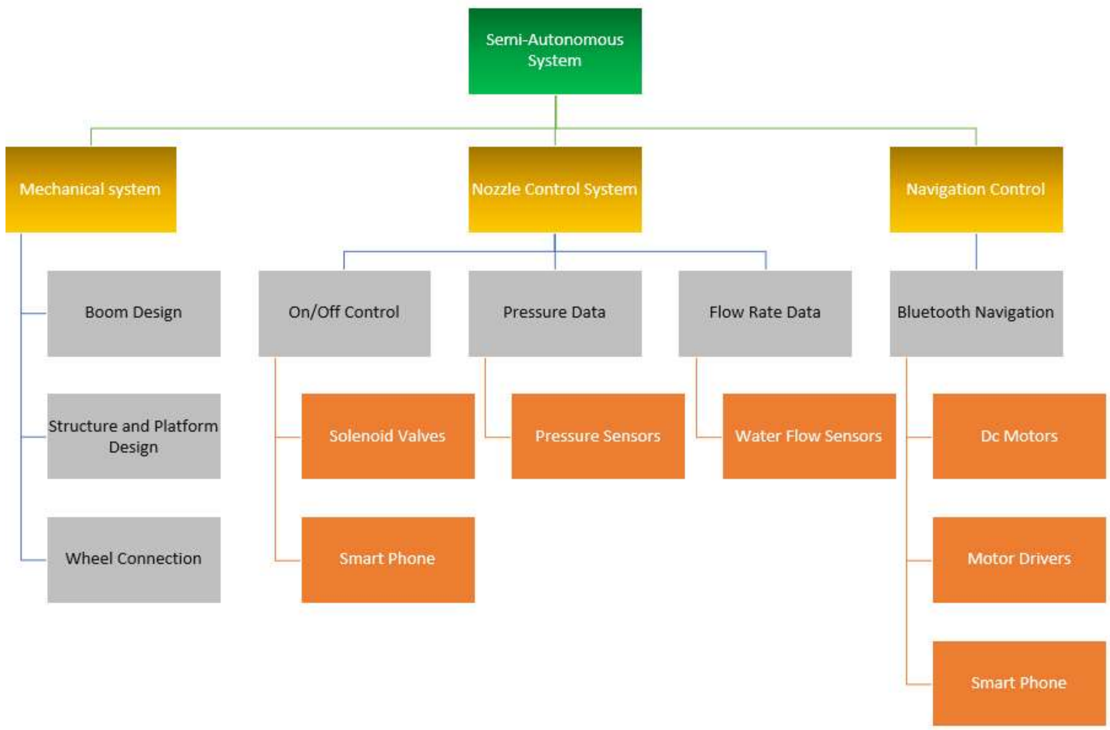


Figure 3.1: High level architecture of the system breakdown

From Figure 3.1, the crop sprayer is made up of 3 sub-systems. The mechanical, navigation, and nozzle control sub-systems. The design process of each sub-system will be discussed.

3.2.1 Design of Mechanical Sub-System

The mechanical subsystem is the build of the entire system without navigation technology and nozzle control. Based on the design specifications, two designs will be analysed, and a final design will be selected as the based frame for the sprayer robot.

3.2.1.1 Mechanical Design Options

The two deciding factors for the mechanical design are the type of wheeled robot and boom orientation. The sprayer robot could be three or four-wheeled, and the boom could be oriented horizontally or vertically. A decision on the type of wheeled robot and boom orientation narrows down the design options for the sprayer robot frame.

(a) (b)

Figure 3.2: (a) A three-wheeled robot (b) A four-wheeled robot.

(a) (b)

Figure 3.3: (a) A horizontal boom sprayer (b) A vertical boom sprayer

3.2.1.2 Evaluation Criteria

Table 3.1: Criteria for selecting an appropriate boom orientation and type of wheeled robot

Criteria for type wheeled robot		**Criteria for boom orientation**	
Criteria	Weight	Criteria	Weight
Balance	0.3	Ease of set-up	0.1
Cost	0.1	Reach	0.3
Efficiency	0.3	Efficiency for row farms	0.3
Ease of set-up	0.1	Uniform Spraying	0.1
Speed	0.2	High wind capacity	0.2

3.2.1.3 Type of Wheeled Robot Matrix

Table 3.2: Pugh Chart for selecting the type of wheeled robot

Criteria	**Baseline**	**Weight**	**Four-wheeled robot**		**Three-wheel robot**	
			r	**w(r-3)**	**r**	**w(r-3)**
Balance	0	0.3	5	0.6	4	0.3
Cost	0	0.1	3	0	4	0.1
Efficiency	0	0.3	5	0.6	4	0.3
Ease of set-up	0	0.1	3	0	4	0.1
Speed	0	0.2	5	0.4	4	0.2
Total	0	1	1.6		1.0	

Type of wheeled robot selected: Four-wheel drive. The four-wheel was selected because it had more balance than the three-wheel. Although an extra wheel increases the cost, the advantages outweigh the disadvantages.

3.2.1.4 Boom Orientation Matrix

Table 3.3: Evaluation Criteria for selecting an appropriate boom orientation

Criteria	Baseline	Weight	Horizontal Boom		Vertical Boom	
			r	w(r-3)	r	w(r-3)
Ease of set-up	0	0.1	4	0.1	3	0
Reach	0	0.3	5	0.6	4	0.3
Efficiency for row farms	0	0.3	5	0.6	4	0.3
Uniform Spraying	0	0.1	4	0.1	3	0
High wind capacity	0	0.2	5	0.4	4	0.2
Total	0	**1**	**1.8**		**0.8**	

Type of boom orientation selected: Horizontal Boom. The Horizontal boom was selected because the crop choice for the project suggests that the crop be sprayed directly over it. A vertically oriented boom, despite its benefits, cannot achieve that properly.

3.2.1.5 Conceptualized Designs

Now that a decision has been made on the type of wheeled robot and boom orientation for the crop sprayer, some conceptual designs will be made, and the best features will be combined to arrive at a final design for the robot.

3.2.1.5.1 Design Concept 1: The Platform Sprayer

This sprayer has all its components on a platform, and the boom is positioned at the back of the platform. The battery is angled to provide space for other components on the platform. This orientation is to prevent bulkiness

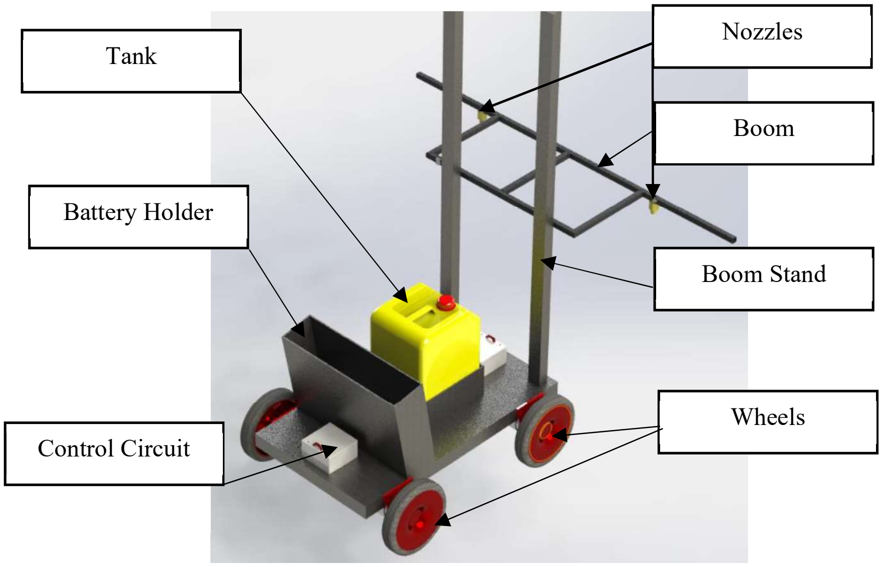


Figure 3.4: CAD model of first conceptualized design

3.2.1.5.2 Design Concept 2: The Compact Sprayer

This design has the water tank caged up in metal bars with navigation controls mounted on the water tank. The battery is positioned at the back while the boom stays at the front of the robot.

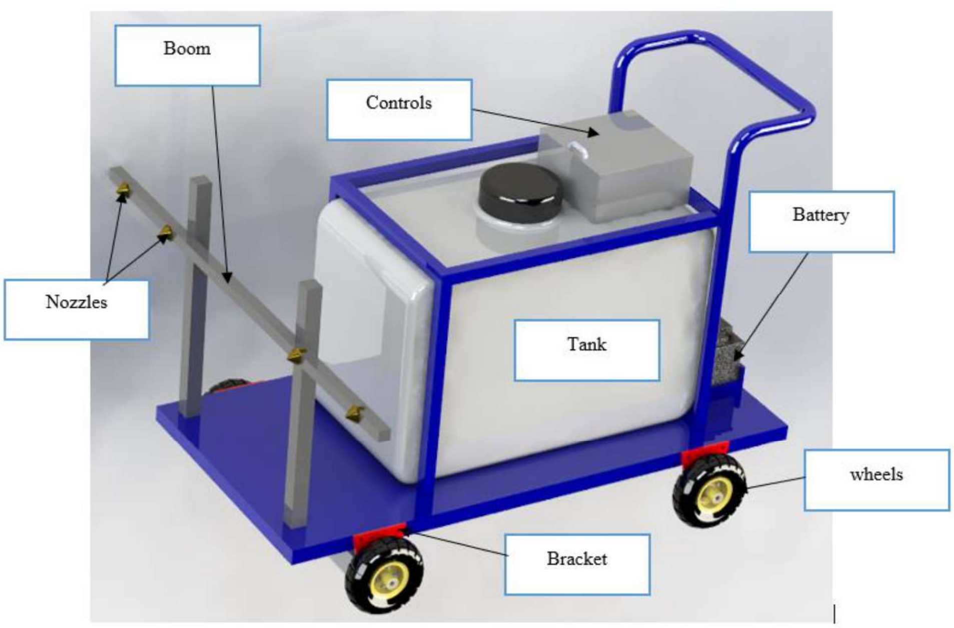


Figure 3.5: CAD model of second conceptualized design

3.2.1.6 Final Design

The Final design is geared more toward the platform sprayer. Some improvements were made by using angled irons to barricade the edges to prevent components from easily slipping off. The batteries were placed on the platform to simplify the design, and the controls for the boom were mounted on the boom for easy access. Different bolt holes were made on the boom holder to help adjust the boom for the different stages of the crop growth.

