VARIABLE RATE SPRAYER FOR UNMANNED GROUND VEHICLE

A Final Year Project Report

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SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

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NUST

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In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

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ABSTRACT

For many years engineers have tried to find a solution to optimize the dosage models of spray rate of PPP in orchards or gardens. Uniform application fails this use on multiple levels. The reasons are discussed below and will be thoroughly mentioned in this paper. Sprayer at an adequate flow rate and volume of PPP being sprayed on a specific site is primarily in the agro based sector of Pakistan.

While environmental concerns and rising levels of drift pollution caused by uniform or conventional spraying techniques might be the biggest threat to the soil, unnecessary expenses inflicted because of wastage of PPP is a concern to our farmer industry of Pakistan. Variable rate of spraying eliminates maximum worries through site-particular basis algorithms that helps reduce the quantity of agrochemicals getting used in the framework precision horticulture.

A sprayer prototype on an unmanned ground vehicle that adapts to the volume of PPP application and the flow rate according to the spatial placement and geometric physical parameters of trees by following a control algorithm. The sprayer works on a continuous basis in real time.

ACKNOWLEDGMENTS

First, we would like to thank Allah Almighty for giving us this opportunity and for having his blessings upon us, our parents for their support and we are grateful to Dr. Sara Babar and Dr. Zaib for their continuous support and guidance throughout the execution of this project and for giving us the starting point to start our journey. We would also like to thank Miss Sabah Zaman for inspiring and motivating us.

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ABBREVIATIONS

UGV	Un-maned Ground Vehicle
VRS	Variable-Rate Sprayer

NOMENCLATURE

C_H	canopy height (m)
C_V	canopy semi-volume (m^3)
C_W	canopy semi-width (m)
Dv0.1	volumetric diameter percentile 10 (µm)
Dv0.9	volumetric diameter percentile 90 (µm)
i_a	application coefficient – actual ($L\ m^{-3}$)
i_o	application coefficient – objective ($L\ m^{-3}$)
NMD	numeric median diameter (µm)
p	working pressure of the system (bar)
Δp_{max}	maximum differential pressure (bar)
p_{max}	maximum working pressure of the system (bar)
p_{min}	minimum working pressure of the system (bar)
q	flow rate for the entire side of the sprayer ($L\ min^{-1}$)
q_j	flow rate at section j ($L\ min^{-1}$)
r	row spacing (m)
R	sampling resolution (samples m^{-1})
S	canopy cross-sectional area (m^2)
s	canopy semi-cross-sectional area (m^2)
s_j	canopy semi-cross-sectional area at section j (m^2)
SV	sprayed volume (L)
T	period of the regulation loop (ms)
v	forward speed ($m\ s^{-1}$)
V_j	control signal for the electromagnetic valve j (V)
VMD	volume median diameter (µm)

CHAPTER 1: INTRODUCTION

1.1 Motivation to work:

Agrochemicals, and even explicitly, utility methods of plant-based items (PPP), were examined due to the economic and ecological costs benefits which might be harnessing from their usage. At first, agrochemicals have been deliberate to be homogeneously dispersed over the plantations, and dosages have been (and are) delivered as according to every unit floor evenly. This has predominant drawbacks and want for variable charge spraying became one of the most game changing technology in the agricultural domain. A few specialists have gone through numerous years examining and creating measurement models for orchards, groves, and other vineyards that works on a criterion including imagery, physical parameters, and textural features.

1.2.1 Uniform Rate Sprayer

With the uniform application rate sprayers, an equivalent portion of pesticide is implemented to every tree. Since there is a variation in the geometry of each tree in the plantation in the orchards, plantations can get over sprayed or below sprayed.

1.2.2 Variable Rate Sprayer

Real time VRS technology gives pesticide utility as in line with the tree size. With the utilization of appropriate sensors, certain characteristics of the trees such as foliage density, and the canopy area can be measured. This can be received and with the micro-processing unit coupled with proper set of rules of digital proportional valves can be managed which in turn can be used to control the flow rate of nozzles in line with tree characteristics. Additionally, sensors can help isolate areas in the middle of trees which permits to govern and control the spray in spaces. Variable rate spraying facilitates in accomplishing accuracy in spraying activity particularly inside the grid of the orchards.

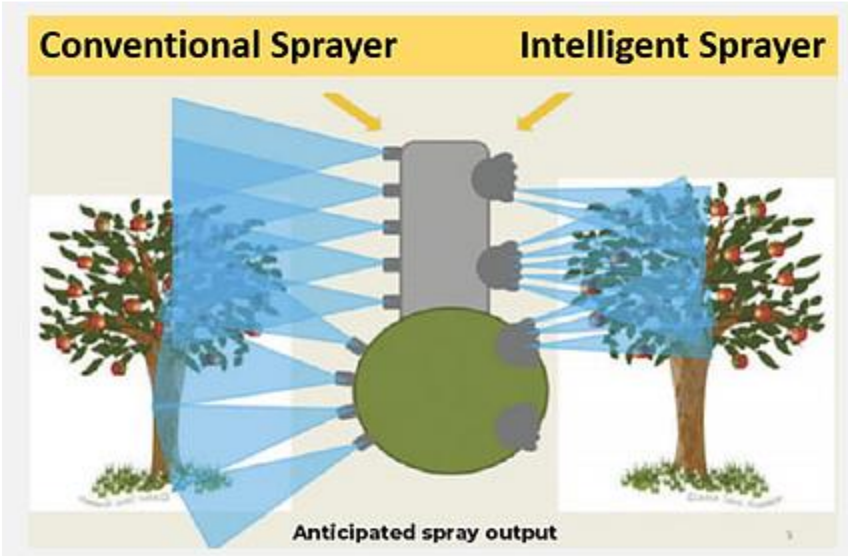


Figure 1: Comparison between Conventional and Variable Rate Spraying

1.2.3 Advantages of Variable Rate Sprayer

There are different spraying techniques for agrochemical field applications, including broadcasting and band applications. The previous is wasteful as it uniformly applied chemicals in agricultural areas disregarding the variable states of the field. By utilizing this procedure of variable spraying 60-70% of showering synthetic substances are wasted. Variable-rate innovation, then again, saves the spraying chemicals and diminishes drift pollution. Practically, about 40% of herbicides and other chemicals can be saved by thinking about the weed patches or potential contaminations in the field during the splashing activity. For tree crops an hedges, around 75% of pesticides can be saved by fluidly applying the synthetic compounds as per the covering construction of trees.

1.2.4 Use of Artificial Intelligence

The utilization of man-made consciousness (AI) can essentially work on the effectiveness chemicals of sprayers. The AI uses data-driven displaying procedures by taking the handled and marked pictures of the objectives as contribution for the advancement of a machine vision framework. Target plants are distinguished based on morphology and surface of plants. In this paper we will primarily discuss the control algorithm implemented on the prototype.

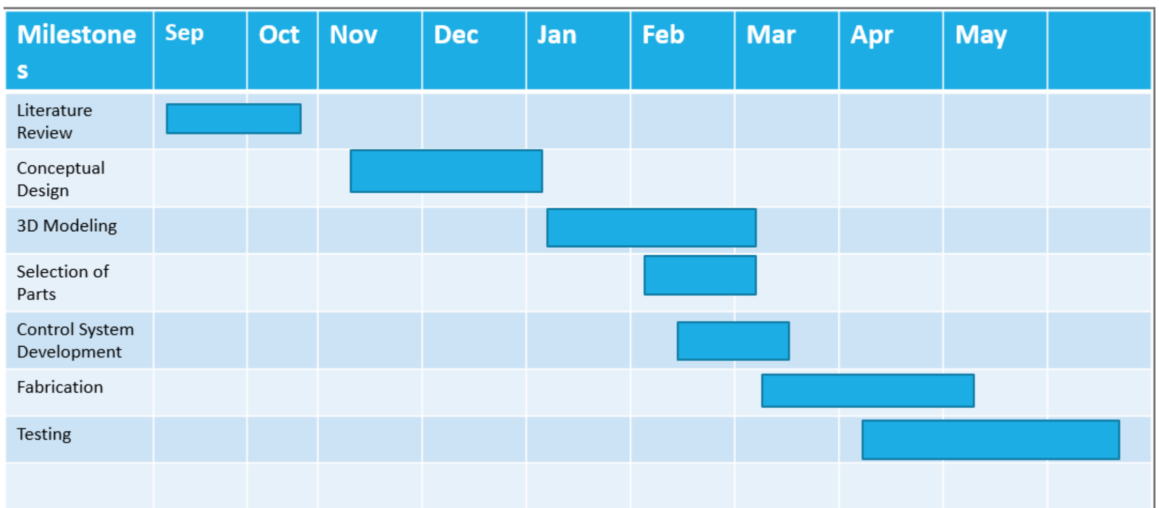
1.2.5 Major Components of Variable Rate Sprayer

The three major parts of the design, development and validation of the Variable Rate Sprayer on Unmanned ground vehicle are discussed below:

For controlled application of pesticides , precise estimation of geometric attributes of the plantation (for example canopy volume, foliage thickness, and so on) is very significant. Pesticide proportion is altered continuously during the spray application, which makes it necessary for the canopy scanning system to provide reliable canopy data, quick and accurate. Electronic sensors can be used to receive and accumulate such information. Sensors can provide the distance of the covering surface from the sensors themselves. Canopy surface distance can be utilized with established tree-row spacing to calculate the depth of canopy. Various sensors were used by specialists to acquire the canopy characterization. For the estimation of tree canopy expansion and tree size, some techniques utilized running units that consisted of an array of ultrasonic sensors. Field tests in peach and apple orchards tracked down the framework to measure canopy width and its semi-cross-sectional area with high accuracy with under 10% normal error. Another model housed a framework with 10 ultrasonic sensors mounted on the upward mast with a microchip for estimation of canopy volume and focused on the impact of vehicle speed on ultrasonic shade volume estimations. Results confirmed ground pace had no vital effect on ultrasonic estimations. Furthermore, these ways were refined by further engineers that equipped ultrasonic sensing with contour maps. They assessed sensor identification capacity with variety in movement speed and encompassing temperature in reenacted field conditions. Changing the movement of the UGV speed had no critical impact on sensor identification except for expansion in encompassing temperature from the highest to the lowest temperature of the trial. Our prototype works on the usage of ultrasonic sensors that takes the canopy's semi cross-sectional area by getting the height and the canopy area from the front facing sensor, this very model is discussed in detail below.

1.2 Project Management

The project was divided into multiple milestones distributed over the span of a year as shown in the figure below:



The first phase was the literature review in which in-depth research was done on various previously manufactured devises that accommodated different methods to apply variable rate spraying of crops and orchards. The second phase focused on the conceptual design of our prototype, the components to be used and the material to be selected. The prototype design was made and analysed in the third phase of the project. The following phases included the acquiring of parts, manufacturing, and testing of the final prototype.

1.3 Project Deliverables

The overall scope of the project is to provide a cost-effective spraying device that can be distributed commercially to the famers of Pakistan. The project mainly focuses on Variable Rate Spraying to reduce the in-turn pollution caused by spraying excess of pesticides.

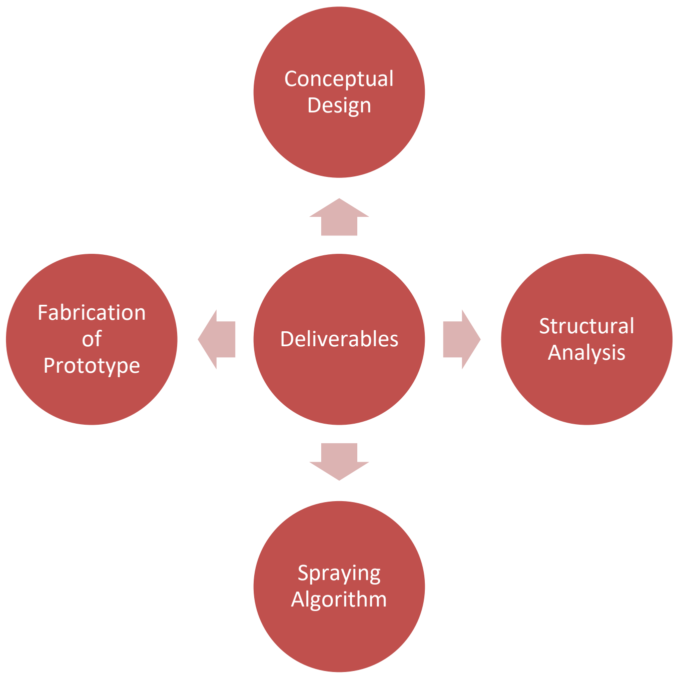


Figure 2: Deliverables

CHAPTER 2: LITERATURE REVIEW

2.1 Variable Rate Method

Variable rate technology has been going for years and several researchers have tried to perfect it on a multiple basis. The most initial model developed primarily worked on the grid system and would spray per base area of the vehicle. Byers et al. (1971) [1] devised a technique to measure the scale of plantation that is spread on ground area per unit and named it tree–row–volume (TRV). The TRV was calculated manually by measuring the height of trees, the width of the trees, and the total row distance in the area. The calculated coefficient was used to determine the rate of volume application the water to be sprayed accompanying PPP spray applications.

