DEDIGN AND FABRICATION OF VARIABLE RATE SPRAYER FOR AGRICULTURE DRONE

A Final Year Project Report

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ABSTRACT

Our FYP project proposes the development of a variable rate sprayer system that can be mounted on an agriculture drone. The objective of this project is to design and implement a system that can accurately and efficiently apply crop protection products in a precise and targeted manner. The variable rate sprayer incorporates an electronic flow control system, which will be responsible for adjusting the flow rate of the sprayer in real-time based on the crop density data.

The crop density data for a sample field is calculated using Deep learning classifier, ResNet 50 which classifies the crop field based on the pest percentage. The classifier is successfully trained up to an accuracy of 82% to classify The field into four categories, with pest below 25%, 25-50% pest, 50 – 75 % pest and above 75% pest.

The Pixhawk flight controller is capable of controlling the flight dynamics of the UAV and the flow rate of the sprayer during the same flight. Therefore, the need for a secondary controller for sprayer is eliminated.

The CFD simulations of the variable rate sprayer at the nozzle are performed to analyze the flow physics inside the nozzle. The results are validated by the experimental validations and the variable flow rates are found to be in line with CFD results.

Overall, the project, when delivered on a large scale is able to reduce the labor time to manually the agriculture field, by about 60-70% and subsequently the costs of spraying is reduced

ACKNOWLEDGMENTS

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Finally, we would like to thank the faculty and staff of our institution for providing us with the necessary resources and facilities to undertake this project. We are grateful for the opportunities and experiences that we have gained during this endeavor.

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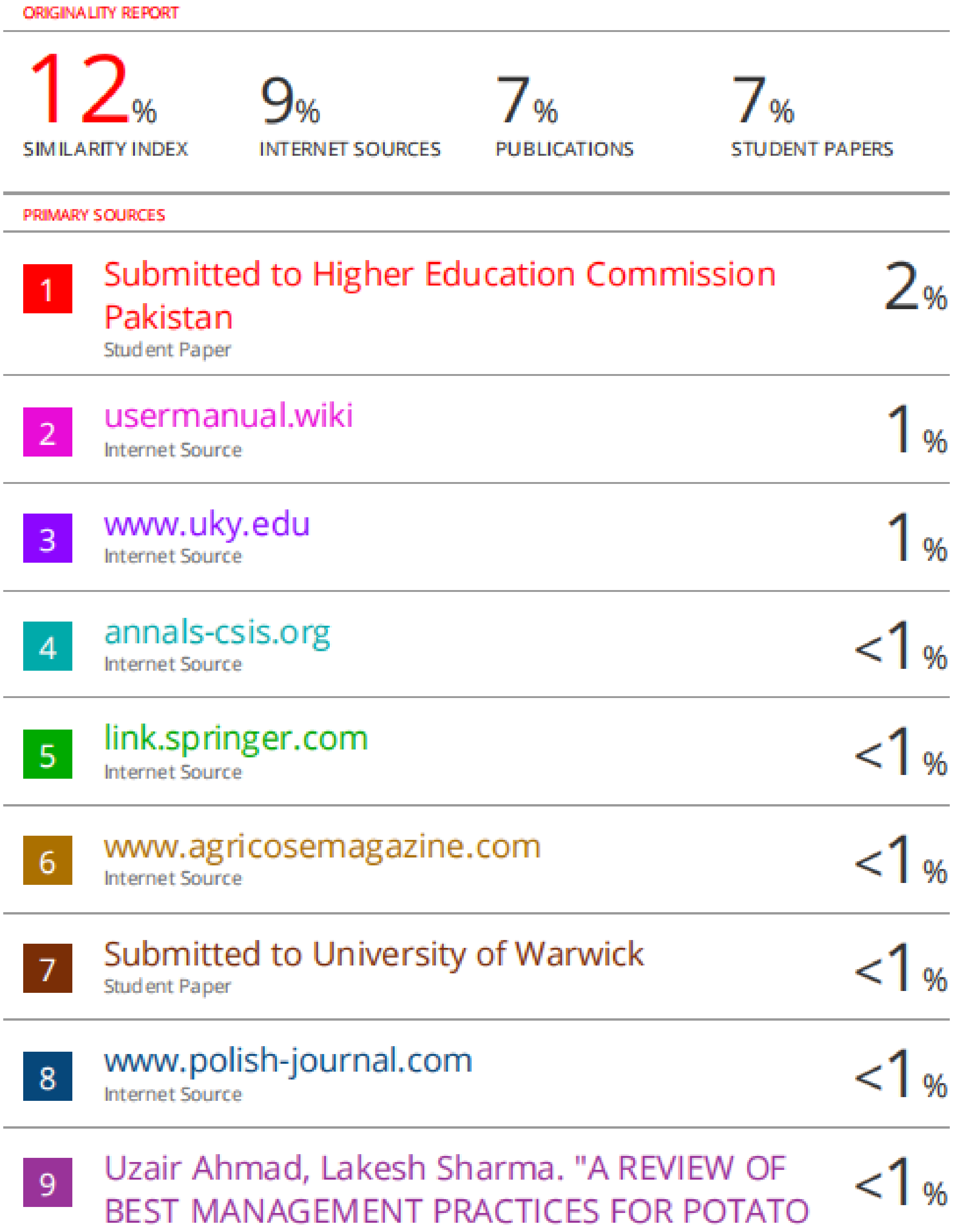

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NOMENCLATURE

t_{flow},	Maximum time the drone can spray
V_{tank}.	Tank Volume
$\dot{V}_{required}$	Required flow rate at the field
$\dot{V}_{agitation}$	Flow rates increase due to agitation
$\dot{V}_{total}$	Total Flow rate at the nozzle outlet
η	propeller efficiency
P:	Motor Electric power
r	Radius of propeller
ρ	Density of air

CHAPTER 1: INTRODUCTION

As the global population grows, so does the demand for food production, and with it, the need for effective pest management strategies. The use of unmanned aerial vehicles (UAVs) for agricultural spraying has become a popular method due to its ability to provide targeted and efficient crop protection. In Pakistan, where agriculture is a crucial sector of the economy, the need for a cost-effective, reliable, and environmentally friendly solution is more critical than ever.

Our final year project aims to address this need by designing and fabricating a variable rate sprayer for agriculture drones. The proposed solution uses a customized nozzle array to adjust the spray rate based on the crop's characteristics, resulting in optimized pesticide delivery and reduced waste. The system incorporates Machine Learning, to classify the pest percentage, enabling precise targeting of pesticide application.

In conclusion, this report presents a novel solution to the challenges faced by the agriculture industry in Pakistan and other developing countries. The variable rate sprayer for agriculture drones offers an affordable, efficient, and environmentally friendly approach to pest management, which has the potential to revolutionize the way farmers protect their crops.

Motivation for work:

Pakistan is an agriculture-based economy, contributing around 20% of the country's GDP and employing over 42% of the labor force [1]. However, the sector faces significant challenges, including inefficient use of resources, low crop yields, and environmental degradation. One significant challenge is the uneven distribution of pesticides and fertilizers during spraying, leading to over-application, crop damage, and environmental pollution.

The development of a variable rate sprayer for an agriculture drone in Pakistan can help address these challenges. With the implementation of this technology, farmers can achieve precise and targeted application of pesticides and fertilizers, leading to improved crop yields, reduced costs, and minimized environmental impact. This technology can benefit small farmers who cannot afford traditional fixed-rate sprayers and cannot bear the loss caused by uneven distribution of pesticides and fertilizers.

The use of drones for precision agriculture is still in its infancy in Pakistan, and this project can contribute to the country's technological advancement in agriculture. The development of a variable rate sprayer for an agriculture drone can promote sustainable agriculture practices and improve the country's food security.

Therefore, the motivation for this project is to develop a variable rate sprayer for an agriculture drone in Pakistan, contributing to sustainable agriculture, improving crop yields, and conserving water resources. This technology can benefit small farmers, reduce costs, and promote the country's technological advancement in agriculture.

Problem Statement:

The agricultural sector faces significant challenges in the form of inefficient use of pesticides and fertilizers, resulting in environmental damage, wastage, and economic losses. Traditional fixed-rate sprayers lack the precision required to apply these chemicals effectively, leading to over-application and uneven distribution, impacting crop yields. A solution to this problem is the development of a variable rate sprayer for an agriculture drone that can adjust the application rate based on crop needs and growth stages, thereby reducing waste, minimizing environmental impact, and improving crop yields.

Deliverables of the Project

- Designing the precision variable rate sprayer for achievable accuracy
- Processing the images of crops to design the prescription map.
- Fabricating/Assembling the Variable Rate sprayer.
- Simulating the UAV and the sprayer inside a virtual environment to achieve the desired results.

CHAPTER 2: LITERATURE REVIEW

Introduction:

The use of Unmanned Aerial Vehicles (UAVs) in agriculture has revolutionized the sector by increasing efficiency and reducing costs. UAVs have various applications in agriculture, including crop monitoring, irrigation management, yield estimation, and pesticide spraying. Pesticide spraying, in particular, is crucial for crop yield and quality, and the use of UAVs in this task has gained significant attention. Numerous research studies have been conducted to assess the performance of different types of agricultural spray drones. This literature review provides a comprehensive overview of the development and application of UAVs for agricultural spraying, highlighting their advantages, limitations, and future prospects.

Review in Literature:

Agriculture:

Agriculture is a crucial industry that has been integral to human civilization since ancient times and remains essential today. It plays a significant role in the global economy by providing employment and income for millions of people worldwide. Additionally, agriculture contributes significantly to the GDP of many countries, such as the United States, where it contributes approximately $1 trillion annually. Moreover, agriculture is essential for ensuring food security, particularly as the global population is projected to reach 9.7 billion by 2050. It provides a diverse range of foods necessary for human nutrition, including fruits, vegetables, grains, and meats.[3]

Furthermore, agriculture has a critical impact on environmental sustainability. While it can contribute to deforestation and loss of biodiversity, sustainable agricultural practices, such as conservation agriculture, can help mitigate these issues. By reducing inputs like water and fertilizers, sustainable agriculture practices help to minimize greenhouse gas emissions and protect the environment. Lastly, agriculture plays a vital role in social and cultural well-being. It holds significant cultural and traditional value worldwide, connecting people to the land and nature. Additionally, it fosters social cohesion and community development by providing a shared goal for individuals to work together towards.[2]

Effect of Pesticides in Agriculture:

The long-term impact of pesticides on the environment and human health is a growing concern. Pesticides, while effective in controlling pests, can also harm non-target organisms and lead to a decrease in soil health and fertility. They can contaminate groundwater, causing potential harm to human health. Additionally, pesticides contribute to a decline in biodiversity by killing beneficial insects and birds, disrupting pollination and increasing the need for more pesticides. The overuse of pesticides has also resulted in the development of pesticide-resistant pests, necessitating stronger and more toxic pesticides. Exposure to high levels of pesticides can have acute and chronic health effects.[1] The decline of bee populations, linked to pesticide use, further threatens agricultural production. To address these concerns, alternative pest control methods such as integrated pest management should be explored to minimize pesticide use and promote sustainable agricultural practices for the benefit of the environment and human health.

Significance of UAVs in Agriculture spraying

Agriculture drones, also known as UAVs, offer promising solutions for pest control in agriculture. Equipped with advanced sensors and imaging technologies, these drones provide real-time data on pest populations and crop health, empowering farmers to make informed decisions. Their high-resolution cameras and sensors capture detailed crop images, which can be analyzed using AI and machine learning algorithms to detect pests and diseases. This enables targeted pest management instead of blanket pesticide applications, reducing costs and environmental harm. Variable rate sprayers on drones apply inputs only where needed, minimizing pesticide use and preserving soil and water quality. Furthermore, drones equipped with multispectral and thermal imaging sensors can identify early signs of crop stress or disease, enabling prompt action for higher yields, better quality produce, and reduced production costs.

Figure 1 Sample Multirotor HexaCopter Sprayer drone © dronefromchina.com

In conclusion, Agriculture drones offer real-time data on pest populations and crop health, aiding informed pest management decisions, resulting in higher yields, better quality produce, and lower costs. With reduced pesticide use, they promote environmental health and protect non-target organisms, making them a promising tool for sustainable and efficient agriculture.

Development of UAVs, over the period of time.

Agricultural spray drones have evolved over the years, with advancements in technology and design to make them more efficient and user-friendly. In 2015, Gul and Mehmood reviewed the different types of sprayers drones available and their applications in agriculture [7]. They discussed the use of multi-rotor and fixed-wing drones for agricultural spraying and their advantages and limitations. They highlighted the need for better battery technology and advanced sensing and imaging systems for precision agriculture.

In 2016, Yuan and Huang reviewed the various types of sprayer drones and their application in agriculture [8]. They discussed the different types of nozzles used in spray drones, including the rotary atomizer, electrostatic nozzle, and pneumatic nozzle. They also highlighted the need for more research on the optimal flight height and speed of UAVs for spraying pesticides and the need for better pesticide formulations suitable for UAV spraying.

In 2018, Liu and Xu provided a comprehensive review of the latest advances in agricultural spraying drones [9]. They discussed the design, operation, and applications of spray drones, including their sensing and imaging systems, flight control algorithms, and safety features. They also discussed the challenges faced by spray drones, such as the limited payload capacity and battery life, and highlighted the need for better collaboration between researchers and farmers to improve the practicality of spray drones.

In 2019, Zahid, Khan, and Mehmood provided an in-depth review of sprayer drones for precision agriculture [10]. They discussed the technology used in spray drones, including the GPS system, imaging sensors, and flight control algorithms. They also compared the performance of multi-rotor and fixed-wing drones for spraying pesticides and highlighted the need for better communication systems between UAVs and the ground station.

Despite these advantages, there are still some limitations associated with the use of spray drones. One major limitation is their limited flight time and range. Most commercial drones have a flight time of only 20-30 minutes and a range of around 2-3 km, which can make it difficult to cover large areas of farmland. In addition, sprayer drones can be expensive to purchase and maintain, which may limit their use for small-scale farmers.

To address some of these limitations, researchers have been working on developing more advanced and efficient sprayer drone designs. Wang et al. [11] presents a design and experiment of a variable spray system for unmanned aerial vehicles (UAVs) based on PID and PWM control. The system allows for precise and efficient agricultural spraying. The results demonstrate the effectiveness of the system in terms of spray uniformity and coverage.