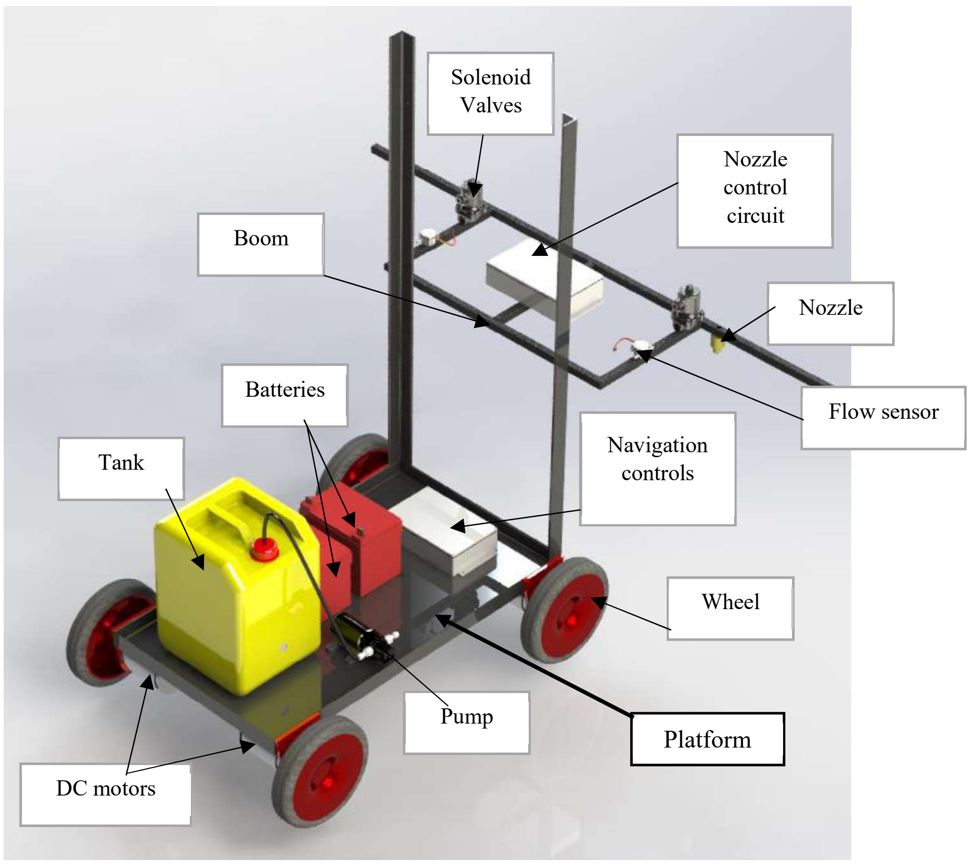


Figure 3.6: CAD model of the finalized design

Component Selection and Sizing:

Water pump sizing: Before sizing the pump, information about the sprayer settings is required. This includes the intended application rate, agitation requirements, average robot speed, etc.

Agitation requirement = Tank volume (L) * 0.125

Tank Volume = 25 L

Nozzle requirement = [output (L/ha) * Ground Speed (km/h) * row spacing (m)] /600

Ground speed of robot = 1 m/s = 3.6 km/h = Speed of spraying

Row spacing = 30" = 0.762 m

Output in L/ha = [Average output of a nozzle (mL/min) x 60] / [Nozzle spacing (cm) x speed of spraying (km/h)]

Average output of a nozzle = 450 mL/min (estimated)

Nozzle spacing = 76.2 cm

Total flow requirement = (Agitation requirement + Nozzle requirement) *1.2

Table 3.4: Sprayer settings for pump sizing

Sprayer setting	**Values**
Agitation Requirements	3.125 (L/min)
Output	98 L/ha
Nozzle Requirement	0.45 L/min
Total Flow Requirement for pump selection	4.29 L/min

A water diaphragm pump (bayite7A102) was used because of availability. The selected pump has a flow of 4 L/min with a cut-off pressure of 100 psi. However, the default cut-off pressure is set within 80-85 psi. The nozzle output used here is an estimated value. After obtaining nozzles, the actual output at a specific pressure will be accounted for.

Batteries: In sizing the batteries, it was necessary to list out all components that the batteries will power. The respective current consumption values for each component were listed and can be found in Table 3.4 below.

Table 3.5: Components and their current consumption

Component	Quantity	Current consumption
Diaphragm Pump	1	3A
DC Motors	2	13.4 (2) = 26.8 A
Solenoid valves	2	1.75 (2) = 3.5 A
Total Current		**27.33**

Total run time of system = 1 hour

Total battery supply (Ah) = Time (h) × total current consumption(A)

Total battery supply = 1 h × 33.3 A = 33.3Ah

The most recommended batteries for robots are Lithium-ion batteries, Lithium polymer batteries, and nickel-metal hydride batteries. But for this project, two 12 V 18 Ah rechargeable lead-acid battery is used because of availability.

Wheels: From the literature review, standard wheels are best suited for the design and fabrication of the sprayer robot. Another consideration is how the wheels will be mounted. For this sprayer, 2 motors drive 2 standard wheels at the front while 2 other standard wheels serve as freewheels. The wheels will be directly mounted to the motor using shafts rather than gears. This type of mount is simple and inexpensive compared to other mounting arrangements. It is also easy to control. There is low drag going forward; however, some drag during turns. A simple steering method called skid steering will be employed.

Nozzles: Nozzles determine the application volume at operating pressure, travel speed, and spacing. Choosing nozzles that create the most significant droplet size while providing appropriate coverage at the required application rate and pressure might help to reduce drift, hence lowering environmental and operator contamination. Herbicide applications in this project will be applied directly over the crop row. This technique requires rectangular nozzle spray (even) tips. Multiple nozzles will be used in this project to increase application efficiency and accuracy. Spacing between the nozzles for corn and soybean is about 30 inches (76 cm) for the banding application method. The nozzles used in this project were obtained in a local shop and had no datasheets. The flow rate will be measured, and that flow rate will be used throughout the paper.

3.2.1.7 Material Selection:

Possible Materials for Platform of Sprayer

Wood

Wood can be used for the chassis of a mobile robot. It is easily accessible in most areas and inexpensive. It is easy to work with as no special tools are required for drilling and cutting holes. This makes it easy to custom the parts mounted on the chassis. Although wood is not waterproof, the application of sealant prolongs the life of the chassis as it is a moisture repellent [14]. On the other hand, wood is not best suited for a robot with many heavy moving parts. Despite sealant usage, wood is also not suitable for a robot with exposure to water for long periods of time as it tends to warp in such cases. Compared to other materials, wood deteriorates with age faster than other materials.

Aluminium

Aluminium is a good choice for the chassis of a robot because it is generally lighter than other metals, hence reducing the system's total weight. It is also softer than most materials, making it easier to machine in cutting and drilling holes. Unfortunately, aluminium is expensive as compared to other materials such as steel. Its soft nature makes it impractical to build a robot that would carry heavy loads. It is also not advisable to use aluminium for making a chassis that requires welding as aluminium is challenging to weld.

Steel

Steel, an alloy made of iron and carbon, is a tough and strong material and can be used for the chassis of a robot. It is relatively cheap and can easily undergo fabrication processes such as welding. It is most advisable to use steel for the chassis if the robot will be carrying heavy loads and would need to withstand harsh conditions. As a result of its hard nature, steel is difficult to machine when using hand tools such as a hand drill. In the case of mobile robots, the heavy nature of steel necessitates the use of larger motors which require the use of plates to mount them on. This causes the overall weight of the robot to increase.

3.2.2 Electrical Design

3.2.2.1 Design of the Nozzle Control Sub-System

A methodology that includes mechanical modifications, sensor and valve installation, electronic component and microcontroller specification, and circuit board design must be developed to develop the proposed system.

The Nozzle control subsystem is to control the application of pesticides or herbicides. It uses solenoid valves to control the fluid flow with the help of Bluetooth communication from a smartphone. Each nozzle is associated with a button on a phone app that allows the solenoid valves to open and close to allow the fluid to flow from the tank and out of the nozzles. Flow and pressure sensors are also connected to the boom to record values of the flow rate and pressure of the fluid. This is to observe how the system reacts to turning the nozzles on and off. The flow chart in Figure 3.7 shows how the nozzle control sub-system will operate.