In later published papers, Byers et al. (1984) [2] wrote that the products deposited in canopies were considerably varied when spraying doses determined by TRV on the canopies that varied in foliage densities. Sutton and Unrath (1984) [3] made modification to the rate of volume application based on TRV by using an arbitrarily defined coefficient while taking into consideration the canopy density. However, errors are bound to happen due to the manual calculations. The results of all previous dose adjustment models in tree crops output a basic dose charge for the complete plot. That is, the spacial variability of the canopy parameters is not taken into consideration throughout the vineyard or orchards.

2.2 Precision Spraying

After excessive capital loss through conventional spraying techniques, the need to introduce variability in these techniques was very imperative for precision horticulture and sight specific agricultural management systems. While precision agriculture has been worked upon very fast in the last few decades, the implementation in horticulture lags behind. The variability in these spraying techniques was implemented in multiple ways starting from the first model that inculcated ultrasonic sensors to monitor foliage density of each patch of plantation it operates in. The next step was to increase the range by introducing optical sensors that would only apply PP in presence of a canopy. The two aforementioned models both apply On/Off or also known as selective spraying techniques. These techniques are successful in cutting down the drift pollution in areas largely but, still lacked real-time or continuous dosage system techniques. Our system relies on a controlled algorithm that solves for the need of site-specific real-time application online selective spraying where the applied PP dose and the flow rate remains constant.

2.3 Canopy Characterization

Later projects, however, did consider canopy variability and respective adjustment of applied PPP amount by using electronic sensors coupled with actuators, only. In 2005, a sprayer model implemented three doses: no dose, full dose and half dose. This model considers the canopy size by estimating some dimension that are extracted by the ultrasonic sensors mounted on each side of the spray boom, sprayed volume (L) period of the regulation loop (ms) forward speed (m s1) control signal for the electromagnetic valve j (V) volume median diameter (lm) a variable-rate, high-frequency valve is used in a continuous way to modify the flowrate.

The next development phase of this prototype improved it in such a way that the application could be site specific, introducing a new variable rate spraying technique as a breakthrough in precision agricultural technology. A new and advanced algorithm was also developed to change the applied volume rate in real-time basis in a non-discreet manner. It is based on TRV I.e., Tree-Row-Volume as it takes into consideration the canopy volume per block area. However, CV estimated in such a way is different this time as instead of identifying trees only, these sensors can produce high spatial resolution and temporal resolution measurements. This introduced a continuity in the prior design that could just operate on three modes: full, half, and none.

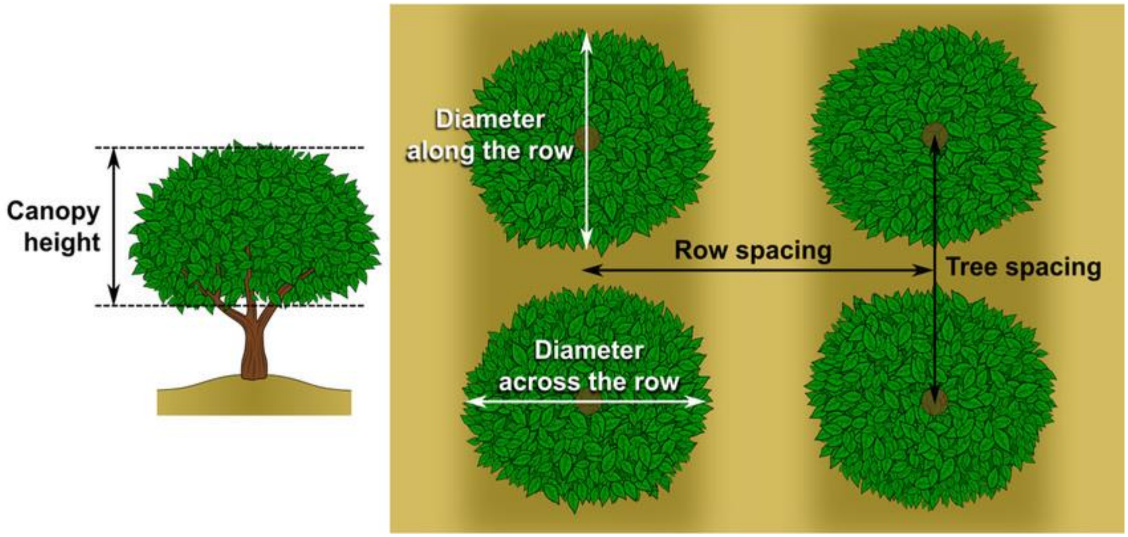


Figure 3: Canopy Characterization

2.4 Previous Projects

Precispray was a project that implemented spraying from a constant distance that sprays different flow rates according to the preexisting contour maps of the area of operation of the machine. Results showed that you could notch up the efficiency of the areas of it was more on a continuous basis and take the number to 40% in this similar technique. another project named Isafruit would imply a dosage model that uses control algorithm that changed the sprayed flow rate on base of canopy volume.

Another prototype resurfaced in 2011 that used a set of nozzles at a certain distance from each other and by using segment by segment pieces of the input it gets from the two ultrasonic sensors at top and bottom of the book. The prototype utilized ultrasonic sensors to calculate the canopy width at two different heights and minimalized the rate of conventionally determined full dosage according to the ratio of the canopy shape models and the height difference between the two widths. This technique helps in modeling an estimated shape of the tree and hence spraying it accordingly with a gradient through the series of nozzles. The configuration estimated by the ratio of heights of the canopy helps in determining that. The novelty of that prototype was the use of an electromagnet to bring continuity in the nozzle spray with variability relating to trees location.

Figure 4: Percispray

2.5 Canopy Characterization Method

Canopy characterization method is the brain of the prototype as it generates an entire loop on which the system is working. The acquisition of data is done by the sensors attached on any configuration or prototype as previously discussed, but the canopy characterization system takes this information and turns that into data that converts the set variable be, canopy semi cross-sectional volume in our case and turns that into flow rate. The models of canopies can be characterized in several ways including cross sectional volume by taking longitudinal and horizontal measurements of the tree subject. It can also be characterized by scanning the trees in digital imaging and producing required parameters on basis on ratios and heights measured. The models include finding canopy height from one end of the book as it moves along the pole and collects data of the height of the plant, the fixed ultrasonic sensors are already in row spacing to each other, so the two translations combined together acquires 2d front facing parameters and using them in the equation to give a cumulative variable, canopy semi cross-sectional area.

2.5.1 Ultrasonic Method

Researchers have previously used ultrasonic sensors in multiple ways because of their long ranging properties to use them agricultural precision technology. The sensor detector ability could be evaluated from the different factors including ambient temperature of area of operation to the UGV speed of operation that gives the most accurate results. Prototypes implemented series of 10 ultrasonic sensors to imitate digital scanning in an analogous way to reduce the cost of cameras by equipping it with a microprocessor. The microprocessor uses the effect of ground speed and other effects . The durability of these results can be tested for measurement of canopy size in a continuous manner. They evaluated sensor detection capability with variations in travel velocity and ambient temperature in simulated subject conditions. Changing travel speed had no huge impact on sensor detection but increase in ambient temperature from 16.7 to 41.6 C and reduced distance by 5 cm.

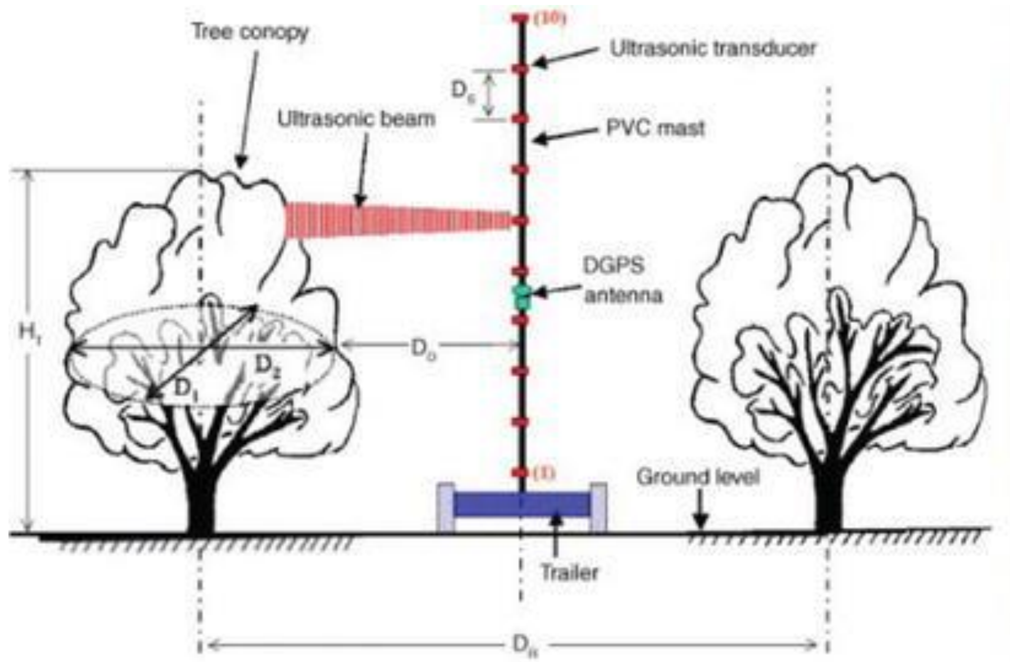


Figure 5: Application of Ultrasonic Sensors

2.5.2 LiDAR Method

To measure tree canopy heights, an airborne laser altimeter was used by Ritchie et al. [36] whereas Nilson [30] used LIDAR system to measure tree heights and stand volume. Low-cost LIDAR system was used by Rossel-Polo et al. [37] for measurement of tree-row volume and total crop surface area in orchards and vineyards. Laser scanning system with the corresponding algorithm was developed by Wei and Salyani [42] to measure tree canopy height, canopy width and volume. Wei and Salyani [43] used a similar laser scanning system for quantification of canopy foliage density and compared it with visual assessment. They concluded the laser measurements and visual assessments had good correlation. Palacin et al. [32] used a ground laser scanner with the corresponding algorithm for tree volume and leaf area measurement in real time. Vehicle mounted laser-based system consisting of a laser scanner, a GPS, an inertial sensor all connected to a computer was developed by Lee and Ehsani for measurement of tree canopy height, canopy width and volume. Field tests in citrus orchards showed great correlation with manual measurements. Citrus canopy volume measurements with ultrasonic and laser sensors and by manual method were compared by Tumbo et al. They concluded that both ultrasonic and laser measurements agreed with manual measurements. These studies showed that the different types of sensors viz., LIDAR, ultrasonic and laser sensors can be reliably used for canopy detection and characterization. Comparing the sensors, laser sensors have been found more reliable and accurate than other sensors. LIDAR also proved to be more accurate than ultrasonic sensors. Some studies showed that ultrasonic sensors are also as accurate as manual measurements. Considering the durability of ultrasonic sensors, they are more suitable for canopy detection and characterization in field conditions.