In 2019 Z Chang et al. [12] proposes a design of a plant protection UAV variable spray system based on neural networks. The system aims to improve the accuracy and efficiency of pesticide spraying, and the results show that the system can achieve better spray uniformity and coverage compared to traditional fixed-spray systems.

Types of Sprayer Drones

Based on physical design and capabilities

Fixed-Wing Sprayer Drones:

Fixed-wing drones are characterized by their ability to cover large areas quickly, making them ideal for large-scale farming operations. According to Liu [9], fixed-wing drones are often equipped with powerful engines and high-capacity spray tanks, allowing them to cover up to 500 acres of farmland in a single flight. Additionally, fixed-wing drones are known for their stability in windy conditions, making them more reliable for outdoor applications. However, they have limited maneuverability and may not be suitable for precise spraying applications in complex terrain [8].

Figure 2 Example of Fixed Wing Sprayer Drone © [23]

Rotary-Wing Sprayer Drones:

Rotary-wing drones, such as quadcopters, have a more compact design and are capable of hovering in place, making them ideal for spraying applications in more complex terrain Moreover, they are more maneuverable than fixed-wing drones, allowing them to spray crops with greater precision. However, their limited flight time and range may be a drawback, as they are not suitable for large-scale farming operations [16].

Figure 3 Example of Multirotor Sprayer Drone © Ardupilot.com

Hybrid Sprayer Drones:

Hybrid drones combine the features of fixed-wing and rotary-wing drones, providing the best of both worlds. According to Tang [17], hybrid drones are capable of vertical take-off and landing, making them suitable for spraying applications in complex terrain, while their fixed-wing design allows them to cover large areas quickly. Additionally, they have longer flight times and ranges compared to rotary-wing drones, making them suitable for both small and large-scale farming operations. However, they are more complex and expensive to operate than fixed-wing or rotary-wing drones [7].

In summary, each type of sprayer drone has its advantages and disadvantages. Fixed-wing drones are best suited for large-scale farming operations, while rotary-wing drones are more suitable for precise spraying applications in complex terrain. Hybrid drones offer the best of both worlds, but they are more complex and expensive to operate. The choice of the type of drone depends on the specific needs and requirements of the farming operation.

Benefit of Multirotor over Fixed Wing

Multirotor UAVs (such as quadcopters, hexacopters, octocopters, etc.) offer several advantages over fixed-wing UAVs for certain applications and hence are proposed for the design. Here are a few reasons why multirotor UAVs may be more suitable, based upon the above-mentioned references.

- **Hovering and Vertical Takeoff/Landing (VTOL) Capabilities**: Multirotor UAVs have the ability to hover in a fixed position and take off and land vertically, which can be advantageous in applications that require precise positioning or require access to areas with limited space for takeoff and landing. For example, multirotor are commonly used in inspection, surveillance, and search and rescue operations.
- **Maneuverability**: Multirotor UAVs have excellent maneuverability, which makes them well-suited for applications that require precise and controlled movements,

such as filming or photography. They can also fly at low speeds and hover in place, which can be useful for inspecting or monitoring specific areas.

- **Easy to Operate:** Multirotor UAVs are generally easier to operate compared to fixed-wing UAVs, as they don't require a runway for takeoff and landing and can be flown in confined spaces. Additionally, they can be operated by a single person and are relatively easy to fly with the help of GPS and other automation technologies.

Benefit of Hexacopter over other Multirotor

Hexacopter are a popular choice for UAV applications due to their ability to provide stable and smooth flight, even in adverse weather conditions recommended by a number of researchers[10][11]. The six rotors of a Hexacopter provide redundancy, allowing the aircraft to remain stable and continue flying even if one or more rotors fail. Additionally, hexacopters are capable of carrying heavier payloads compared to quadcopters, making them suitable for applications such as aerial photography and surveillance. Research has shown that hexacopters also have better wind resistance and stability compared to quadcopters, making them more reliable for outdoor missions. Overall, hexacopters offer unique capabilities that make them a popular choice for various UAV applications.

Overall Proposed Design:

So based upon the above discussions, we can easily conclude that the effective design for our case will be.

Table 1 Literature proposed Design.

UAV type	Multirotor
Type of multirotor	Hexacopter
Controller	Pixhawk series
Navigation mechanism	GPS Navigated

The design includes the use of a HexaCopter drone, which is a multi-rotor vehicle powered by lithium-ion batteries. The drone is equipped with a tank located at the bottom that holds the spraying material, and it has two nozzles for dispensing the spray. All programming and control will be handled through the use of the Pixhawk controller 2.4.8, which will provide precise control over the drone's movements and operations. The sprayer will operate based on the drone's GPS location, ensuring that the spraying is done with high accuracy. The design of the system is compact and efficient, enabling it to cover a significant area in a short amount of time. Overall, the project's design aims to provide an effective solution for precision agriculture that maximizes efficiency and minimizes waste.

Nozzle and its Types

Generally Different Types of spray Nozzles are used for different agriculture purposes. Generally, they are classified as follows.[18]

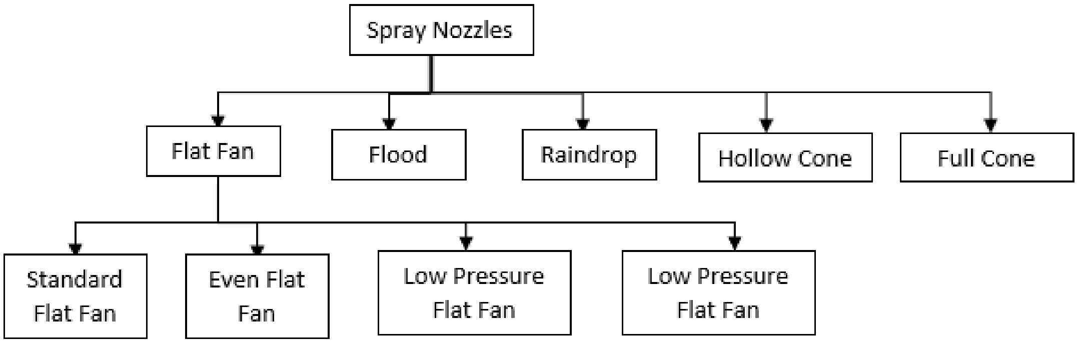


Figure 4 Classificatiopn of Market Available nozzles

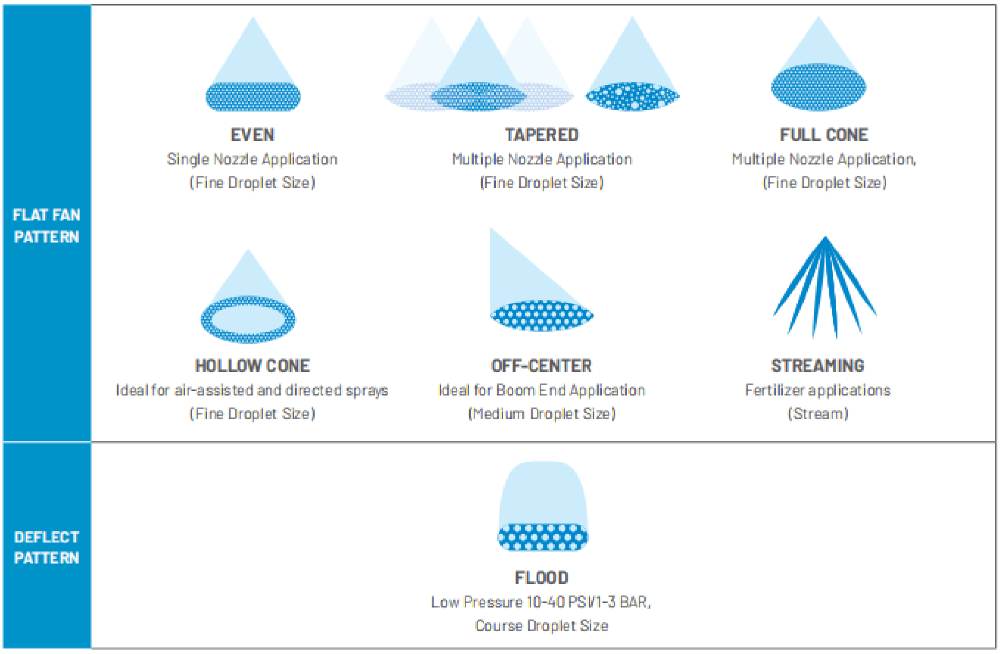


Figure 5 Flow Pattern of Different Nozzles © [18]

Flat fan

Flat-fan nozzles are widely used for broadcast spraying of herbicides. These nozzles produce a tapered-edge, flat fan spray pattern.

- **standard flat fan** normally operates between 30 and 60 pounds per square inch (psi)
- **even flat fans** apply uniform coverage across the entire width of the spray pattern. They are used for banding pesticide.
- **low pressure flat-fan** develops a normal flat-fan angle and spray pattern at operating pressures between 15 and 20 psi.
- **The extended range flat fan** provides excellent drift control when operated between 15 and 25 psi.

Flood Type

Flood nozzles are popular for applying suspension fertilizers where clogging is a potential problem. These nozzles produce large droplets at pressures of 10 to 25 psi.

Raindrop Type

Raindrop nozzles produce large drops in a hollow-cone pattern at pressures from 20 to 50 psi.

Hollow-cone nozzles

Hollow-cone nozzles generally are used to apply insecticides or fungicides to field crops when foliage penetration and complete coverage of the leaf surface is required. `

Full Cone Type

The wide-angle, full-cone nozzles are a good choice if drift is a concern because they produce larger droplets than flood nozzles.

CHAPTER 3: METHODOLOGY

Design Overview

Our design overview starts with a basic architecture of the UAV Functionality. The AI model classifies the available field images according to their dosage requirements. The Main Controller receives the field coordinates from the GPS module. The Data for the Field generated through AI models, is provided to the controller and the mission is planned accordingly. The Controller Firmware then decides the amount of pesticide to be sprayed. PWM (Pulse Width modulation) signal alters the output, thus varying the flow rate of the pump.

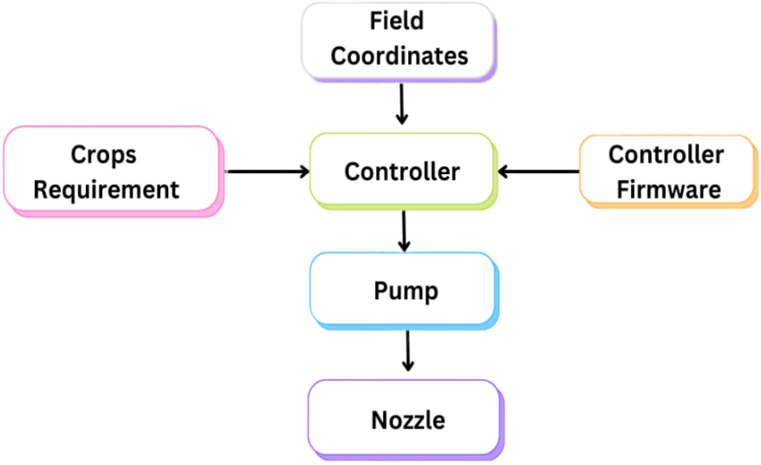


Figure 6 Standard Design Configuration

Computer Vision:

Computer vision involves enabling machines to interpret visual information through techniques like object recognition, tracking, segmentation, and classification. Image processing manipulates digital images to enhance quality or extract information. By leveraging these techniques, one can preprocess datasets, extract relevant features, and train models for accurate classification, improving project outcomes.

Dataset its classification:

The dataset for this project consists of drone images of sugarcane fields. The images were manually classified into four categories based on the quantity of pests present in the sugarcane fields. The pest levels were classified into four categories, with the rates as "0-25%", "26-50%", "51-75%", and "76-100%".

Table 2 Dataset Classification

Classification	Class Definition	Percentage of pest infestation
First Class	Class 0	0-25%
2nd Class	Class 1	26-50%
3rd Class	Class 2	51-75%
4th Class	Class 3	76-100%

We created four folders for the images, each corresponding to a different pest level. To classify the images automatically, we used a classifier of machine learning. To train our model, we used the dataset of drone images and the classifier, a pre-trained convolutional neural network (CNN) that is commonly used for image classification tasks.


Classifier 0 pest 0-25% *Classifier 1 pest 26-50%* *Classifier 2 pest 51-75%* *Classifier 3 pest 76-100%*

Figure 7 Four Levels of our Data Classification of Sugarcane Field

We utilized transfer learning, a technique that involves reusing a pre-trained model's weights and architecture to perform a new task. We fine-tuned the machine learning model by adding a new fully connected layer with four output nodes corresponding to the pest levels. The dataset consists of a total of 1,000 images, with 250 images in each pest level category.

In conclusion, we trained our model using a classifier, a pre-trained CNN commonly used for image classification tasks. We fine-tuned the model by adding a new fully connected layer to perform the new task of classifying pest levels in sugarcane fields.

Machine Learning Classifiers:

Pretrained classifier models:

These are machine learning models that have been trained on a large dataset, often using deep learning techniques, and are made available for use by developers. Pretrained models can be used as a starting point for new applications, allowing developers to leverage the power of deep learning without having to train their own models from scratch. Some popular pretrained models include VGG16, InceptionV3, MobileNet, and ResNet50.