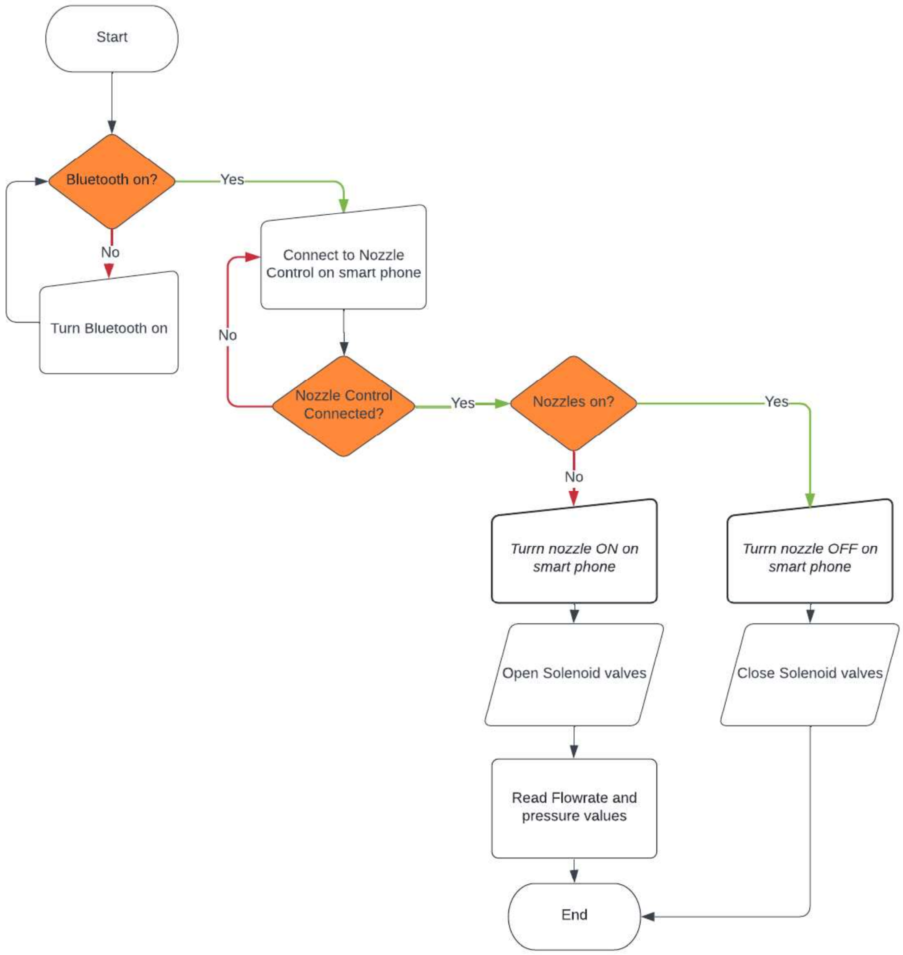


Figure 3.7: Flowchart model of the nozzle control sub-system

3.2.2.1.1 Component Selection: The components needed in the nozzle control sub-system include a microcontroller, Bluetooth module, solenoid valves, flow sensors, pressure sensors, and relays. These components are discussed in detail in the sections that follow.

3.2.2.1.1.1 Microcontroller: The aim of using a microcontroller is to control all the functions under the nozzle control subsystem. This includes creating a Bluetooth interface and connection for the system, allowing users to pair their smartphone with the system to control the solenoid valves. The Arduino UNO microcontroller shown in Figure 3.8 is selected for the system. There are many powerful and better options, but the Arduino UNO is selected because it is low-cost and one of the more accessible options for beginners. Selecting this microcontroller would require a Bluetooth module to achieve the Bluetooth functionalities

Figure 3.8: Arduino UNO microcontroller

3.2.2.1.1.2 Solenoid Valves: These valves are commonly used to control fluid or gas flow. There are various types, but the main variant used in the nozzle control system is the direct-operated solenoid valve. These directly open or close the main orifice, which is the only path in the valve. Its function in the system is to control the flow of pesticides or herbicides by fully opening or closing the valve to allow or prevent flow through the nozzles respectively. Two 12 V DC-powered valves are used, each with a maximum pressure of 142 psi. Figure 3.9 shows the solenoid valves used.

Figure 3.9: 1/4” Solenoid valve

3.2.2.1.1.3 Relay: A relay is necessary for the nozzle control system because the microcontroller controls the solenoid valves with a low power signal. It will ensure complete electrical isolation between the microcontroller and the two solenoid valves. This protects the circuit from burning out. A four-channel relay will be used because it was readily available; however, a two-channel is appropriate since only two solenoid valves are used. Figure 3.10 shows a two-channel relay.

Figure 3.10: A two-channel relay

3.2.2.1.1.4 Pressure Sensor:

The purpose of the pressure sensor is to take the reading of the pressure of the fluid that is being delivered to the nozzle. This is necessary for 2 reasons. The first is to keep track of the pressure corresponding to the required flow rate. The second is to monitor how on and off control of the nozzle affects the pressure delivered to the nozzles during testing. An industrial pressure sensor is used for this project with a maximum cut-off pressure of 100 psi. Figure 3.11 shows an image of an Industrial pressure sensor.

Figure 3.11: A pressure sensor

3.2.2.1.1.5 Water Flow Sensor:

The purpose of the water flow sensor is to measure the rate of flow of the fluid that will be delivered to the nozzles. This will help to monitor how the on and off control of the nozzle affects the flow rate delivered to the nozzles during testing. For this project, The YF-S201 model is used. It has an operating range of 1-30 L/min and can take up 1.75 Mpa or less water pressure. Figure 3.12 shows an image of a water flow sensor.

Figure 3.12: A flow sensor

3.2.2.1.1.6 Bluetooth Module:

Since an Arduino UNO was selected as the microcontroller to run the system, a Bluetooth module is required to achieve the Bluetooth tasks. Using an ESP32 would require no Bluetooth module, but there were initial issues with the ESP32. However, both the Arduino UNO and Bluetooth module were readily available, considering the cost. It is advisable to use an ESP32 since the cost of one is less than the Arduino UNO and Bluetooth module. Figure 3.13 shows an HC-05 Bluetooth module used in this project. It has a range of less than 100 m.

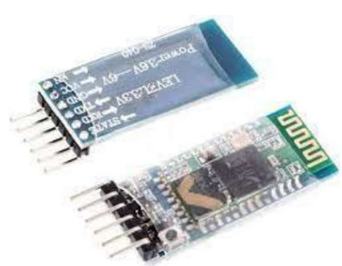


Figure 3.13: HC-05 Bluetooth module

3.2.2.1.2 Circuit Design

Having selected all the components for the nozzle control sub-system, a complete design of how all the components come together must be created to help visualize the system before implementation. One microcontroller is enough to power all the connections. Table 3.4 summarizes the pin connections of the major components on the Arduino UNO.

Table 3.6: Pin configurations of components on both microcontrollers

Component	Pin on Microcontroller
Pressure Sensor 1 (left nozzle)	A0
Pressure Sensor 2 (right nozzle)	A1
Solenoid valve 1 (left nozzle)	12
Solenoid valve 2 (right nozzle)	13
Flow sensor 1 (left nozzle)	2
Flow sensor 2 (right nozzle)	3

The relay is not included here because although the relay channels are the ones that occupy the pins for the solenoid valves, it serves as a bridge for the valves to be connected to the pins on the microcontroller. Based on the pin configurations, a block diagram and breadboard view of the circuit are shown in Figures 3.14 and 3.15, respectively.

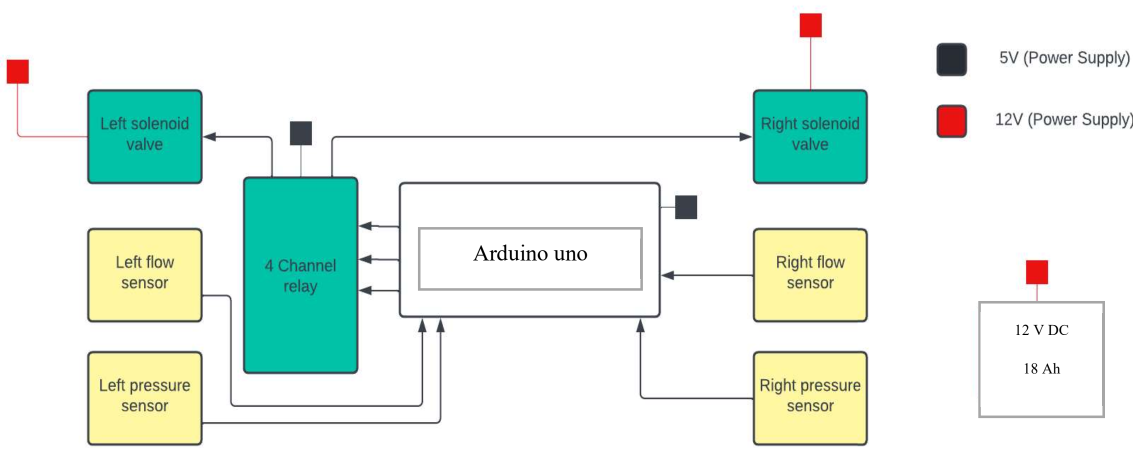


Figure 3.14: Block diagram of nozzle control circuit design on the microcontroller

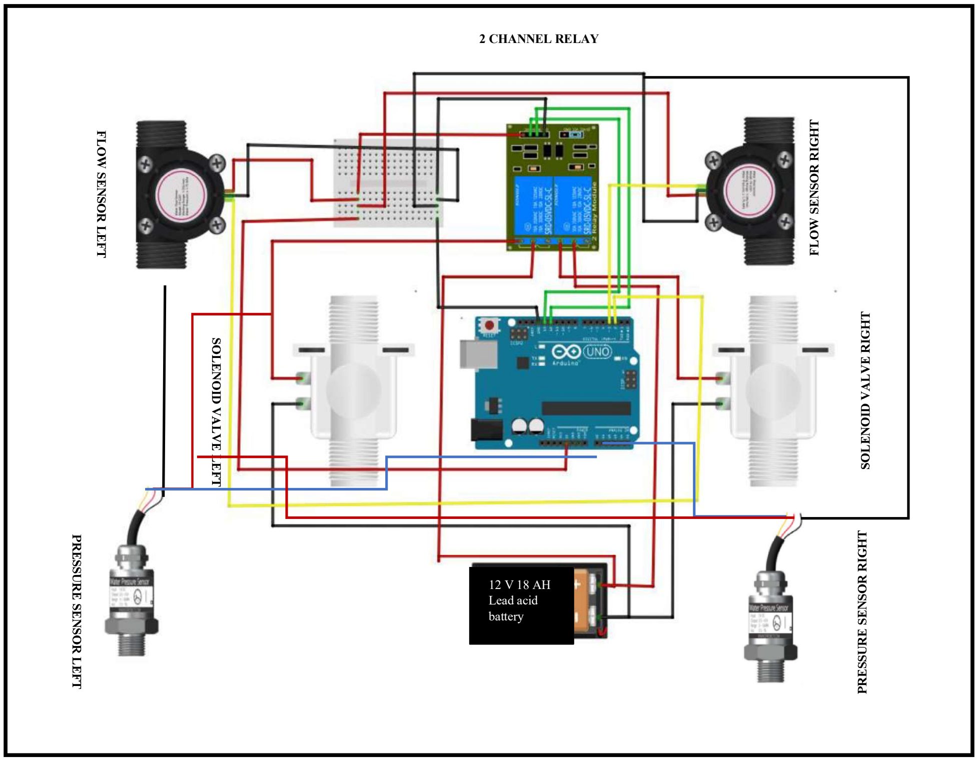


Figure 3.15: Breadboard view of nozzle control circuit design

3.2.2.1.3 Bluetooth Application Design

The Bluetooth application is only available on Android smartphones. MIT app inventor was used to design the Bluetooth interface. Per the requirements in chapter 3, the Bluetooth app has 2 buttons, one for each nozzle. When a button is clicked, it can either be red or grey. Red means it is active, and a command is sent to the microcontroller, sending it to the solenoid valve and opening it. This allows the fluid to flow to the nozzles. Greying the button out executes the opposite and closes the solenoid valves preventing the fluid from flowing to the nozzles. The Code blocks for creating the Bluetooth app are shown in Figure 3.16.