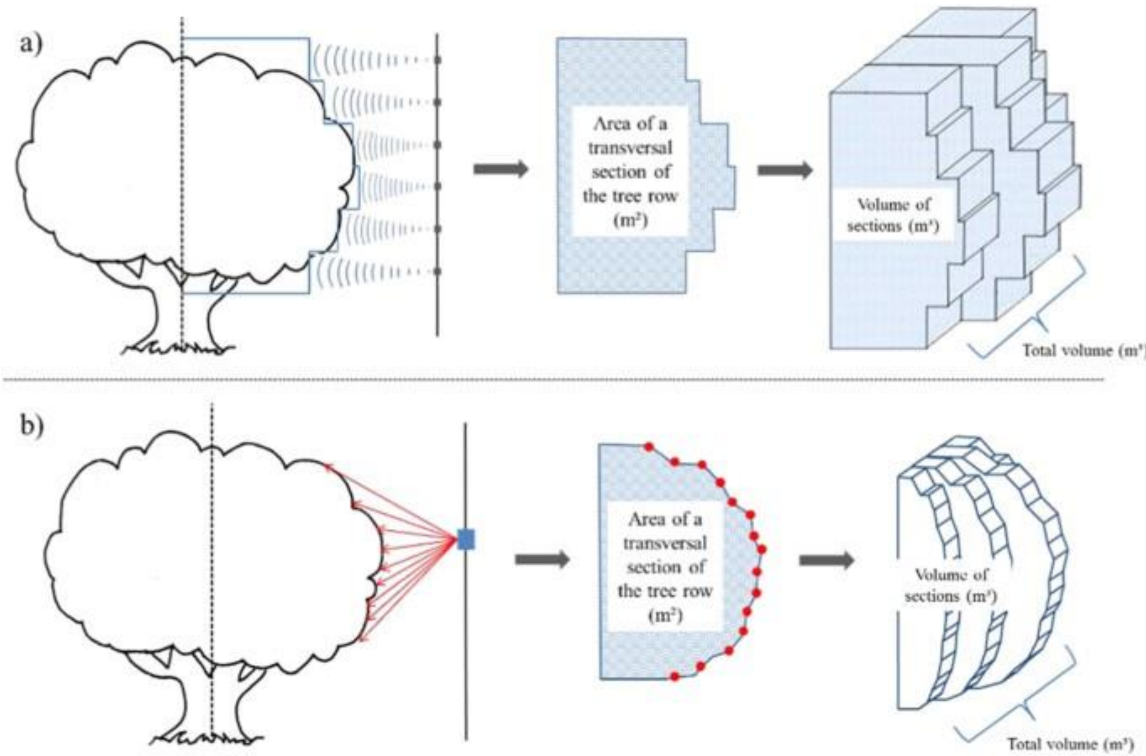


Figure 6: Application of LIDAR for VRS

CHAPTER 3: METHODOLOGY

3.1 Hydraulic Circuit

An experimental circuit for the hydraulic mechanism was put into testing to check if the components are working properly and in order to determine the most optimum work parameters for each part and component of the prototype. The components of the circuit were a pump, pressure regulator, a tank and three nozzles that are found in commercially available sprayers. In addition, we placed a flowmeter, a high-frequency electromagnetic solenoid variable-rate valve to adjust the flow rate of the PP being sprayed in real time, and an electromagnetic ON/OFF solenoid valve to help the variable-rate valve to cut the voltage off completely or to turn it on in 10V model. The components used are listed in the section below.

3.2 Circuit Components

Hydraulic circuit of the machinery is given in figure below.

1. Tanks

2. Filters

3. Pump

4. Pressure Regulator

5. Distributor 1

6. Distributor 2

7. Flowmeter

8. Cut-off Valves

9. Variable-Rate Valves

10. Isolation Valves

11. Pressure Gauge

12. Anti-drip Valves

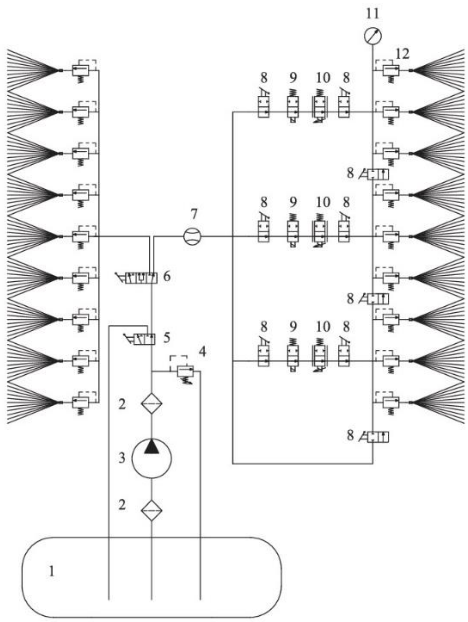


Figure 7: Spraying Mechanism

Table 1: Components of the spraying mechanism

Components	Characteristics	Signal characteristics
Variable-rate valve	Internal diameter 2.4 mm	0–10V_{DC}
ON/OFF valve	ON/OFF	12V_{DC}
Pressure sensor	0–25 bar	4–20 mA
Electromagnetic flow meter	0–30 L min^{-1}	4–20 mA
Turbine flow meter elementary circuit	0.50–7.5 L min^{-1}	4600 pulses/l
Turbine flow meter sprayer prototype	3–40 L min^{-1}	4200 pulses/l
Compact Field Point controller	188 MHz processor 128 MB SDRAM	1 Ethernet port 3 RS-232 ports
Analog input module	8 voltage or current input channels	-30–30V_{DC} -20–20 mA
Analog output module	8 Analog output channels	0–10V_{DC}
High-speed counter module	8 counter input channels	5–30V_{DC}
Digital input/output module	8 input channels 8 output channels	11–30V_{DC}
Ultrasonic sensors	Range 40–300 cm	0–10V_{DC}

3.3 Controller

The electronic regulator was a similar programmable controller for automation of the UGV utilized in the experimental circuit running explicitly in the model. To make the spraying mechanism work in the field without requiring a PC, we planned a system of LEDs and switches associated with the controller. From the controller, it was feasible to begin and stop the UGV and in turn the sprayer in the field test, and to start data acquisition from the field trials.

Figure 8: Wireless Controller for UGV

The controls on the controller work to facilitate the movement of the UGV.

A – Turn Right

B – Forward

C – Turn Left

D - Backward

3.3.1 Control Options

The model had the option to spray either in conventional mode or in VRS mode. In the conventional operating mode, a consistent stream rate was splashed all through the area of treatment. This was accomplished by sending a consistent 10V control signal to the variable-rate valves and an advanced 'ON' signal to the remotely control the valves. In the variable-rate mode, the control signal sent off the variable-rate not set in by the inverse proportionality of the capacity between the applied voltage and the sprayed stream rate. These experiments and test trials are still in the research and being used experimentally when controller mode is in open loop. The Cut-off valves were shut when the variable valves received a control sign of 0 V. The final field test comprised of two checks relying upon the selected spraying mode. When running a test where steady rate mode was selected, the controller conveyed a 10V control message to completely open the variable-rate valves and an ON advanced sign to the remove valves. This strategy tried whether the valves opened accurately. While testing in variable rate mode, an ON advanced signal was sent off to the cut off valves, while the control signal shipped off the variable-rate valves was equivalent to the voltage gained from their individual ultrasonic sensors progressively. This strategy tested the variable-rate capacity of the valves in use when parameters were at varying distances and angles from the sensors. To alter the sprayed stream rate at a given examining goal (for example 5 or 10 examples for every meter), the regulation loop execution time in the software automatically adjusted to the forward speed of the model as indicated by Eq. (1).

$$T = \frac{1000}{R \cdot v} \qquad (1)$$

where T is the period of the regulation loop (ms sample^{-1}); R is the sampling resolution (samples m^{-1}); v is the forward speed of the sprayer (m s^{-1}).

Equation 1

3.4 Variable Spray Control

The calculations for the control used in the variable-rate application mode is a significant enhancement from the past model from [10] (Solanelles et al., 2006). The calculation rely on deciding the volume of the canopy electronically and applying a coefficient to change it into the rate of volume application that is to be sprayed, in a way like the TRV technique.

3.5 Threshold of application

In particular, the coefficient of application is the fluid volume needed to appropriately spray the active ingredient used in a particular unit covering volume. The application coefficient is not entirely defined for every plantation be it from from field tests or by experience. The objective of the calculations from the control was to take the sensor readings at steady augmentations along each line (as per the client necessities and the sensors utilized) to change the rate of volume application as it needs be, this is done to keep up with beyond what many would consider possible a consistent measure of ingredient actively deposited stored per unit leaf region. The canopy characterisation was additionally improved by planning it to utilize either ultrasonic sensors (Escolà et al., 2011) or LiDAR sensors (Rosell et al., 2009a,b; Sanz-Cortiella et al., 2011). We utilized information acquisition system with ultrasonic sensors and a new processing unit that implements different flow rate based on acquired data. Therefore, our prototype is a more accurate real-time spraying mechanism with variable-rate orchard sprayer that is fixed on a UGV base.

3.6 Mathematical model

The semi-cross-sectional areas calculated by the canopy characterization system that were further multiplied by the forward-front facing speed of prototype sprayer give the area of plantation that is passing in front of the nozzles per unit time. The use of the objective (intended) application coefficient and a constant to make sure that the units are harmonised and homogenous enables accurate estimation of the instantaneous flow rate that can be sprayed at a certain time and place in the garden by one side of the sprayer boom that is fixed on the UGV prototype. To increase the sprayer vertical resolution and the sensitivity the sprayer boom was divided into three independent sections that are individual spraying sections, each spraying a corresponding area of target or level of the canopy. This solution enabled spraying at various flow rates according to Eq. (2). As these parameters are acquired by the sensors the data is analysed, retrieved, and processed to obtain the exact canopy volume and the respective sprayed volume accordingly, the variables registered and calculated from this data are canopy semi-cross-sectional areas and the instantaneous sprayed flowrate. From these variables other information, other major variables are calculated such as the instantaneous canopy-volumes (Eq. (3)), t), total canopy volume, sprayed volume in each canopy volume selected (Eq. (4)), actual instantaneous spaying application (eq (5)) coefficient and the average normalised coefficient of application.

3.7 Circuit for Sprayer

The circuit for the sprayer integrating all the components of the system was made using Proteus and tested physically. The algorithm flowchart is as follows:

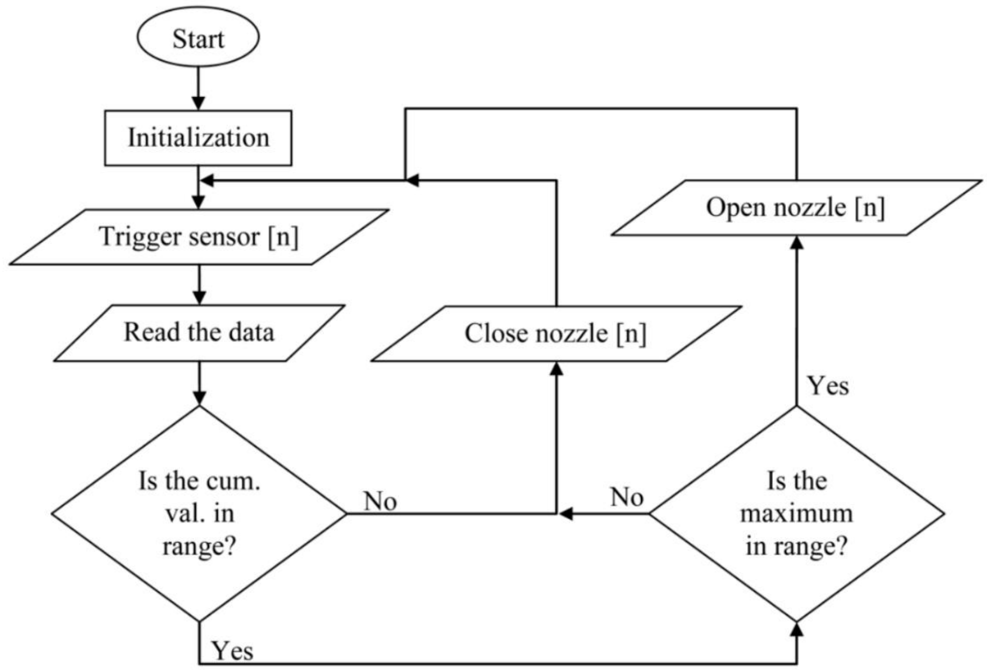


Figure 9: Flowchart for Spraying Mechanism

Circuit diagram mapped out on proteus is given below in Fig. 10.