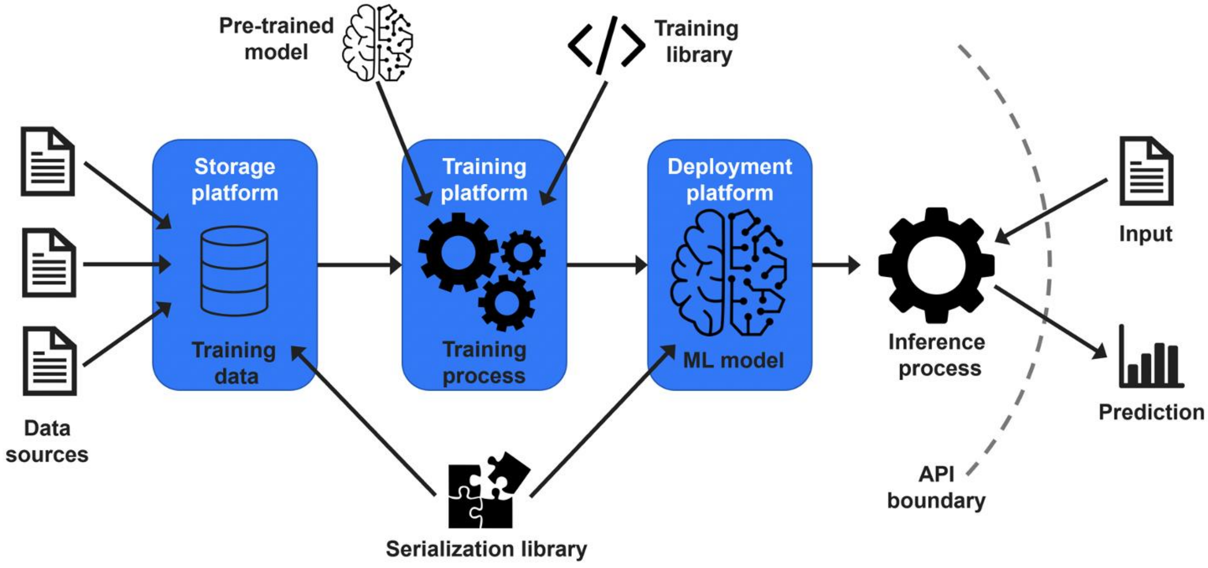


Figure 8 Machine Learning Pipeline © Datatron.com

ResNet50:

ResNet50 is a widely used pretrained classifier model for image classification tasks. It is a deep neural network consisting of 50 layers, and it uses skip connections to address the problem of vanishing gradients during training. Skip connections allow the network to learn residual functions, which are the differences between the input and output of a layer, making it easier for the network to optimize the weights of the layers.

Advantages of ResNet50:

ResNet50 has several advantages that make it a popular choice for image classification tasks.

- ResNet50 is a powerful pre-trained deep learning model for image classification tasks.
- The model has been pre-trained on a large dataset of images, making it capable of recognizing a wide range of objects and features in images.
- ResNet50 is a deep neural network architecture that has been designed to address the issue of vanishing gradients, allowing for deeper networks to be trained.
- The residual connections in ResNet50 allow for the model to learn and identify small, subtle details in images that might be missed by other models.
- The ResNet50 model has been shown to achieve state-of-the-art performance on a variety of image classification tasks.
- ResNet50 can be fine-tuned on a smaller dataset for specific image classification tasks, further increasing its accuracy and versatility.

ResNet50 Model Architecture:

ResNet50 is a widely used convolutional neural network (CNN) architecture for image classification. It addresses the problem of vanishing gradients during training by utilizing skip connections, allowing the network to learn residual functions. ResNet50 consists of 50 layers organized into blocks, each containing convolutional layers, batch normalization layers, activation functions, and skip connections. The input image passes through these blocks, reducing spatial dimensions and increasing filter numbers. The final block includes a global average pooling layer and a fully connected layer with 1000 output nodes for ImageNet classes, which can be modified for different classification tasks.

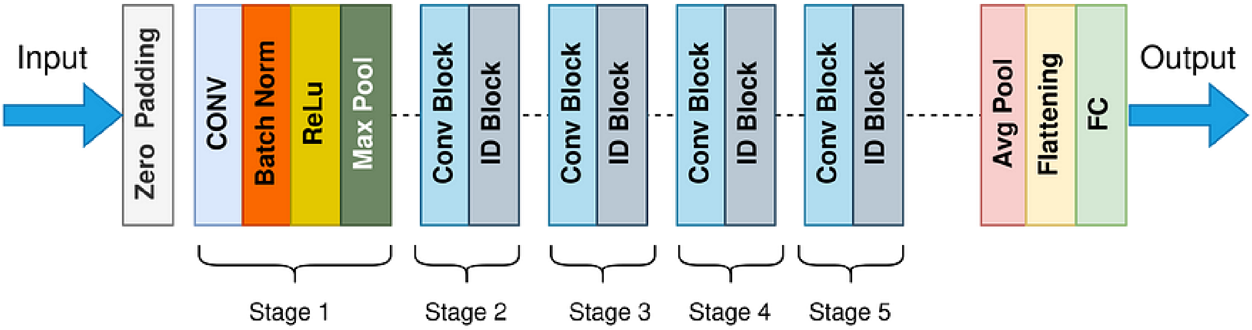


Figure 9 ResNet50 Model Architecture

Model Training:

To train our model using the ResNet50 architecture, we followed the transfer learning approach. We utilized the pre-trained ResNet50 model, which was trained on the large ImageNet dataset to extract meaningful features from images. We then fine-tuned the model on our sugarcane field pest detection dataset to classify the images into one of the four pest levels (0-25%, 26-50%, 51-75%, 76-100%).

We first divided the dataset into four folders, each containing images of sugarcane fields with a variable spray rate corresponding to one of the four pest levels. We then used the ResNet50 model to extract features from each image in the four folders. These features were then used to train a classifier to classify the images into one of the four pest levels.

To do this, we wrote a Python code that utilized the Keras deep learning library. We used the pre-trained ResNet50 model as a feature extractor, and we added a new dense layer with four output nodes to classify the images. We also utilized early stopping to prevent the overfitting of the model.

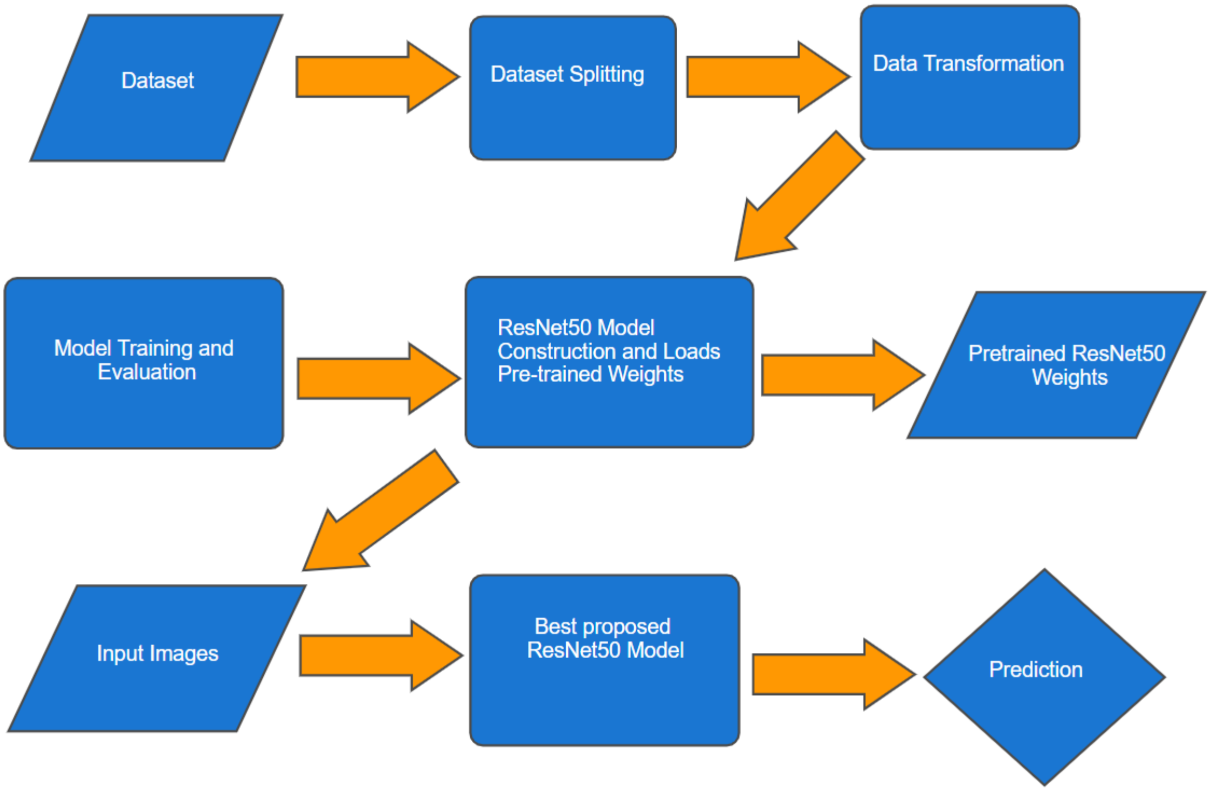


Figure 10 Transfer Learning with ResNet50

During training, we fine-tuned the ResNet50 model by updating the weights of its last few layers, while keeping the initial layers fixed. This helped to prevent the model from overfitting to our dataset and to improve its generalization performance. By using transfer learning with the pre-trained ResNet50 model, we were able to achieve good performance with a relatively small dataset of only 1000 images.

In conclusion, we have chosen to train our model using the ResNet50 classifier, a pre-trained convolutional neural network (CNN) that is commonly used for image classification tasks. We utilized transfer learning, fine-tuning the ResNet50 model by adding a new fully connected layer with four output nodes corresponding to the pest levels. We have split the dataset of 1000 drone images into four folders based on the variable spray rate, and we have written a code to enhance the images using the pre-trained ResNet50 model. By using this approach, we aim to leverage the power of deep learning to accurately classify the images based on the quantity of pests, which can help farmers in making more informed decisions and improving the yield of sugarcane crops.

Inference:

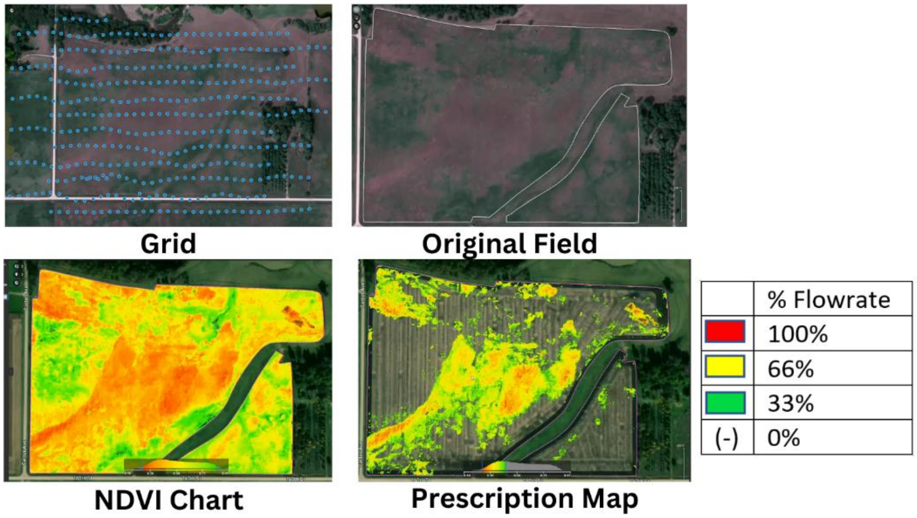
Inference is a crucial step in utilizing a pre-trained model such as ResNet50 for image classification. It involves passing an input image through the layers of the neural network to generate a prediction based on the learned weights and biases of the model. ResNet50 is well-suited for image classification as it has been trained on a large dataset, enabling it to recognize various objects and features. In our project, the enhanced images of sugarcane fields will be classified using ResNet50 to determine the pest quantity category. This prediction will inform decisions regarding pest management strategies in the sugarcane fields. Overall, inference enables the model to leverage its learned knowledge to make accurate predictions on new, unseen data.

Prescription Map:

A prescription map is a map that contains information about the specific requirements for spraying in a particular area. This information includes the necessary amount of spray to be applied to each location within the area, as well as other details about the terrain and any obstacles that may be present.

To generate a prescription map, we will utilize images and a trained model. The images will provide us with a detailed view of the area to be sprayed, while the trained model will help us identify the best approach for spraying based on factors such as terrain, crop type, and weather conditions.

Once the prescription map has been generated, it will guide the drone to its specific position for spraying. The map will contain all the necessary information required to complete the spraying process, including details on how much spray to apply at each location, the best approach for avoiding obstacles, and other relevant information.



Grid

Original Field

NDVI Chart

Prescription Map

Figure 11 Flow Classification according to the prescription map

Main Components of UAV Design:

The expected Payload of the Drone is 1.5-2 kg, which is well enough to lift a Prototype Drone used for testing purposes. Practically the drone usually has 15-20 kg of Payload.

Key components to be used in the development of UAV are:

- Flight controller
- Motors and propellers
- Battery

- Sensors
- Telemetry
- GPS Module
- Spray Tank
- ESC (Electronic Speed Controller)
- Pump
- Nozzles

The final UAV in its form is presented as follows.

Figure 12 UAV with sprayer tank and Nozzle

The main components of UAV are enlisted and described as follows.

Frame and propellers:

The frame is the physical structure of the drone that holds all the components together. It needs to be lightweight and sturdy to support the drone's weight and withstand the stress of flying and landing.

Keeping in view the Payload of 2.5 kg, the following Frame is chosen, Because of its Durability and market Availability.

- DJI F550 Hexacopter Frame

Figure 13 DJI F550 Hexacopter Frame © DJI

Flight controller:

The flight controller is the brain of the drone, responsible for controlling its movements and stability during flight. It receives input from sensors such as GPS and accelerometers and uses algorithms to determine the drone's position and orientation.

The Following Controller is Used for Open-Source Firmware, built in sensors, and easy programmability.

- Pixhawk 2.4.8

The Pixhawk 2.4.8 is a popular flight controller used in many agricultural drones. It is an open-source autopilot system that provides advanced features such as GPS positioning, waypoint navigation, and autonomous flight.

It is a small, lightweight module that can be mounted on the drone's frame. It features a 32-bit processor and a variety of sensors, including a 3-axis accelerometer, 3-axis gyroscope, and 3-axis magnetometer. It also has a built-in barometer for measuring altitude.

Figure 14 Pixhawk 2.4.8 © docs.px4.io/main/en/

In addition to its sensors, the Pixhawk 2.4.8 has a range of communication ports for connecting to other devices, such as GPS modules, cameras, and telemetry systems. It also supports various communication protocols, including MAVLink, which is commonly used for communication between drones and ground control stations.

One of the key benefits of using the Pixhawk 2.4.8 is its flexibility. It can be programmed and customized to meet the specific needs of different agricultural applications. For example, it can be configured to perform precise spraying operations by integrating with a spraying system and adjusting the flow rate based on the drone's speed and altitude.

Motors:

The motors and propellers provide the thrust needed to lift and move the drone in the air. They need to be powerful enough to carry the weight of the drone and any additional payload, such as sprayer.

The Following Motors are Used.