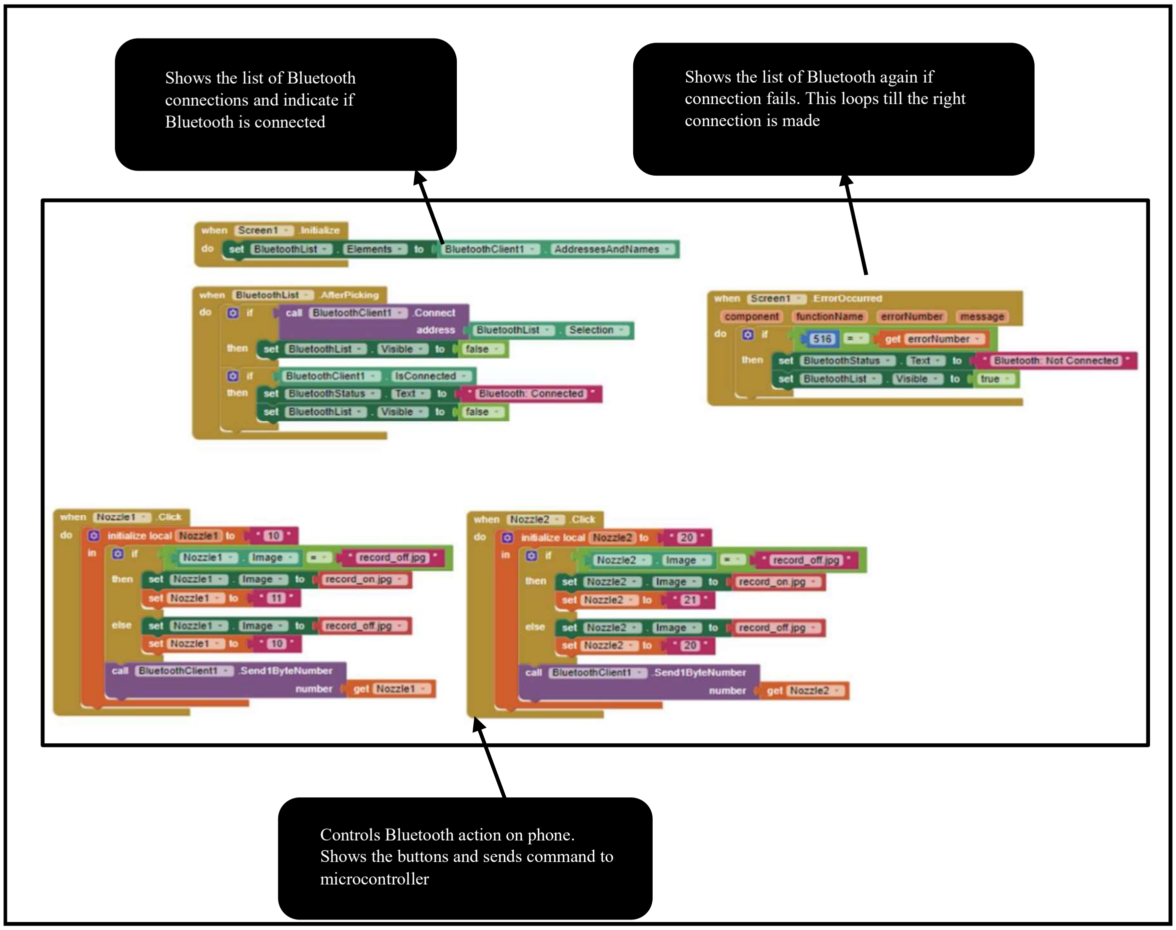


Figure 3.16: MIT app inventor code blocks for nozzle control

3.2.2.2 Design of the Navigation Control Sub-System

The navigation control sub-system involves directing the crop sprayer through the farm rows. The code for this will be structured in Arduino using the same microcontroller used for the nozzle control system. This is because the crop sprayer will be controlled using Bluetooth navigation. The same Bluetooth interface used to control the nozzles will control navigation. This is to help have all controls in one space for simultaneous control.

Component Selection and Sizing: The components needed in the navigation control sub-system include a microcontroller, a motor driver, and dc motors. These components are discussed in detail in the sections that follow.

DC motor: From the literature review, we know what DC motors are and their functions. An online resource is utilized in selecting the DC motors for this project. This resource allows inputting some parameters and gives all the specs to a suitable motor. The necessary inputs include the weight of the robot itself, the payload on the system, the diameter of the wheel, and the operating speed of the robot. The robot's speed is determined by the RPM of the motor, the diameter, and how the wheel is coupled to the motor. If the wheel is directly coupled to the motor, only the RPM and wheel diameter is necessary to determine the speed.

Table 3.7: DC motor sizing specifications

Input Parameters	**Output Specifications**
Total mass (mass of robot + payload) = 50 Kg	Angular velocity (rev/min) = 83.588
Number of drive motors = 2	Torque (Nm) = 31.259
Radius of drive wheel = 0.1143 m	Total power (W) = 273.48
Maximum incline >= 20	Maximum current (A) = 22.790
Supply voltage 12 V	Battery (Ah) = 22.790
Desired acceleration = 0.2 m/s^2	
Desired operating time = 1HR	
Total efficiency (65%)	

Based on the output specifications, a motor is selected, but the selected motor should have its specifications above what has been specified. An MY10167 24V 250W brushed gear DC motor was selected for the sprayer robot based on availability. It has a rated torque of 24 Nm at 120 rpm—Rated current of 13.4 A.

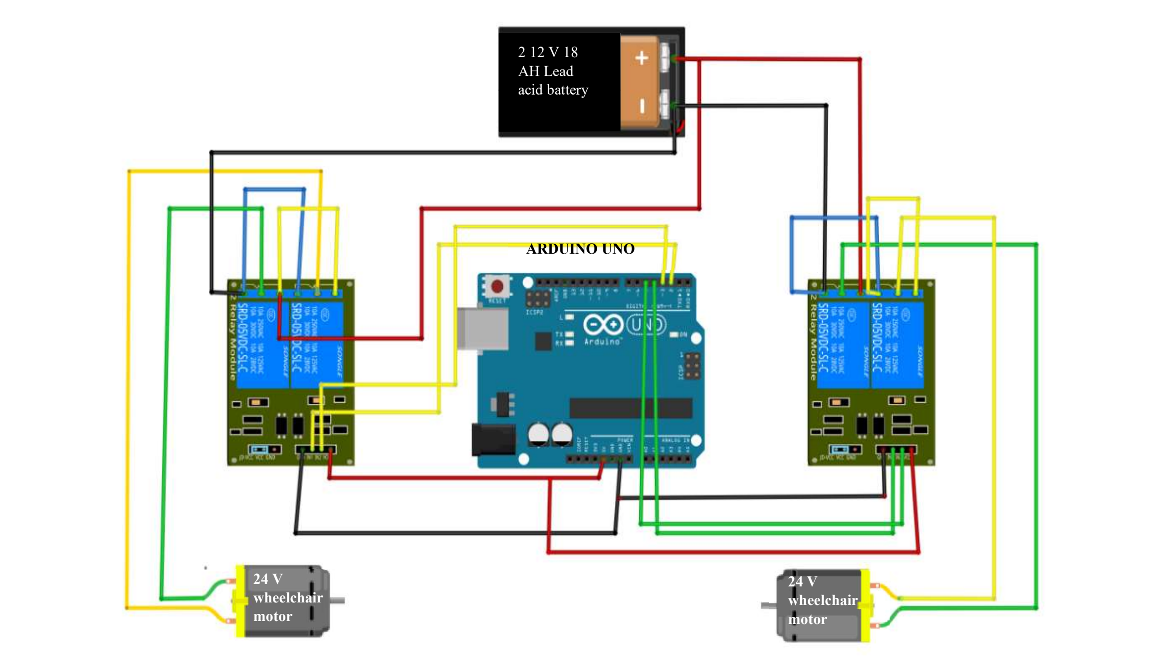
Figure 3.17: Brushed DC gear motor

Motor driver: A motor driver is essential to run the motors for navigation. They are mainly used for motor interfacing. They act as an interface between the motors and control circuit, the microcontroller. The microcontroller circuit works on low current signals while the motor driver requires a high current. So, the drivers take the low-current control signal, change it into a high-current signal, and use it to drive the system's motors. Selecting a motor driver depends on the type of motor used and their ratings. i.e., current and voltage. The BTS7960 43A H-bridge motor driver is suitable for this project and is shown in Figure 3.18.