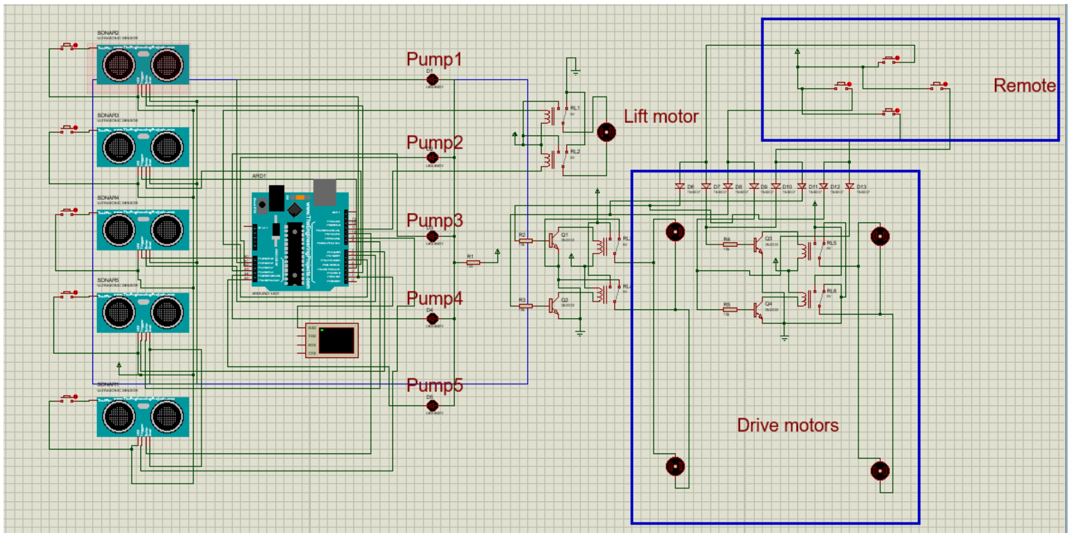


Figure 10: Circuit Diagram

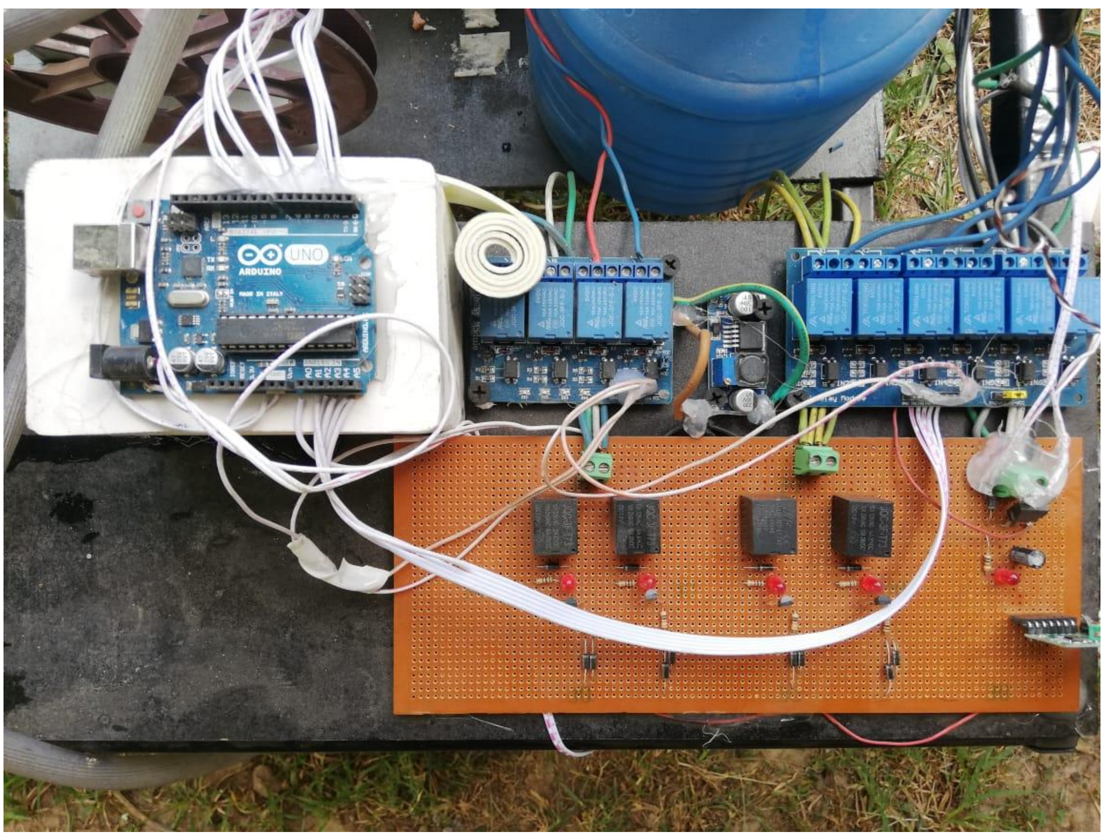


Figure 11: Circuit on UGV

3.8 Prototyping

3.8.1 Initial Design

After initial literature review, the model designed was a closed casing UGV structure with a vertical boom with an array of sensors and nozzles. The parametric and physical characteristics of the initial design were iterated to best fit the cost range and to make the device more cost-effective and easily accessible. The maintenance issues were resolved by making the closed chassis into an open unit.

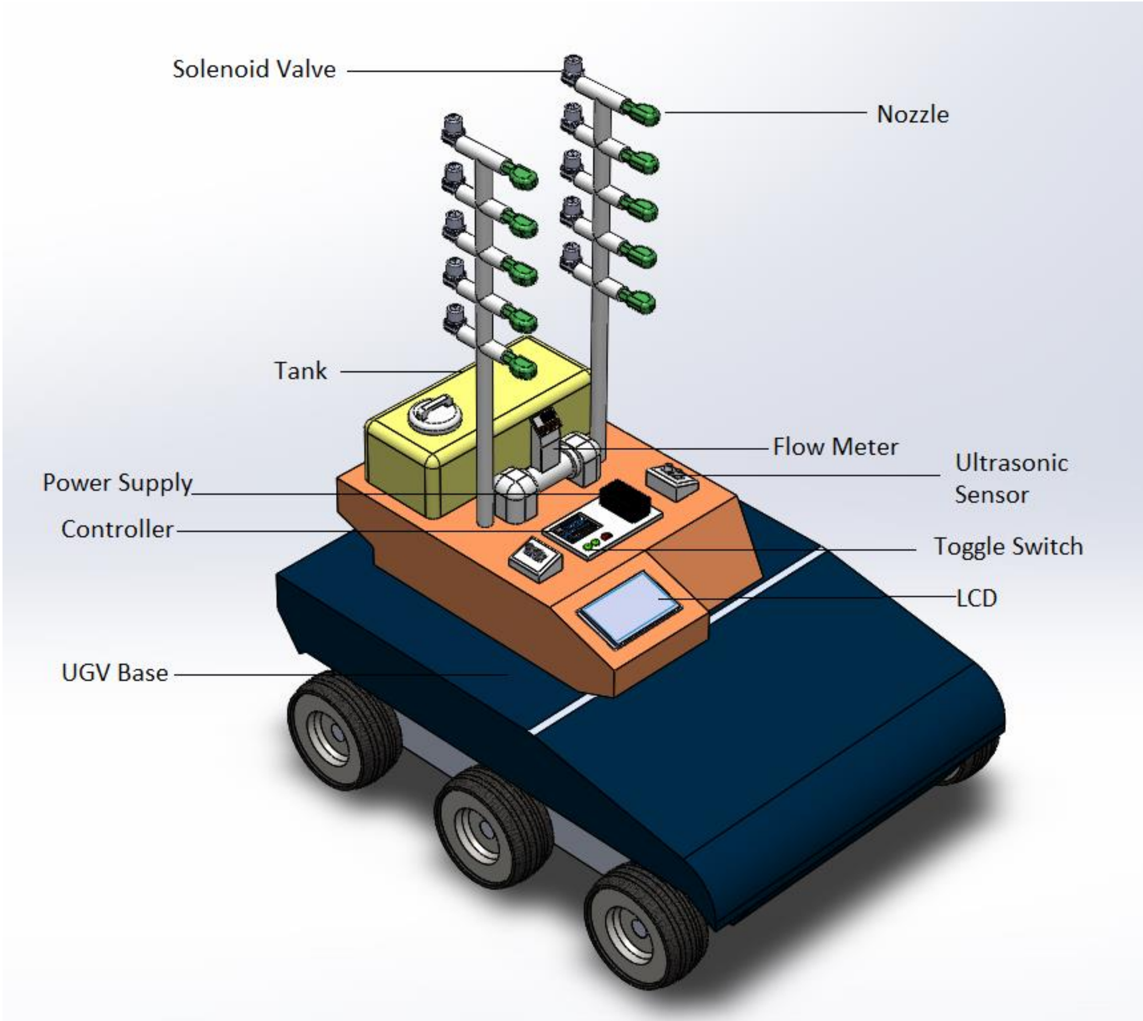


Figure 12: Initial Design

3.8.2 Design Iteration

The design was iterated to a much more simplified and easier to manufacture design. The material and components available to us locally were also taken into consideration. The final iteration of the design is as show in the figure below.

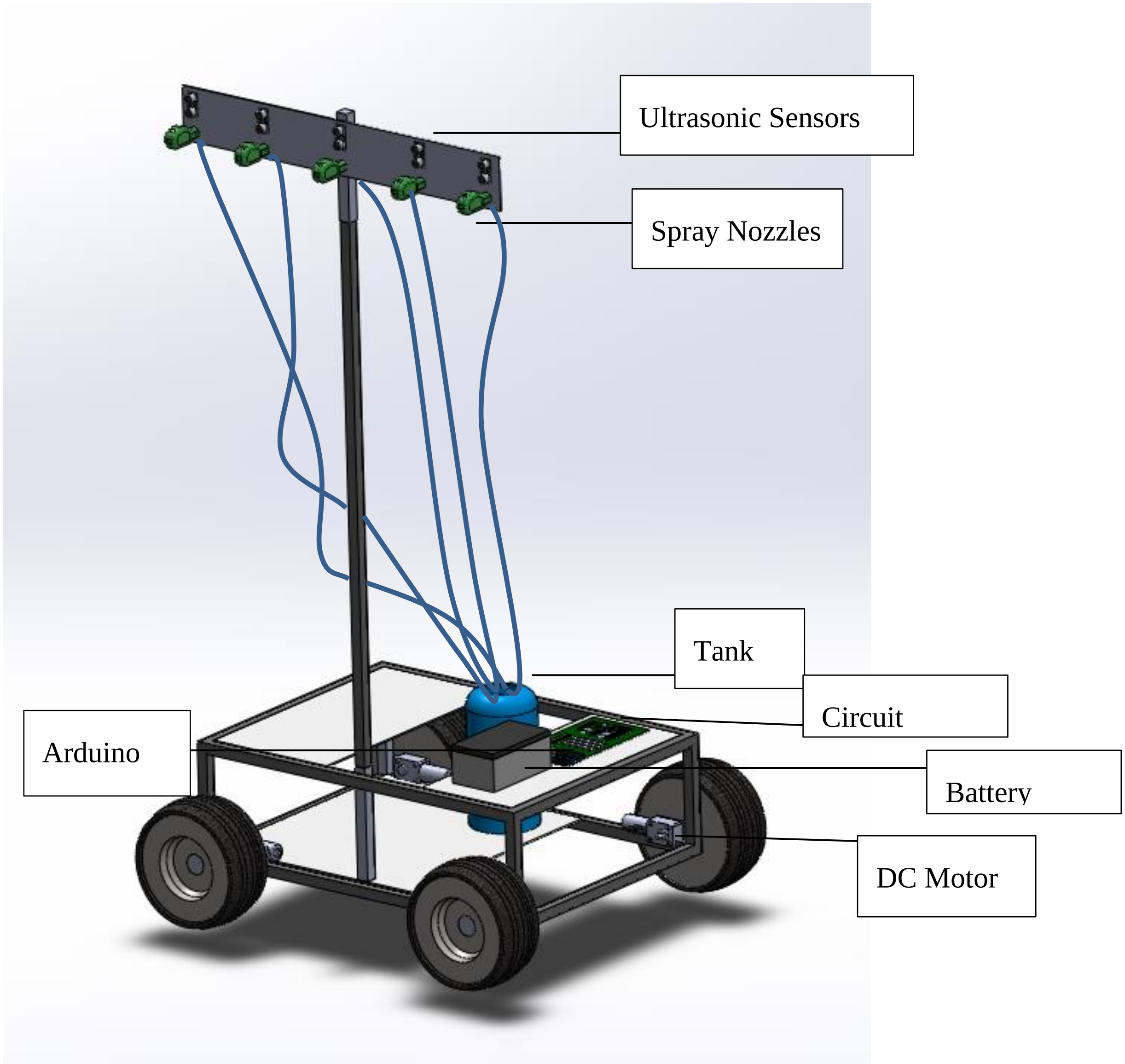


Figure 13: Final Design

3.8.3 System Components

The list of components used in the device are given as follow:

Table 2: List of Components

Subdivision of Prototype	**Components**
UGV Chassis	Steel Alloy Square Pipes
	Rough Terrain Wheels
	DC Motors
	Pulley
	Rope
	Hardboard Sheets
Spray Mechanism	Spray Nozzles
	Ultrasonic Sensors
	Pipes
	Pumps
	Arduino
	Battery
	Circuit Component
	Wireless Module

3.8.5 Final Prototype

The following figure shows the final working prototype in real time.