- DJI 2212/920 kV

Figure 15 DJI 2212/920 kV motors © [24]

Battery:

The battery provides the power needed to run the drone's electronics and fly it in the air. It needs to be lightweight and long-lasting to provide enough flight time for the drone to complete its mission.

The Following Battery is used. The Following battery is expected to give a flight time of about 7-10 minutes, based upon the calculated load.

- High Discharge 5000 Mah LiPo Battery

Figure 16 High Discharge 5000 mAh LiPo Battery © [24]

Sensors:

Sensors such as GPS, accelerometers, and gyros provide information about the drone's position, altitude, and orientation. They are crucial for maintaining stability and controlling the drone's movements during flight.

The following Sensors are built in the Pixhawk Controller

- MPU6000 as main accel and gyro
- ST Micro 16-bit gyroscope
- ST Micro 14-bit accelerometer/compass (magnetometer)
- MEAS barometer

Telemetry:

Telemetry is a communication system used to transmit real-time data and information from a remote object, such as a drone, to a ground control station or other receiving device.

The telemetry system consists of two parts: a telemetry transmitter mounted on the drone and a telemetry receiver located on the ground. The transmitter collects data from various sensors on the drone, such as GPS, altitude, battery level, and motor status, and sends this data in real-time to the receiver on the ground.

The telemetry data is transmitted via a radio signal, because radio signal enables travelling at wide ranges (highly efficient telemetries can even transmit data up to 8 kms). The receiving device on the ground displays the telemetry data in a user-friendly format, allowing the operator to monitor the drone's status and make informed decisions based on the data.

The following Telemetry is used for the UAV.

- SiK Radio Telemetry 433 Hz, 500mW

Figure 17 SIk Radio Telemetry 433 Hz, 500mW © [24]

Some of the benefits of telemetry for agriculture drones include:

- **Real-time monitoring:** Telemetry provides real-time data and information about the drone's performance and status, allowing farmers or operators to monitor the drone's activities during flight and make necessary adjustments.
- **Improved safety**: Telemetry allows farmers or operators to detect and respond quickly to any potential issues or malfunctions, reducing the risk of accidents and improving overall safety.

GPS Module:

A GPS module is a device that uses Global Positioning System (GPS) technology to determine the precise location of an object, such as an agricultural drone.

One of the main benefits of using a GPS module in agriculture drones is its accuracy. GPS technology can provide location information with high precision, typically within a few meters. This level of accuracy is essential for precision agriculture applications, such as crop monitoring and mapping.

The Following GPS Module is Used

- Ublox M8N GPS Module

Figure 18 Ublox M8N GPS Module © [24]

Spray Tank:

The spray tank is a critical component of the agricultural drone spraying system, responsible for holding the liquid solution that will be dispensed through the nozzles during the spraying operation.

In our project, the spray tank has a capacity of 0.5 liters, which is suitable for small sized agricultural areas, best for prototyping and testing.

The spray tank is made of lightweight ABS plastic material, which allows for easy maneuverability and reduces the overall weight of the drone. The plastic material used in the tank is also durable and resistant to chemicals, ensuring that it can withstand exposure to the liquid solution.

The sprayer tank will be 3D printed and its 3D CAD model is presented.

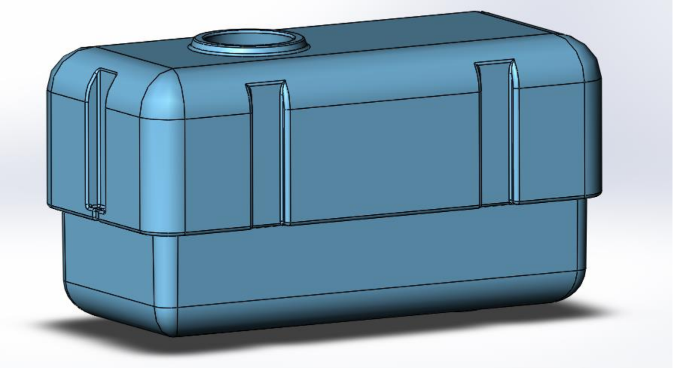


Figure 19 3D printed Spray Tank

The spray tank will be connected to the pump and nozzles through a series of hoses and fittings. The pump transfers the liquid solution from the tank to the nozzles, where it is dispensed in a controlled manner over the target area.

Working Flow Diagram

The following figure summarizes the flow if the electronic circuitry of the drone.

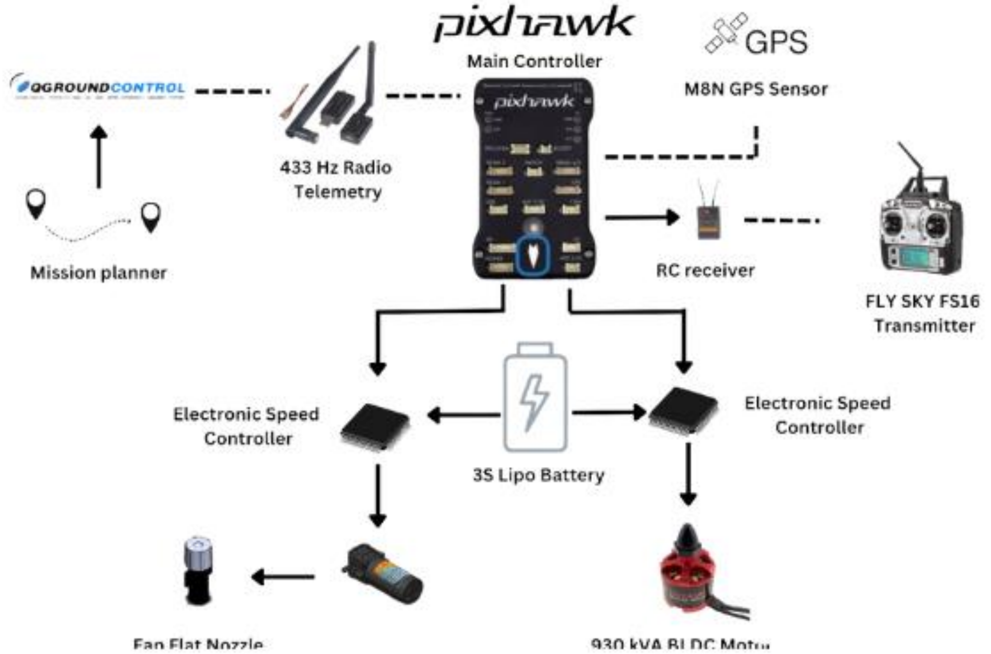


Figure 20 Electronic Flow Diagram of the Sprayer Drone

Pump and its Selection

The pump is a key component of the agricultural drone spraying system, responsible for transferring the liquid solution from the spray tank to the nozzles for dispensing.

Types of Pumps used agriculture.

Generally, there are a number of pumps available for the agriculture purposes. Depending on the usage we have the following pumps. With their operating pressure and Flow rate

Table 3 Market available pumps for agriculture with their Operating pressures and Flow rates

Pump Type	**Operating Pressure**	**Flow Rate**
Centrifugal	**0-150 psi (0-10 bar)**	**0-1078 gpm (0-4080 Ipm)**
Shurflo Diaphragm	**0-150 psi (0-10 bar)**	**0-5 gpm (0-20 1pm)**
Roller	**0-300 psi (0-20 bar)**	**0-60 gpm (0-225 lpm)**
HYPRO Diaphragm	**0-725 psi (0-50 bar)**	**0-60 gpm (0-225 lpm)**
Piston/Plunger	**0-1000 psi (0-69 bar)**	**0-10 gpm (0-38 Ipm)**
Plunger	**0-3600 psi (0-248 bar)**	**0-45 gpm (0-170 Ipm)**

Electrical Connectivity of Pump

The pump is connected to the drone's flight controller and is controlled through the varying PWM signals of the controller. The flight controller adjusts the pump speed and flow rate based on the spraying parameters.

Pump requirement for a UAV

For a UAV, where the only source of power is the battery, it is most suitable to use a pump with the following.

- Low volumetric flow rate (about 0.2-2 LPM)
- Low Operating pressure (20-100 psi)

So, based upon the above-mentioned table we have the following pump.

- Shurflo Diaphragm Pump

Flow requirement Calculation

For an average flow time t_{flow}, Capacity of tank, V_{tank}. Required flow rate at the nozzle exit will be $\dot{V}_{required}$ is calculates as

$$\dot{V}_{required} = \frac{V_{tank}}{t_{flow}}$$

Flow required for agitation $\dot{V}_{agitation}$

$$\dot{V}_{agitation} = 0.05 \times \dot{V}_{required}$$

Total Flow Required $\dot{V}_{total}$

$$\dot{V}_{total} = \dot{V}_{required} + \dot{V}_{agitation}$$

Table 4 Toral Flow rate Calculation

Average Flow time	t_{flow}	3 min
Tank Capacity	V_{tank}	0.5 L
Required flow rate at the nozzle exit	$\dot{V}_{required}$	0.166 LPM
Flow required for agitation	$\dot{V}_{agitation}$	0.008 LPM
Total Flow Required	$\dot{V}_{total}$	0.174 LPM

NOTE: We can use a pump and nozzle with a max flow rate of 5 LPM easily.

Selected Pump

Denso Brushed Pump for water spraying Toyota.

The pump has the following Characteristics:

Table 5 Specifications of selected Pump

Working Voltage	12V
Power	70W
Current	3A
Max Pressure	170 psi (1.17 MPa)
Flow Rate	4.5 LPM

Figure 21 High-pressure spray 12V water pump © amazon .com

Respective ESC

Since we are using a brushed pump, a brushed ESC is used. The following ESC is used to control the output of the pump motor.

Figure 22 320a Waterproof Brushed ESC

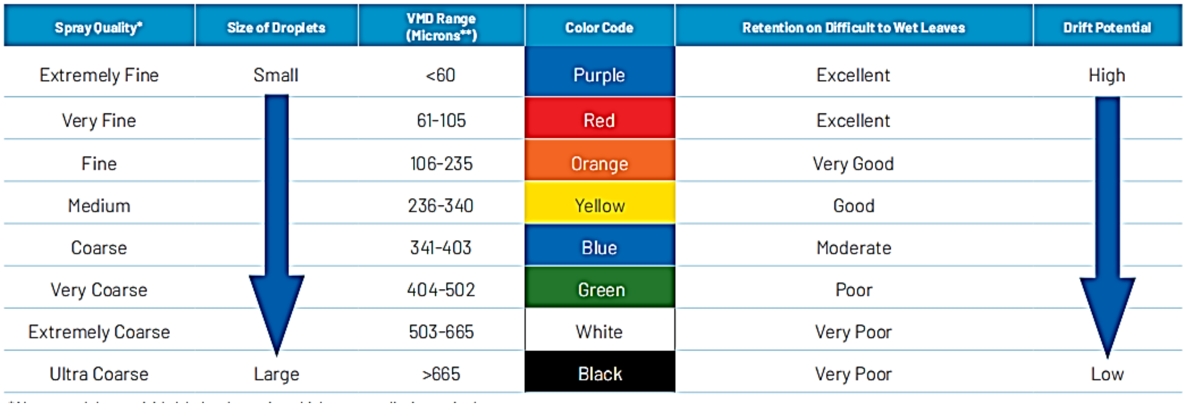
Nozzle and its selection:

Selection Parameters

Following Parameters are considered during Nozzle selection.

- Spray Quality
- Size of Droplets (VDM Range)
- Drift Potential

Following is a table which shows the general colour coding used for different nozzles. It also shows the relation between spray droplets and the drift potential, how increasing the size of droplets reduces the drift potential.



Spray Quality*	Size of Droplets	VMD Range (Microns**)	Color Code	Retention on Difficult to Wet Leaves	Drift Potential
Extremely Fine	Small	<60	Purple	Excellent	High
Very Fine		61-105	Red	Excellent	
Fine		106-235	Orange	Very Good	
Medium		236-340	Yellow	Good	
Coarse		341-403	Blue	Moderate	
Very Coarse		404-502	Green	Poor	
Extremely Coarse		503-665	White	Very Poor	
Ultra Coarse	Large	>665	Black	Very Poor	Low

Figure 23 The general colour coding used for different nozzles, with droplet sizes and drift potential © [18]

Selected Nozzle

Using the Product Catalogue provided by Pentair, a water solution company, the following Type of Nozzle is used. Two of these nozzles are used alongside each other, to cover maximum area:

- FanTip Nozzle 110Deg spray angle Variable pressure

The Nozzle has the following Characteristics as depicted in the figure.

01. Simple; Non-Air Inducted technology
02. Polyacetal; single piece design
03. Suitable Size

Figure 24 FanTip Nozzle 110Deg spray angle © [18]

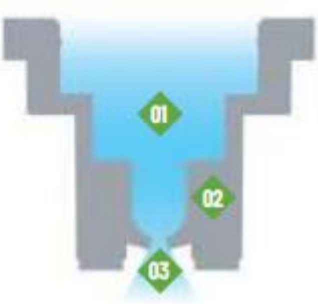
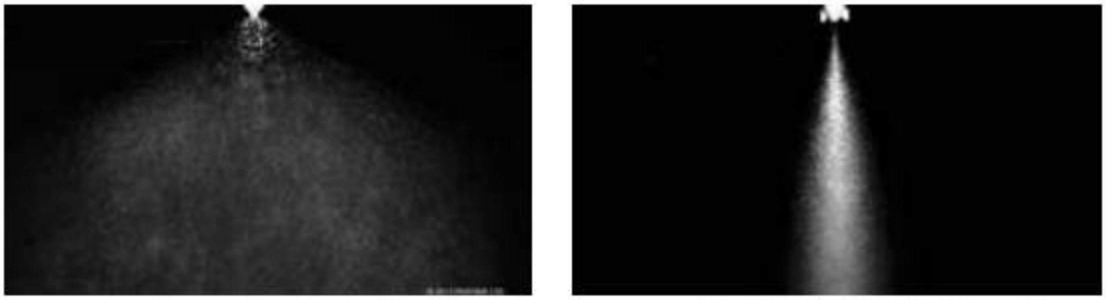


Figure 25 FanTip Nozzle Characteristics © [18]

The Figure below shows how the nozzle sprays in different operating conditions.



Low pressure performance allows for complete pattern formation and even coverage down to 15 psi(1 BAR).

Dense spray pattern of medium to fine droplets provides superior coverage.