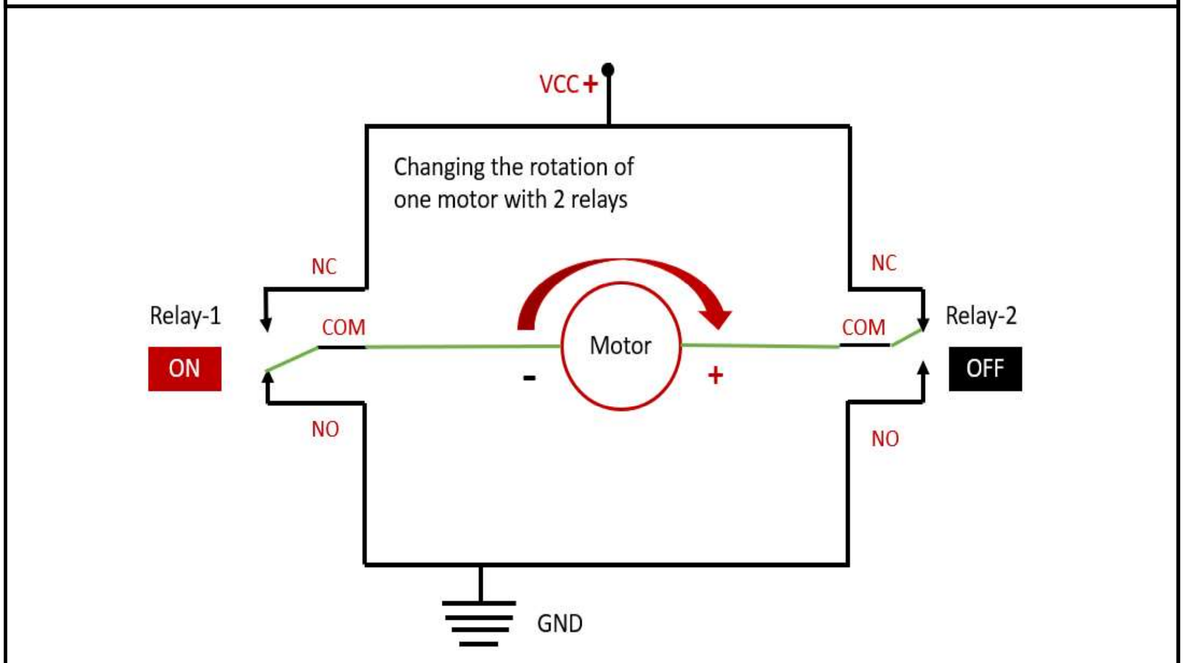
Figure 3.18: BTS7960 43A H-bridge motor driver

A motor driver is not used in this project because of some challenges. Due to this, 2 pairs of 2 channel relays will be used to drive the system.

Circuit Design: Figure 3.19 shows the breadboard view and operating concept of the relays with the motor.



Breadboard view



How the motors rotate

Figure 3.19: Breadboard and operating concept of the navigation

Bluetooth Application Design:

When a navigation button is pressed, the code sends a string associated with that direction to the Arduino IDE. Once it receives that string, a condition statement is set up such that, The system executes a command that will move the sprayer robot in the selected direction.

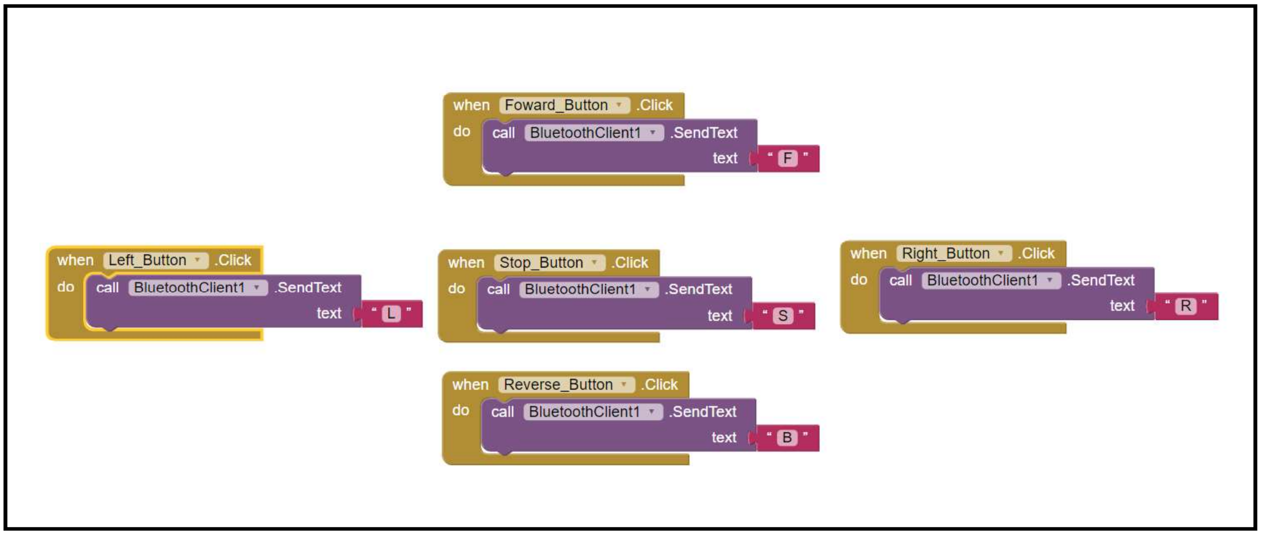


Figure 3.20: MIT app inventor code blocks for navigation control

Chapter 4: Analysis

In this chapter, an analysis of the load on the system was performed to determine if the proposed material is suitable for the platform. Before performing the analysis, a trial is done to confirm that the computations used to analyse the system give accurate results. This trial is done by performing an analytical calculation and simulating the conditions in SOLIDWORKS. The results are presented, and the platform analysis is performed and a simulation of how the nozzle control functions is presented.

4.1 Mechanical

4.1.1 Platform Simulation

4.1.1.1 Analytical Calculations

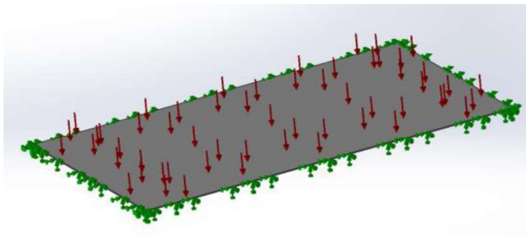
The results of the analytical calculations using Roark's formulas for stress and strain are presented in Table 4.1. and the detailed calculations are presented in Appendix A.1. Following the calculations, the results from the numerical calculations are presented in Figure 4.1 and

Table 4.1: Analytical Static Analysis on flat plate

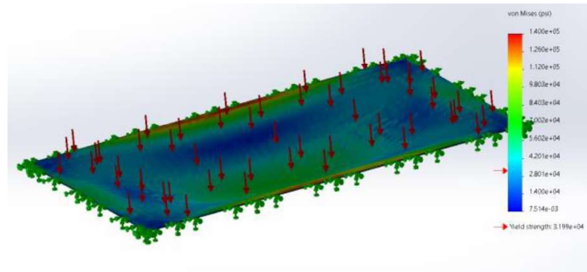
Parameters	Values
a (long side)	35 in
b (short side)	20 in
t (thickness of the plate)	0.12 in
q (Uniformly distributed pressure load)	10 psi
α	0.0989
β	0.5559
γ	0.497
E (Youngs Modulus)	30,457,924.9 psi
$\sigma_{max} = \frac{-\beta q b^2}{t^2}$	154,416.67 psi
$Y_{max} = \frac{-\alpha q b^4}{E t^3}$	-3.00 in

Where Y is the deflection of the system.

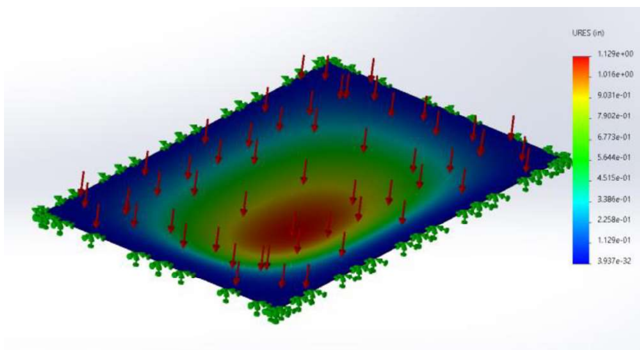
4.1.1.2 Test Static Numerical Analysis



(a)



(b)



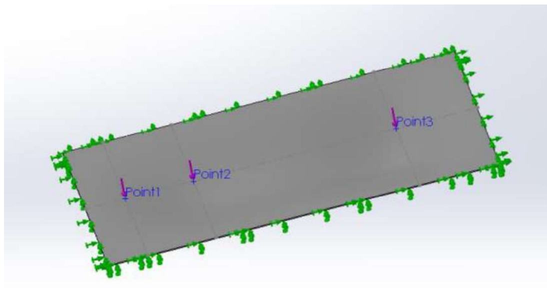
(c)

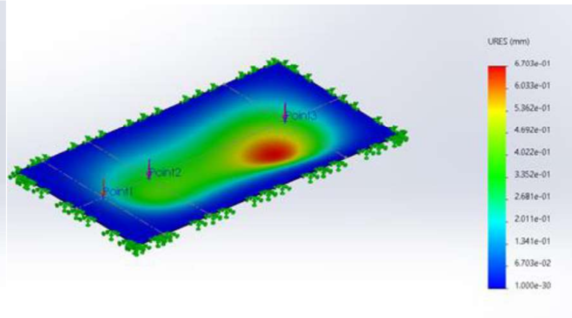
Figure 4.1: (a): Platform with constrains and point forces (b) von Mises stress (c) Deflection

From Figure 4.1, A pressure of 10 psi is uniformly distributed on the platform and the stress recorded is 140 ksi which is close to the analytical results of 154 ksi however, the deflection of 1.13 in is of by almost 2 inches. This difference is attributed to the difference in formulas used for the computation. The analytical calculations use Roark's formula while the numerical uses von Mises stress.

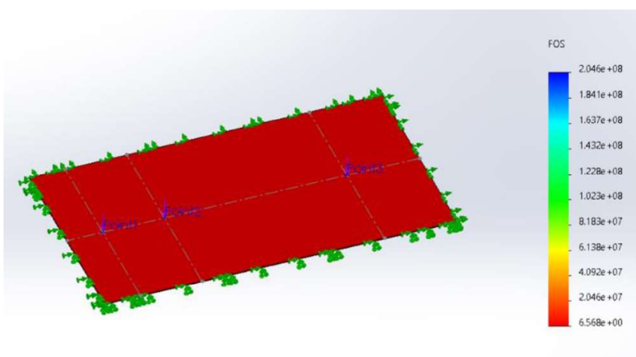
4.1.1.3 Static Numerical Analysis

The effect of the payload on the platform was simulated for mild steel to determine if the material was suitable to carry the load on the system. Static analysis was performed on the platform with all four edges fixed (simply supported flat plate). The specific loads at specific locations on the platform were identified on the plate. Example: The 25 Kg water tank is presented at point 3, as shown in Figure 4.1a. The major takeaway of the analysis is on the minimum factor of safety and the deflection on the platform. The static analysis for mild steel is shown in Figure 4.1, and the table that summarizes the results is shown in Table 4.1.