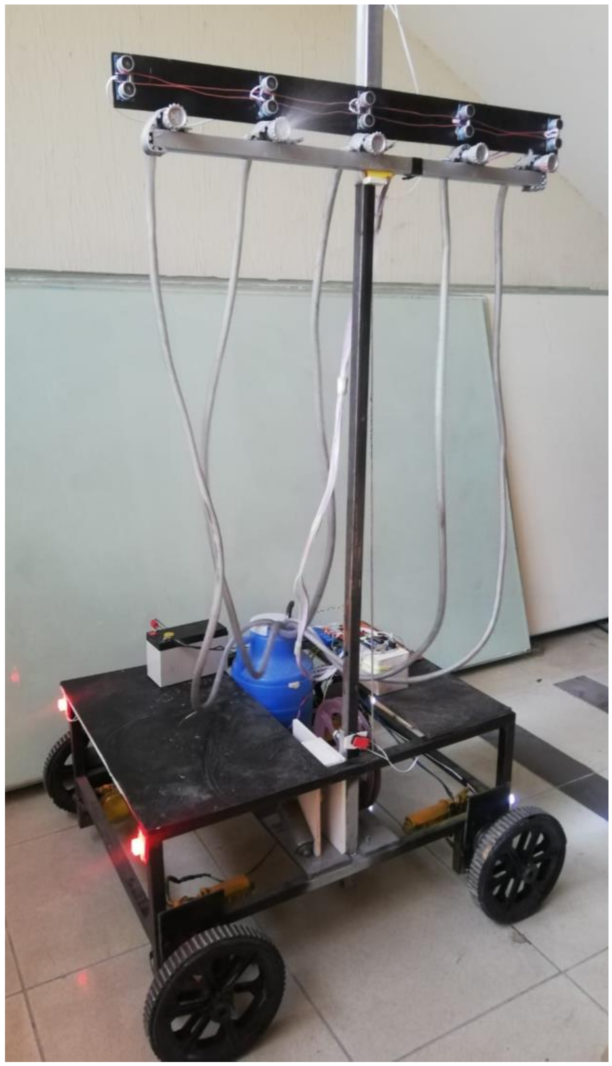


Figure 14: Prototype

CHAPTER 4: RESULTS AND DISCUSSIONS

Before taking the device for trial runs and field validation tests. The flow rate and relative span, distribution of droplets and droplet sizes are selected. This is a hit and trial process in which computational fluid dynamics software ANSYS fluent is used, and the optimal conditions are selected in our operation range. These key considerations are as follows:

4.1 Droplet Distribution

The distribution of droplets is studied under dynamic conditions on ANSYS Fluent and appropriate droplet size and spans are selected for the trials.

4.2 Droplet size

The volumetric median and numeric median diameters are calculated within the 10-90 percentile of the distribution.

4.3 Span

Nozzles on different heights have different spans, these projectile spans are calculated for both cases.

4.4 Relative Span

In variable rate mode since the flow rate is constantly changing, span is calculated with respect to the absolute value in conventional mode.

Utilizing the ultrasonic canopy system that characterizes, a plantation sprayer prototype with a variable-rate spraying calculation to adjust the rate of volume application to the canopy volume was created by Escola et al. [6]. Notwithstanding the shade portrayal framework, the tree model made up of the regulator executing a variable-rate calculation and the operations of the actuators. The regulator decides the expected stream rate. The stream rates sprayed were varied by using electromagnetic variable-rate valves. Test aftereffects of the model uncovered solid connections between the anticipated and the sprayed flow rates ($R2 = 0.935$) and between the tree cross-sectional regions and the showered stream rates ($R2 = 0.926$). Gil et al. [12] additionally planned, carried out and approved an identical model for grape plantation crops. Liu et al. [24] fostered a stream rate control framework with chip and a heartbeat width regulation (PWM) controlled solenoid valves to control the stream paces of multichannel spouts freely for the variable rate sprayer.

The algorithm of framework control was monitored through a PC and was additionally used to link the sprayer head and the controller. The created framework was assessed in the lab to check the accuracy of the control framework with three spouts (0.530-1.703 L/min) working at four different tensions (138-345 kPa) and ten obligatory cycles (10-100 percent).

The circuit controlled with a microcontroller delivered PWM signals with wanted heartbeat widths in sync with the cycles and direct sprayer yields were accomplished precisely in accordance to the patterns of the PWM-controlled valves. From these trials, it very well may be summed up that the ongoing variable rate innovation is ending up an essential apparatus for the accuracy of spraying in vineyards or orchards in Pakistan. The performance parameters of the prototype are discussed below.

4.5 Response time:

Response time determines the operating frequency and the minimum distance for various actuations. The technique for establishing the maximum response time of the essential circuit consisted of sending a signal to all the valves opened and recording the readings of all the sensors. The maximum reaction time will be the minimal reaction time of any of the sensors imparting a steady reaction signal.

4.6 Flow rate range

The actuation of the cut-off valve determines the flow rate range under three given possibilities:

(1) Open at all times: spraying is allowed at all control signals,

(2) open when the signal from variable-rate control is higher than 1 V,

(3) open when a signal is higher than 2V for variable-rate control.

An appropriate working pressure is chosen for this combination of trials. The figure below shows the scatter plot for flow rate vs the control signal.

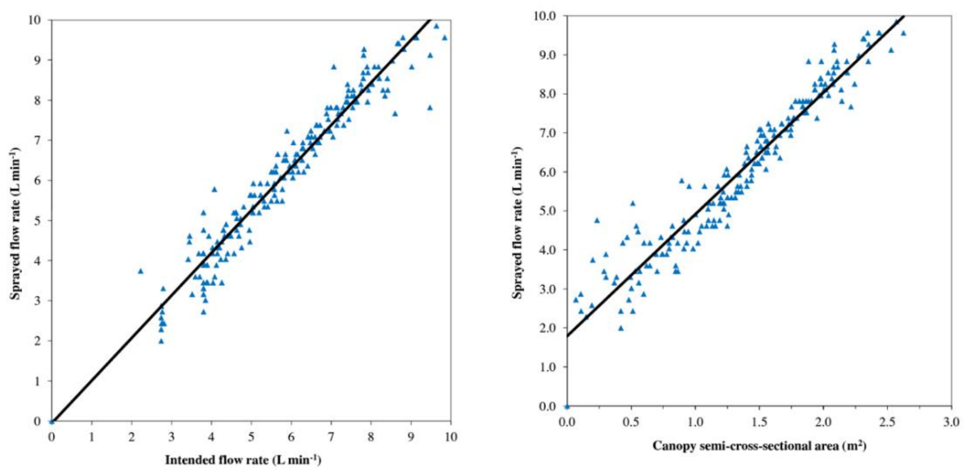


Fig. . Scatter diagram of the sprayed flow rates as a function of the intended flow rate determined by the variable-rate controller algorithm. The solid line represents the fitted simple linear regression model.

Fig. . Scatter diagram of the sprayed flow rates as a function of the semi-cross-sectional areas estimated by the LiDAR sensor according to the variable-rate controller algorithm. The solid line represents the fitted simple linear regression model.

Figure 15

4.7 Sprayed flow rate accuracy

The prototype was driven in front of a tree row for the field tests. The test results were noted to be in favorable range.

The statistical correlations between the resulting parameters acquired by the Ultrasonic sensors are as follows:

1. The actual and estimated sprayed flow rate
2. Instantaneous sprayed flow
3. Canopy semi-cross-sectional area.

Table 3: Field Trials

	Estimated	Actual
Flow Rate	0.05L/s	0.05L/s
Spray Area	100	70cm
Canopy Area	90cm	80cm

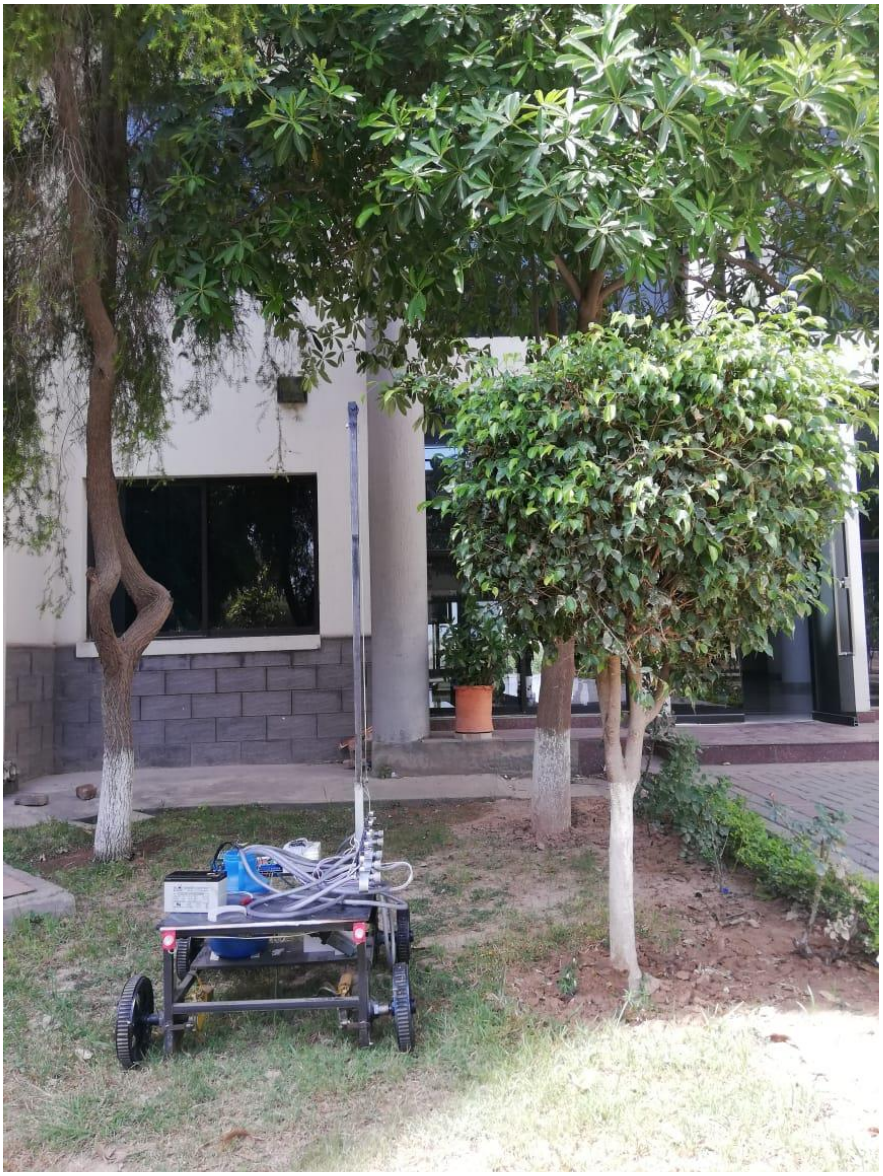


Figure 16: Field Validation Trials

This innovation assists with decreasing the pesticide misfortunes as well as assists with applying just the required amount of shower consequently accomplishing a lot of saving in compound pesticide use.