Figure 26 Variation of spray angle and flow rate with pressure © [18]

Payload Calculations:

Payload calculations are very important in determining the performance of the UAV as it carries the reverse relation with the time of flight of the drone and hence the minimum the payload is, the better the UAV's performance. The payload calculations are as follows.

Table 6 Payload Calculations

density of water (Kg/m^3)	998
volume of water in sprayer tank (mL)	500
mass of water (Kg)	0.499
mass of tank and Pipes (Kg)	0.08
mass of pump (Kg)	0.5
mass of nozzle (Kg)	0.25
Spraying System mass (Payload) (Kg)	**1.329**
frame weight (Kg)	0.478
motors	1.14
other accessories	0.3
Drone Mass (Kg)	**1.918**
total mass (Kg)	**3.247**

The following table shows the mass of drones and other accessories included in it.

So according to the mass the required thrust is:

Table 7 Required Thrust according to mass.

thrust to weight ratio	4:1
total required thrust (Kg)	12.988

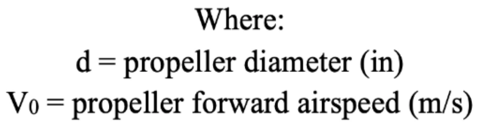
Total required thrust per motor (Kg)	2.164667
Required Thrust for Payload (Kg)	5.316
Required thrust per motor for Payload (Kg)	0.886

Now provided thrust of drone is calculated as:

According to the propeller diameter, pitch, and RPM:[19]

According to [19] the following function is derived for thrust per motor.

$$Thrust \ = \ 4.392x10^{-8} \ \cdot RPM \ \frac{d^{3.5}}{\sqrt{pitch}}(4.233x10^{-4} \ \cdot \ RPM \ \cdot \ pitch - V_0)$$



Where:
d = propeller diameter (in)
V_0 = propeller forward airspeed (m/s)

Propeller Pitch = 3.8 in = 0.096 m
Propeller Diameter = 10 in = 0.254 m
RPM = 11000
Propeller Forward Air Speed = 3 m/s

Table 8 Thrust Calculation per motor.

thrust for single propeller (N)	11.516
thrust for HexaCopter (N)	69.09597
lifting capacity (Kg)	7.043422
for each propeller (Kg)	1.173904

By keeping factor of safety of 2 we have lifting capacity = 3.52 Kg

According to motor power and propeller efficiency:

The thrust force of the selected electric motor and propeller pairs was calculated with the following formula.

$$\boldsymbol{T = [2\pi(\eta * P)^2 \, r^2 \, \rho]^{\frac{1}{3}}}$$

Here.

η: $propeller\ efficiency\ (between\ 0.7 - 0.9), preferred\ :\ 0.7$
P: $electric\ motor\ power\ (Watt),$
$Voltage\ applied\ =\ 12V$
$Electric\ motor\ power\ =\ 300\ W$
$Motor\ Power\ efficiency\ =\ (0.7 - 0.9), Preferred\ 0.7$
r: $radius\ of\ propellers\ (m), =\ 12.7\ cm\ =\ 0.127\ m$
ρ: $air\ density\ (1.22\ kg/m3)$

Table 9 Thrust Calculation per motor.

calculated thrust from single motor (N)	12.28778
thrust for 6 motors (N)	73.72668
lifting capacity of motors (Kg)	7.515462
lifting capacity per motor (Kg)	1.252577

By keeping factor of safety of 2 we have lifting capacity = 3.75 Kg

Flight Control Parameters and Their Setup

Flight control is an important step in initializing the flight.

- **Complete the wiring of UAV**. Connect all the wirings and the connection accordingly. The following **Error! Reference source not found.** from the px4 documentation is very helpful in determining the connections.

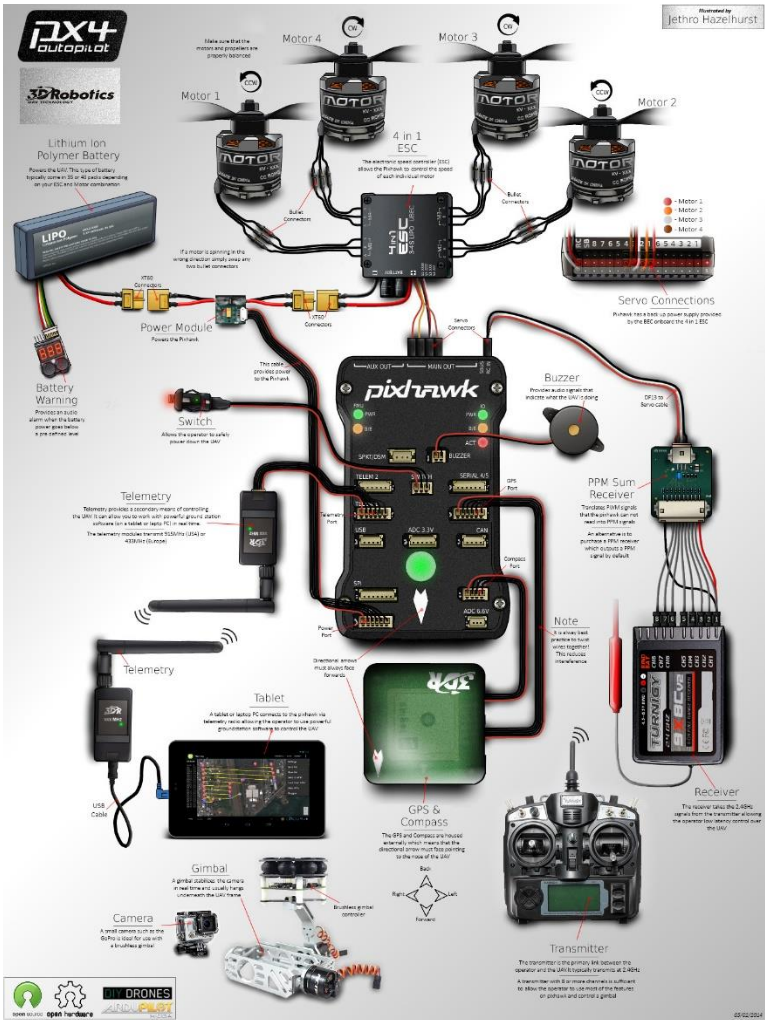


Figure 27 Connection for Pixhawk flight controller

- **Connect the Pixhawk**: Connect the Pixhawk flight controller to your computer using a USB cable. Ensure that the Pixhawk is powered and detected by your computer.
- **Install QGroundControl**: Download and install QGroundControl,
- **Connect QGroundControl to the Pixhawk:** Launch QGroundControl and establish a connection with the Pixhawk. In QGroundControl, select the appropriate connection type (USB, Wi-Fi, or telemetry radio) and ensure it is connected to the correct serial port.
- **Calibrate Sensors**: Perform sensor calibration to ensure accurate readings and reliable flight control. QGroundControl provides a guided calibration process for calibrating the compass, accelerometer, gyroscope, and other sensors.
- **Configure Flight Modes:** Set up flight modes to define different behaviors and actions for your Hexacopter. QGroundControl allows you to customize flight modes based on your preferences and mission requirements. Common modes include Stabilize, Altitude Hold, Position Hold, Auto, and Return to Launch (RTL).
- **Set Radio Control Input:** Configure your radio control system to map specific controls to corresponding flight modes and functions in QGroundControl. This step ensures that

your transmitter and receiver are correctly bound and aligned with the flight control commands.

- **Configure Safety Parameters**: Adjust safety parameters such as geofencing limits, maximum altitude, and flight boundaries to ensure safe operation of your Hexacopter. These settings help prevent the Hexacopter from flying beyond defined boundaries or altitudes.
- **Perform Initial Tests and Setup**: Conduct initial tests in a controlled environment to verify the flight control inputs and outputs. Verify that the motors, servos, and other components are responding correctly to the commands from the Pixhawk. Adjust any necessary settings or configurations based on these tests.
- **Fly in Manual and Autonomous Modes:** Once you have completed the setup and tests, you can fly the Hexacopter using QGroundControl in both manual and autonomous modes. In manual mode, you have direct control over the aircraft, while in autonomous mode, you can define missions and waypoints for the Hexacopter to follow.

CHAPTER 4: RESULTS AND DISCUSSIONS

The results of each delivery and section are discussed individually.

The Computer Vision model

The project aims to develop a classifier for crop images to identify and classify pest damage accurately. By training the classifier using a dataset of crop images with varying levels of pest damage, it can effectively categorize the severity of the damage. This classification can help farmers and agricultural professionals make informed decisions for pest management and crop protection, ultimately optimizing crop yield and minimizing losses due to pest damage.

Evaluation Criteria

The evaluation of the trained model is based upon the following criteria.

- Accuracy
- Loss:
- F1 Score
- Precision:
- Recall

The reason behind these criteria is explained.

- **Accuracy**: Accuracy is crucial in crop pesticide detection as it measures the overall correctness of the model's predictions. A high accuracy indicates the model's ability to correctly classify images as pesticide-free or pesticide-affected, enabling accurate decision-making for pest management strategies.
- **Loss:** Loss functions in crop pesticide detection quantify the discrepancy between predicted and actual pesticide labels, aiding in the optimization of model parameters. Minimizing the loss helps the model learn patterns and features related to pesticide presence, improving the accuracy of pesticide detection.
- **F1 Score**: The F1 score is valuable in crop pesticide detection as it balances precision and recall, providing a comprehensive evaluation of the model's performance. It ensures that both the detection of pesticide-affected crops (recall) and the avoidance of false positives (precision) are considered, enabling more reliable pesticide detection systems.
- **Precision:** Precision in crop pesticide detection measures the proportion of correctly identified pesticide-affected crops out of all crops predicted as pesticide-affected. High precision is crucial as it ensures that the model accurately identifies

pesticide-affected crops, preventing unnecessary pesticide application and minimizing potential crop damage.

- **Recall:** Recall, also known as sensitivity, in crop pesticide detection measures the proportion of correctly identified pesticide-affected crops out of all actual pesticide-affected crops. High recall is essential as it ensures that the model captures as many instances of pesticide-affected crops as possible, reducing the risk of missed detections and allowing timely pest management interventions.

Results Of the Deep Learning Model

Using the Evaluation criteria, the following results were achieved for each criterion.

Table 10 Results of the Deep Learning model

Evaluation Criteria	Value	Percentage
Accuracy	0.815	81.5%
Loss	0.197	19.7%
F1 Score	0.854	85.4%
Precision	0.866	86.6%
Recall	0.843	84.3%

The Accuracy of 81% for a data of 1000 images is fairly acceptable considering a low train data set and with a considerable biasness. The confusion matrix for the trained data set is shown.

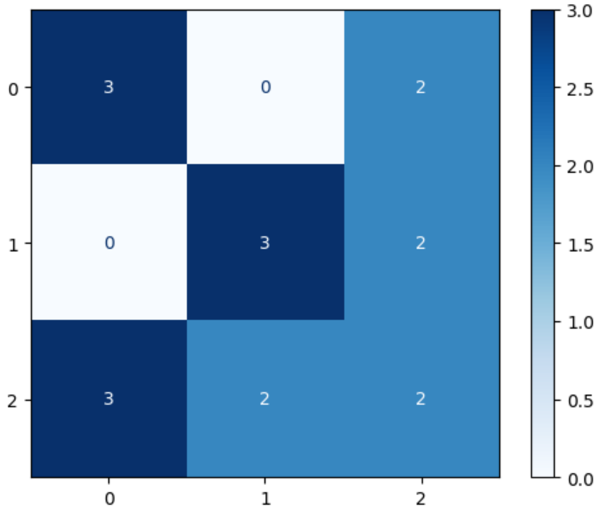


Figure 28 Confusion matrix

Similarly, you can observe the plots for accuracy and loss for the data set.

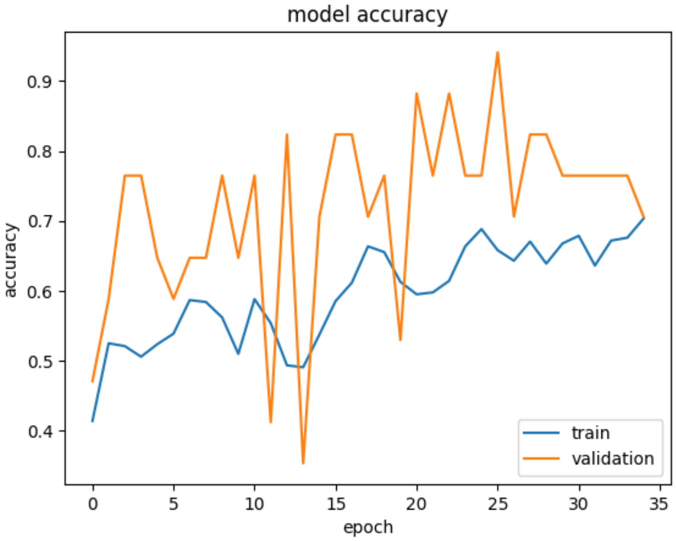


Figure 29 modal accuracy of the trained model

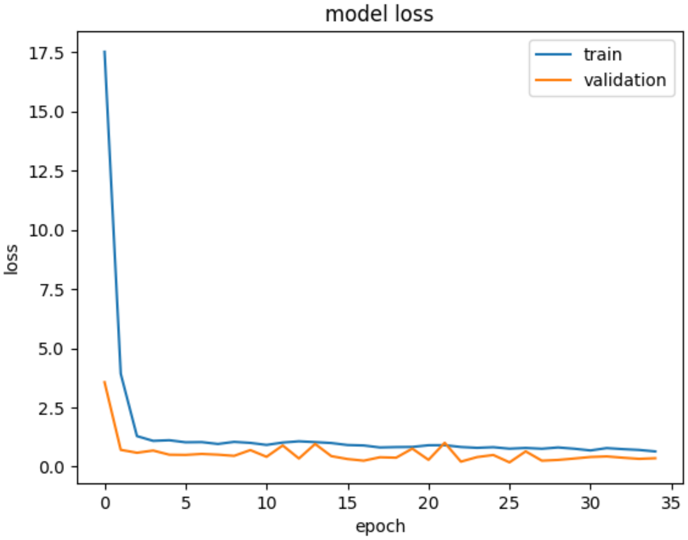


Figure 30 model loss of the trained model

Discussions

The accuracy of 81% is justified and is enough to categorize the crops based on the pest requirement. As evident from the model accuracy plot and model loss plot, the accuracy is improving as epoch are increasing. However, the low accuracy can be justified due to:

- **Complexity of the Task**: If the task of classifying crop images based on pest damage is inherently challenging and involves subtle visual differences between healthy and damaged crops, achieving an accuracy of 81% can be considered reasonable. It indicates that the model is able to capture a significant portion of the distinguishing features and patterns related to pest damage.
- **Class Imbalance**: It is important to examine the class distribution in the dataset. If the dataset is imbalanced, meaning that one class (e.g., healthy crops) dominates the majority of the samples, the accuracy may not provide a complete picture. In such cases, accuracy alone can be misleading, and other evaluation metrics like precision, recall, or F1 score should be considered to assess the model's performance.
- **Contextual Considerations**: The significance of accuracy and loss should be assessed in the context of the specific application. For example, if the classifier is

intended to assist farmers in identifying potential pest damage for early intervention, an accuracy of 81% can still provide valuable insights and aid decision-making, even if it is not perfect.