(a) (b)



(c)

Figure 4.2: (a): Platform with constrains and point forces (b) deflection (c) FOS

Table 4.2: Results for static analysis on platform

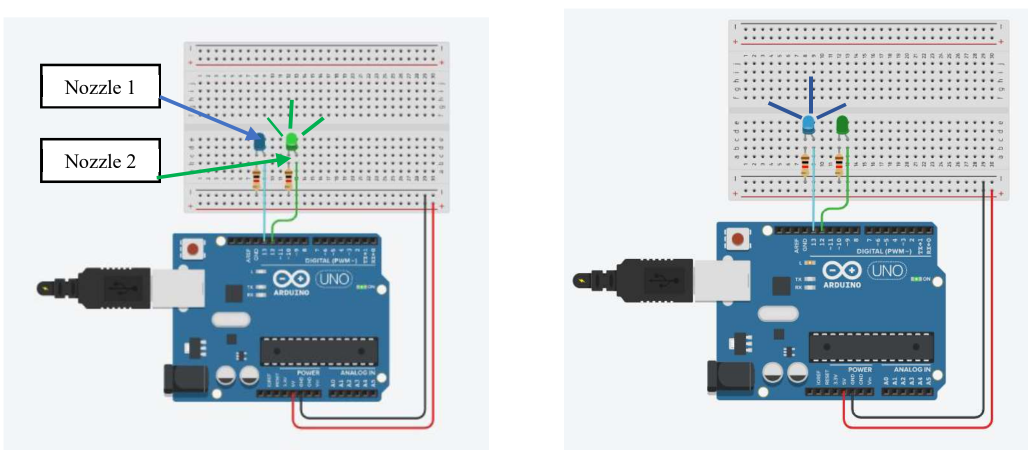
Material	**Max.Displacement (mm)**	**Factor of Safety**
Mild Steel	0.67	6.6

From the results, the maximum displacement on the system was experienced at point three. This is because point three had the most significant weight. This displacement is insignificant and shows that the system can handle the payload. A safety factor (FOS) of 6.6 is recorded, which supports the fact that the system is more than safe to carry the current load. It can at least carry twice that weight, but that will require a different DC motor.

4.2 Electrical

4.2.1 Nozzle Control

Before the Nozzle control system is implemented, A simulation of how it will function is performed in tinker cad, and the results are presented in Figure 4.3.



(a) (b)

Figure 4.3: (a) Simulation to turn nozzle 2 on (b) Simulation to turn nozzle 1 on

The LEDs represent the nozzles. One nozzle is turned on while the other is turned off via the Bluetooth command on the android application.

Chapter 5: Implementation

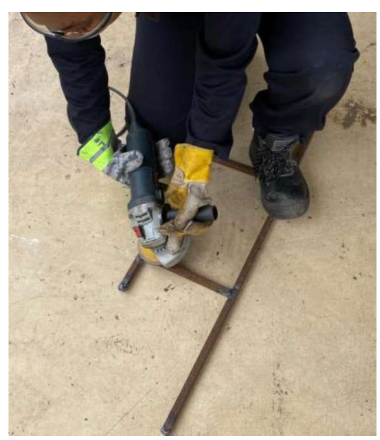
This chapter presents the fabrication process of the final design of the crop sprayer. The process includes the mechanical, nozzle control, and navigation system. The implementation outcome is compared to the requirements of the project and analysed.

5.1 Mechanical Sub-System

5.1.1 Implementation of Platform and Boom

For the platform of the crop sprayer, a long mild steel L-shaped angle bar was cut into six pieces with the angle grinder; four of these bars were used to form the base frame of the platform. Two bars of length 20 inches were welded to the other 2 bars each of length 35 inches. The remaining two bars of length 45 inches were bolted to the base frame, and a small iron pipe was bolted in between the bars to ensure stability with bolts and nuts. Three parallel holes were drilled into each bar using the hand drill with a separating distance of 12 inches. Each hole had a diameter of 6 mm. A mild steel sheet was cut and placed into the base frame to form the platform's base, as shown in Figure 5.1a. The boom was implemented by welding 4 small iron pipes together, and the angle grinder was used for finishing, as shown in Figure 5.1b. Two holes of diameter 6mm were drilled into the boom for mounting.

(a)

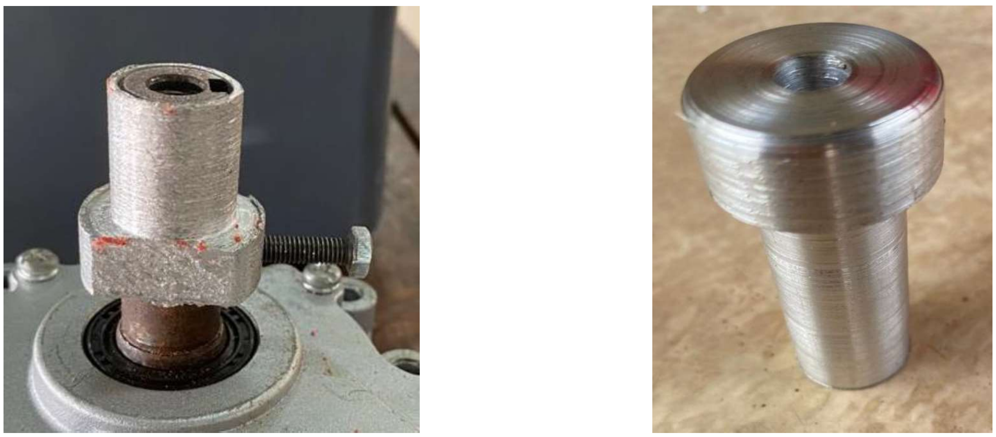


(b)

Figure 5.1: (a) Platform (b) Boom finishing

5.1.2 Connection of Wheels and DC Motor to System

The two front wheels of the sprayer were each connected to a DC Motor, and the rear wheels were connected to small, fabricated shafts connected to the base of the sprayer. Six small shafts were fabricated out of Aluminium and Steel cylindrical blocks to connect the wheels to the crop sprayer. The Lathe Machine was used to shape each piece of a cylindrical block into the appropriate sizes, as shown in Figure. 5.2.



(a) (b)

Figure 5.2: (a) Machined Part for DC Motor (b) Machined part for rear wheels

The sides of the machined shaft in Figure 5.2a were cut using a hack saw. This was done to connect the motor to one end of the wheel so that any movement from the dc motor would be transferred to the wheel connected. A hole was drilled into this piece, and a thread was created in the hole using a tap. A bolt was screwed into the threaded hole to fasten the shaft to the motor. The shaft in Figure 5.2b was placed in the inner diameter of the wheel on the other side, and a long bolt was placed in the hole of the shaft and was screwed to the threaded hole of the motor, as shown in Figure 5.3. The two rear wheels were each connected to a shaft of the length of 90 mm, and a hole of diameter of 6 mm was drilled into the sides of each shaft.

Figure 5.3: Shaft connection to wheel

Four mild steel plates of width 3 mm were cut, and 3 holes were drilled into each. The plates were welded to the platform, and the dc motors were mounted onto the plates through the mounting holes with bolts and nuts, as shown in Figure 5.4a. Four other mild steel plates were cut into a pentagonal shape, and a hole of 21 mm was drilled into the centre of each plate. The plates were then welded unto the platform. The shafts fit into the holes, as shown in Figure 5.4b, and the wheels were connected to the shafts. Bolts and nuts were screwed into holes at the tip of the shaft to keep the wheel in position.

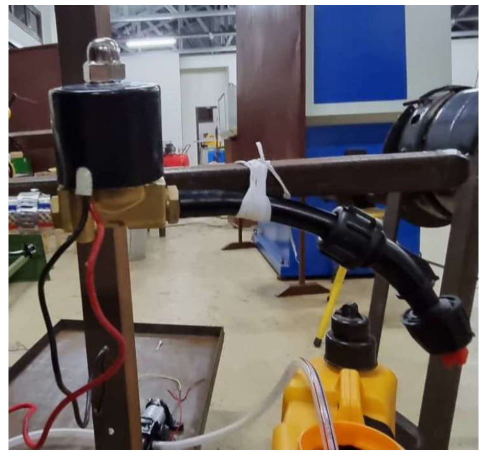
Figure 5.4a: DC Motor mounted on front-wheel plates through mounting holes

Figure 5.4b: Shaft placed on rear wheel plates

5.1.3 Boom Connections

The sprayer connection consists of a 25-litre gallon connected to a pump which a 24 V battery will power. The pump is connected to a T connector hose with both ends, each connected to a flow sensor, pressure sensor, solenoid valve, and a nozzle as seen in Figures 5.5a and b.

(a)



(b)

Figure 5.5: (a) and (b) Boom connections with sensors and nozzles

5.1.4 Finishing the system

The whole platform and boom were sandpapered using the sanding machine. The platform was then sprayed with red anti-rust paint using the paint spray gun, as shown in Figure 5.6. The boom was then mounted onto the platform by screwing a bolt through the hole in the boom and connecting it to the holes on the platform.

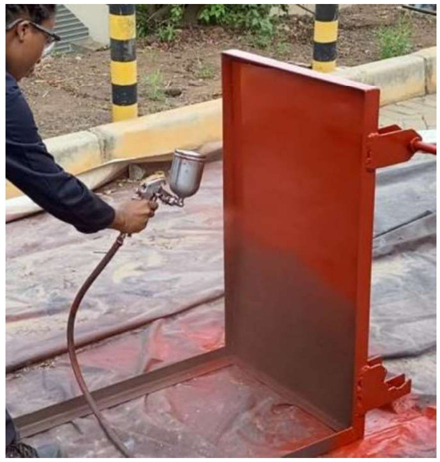


Figure 5.6: Spraying system with a paint spray gun

The completed system is shown in Figure 5.7, comparing all the dimensions and values to the design requirements in chapter 3.