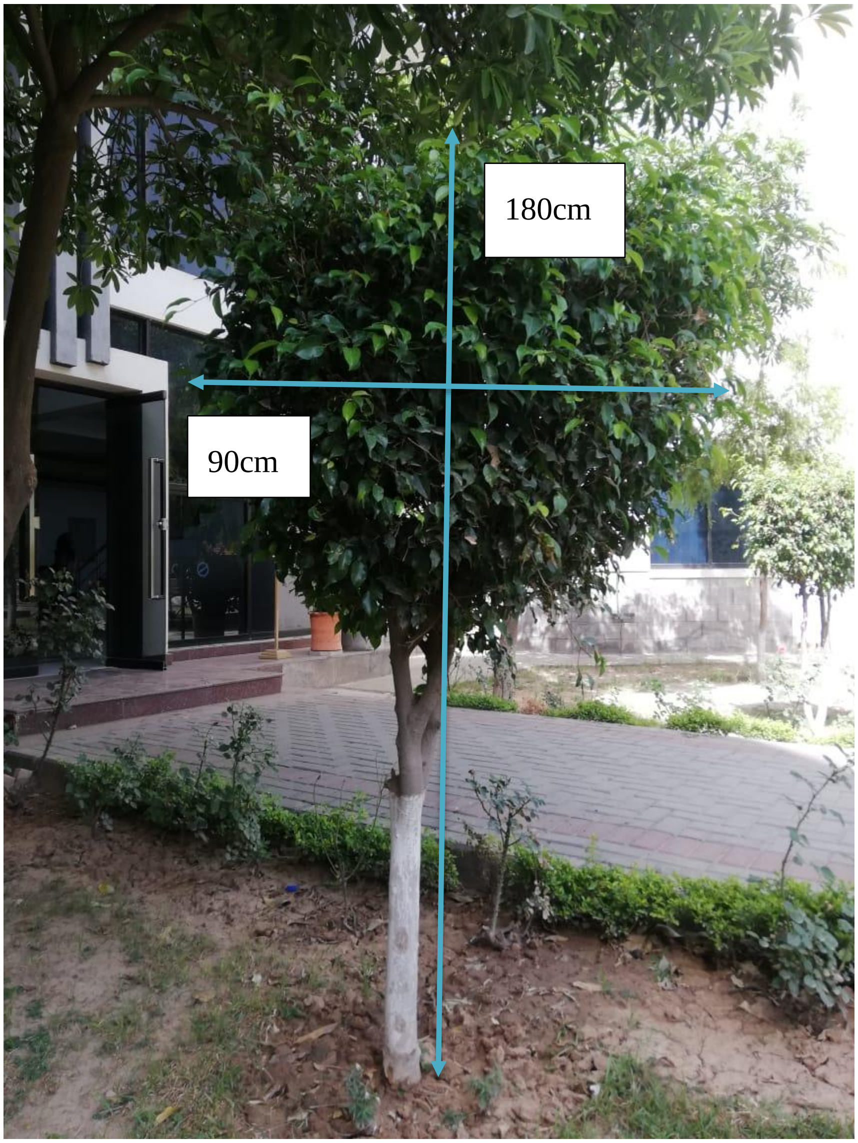


Figure 17: Canopy Characterization

Researchers have differed the spout release in view of the shelter size, overhang volume, foliage thickness and so on utilizing appropriate detecting framework, controlling unit, and corresponding valves. Furthermore, the environmental concerns are drastically seen to be removed as well, the concentration of PPP in streams and agricultural soils due to drift pollution has decreased.

4.8 Structural Analysis

Structural analysis of the chassis was done using SOLIDWORKS. The chassis was put under static testing to simulate the load bearing capacity, the results for the structural analysis of the chassis are given below.

4.8.1 Stress Analysis

The figure below shows the Von Mises Stress Analysis of the chassis under 300N of load. As can be seen that the chassis can bear the load without coming close to the yield strength.

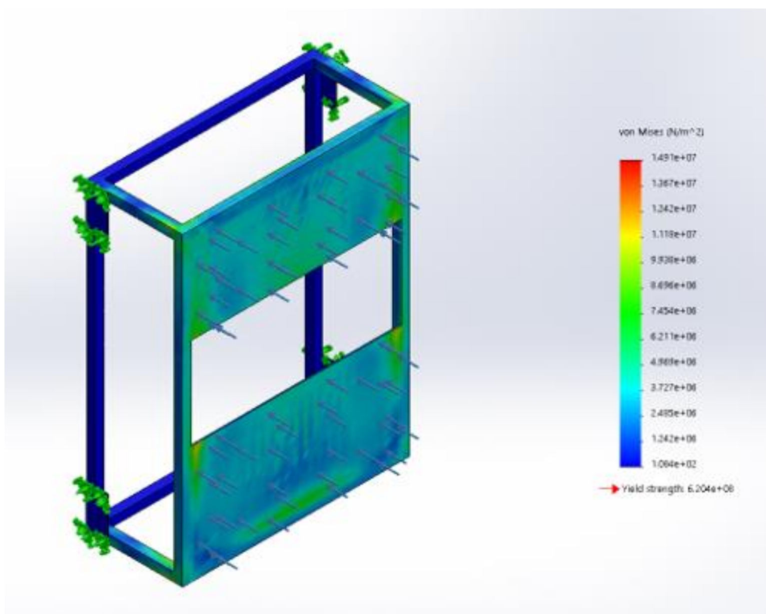


Figure 18: Von Mises Stress Analysis

Table 4: Von Mises Stress Analysis

Name	Type	Min	Max
Stress1	VON: von Mises Stress	1.084e+02 N/m^2 Node: 11563	1.491e+07 N/m^2 Node: 8938

4.8.3 Displacement Analysis

The figure below shoes the displacement analysis of the chassis under applied force of 300N.

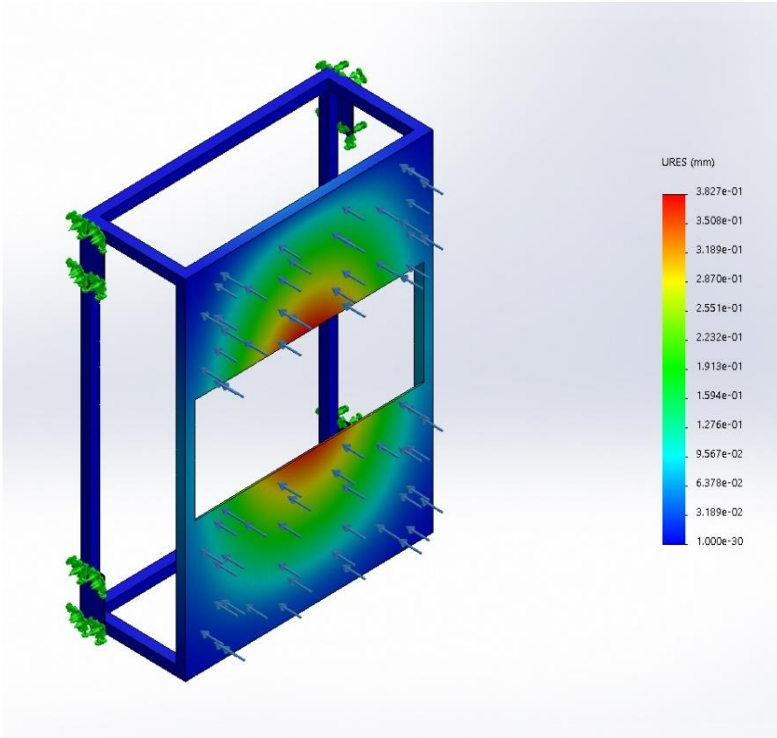


Figure 19: Displacement Analysis

Table 5: Displacement Analysis

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00 mm Node: 17	3.827e-01 mm Node: 13116

4.8.4 Strain Analysis

The figure below shows the strain Analysis of the chassis under applied load of 300N.

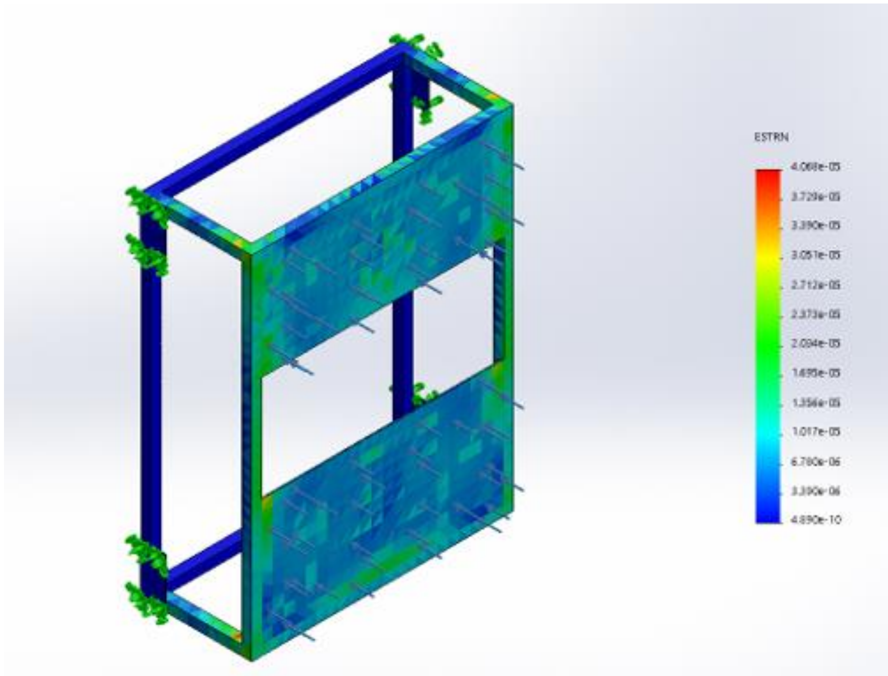


Figure 20: Strain Analysis

Table 6: Strain Analysis

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	4.890e-10 Element: 25	4.068e-05 Element: 3288

4.8.5 Factor of Safety

The following plot shows the factor of safety that the chassis can hold before it yields under an immense load.

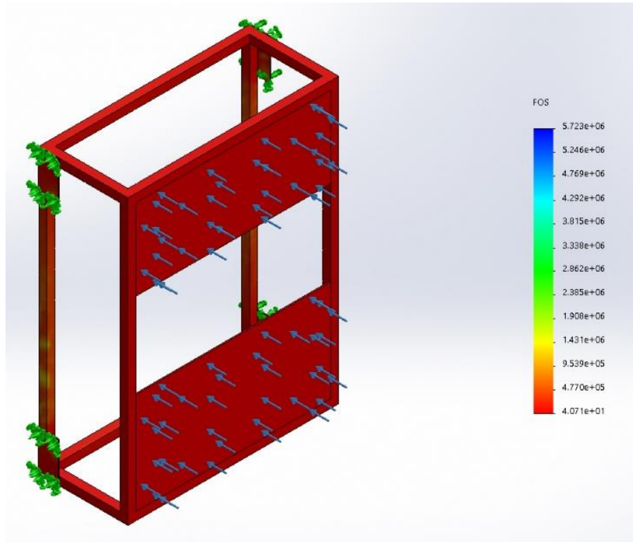


Figure 21: Factor of Safety

Table 7: Factor of Safety

Name	Type	Min	Max
Factor of Safety1	Automatic	4.071e+01 Node: 632	5.723e+06 Node: 11563

Parametric Structural Analysis Results

Loading Cases for Chassis			
Maximum Von Mises Stress	1.491e+07 N/m^2	Yield Strength	6.204e-08N/m^2
Maximum Displacement	3.827e-01 mm		
Maximum Strain	4.068e-05		
Factor of Safety	41		

4.9 Cost Analysis

The cost estimates and analysis for the prototyping is carefully considered with the purpose of the project in mind. The detailed breakdown of total cost of manufacturing is given in the table below.