- **Comparative Analysis**: It is beneficial to compare the achieved accuracy and loss with the performance of other models or existing approaches on the same dataset or similar tasks. If the trained classifier outperforms previous methods or achieves results in line with the state of the art, it further justifies the accuracy of 81% and loss of 19%.

Design evolution of Sprayer

The design of the sprayer tank evolved during the design process. The calculations provided in section of the Payload calculation are accurate and provide an overview of the drone's payload capacity. However, throughout the process, it was understood that the sprayer tank performs better if the payload is further decreased, and a tank of lower mass is used. Therefore, instead of using the 3D printed Tank as shown in Figure 32 the sprayer tank will lower payload is assembled as shown in Figure 31.

Figure 31 Final Sprayer Tank and Single Nozzle arrangement

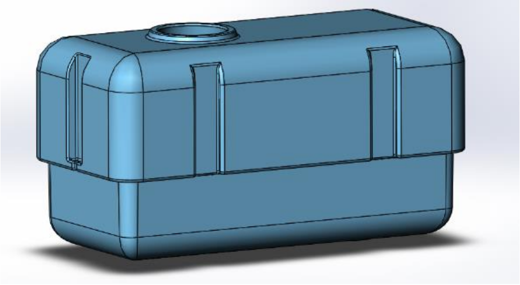


Figure 32 3D printed storage Tank

CFD Analysis of Nozzle

Why CFD Simulation

CFD analysis is an invaluable tool for comprehensively studying the flow physics of a sprayer nozzle. Firstly, it offers a cost-effective and efficient alternative to physical experiments. Conducting experiments can be expensive, time-consuming, and limited in terms of the number of scenarios that can be tested. CFD analysis allows for the exploration of various design configurations, operational parameters, and environmental conditions virtually, enabling engineers to rapidly evaluate multiple scenarios without the need for costly prototypes. This accelerates the design process and provides valuable insights into the flow behaviour of the sprayer nozzle.

Secondly, CFD analysis provides a detailed understanding of the complex flow phenomena involved in sprayer nozzle operation. It allows for the simulation of turbulent flows, multiphase interactions, and intricate geometries, which are challenging to capture through experimental techniques alone. By analysing the velocity variations, pressure effects, and spray patterns within the nozzle, CFD analysis enables engineers to gain insights into the flow physics and identify potential issues such as recirculation zones, regions of high turbulence, or uneven spray distribution. This information is crucial for optimizing the sprayer's performance, improving spray coverage, and achieving desired outcomes in various applications.

In summary, CFD analysis is advantageous for analysing the flow physics of a sprayer nozzle due to its cost-effectiveness, ability to explore multiple scenarios, and detailed understanding of complex flow phenomena. By utilizing CFD, engineers can optimize the sprayer design, evaluate various operational parameters, and gain valuable insights into the velocity variations and pressure effects that impact spray performance. Ultimately, CFD analysis enhances the design process, accelerates development, and leads to improved sprayer nozzle performance and efficiency.

Objective of Simulation

The primary aim of the Computational Fluid Dynamics (CFD) Analysis is to examine the underlying flow phenomena and the changes in velocity associated with fluctuations in pressure. Ultimately, our goal is to corroborate the findings obtained from CFD analysis by comparing them with experimental outcomes. The mass flow at the nozzle outlet will be compared and validated to the experimental flow rates.

Nozzle Geometry

The Nozzle Geometry is generated using the parameters of the following Nozzle.

- Fan Flat Variable Pressure 110 degrees

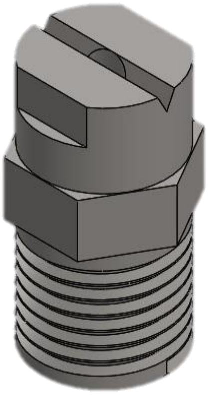


Figure 33 3D model of the nozzle

Using the Nozzle Geometry, the Flow Domain in created in Design modeller. Using the dimensions from the Nozzle Geometry, the flow domain in generated

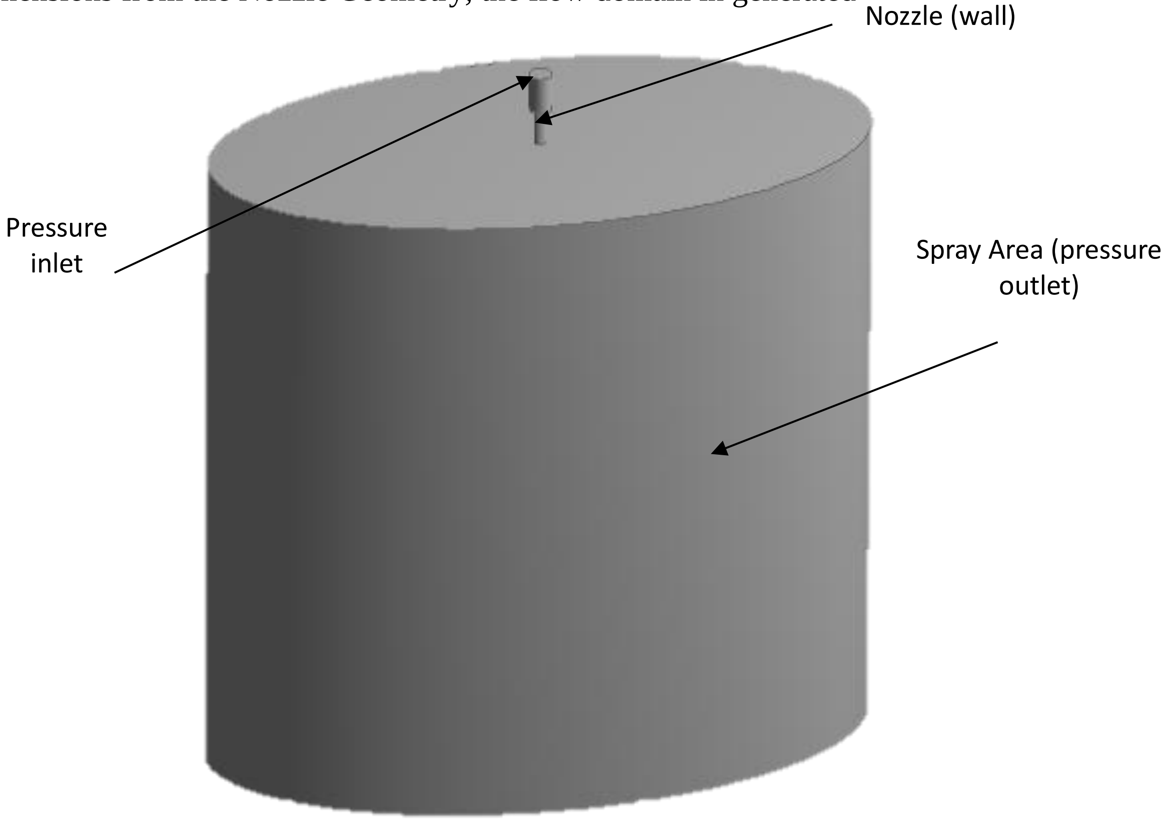


Figure 34 Computational Domain

Meshing

A tetrahedra mesh was generated with high element density at the nozzle efflux. The mesh properties are discussed below.

Table 11 Meshing Details

Element Type	Tetrahedral Dominated
Number of elements	71611
Number of Nodes	14389
Target y+ value	75

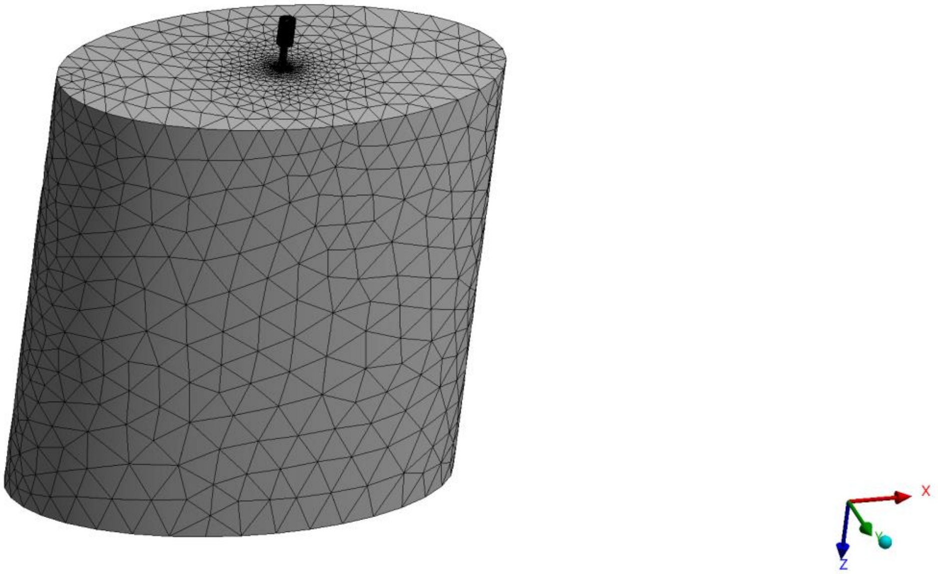


Figure 35 3D Mesh with 71000 elements

Case setup

The Case setup is performed on the ANSYS Fluent. The objective is to define a stable simulation scheme which can deliver efficient results and shows better convergence. The following scheme is developed.

Table 12 Case Setup in fluent

Time dependency	Steady
Turbulence model	k-w-SST
Pressure Velocity Coupling	Coupled Scheme

Inlet	Pressure inlet
Outlet	Pressure outlet

Boundary Conditions

Inlet	Pressure Varies form 80 psi to 150 psi
Outlet	Steady Gauge pressure of atmospheric conditions

Results

The results were objectively justified and accurate. The velocity variation is shown below. These velocity contours are displayed on a plane drawn on XZ plane with zero offset.

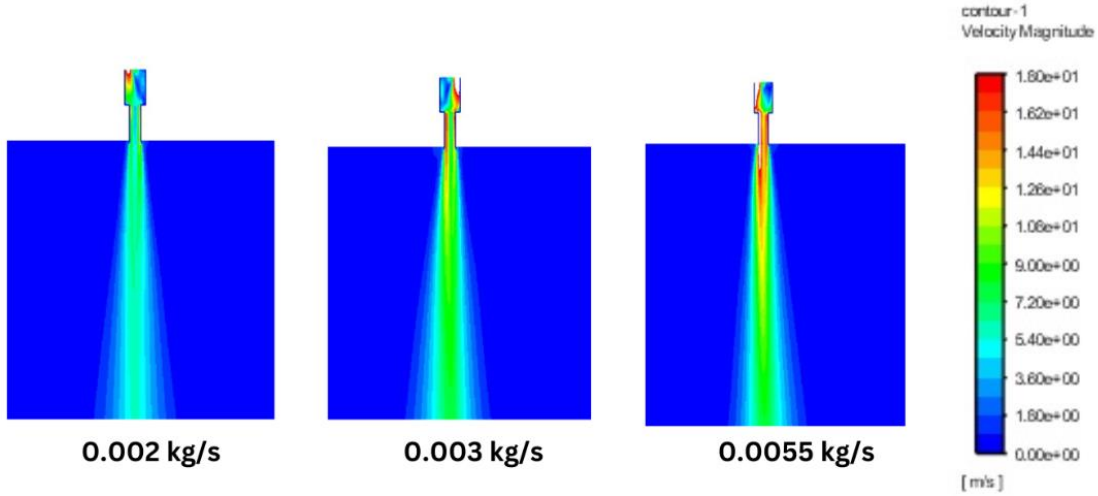


Figure 36 Velocity at nozzle outlet

We can observe the effect of increasing the inlet pressure as the velocity increases. The flow inside the nozzle is highly pressurized and highly turbulent. This high pressure creates enough thrust for the flow to create an angle at the outlet and a significant mass flow.

The mass flow rates at different pressures are measured at the nozzle outlet.

Table 13 Mass flow rate at the nozzle outlet using CFD.

Inlet Pressure	Mass flow rate
80 psi	0.002 kg/s
110 psi	0.003 kg/s

150 psi	0.055 kg/s

The Variable Spray Mechanism

The UAV’s prim objective is spray at different flow rates according to the field requirement. Therefore, it is necessary to analyze the flow pattern of the spray nozzle at different pressures from the pump.

Evaluation criteria

The evaluation criteria are the following.

- The pump is working and able to spray under the same conditions when the UAV will be flying.
- The pump is able to spray the at variable speeds. These variable pressures correspond to change in mass flow rates.
- These mass flow rates are comparable to the mass flow rates of the CFD analysis.