Figure 5.7: Completed design

The width of the fabricated sprayer from the centre of one tyre to the other is 63.5 cm which is less than 75 cm as stated in the design requirements. This is to help the sprayer move through the rows with ease. The distance between the ground to the motors is 6 cm, while that between the chassis and the ground is 21.6 cm. This distance meets the design requirement of at least

17 cm; however, the distance between the motors and the ground was not accounted for. Also, the distance between the two nozzles is exactly 76 cm.

5.2 Nozzle Control Sub-System

Based on the design of the nozzle control, Arduino IDE was used to set up the system to achieve its requirements. Each sensor and solenoid valve were programmed, calibrated separately, and combined to create the nozzle control system. The system was set up for field tests. The setup consists of a 25-litre tank, a diaphragm water pump, a hose, and a 30-inch spray boom with two nozzles in series.

The logic control is implemented using Arduino IDE. The microcontroller communicates with the android application via the Bluetooth module. The application allows the operator to send commands to open or close the nozzles individually while displaying the instantaneous pressure-flow values. The microcontroller writes open/close commands to the solenoid valves via digital outputs; it also reads pressure sensors via analogue inputs and reads flow sensor pulses from interrupt pins on the Arduino UNO. This controller counts pulses via interruptions during an interval of one second. Thus, it must stop the rest of the processing to avoid losing any sensor pulse. The code for implementing this is presented in Appendix A.2.

All electronic circuits and controllers were assembled within a junction box. Figure 5.8 shows the automated system installed on the mechanical system for field testing.

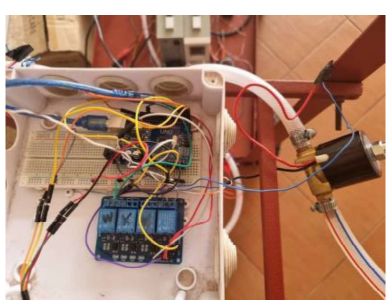


Figure 5.8: Nozzle control field set-up

5.3 Navigation Control Sub-System

Based on the design of the navigation control sub-system, Arduino IDE was used to set up the system to achieve its requirements. Each DC motor is connected to a two-channel relay. The 2 batteries are connected to the relays while the relays are connected to the Arduino Uno. The relays have three normally open, normally closed, and common connections. Each motor is connected to the common of the two relays. The negative terminal to the common of relay 1 and the positive terminal to the common of relay 2. The same is repeated for relays 3 and 4 for the second motor. The Normally closed of both relays 1 and 2 are connected, and the same is done for relays 3 and 4. The Normally open for relays 1 and 2 are connected, and the same is repeated for relays 3 and 4. This setup allows for the relays to turn on when the contact is low and off when it is high. The high and low setup prevents the system from controlling the speed. The Forward movement is done by making one relay of each motor low (relays 1 and 4). This type of manipulation allows for movement in the left, right, and reverse direction and stops the system. The code for executing this is shown in Appendix A.3. Figure 5.9 shows the navigation control system installed on the mechanical system for field testing.

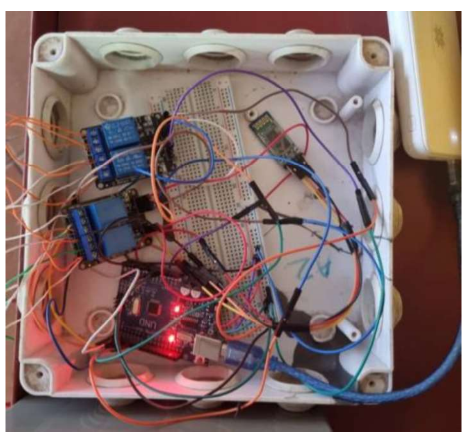


Figure 5.9: Navigation control system setup

The system is set up for a speed test and field test. The speed test includes testing to confirm the speed the DC motors provide with a 12V power supply. The field test checks how well it adapts to the field with the Bluetooth control.

5.4 Bluetooth Interface

The Bluetooth interface for navigation is also implemented directly below the nozzle control commands. The commands are written in full to make it easier for operators to know how to operate it. Figure 5.10 shows the Bluetooth Interface for both the nozzle and navigation control.

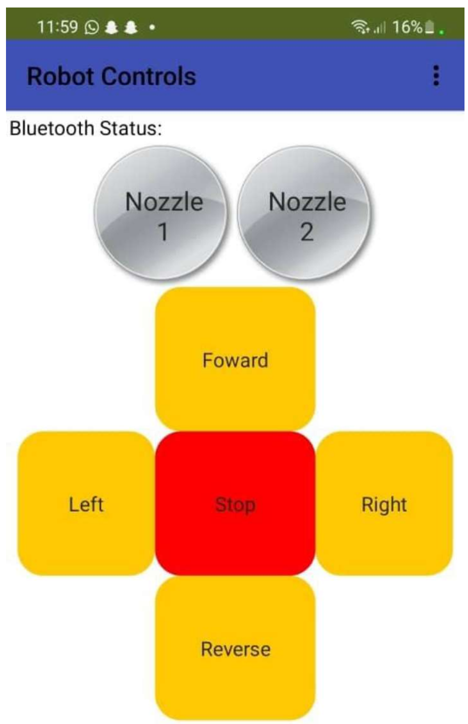


Figure 5.10: Bluetooth interface of nozzle and navigation control system

Also, most of the components and materials used for fabricating and automating the system were readily available for use. However, the estimated cost for automating the system is around 375 US dollars. Comparing this cost to drones and tractors, it is cost-effective for medium-scale farmers.

Chapter 6: Results and Discussion

This chapter presents the results obtained from testing two subsystems of the sprayer robot. The results of the nozzle control obtained from testing each component used are also presented, including field tests and the results of the Navigation control system.

6.1 Nozzle Control Sub-System

6.1.1 Component testing

The pressure and flow sensors are calibrated and tested to know their level of accuracy before proceeding to the field tests.

6.1.1.1 Pressure sensor

The diaphragm pumps have their voltage directly proportional to the pressure supplied. The default set cut-off pressure is at 85 psi. This value is achieved at 12 V DC. The power supplied to the pump was 5 V DC. Hence the expected pressure reading should be around 35 to 36 psi. Values obtained from the pressure sensors were highly inconsistent and inaccurate. This meant that the sensors could not be used to collect accurate data.

6.1.1.2 Flow Sensor

The flow sensors are programmed to display both the flow rate and volume of the fluid. To test that the values from the flow sensors are accurate, they must be tested first. A volume of water is pumped through the sensor at 36 psi, and the value recorded is noted to test the volume. The pumped water is then transferred to a measuring cup to determine its volume. The process is repeated 5 times, and an average is recorded. The values are compared, and the percentage error is calculated. The flow through the flow sensor is timed for 30 seconds to test the flow rate, and the flow per minute is calculated. This test is repeated 5 times, and the average value and percentage error are calculated. Figure 6.1 shows the setup for testing the flow sensors, and Tables 6.1 and 6.2 show the average results from manual flow rate testing and the flow sensor flow rate testing, respectively.

Figure 6.1: Setup for testing flow sensors

Table 6.2: Average manual test values at 30 seconds

Manual Values	**Nozzle 1**	**Nozzle 2**
Flow rate (L/min)	0.648	0.621
Volume (mL)	324	310.4

Table 6.3: A Flow sensor test values at 30 seconds

Sensor Values	**Nozzle 1**	**Nozzle 2**
Flow rate (L/min)	0.66	0.628
Volume (mL)	330.6	314

6.1.1.2.1 Percentage Errors for Flow rate values

Using the manual values as the standard values, the percentage errors for the flow sensor values are calculated. The results show that the error is relatively small and can be neglected. This error can be attributed to the sensitive nature of the flow sensors. The rotor inside the flow sensor that rotates to give the hall effect sensor pulse is very sensitive to even air. Extra care should be taken to make the system is airtight for correct values.

Table 6.4: Percentage errors of the flow sensor

Nozzles	Percentage error (%)
Nozzle 1	1.85
Nozzle 2	1.13

From Table 6.2, The flow rate for the nozzles used in this system is around 0.6 L/min. However, it is observed that the flow rate from nozzle 2 is slightly lower than that of nozzle one. This is due to slight errors in ensuring that the hose length from the pump to each nozzle is equal. At this determined flow rate, the effect of the nozzle on/off control is analysed.

6.1.2 System testing

6.1.2.1 Field test

The main results obtained from the field test is proof that the concept of nozzle automation is feasible even with low-cost sensors and valves.

The first test performed with the field setup focuses on validating the system, ensuring that the valves open and close via commands from the Bluetooth application. The second test was to check how the sprayer responds in terms of the flow for various scenarios of opening and closing the nozzles. Table 6.4 shows the set of data observed in the test. The pressure is set at 36 psi initially, with both nozzles open.

Table 6.4: Average values collected during a field test of nozzle control system

Flow rate 1 (L/min)	Flow rate 2 (L/min)	Nozzle 1	Nozzle 2
0.648	0.621	ON	ON
-	0.800	OFF	ON
0.824	-	ON	OFF

Figure 6.2 shows the behaviour of the flow rate as the nozzles are closed sequentially from 1 to 2. By closing nozzle 1, it is observed that the flow rate from nozzle 2 increases by 28 %. Closing nozzle 2 and opening nozzle 1 show an increase in flow rate by 27 %. The increase in flow rate for both nozzles is precise. This increase can be attributed to pressure variations even though pressure values were not recorded. An automatic pressure regulator with some control strategy can be used to adjust values to keep the pressure stable and flow rate at the initial values.