Table 8: Cost Analysis

Components/Services	Price	Quantity	Cost(PKR)
	Components		
Nozzles	150	5	750
Ultrasonic Sensors	200	5	1000
Pipes	25/ft	30ft	750
Pumps	500	5	2500
Steel Alloy Pipes	250/kg	10kg	2500
Wheels	250	4	1000
DC Motors	2500	5	12500
Pulley	100	1	100
Rope	25	1	25
Battery	2300	1	2300
Arduino	2000	1	2000
Electronic Components	1500	N/A	1500
Hardboard	500	N/A	500
	Services		
Welding	1000	N/A	1000
Transportation	3000	N/A	3000

Electrical Work	2000	N/A	2000
Total			**33,425**

CHAPTER 5: CONCLUSION AND RECOMMENDATION

At last, we summarize the project along with some recommendation for future improvements that can be implemented to make an even better working prototype. To summarize it all, the project included various stages such as Literature Review, Conceptual Designing, modeling, simulations, and fabrication of the project. Specifics of the project are detailed below.

5.1 Prototype Specification

The prototype manufactured uses ultrasonic sensors to accumulate data of the geometric characteristics of a plantation and a control algorithm to spray pesticides on the plant surface. The prototype uses five ultrasonic sensors in an array mounted on a pole on one side of the UGV. The UGV is controlled by a remote controlling device.

5.2 Summary of the Project

The project was chosen and implemented with sole purpose of providing a cost-effective working prototype to our local farmers where already being made devices are beyond the budget of farmers. The project was studied in the literature review by studying various already manufactured model in the world. We took out the parts that were necessary to implement the project within a given budget. The conceptual design of the project was made an iterated over the span of our managing timeline. The components we used were made sure to be locally available for ease of manufacturing in Pakistan.

5.3 Deliverables

The deliverables of our project i.e.

1. Conceptual Design
2. Spraying Algorithm
3. Modelling and Simulation
4. Fabrication

Were successfully delivered with field test results. Various components were looked upon and we decided to go with cost-efficient but reliable ones. The fabrication of chassis and the spraying mechanism were done separately and then fused together.

Table 9: Cost Comparison

Prototype	Cost (PKR)
Commercially Available Devices (Titan Flying)	200,000-300,000
Our Prototype	33,425

5.4 Recommendations

For future improvements in the design and components used a better housing for the UGV can be made by deploying lightweight but resilient materials. The sensors used in this prototype were ultrasonic sensors to reduce the cost. LIDAR sensors can be used for better image acquisition and accurate VRS. The chassis can be modified by using suspension and better off-road wheels. And the control algorithm can be made better by involving various other factors for canopy characterization.

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APPENDIX I: ARDUINO CODE FOR SPRAYING MECHANISM

```
int i=0,chk=0,down=0;
int d=35;

int trig1 = 1; /* connect trigger pin of Ultrasonic to pin number 13 */
int echo1 = 2; /* connect echo pin of Ultrasonic to pin number 12 */

int trig2 = 3; /* connect trigger pin of Ultrasonic to pin number 13 */
int echo2 = 4; /* connect echo pin of Ultrasonic to pin number 12 */

int trig3 = 5; /* connect trigger pin of Ultrasonic to pin number 13 */
int echo3 = 6; /* connect echo pin of Ultrasonic to pin number 12 */

int trig4 = 7; /* connect trigger pin of Ultrasonic to pin number 13 */
int echo4 = 8; /* connect echo pin of Ultrasonic to pin number 12 */

int trig5 = 9; /* connect trigger pin of Ultrasonic to pin number 13 */
int echo5 = 10; /* connect echo pin of Ultrasonic to pin number 12 */
void setup()
```

```
{
  Serial.begin(9600);
  pinMode(trig1, OUTPUT);
  pinMode(echo1, INPUT);
  pinMode(trig2, OUTPUT);
  pinMode(echo2, INPUT);
  pinMode(trig3, OUTPUT);
  pinMode(echo3, INPUT);
  pinMode(trig4, OUTPUT);
  pinMode(echo4, INPUT);
  pinMode(trig5, OUTPUT);
  pinMode(echo5, INPUT); pinMode(A0, OUTPUT);
  pinMode(A1, OUTPUT);
  pinMode(A2, OUTPUT);
  pinMode(A3, OUTPUT);
  pinMode(A4, OUTPUT);
  pinMode(A5, OUTPUT);
  pinMode(11, OUTPUT);
  digitalWrite(A0, HIGH);

  digitalWrite(A1, HIGH);

  digitalWrite(A2, HIGH);

  digitalWrite(A3, HIGH);

  digitalWrite(A4, HIGH);

  digitalWrite(A5, HIGH);
    digitalWrite(11, HIGH);
}
```

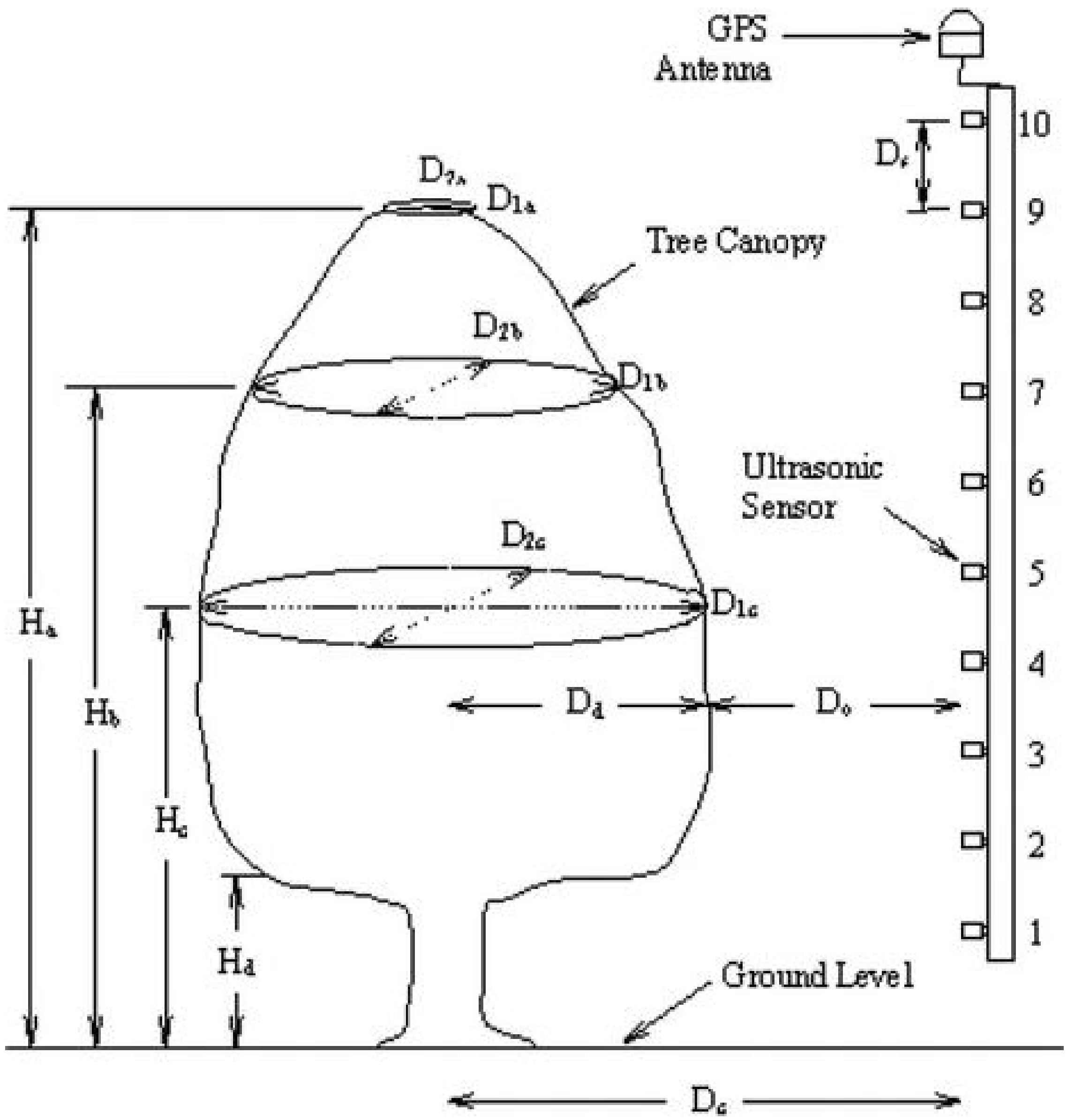
```
void loop() {

  long t1 = 0, h1 = 0; // Transmitting pulse
  digitalWrite(trig1, LOW);
  delayMicroseconds(2);
  digitalWrite(trig1, HIGH);
  delayMicroseconds(10);
  digitalWrite(trig1, LOW);// Waiting for pulse
  t1 = pulseIn(echo1, HIGH);// Calculating distance
  h1 = (t1 / 2) / 29.1; // Sending to computer
  Serial.print(h1);// Serial.print(" cm\n");
  Serial.print("\n");//condition for motors

  long t2 = 0, h2 = 0; // Transmitting pulse
  digitalWrite(trig2, LOW);
  delayMicroseconds(2);
  digitalWrite(trig2, HIGH);
  delayMicroseconds(10);
  digitalWrite(trig2, LOW);// Waiting for pulse
  t2 = pulseIn(echo2, HIGH);// Calculating distance
  h2 = (t2 / 2) / 29.1; // Sending to computer
  Serial.print(h2);// Serial.print(" cm\n");
  Serial.print("\n");//condition for motors
  long t3 = 0, h3 = 0; // Transmitting pulse
  digitalWrite(trig3, LOW);
  delayMicroseconds(2);
  digitalWrite(trig3, HIGH);
  delayMicroseconds(10);
  digitalWrite(trig3, LOW);// Waiting for pulse
  t3 = pulseIn(echo3, HIGH);// Calculating distance
  h3 = (t3 / 2) / 29.1; // Sending to computer
  Serial.print(h3);// Serial.print(" cm\n");
  Serial.print("\n");//condition for motors
```

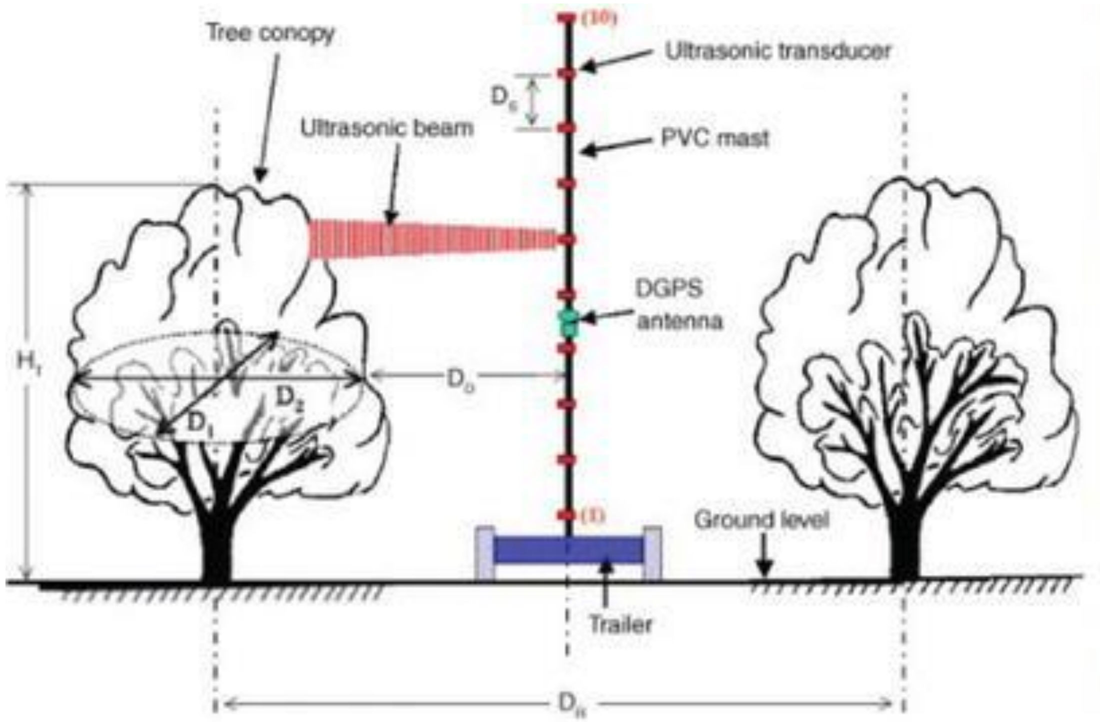
```
long t4 = 0, h4 = 0; // Transmitting pulse
digitalWrite(trig4, LOW);
delayMicroseconds(2);
digitalWrite(trig4, HIGH);
delayMicroseconds(10);
digitalWrite(trig4, LOW);// Waiting for pulse
t4 = pulseIn(echo4, HIGH);// Calculating distance
h4 = (t4 / 2) / 29.1; // Sending to computer
Serial.print(h4);// Serial.print(" cm\n");
Serial.print("\n");//condition for motors

long t5 = 0, h5 = 0; // Transmitting pulse
digitalWrite(trig5, LOW);
delayMicroseconds(2);
digitalWrite(trig5, HIGH);
delayMicroseconds(10);
digitalWrite(trig5, LOW);// Waiting for pulse
t5 = pulseIn(echo5, HIGH);// Calculating distance
h5 = (t5 / 2) / 29.1; // Sending to computer
Serial.print(h5);// Serial.print(" cm\n");
Serial.print("\n");//condition for motors


Serial.println("............");//condition for motors
```

```
if (h3>5&&h3<d&&down==0 )
{ chk=1;
  }
  if(i<=23&&chk==1)

   { digitalWrite(11, LOW);
  delay(100);
    digitalWrite(11, HIGH);

  if (h1 > 5 && h1 < d)
    digitalWrite(A1, LOW);

  else
    digitalWrite(A1, HIGH);


  if (h2 > 5 && h2 < d)
    digitalWrite(A2, LOW);
  else
    digitalWrite(A2, HIGH);

  if (h3 > 5 && h3 < d)
    digitalWrite(A3, LOW);
  else
    digitalWrite(A3, HIGH);

  if (h4 > 5 && h4 < d)
    digitalWrite(A4, LOW);
  else
    digitalWrite(A4, HIGH);

  if (h5 > 5 && h5 < d)
    digitalWrite(A5, LOW);
```

```
    -
  else
    digitalWrite(A5, HIGH);
      delay(300);i++;
      Serial.print("up=");
      Serial.println(i);}

if(i>23)
{
chk=0;
down=1;
}
if(i<=0)
{
down=0;
delay(5000);
}
  if(i>=0&&down==1)
  {  digitalWrite(A0, LOW);    // turn the LED off by making the voltage LOW
  delay(70);
      digitalWrite(A0, HIGH);    // turn the LED off by making the voltage LOW
  delay(500);   i--;
        Serial.print("down=");
      Serial.println(i);}


}
```