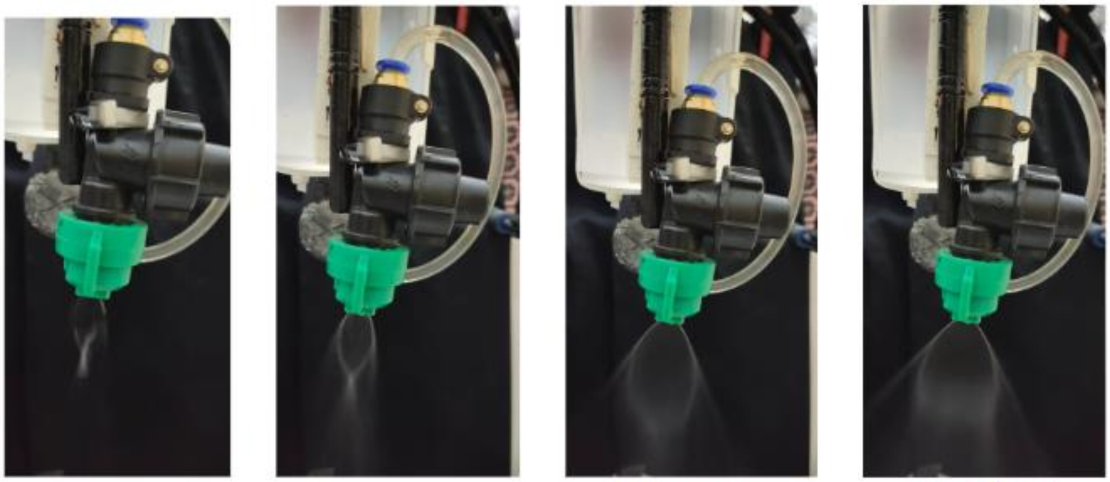
Results

The specified pressures at which the system will spray against the classified crop damage is shown below.

Table 14 Mass flow rate Comparison. CFD vs Practical

Crop Damage	Pressure	Mass flow outlet (CFD)	Mass flow outlet (practical)
0-25%	50 psi	~0 kg/s	~0 kg/s
25-50%	80 psi	0.002 kg/s	0.0015 kg/s
50-75%	110 psi	0.003 kg/s	0.0025 kg/s
75-100%	150 psi	0.0055 kg/s	0.005 kg/s

The figure below shows the specific pressure variation and the resulting mass flow rate. The images are recorded while the drone is armed, and the propellers are removed. This is to ensure personal safety and prevention of an injury.



`0 kg/s

0.0015 kg/s

0.0025 kg/s

0.005 kg/s

Figure 37 Visual representation of variable rate spray

Discussions

The sprayer is able to spray at different speeds corresponding to the signal it receives from the brushed ESC. The path through which the pump is spraying is explained below.

When comparing the results of practical and the CFD analysis, we observe the results are comparable and the error can be accounted for practical losses of in environment pressures.

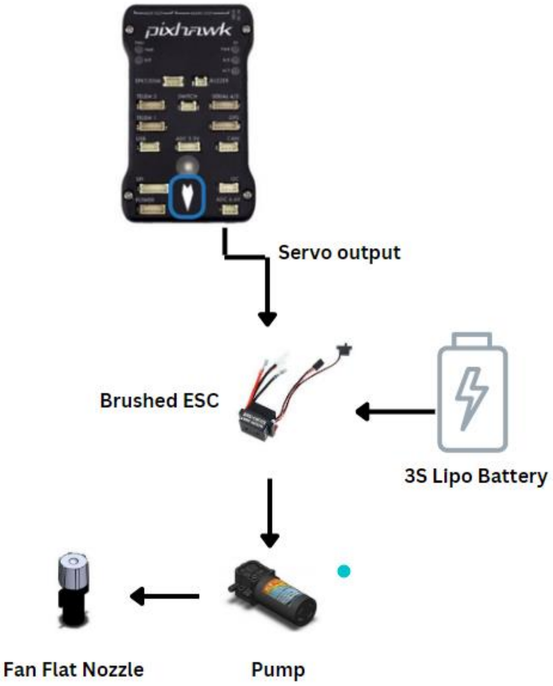


Figure 38 Pumping Mechanism using PWM servo from Pixhawk.

SITL to Virtually Simulate UAV

What is SITL(Software in the loop)

Software-in-the-Loop (SITL) is a simulation technique used in UAV development to test and validate the software components of the system. It involves running the UAV's software on a computer or hardware platform while simulating the other physical hardware components, such as sensors, actuators, and the flight controller, in software. SITL offers several advantages for UAV simulation. Firstly, it is cost-effective as it eliminates the need for expensive physical hardware. Developers can test and validate their software without the requirement of actual UAVs, which can be costly to acquire and maintain. This enables more frequent testing and iteration, resulting in faster development cycles and reduced overall costs.

Secondly, SITL provides a safe testing environment. Simulating UAV hardware in software eliminates the risk of damaging physical assets or causing harm to personnel during testing. It allows developers to identify and resolve potential issues and failures in a controlled environment before deploying the software on an actual UAV. By mitigating risks, SITL helps ensure the safety and reliability of the UAV system. Furthermore, SITL simulations can be easily scaled up to test swarm behaviour and coordination among multiple UAVs, without the need for an equal number of physical vehicles. This scalability enables developers to validate complex scenarios and communication protocols, facilitating the development of sophisticated UAV systems. In conclusion, SITL is a valuable tool for UAV simulation, offering cost-effectiveness, safety, scalability, and the ability to iterate quickly and test different software configurations and algorithms.

Past experiences

Previously many researchers have used this technique for testing and validation of UAV flights. Qais H. et al have validated the results for quadcopter [25]. Centralized swarming UAV for collaborative missions have been using ROS and SITL techniques [26]. However Viridiana et al. have used the technique for the SITL simulation of sprayer drones [27][27]. This shows how effective this technique can be when used effectively.

Why using in this project/ Objectives of using SITL

Our objective for using Software in the loop in our simulation is due to following reasons.

- **System Validation:** Validate the functionality and performance of your UAV system using SITL simulation. Ensure that the software components, such as the flight control algorithms, sensor integration, and actuator control, are working correctly and producing the desired behaviour in a simulated environment.
- **Algorithm Testing:** Test and evaluate different control algorithms and strategies for your UAV. Implement and simulate various control algorithms, such as PID control, adaptive control, or model predictive control, and assess their performance

in terms of stability, responsiveness, and accuracy. Compare and analyse the results to determine the most suitable control algorithm for your UAV.

- **Mission Planning and Execution:** Develop and test mission planning and execution capabilities for your UAV in the SITL simulation environment. Design and simulate mission scenarios, such as autonomous take-off and landing, waypoint navigation, obstacle avoidance, and payload delivery, to ensure that your UAV can successfully perform these tasks in a virtual environment.

Approach

Our main objective is to assemble a UAV in a virtual environment to simulate its physics. Following steps are followed:

1) Setting up the Simulation Environment:
    - Installing ROS melodic (Robot Operating System) and Gazebo, ensuring compatibility between the versions.
    - Setting up a ROS workspace to organize your project files and packages.
    - Create a ROS package specifically for your UAV simulation.
2) Modelling the UAV:
    - Using the build in 3D model for the UAV
    - Importing the UAV model into Gazebo, specifying its physical properties such as mass, inertia, and dimensions.

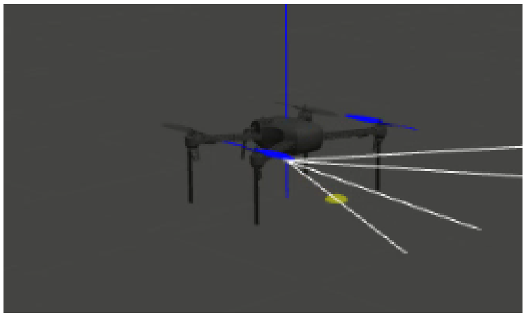
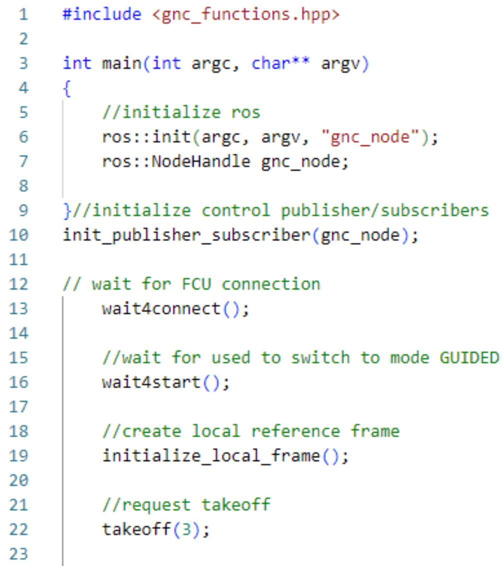


Figure 39 UAV Model in Gazebo

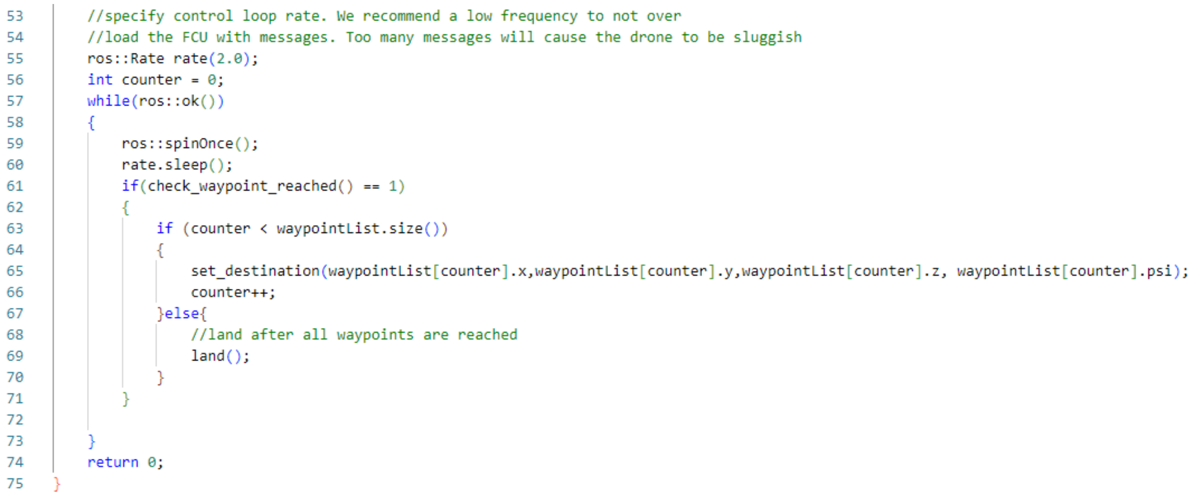
3) Implementing Flight Control:
    - Develop the flight control algorithms for the UAV using ROS. This includes attitude and position control, stabilization, and navigation.
    - Configure the flight control parameters and tuning for optimal performance in the simulation.
    - Integrate the flight control algorithms with the simulated UAV model in Gazebo.

- The following C++ Code describes the mission planning and waypoints establishment.



```
#include <gnc_functions.hpp>

int main(int argc, char** argv)
{
    //initialize ros
    ros::init(argc, argv, "gnc_node");
    ros::NodeHandle gnc_node;

}//initialize control publisher/subscribers
init_publisher_subscriber(gnc_node);

// wait for FCU connection
    wait4connect();

    //wait for used to switch to mode GUIDED
    wait4start();

    //create local reference frame
    initialize_local_frame();

    //request takeoff
    takeoff(3);

```

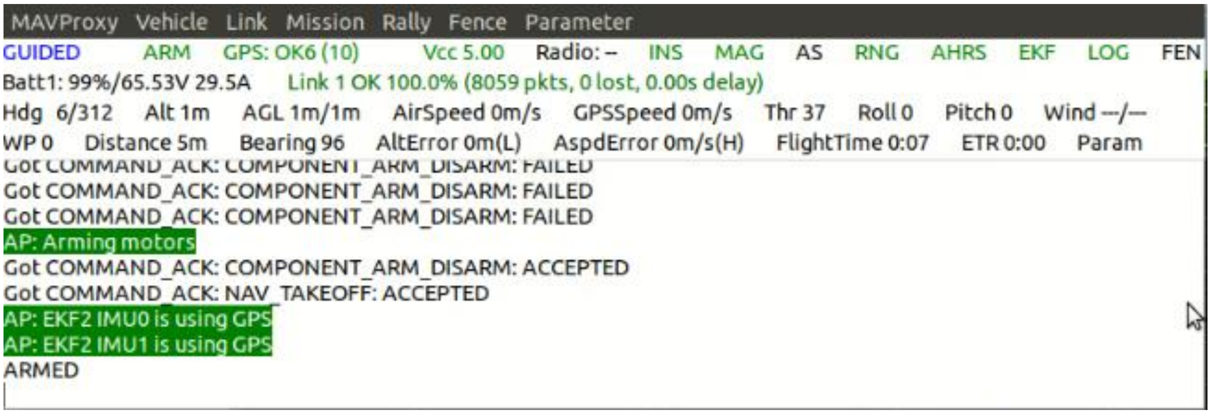
```
    //specify some waypoints
    std::vector<gnc_api_waypoint> waypointList;
    gnc_api_waypoint nextWayPoint;
    nextWayPoint.x = 0;
    nextWayPoint.y = 0;
    nextWayPoint.z = 3;
    nextWayPoint.psi = 0;
    waypointList.push_back(nextWayPoint);
    nextWayPoint.x = 5;
    nextWayPoint.y = 0;
    nextWayPoint.z = 3;
    nextWayPoint.psi = -90;
    waypointList.push_back(nextWayPoint);
    nextWayPoint.x = 5;
    nextWayPoint.y = 5;
    nextWayPoint.z = 3;
    nextWayPoint.psi = 0;
    waypointList.push_back(nextWayPoint);
    nextWayPoint.x = 0;
    nextWayPoint.y = 5;
    nextWayPoint.z = 3;
    nextWayPoint.psi = 90;
    waypointList.push_back(nextWayPoint);
    nextWayPoint.x = 0;
    nextWayPoint.y = 0;
    nextWayPoint.z = 3;
    nextWayPoint.psi = 180;
    waypointList.push_back(nextWayPoint);

```



```
    //specify control loop rate. We recommend a low frequency to not over
    //load the FCU with messages. Too many messages will cause the drone to be sluggish
    ros::Rate rate(2.0);
    int counter = 0;
    while(ros::ok())
    {
        ros::spinOnce();
        rate.sleep();
        if(check_waypoint_reached() == 1)
        {
            if (counter < waypointList.size())
            {
                set_destination(waypointList[counter].x,waypointList[counter].y,waypointList[counter].z, waypointList[counter].psi);
                counter++;
            }else{
                //land after all waypoints are reached
                land();
            }
        }

    }
    return 0;
}
```

4) Develop Mission Scenarios:

- Define mission scenarios and objectives for the UAV in the simulation.
- Implement mission planning and execution algorithms using ROS to autonomously control the UAV in the simulated environment.