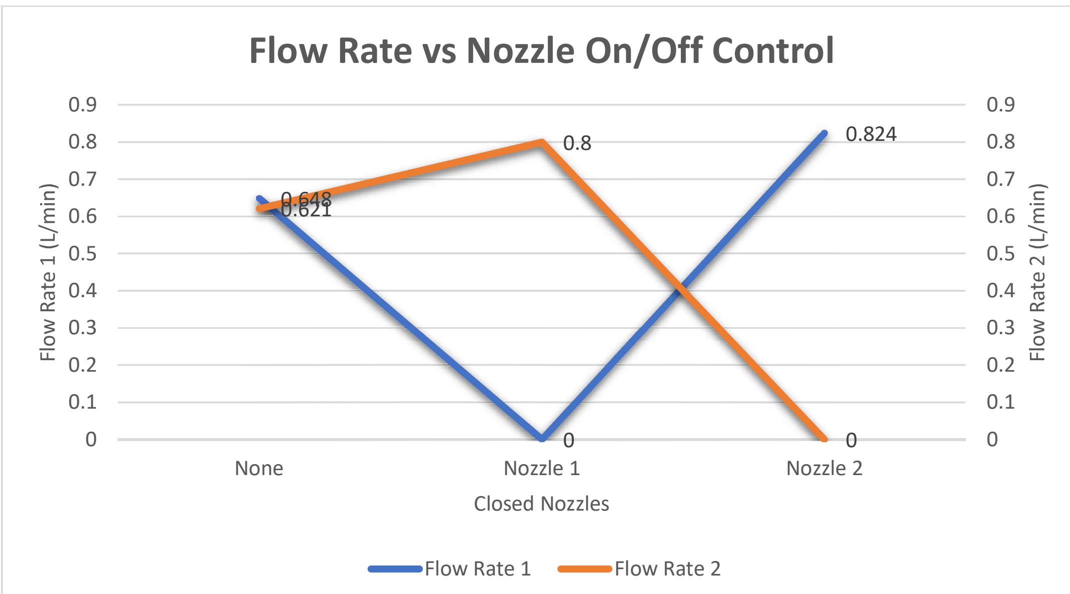


Figure 6.2: Flow rate and closed nozzles variation

6.3 Navigation Sub-System

6.3.1 System Testing

6.3.1.1 Speed test

Testing this system includes testing the speed of the DC motors. Since relays were used to run the motors, The speed can only be controlled by varying the voltage supplied to the motors. Each motor is supplied with 12 V DC and tested. A distance of 3 m is marked out with a tape measure, and the sprayer robot is made to travel that distance. It is timed, and the m/s is calculated. The value obtained is compared to the required speed. Figure 6.2 shows the speed test setup, and Table 6.5 shows values from the speed test

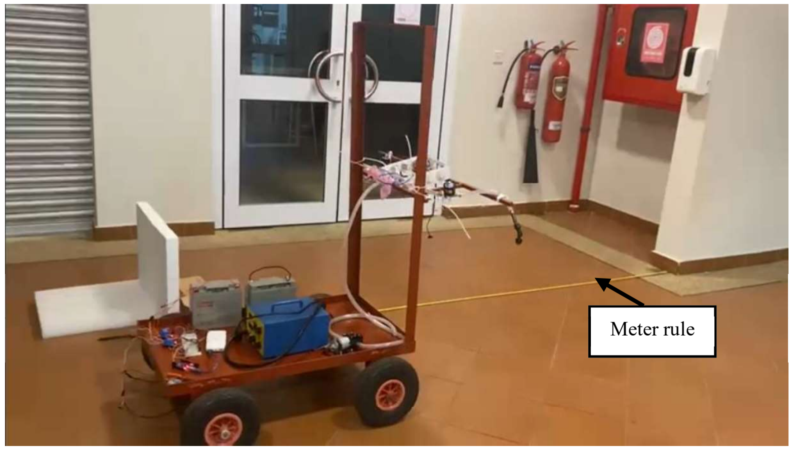


Figure 6.2: Speed test setup

Table 6.5: Data collected during the speed test

Tests	Time (s)
Test 1	5.64
Test 2	5.52
Test 3	5.43
Test 4	5.63
Test 5	5.58
Average	**5.56**

It took 5.56 seconds for the sprayer to travel the 3 m distance under standard conditions. Hence, the sprayer has an average speed of 0.539 m/s. This value is below the required minimum speed stated in the system's mechanical design requirements. Half of the required voltage was supplied to the DC motors (12 V DC). Supplying the DC motors with 24 V DC increases the speed to 1.078 m/s. This value is within the range of speed for banding spraying.

6.3.1.2 Operating time

To run the system at a minimum of 1 m/s, the dc motors will need a 24 V DC power supply from the batteries (Connected in series). The batteries used for the prototype are rated 12 V 18 Ah. To calculate the battery run-down time, the appliance load in watts is needed. Each motor is rated 250 W; hence the total load is 500 W.

Battery run-down time = (10 x battery capacity in amp hours) divided by (appliance load in watts)

= (10 x 18) / 500

= 0.36 hours or 21.16 minutes

This run-down time is short; however, the initially calculated battery capacity of 33.3 Ah would have a run-down time of 1 hour 6 mins which falls within the required operating time

Chapter 7: Conclusion and Future Work

This chapter presents a summary of the project goals and what was implemented. It also highlights the challenges faced and limitations of the project. It also addresses future improvements that can be implemented to better the project.

7.1 Conclusion

This paper proposes a cost-effective semi-autonomous sprayer using individual nozzle and navigation control via Bluetooth. The solution set up a site-specific on/off application using solenoid valves for nozzle control and DC motor and relays for navigation control. The automation control was implemented in the Arduino IDE. The paper also presented the design and construction of the sprayer's adaptation to a field system. Experiments were carried out, and the results were observed. The main contribution of this work was the proposal of a robotic system to the problem of pesticide spraying in terms of not being able to control the nozzles and being labour intensive. Nozzles can now be controlled, and the farmer does less manual work spraying the farm.

Limitations to this paper included the calibration of the pressure sensors. The values collected from testing the pressure sensors were not accurate; hence, pressure values were unavailable. When flow rate values increased during on/off control of the nozzles, it could only be assumed that an increase in pressure resulted in the increase in flow rate values but could not be proven. A short circuit experienced during testing of the components resulted in relays for navigation instead of the appropriate motor drivers. Due to this, the speed could not be controlled since relays do not allow for speed control. There was a delay in procuring appropriate components; hence, available substitutes were used to fabricate the prototype. The required battery capacities could not be used because all the available ones were not functional.

7.2 Future Works

To help Improve the crop sprayer, we suggest an improvement in the nozzle control system. The idea is to introduce a system that tunes parameters automatically when they deviate from the required value. When one nozzle is closed, the effect on pressure and flow is noticed at the other nozzle (Increased values), so those parameters can be automatically tuned to the required values. We propose including GPS and sensors to automate the crop sprayer for advanced navigation control fully. The overall system can be significantly improved. The results of this system can be available for further improvement by interested parties.

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Appendices

A.1 Analytical Static Analysis of flat plate

Long Side (a) = 35in

Short Side (b) = 20in

Pressure Load (q) = 10psi = 0.0689476 MPa

Plate Thickness (t) = 3mm = 0.12in

E = 30,457,924.9 psi

$$\frac{a}{b} = \frac{35}{20} = 1.75$$

Using Linear Interpolation to find α, β, γ

β

$x = 1.75$ $x_1 = 1.6$ $x_2 = 1.8$

$y = ?$ $y_1 = 0.5172$ $y_2 = 0.5688$

$$y = y_1 + (x - x_1)\frac{(y_2 - y_1)}{(x_2 - x_1)}$$

$$y = 0.5172 + (1.75 - 1.6)\frac{(0.5688 - 0.5172)}{(1.8 - 1.6)}$$

y = 0. 5559

∴ β = 0.5559

α

$x = 1.75$ $x_1 = 1.6$ $x_2 = 1.8$

$y = ?$ $y_1 = 0.0906$ $y_2 = 0.1017$

$$y = 0.0906 + (1.75 - 1.6)\frac{(0.1017 - 0.0906)}{(1.8 - 1.6)}$$

y = 0.0989

∴ α = 0.0989

γ

$x = 1.75$ $x_1 = 1.6$ $x_2 = 1.8$

y = ? $y_1 = 0.491$ $y_2 = 0.499$

$$y = 0.491 + (1.75 - 1.6)\frac{(0.499 - 0.491)}{(1.8 - 1.6)}$$

y = 0.497

∴ γ = 0.497

$$\sigma_{max} = \sigma_b = \frac{\beta q b^2}{t^2} = \frac{0.5559 \times 10 \times 20^2}{0.12^2}$$

σ_{max} = 154416.67 psi = 1064.665 mPa

$$Y_{max} = \frac{-\alpha q b^4}{E t^3} = \frac{-0.0989 \times 10 psi \times 20^4 in^4}{0.12^3 \times 30457924.9\, psi}$$

$$Y_{max} = -3.00\ in$$

A.2 Manual Volume test values at 30 seconds

Manual Volume (mL)	Nozzle 1	Nozzle 2
Test 1	325	313
Test 2	325	310
Test 3	324	310
Test 4	323	309
Test 5	323	310
Average Volume	**324**	**310.4**

A.3 Manual Flowrate test values at 30 seconds

Manual Flow rate (L/min)	Nozzle 1	Nozzle 2
Test 1	0.650	0.626
Test 2	0.650	0.620
Test 3	0.648	0.620
Test 4	0.646	0.618
Test 5	0.646	0.620
Average flow rate	**0.648**	**0.621**

A.4 Flow sensor Volume test values at 30 seconds

Flow sensor Volume (mL)	Nozzle 1	Nozzle 2
Test 1	328	311
Test 2	330	315
Test 3	329	312
Test 4	332	312
Test 5	334	320
Average Volume	**330.6**	**314**

A.5 Flow sensor flow rate test values at 30 seconds

Flow sensor Flow rate (L/min)	Nozzle 1	Nozzle 2
Test 1	0.656	0.622
Test 2	0.660	0.630
Test 3	0.658	0.624
Test 4	0.664	0.624
Test 5	0.668	0.64
Average flow rate	**0.66**	**0.628**