APPENDIX II: CANOPY CHARACTERIZATION





Tree conopy
Ultrasonic beam
(10)
Ultrasonic transducer
PVC mast
DGPS
antenna
(1)
Ground level
Trailer

APPENDIX III: FIRST MODEL SIMULATION

Following images of stress analysis of the first design shows that the final design, although different, but has the same structural equivalency to bear certain lo

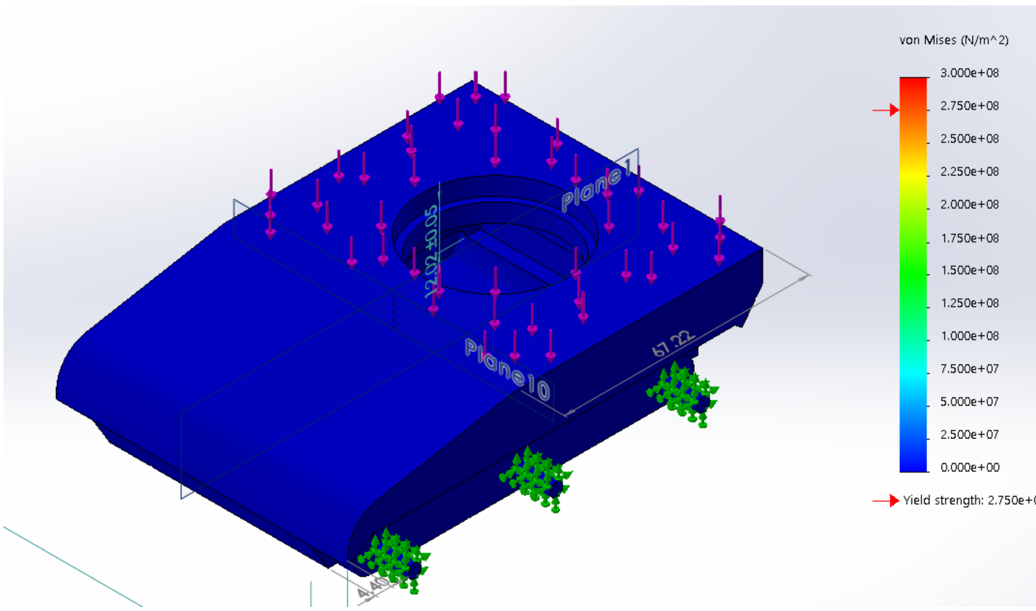


Figure 22: Von Mises Stress Analysis on First Design

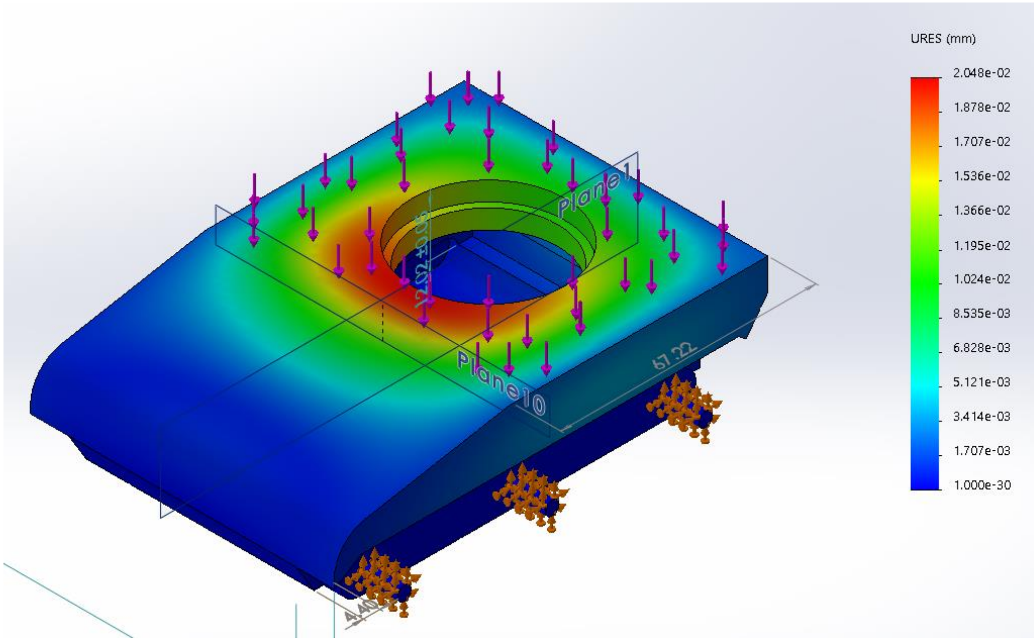


Figure 23: Displacement Analysis on First Design

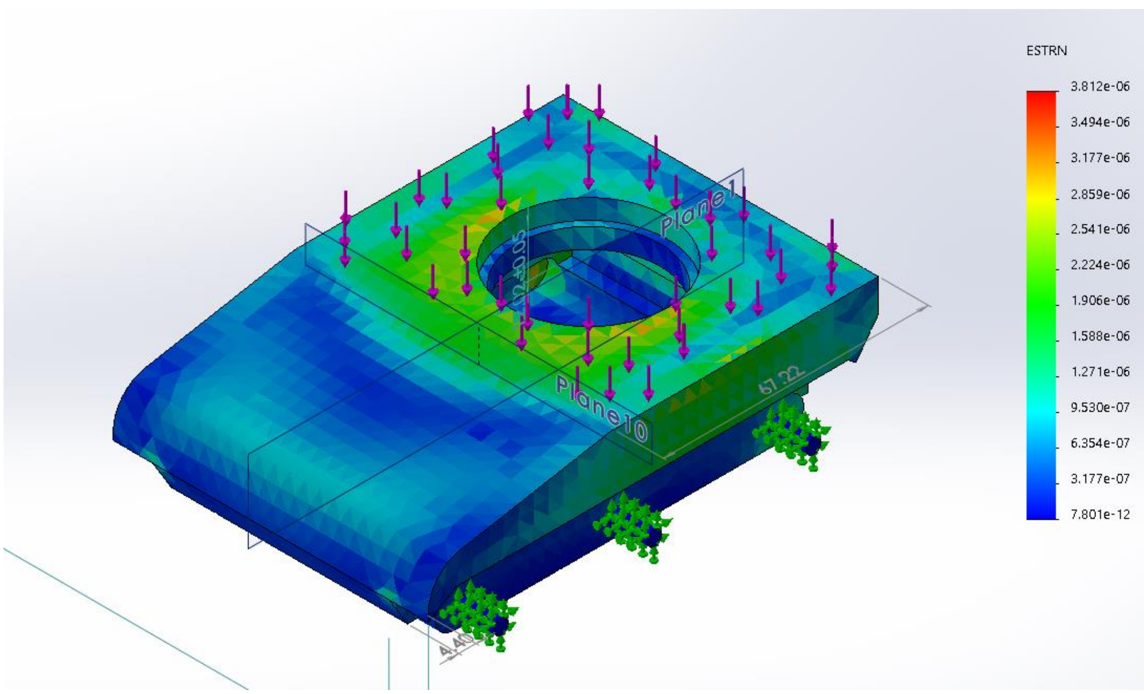


Figure 24: Strain Analysis on First Design

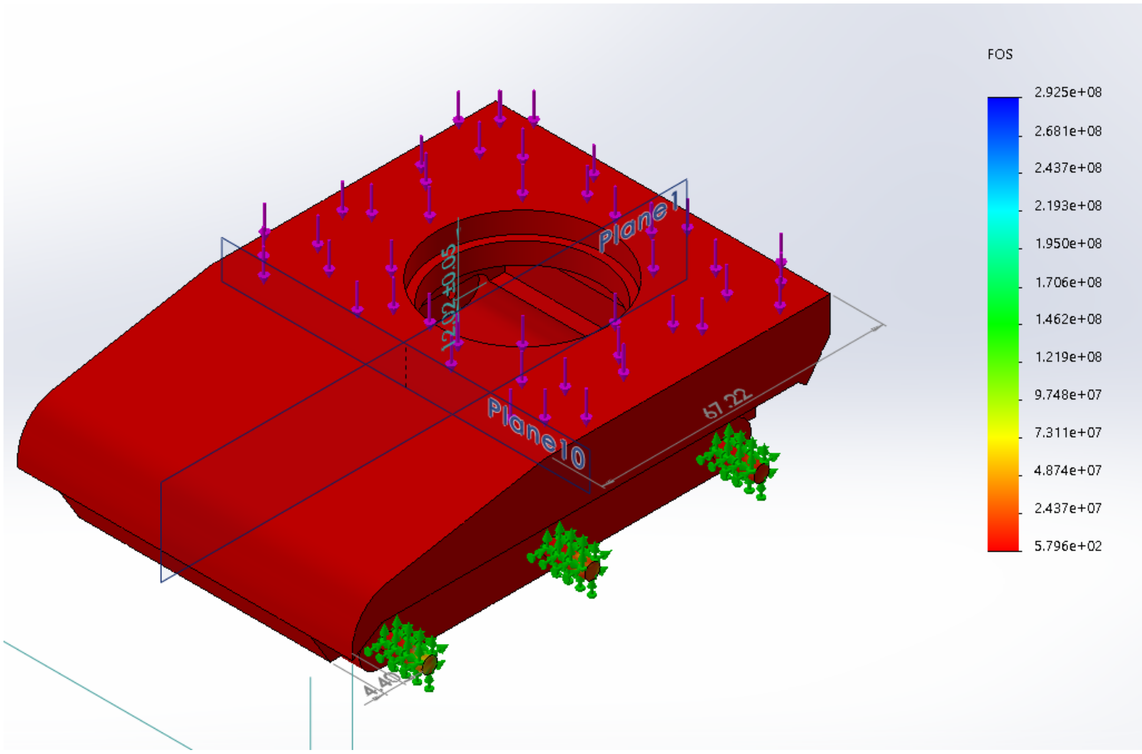


Figure 25: Factor of Safety on First Design