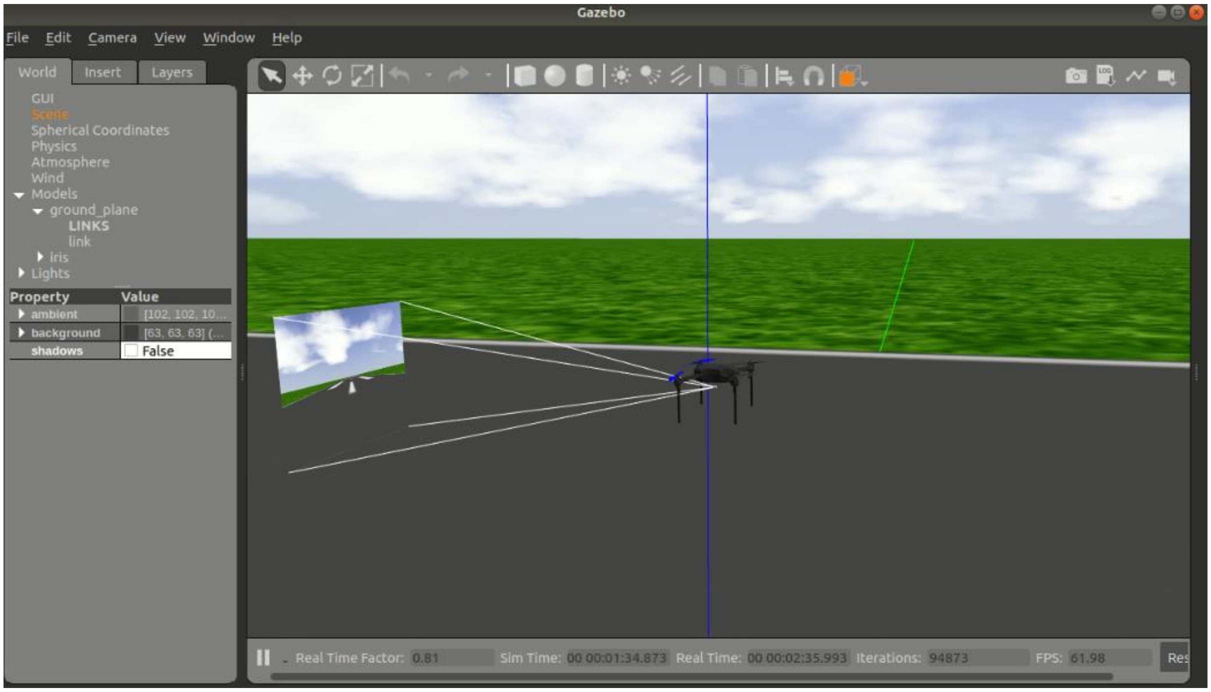
```
GUIDED      ARM    GPS: OK6 (10)      Vcc 5.00    Radio: --    INS    MAG    AS    RNG    AHRS    EKF    LOG    FEN
Batt1: 99%/65.53V 29.5A      Link 1 OK 100.0% (8059 pkts, 0 lost, 0.00s delay)
Hdg 6/312    Alt 1m    AGL 1m/1m    AirSpeed 0m/s    GPSSpeed 0m/s    Thr 37    Roll 0    Pitch 0    Wind ---/---
WP 0    Distance 5m    Bearing 96    AltError 0m(L)    AspdError 0m/s(H)    FlightTime 0:07    ETR 0:00    Param
Got COMMAND_ACK: COMPONENT_ARM_DISARM: FAILED
Got COMMAND_ACK: COMPONENT_ARM_DISARM: FAILED
Got COMMAND_ACK: COMPONENT_ARM_DISARM: FAILED
AP: Arming motors
Got COMMAND_ACK: COMPONENT_ARM_DISARM: ACCEPTED
Got COMMAND_ACK: NAV_TAKEOFF: ACCEPTED
AP: EKF2 IMU0 is using GPS
AP: EKF2 IMU1 is using GPS
ARMED
```

Figure 40 Mavlink Console Showing all the physical Parameters of UAV

Results

The Following figure is a screenshot of the UAV, flying in the mission stated. The mission stated is.

- Arm
- Take-off to height of 5 m
- Move in a square waypoint pattern.
- Return
- Land



Property	Value
ambient	[102, 102, 10...
background	[63, 63, 63] (...
shadows	False

Real Time Factor: 0.81 Sim Time: 00 00:01:34.873 Real Time: 00 00:02:35.993 Iterations: 94873 FPS: 61.98

Figure 41 The UAV in flight during SITL Simulation

The complete video can be viewed here. The QR code of the flight is attached.

The Final Flight

The objective of the FYP is to analyze the variable spray during the flight. After successfully describing the preflight analysis and the safety checks, we are able to demonstrate the variable spray phenomenon during the flight.

The objective of the final flight is to

- Flight of the drone as planned through QgroundControl.
- Spray During the flight

Result

The final video for the flight can be observed here. A screen shot from the flight is attached in the figure. The QR code for the link is attached.

Figure 42 UAV flight without sprayer

Figure 43 UAV flight with sprayer

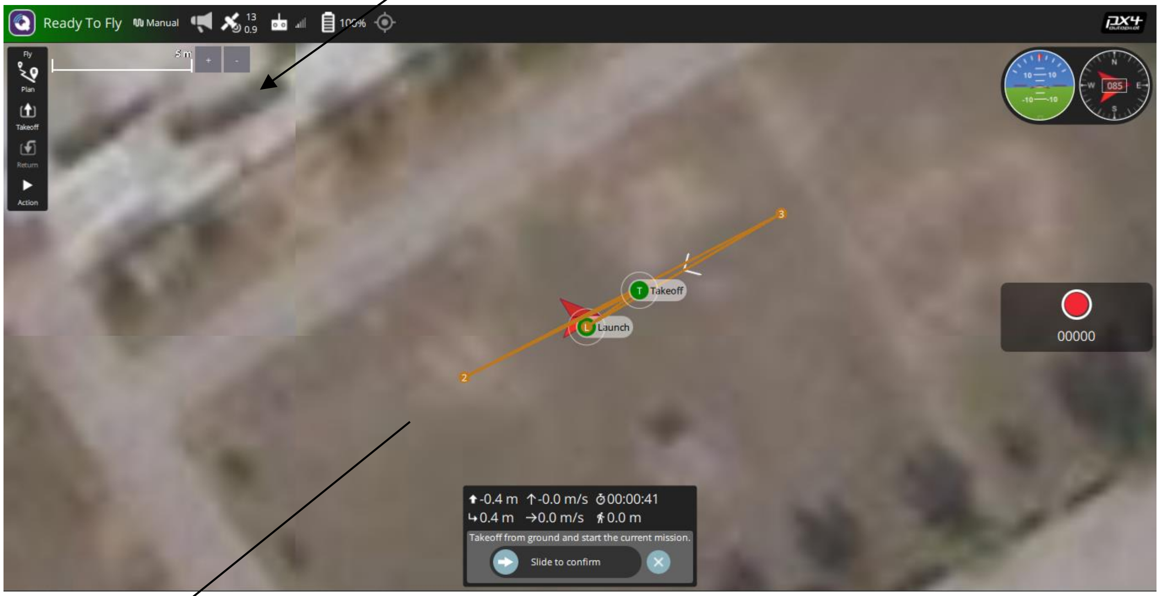
Discussions

The flight test was successful in terms of the fact that the flight with and without the sprayer was almost according to the mission planned. The objective was to fly in the mission planned as follows.

- Arm
- Take-off
- Move to waypoint 2.
- Spray
- Move to waypoint 3.
- Return to Land position Land.

However, the mission was not fully successful as the drone was wobbling due to excessive wind and battery issues.

SMME Backside
Facing MRC



-0.4 m ↑-0.0 m/s 00:00:41
↳0.4 m →0.0 m/s 0.0 m

Takeoff from ground and start the current mission.

SMME backyard

CHAPTER 5: CONCLUSION AND RECOMMENDATION

Summary of the project

This FYP project successfully developed and implemented a variable rate sprayer system for an agriculture drone, specifically focusing on its integration with autonomous flights. The project aimed to optimize crop protection practices by accurately and efficiently applying crop protection products in a precise and targeted manner.

Through the integration of the variable rate sprayer system with autonomous flights, the project achieved significant advancements in agricultural technology. The system incorporated an electronic flow control mechanism that adjusted the flow rate of the sprayer in real-time based on crop density data collected by the drone's sensors.

The FYP project underscored the significance of computational fluid dynamics (CFD) simulations in optimizing the design of the sprayer system, providing valuable insights into airflow patterns and droplet dispersion. Additionally, Software-in-the-Loop (SITL) simulation facilitated thorough testing and validation of autonomous flight control algorithms and the variable rate sprayer system, reducing costs and risks associated with physical equipment testing. By integrating the variable rate sprayer system with autonomous flights, the project effectively addressed agricultural challenges, such as optimizing crop protection, reducing chemical usage, and advancing precision farming.

Impact on Farmer and the agriculture industry

Practically observing, the project can have a great impact on the farmers and largely on the agriculture industry. The following are some of the benefits the farmer can have through our project when implemented on a large scale.

- **Precision Application**: By incorporating the variable rate sprayer system with autonomous flights, the project enables precise and targeted application of crop protection products. The system adjusts the flow rate of the sprayer in real-time based on crop density data, ensuring optimal coverage while minimizing waste.

This precision application minimizes the risk of over-application or under-application, leading to more effective crop protection and improved yields.

- **Efficiency and Time Savings**: The integration of autonomous flights allows for efficient and timely spraying operations. Drones can cover large areas quickly and autonomously, reducing the time and labor required for manual spraying. This saves farmers significant time and resources, enabling them to focus on other important farming tasks.
- **Cost Reduction**: The precise application of crop protection products facilitated by the variable rate sprayer system helps reduce chemical usage. By targeting specific areas with the right amount of chemicals, farmers can minimize costs associated with excess product usage. Additionally, the adoption of autonomous flights and the utilization of simulation techniques, such as SITL, reduce the costs and risks associated with physical equipment testing.

Problems and their remedies

As with any engineering project, there are several issues encountered during the operation of our precision agriculture system. These issues provide an opportunity to dive deep into the core functionalities of the controls, thus giving a better understanding of how things are actually working. Some of these problems are discussed below:

- **Wiring and Connections**: Although the standard procedure is available for connections, the documents at some points remain silent and we ourselves have to establish a correct way of assembling based on our understanding.
- **Issues with the controller**: The controller available to us Pixhawk 2.4.8 had built in error and technically unstable during flights. It was due to the power rails voltage supply issue as it was continuously shown below 5V. However, this can be reduced by using a better version of the controller and using an efficient battery.
- **Battery Charging**: The battery life is very low. This resulted in a net flight time of less than 4 minutes. Therefore, it required frequent charging and care during charging and discharging not to overcharge.
- **Components availability**: although we were largely supported by the SMME labs, but any component which we required is either not available in Pakistan or is available at high cost and mostly arrive after much time.
- **Limited Data for AI Model training**: The limited data of 1000 images in less considering 4 classes and a very fine classifying nature. Therefore, techniques are applied for Data augmentation to increase accuracy as much as possible.

Future Recommendations

- Use a frame and motors with higher payload capacity. This gives the leverage to enhance the spraying capacity to a larger capacity, eventually having a larger spray time. Mostly recommended is using a minimum payload of 6 kg.
- Obtain better Data set for image classification training. Because the larger the data set, the larger the probability that the differences will be captured between the images.
- Devise a mechanism for onboard detection of crop disease. This will enhance the efficiency and effectiveness of the autonomous spraying. This design can be achieved by using the trained model on board and using high GPU device such as Jetson Nano for onboard processing, and a camera. The camera provides an image which when classified on the base of crop disease, will spray accordingly.

Future Problems May Arise During Flight

A detailed discussion was carried out with the industry experts and a number of issues were raised when implementing the project on a large scale. In order to mitigate these issues, we have identified the following recommendations for these issues.

Nozzle Blockage:

Extensive Dust in the fields of Pakistan causes the nozzle to block. To prevent nozzle blockage, we recommend incorporating a filtration system that removes impurities from the solution before it is sprayed. This will reduce the likelihood of blockages and ensure a consistent spray pattern.

Motor Dust Issues:

The same issue with the motors. To address motor dust issues, we recommend sealing the motors and using high-quality bearings to reduce wear and tear. Additionally, regular maintenance checks and cleaning of the motors can prevent dust buildup.

Battery Recharging:

The battery timing is not up to the mark to cover the full agriculture field. It usually drains down before completion of spraying operation. In order to minimize downtime due to battery recharging, we recommend using high-capacity batteries with a long operating time. Additionally, it may be useful to have spare batteries on hand for quick replacements.

Payload vs Flight Time Relation:

Increasing the Payload Reduces the flight time. This creates issues in the case of high liquid taken on board. To optimize the payload vs flight time relation, we recommend conducting a comprehensive analysis of the UAV's capabilities and adjusting the payload accordingly. Additionally, it may be useful to conduct regular tests to monitor the UAV's flight time and payload capacity.

In summary, we recommend incorporating these measures to address potential issues and improve the performance of our precision agriculture system. By implementing these recommendations, we hope to minimize downtime and ensure that the system operates efficiently and effectively.

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APPENDIX I: PESTICIDES USED IN SUGARCANE FIELD

Pesticides are used to control or eliminate pests and diseases in sugarcane crops. They work by killing or repelling pests and diseases or by disrupting their life cycles.

Here are some of the commonly used pesticides for sugarcane crops in Pakistan:

- Imidacloprid: It is a systemic insecticide that is effective against sucking pests such as aphids, whiteflies, and leafhoppers. The attached figure shows a sample product by Bayers Co. which has 20% Imidacloprid.

Figure 44 Bayers Co. which has 20% Imidacloprid

- Chlorpyrifos: It is a broad-spectrum insecticide used to control various pests in sugarcane, including termites, stem borers, and leafhoppers. The following is a product of engro Co. Chlorpyrifos 200 mL product.

Figure 45 product of engro Co. Chlorpyrifos 200 mL

- Cypermethrin: It is a synthetic pyrethroid insecticide used to control pests in sugarcane, including the sugarcane borer and the sugarcane shoot borer. The following is a product of skitter Co. has 10% Cypermethrin.

Figure 46 a product of skitter Co. has 10% Cypermethrin.

All the above-mentioned pesticides are sprayed on sugarcane according to the disease.