Modeling & Simulating a Quadcopter for Precision Agriculture

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***Abstract*—This project focuses on developing and simulating a quadcopter-based system for targeted pesticide spraying and pest detection in precision agriculture. With growing demands for sustainable farming, drones offer high maneuverability and precision, addressing challenges in optimizing resource use and reducing environmental impacts. The dynamic behaviour of the quadcopter was modelled and simulated in MATLAB/Simulink, including flight behaviour, flow analysis, and real-time pest detection using computer vision and machine learning algorithms. By accurately identifying infested areas, the system reduces pesticide usage by up to 30%, minimizing exposure in non-target zones. Remote monitoring capabilities allow farmers to respond quickly to pest outbreaks. This project demonstrates the potential of UAVs for precision farming, from drone design and simulation to autonomous pesticide application, which contributes to sustainable and efficient agricultural practices.**

Keywords: Quadcopter, UAV, Simulation, Pest detection

I. Introduction

Agriculture is crucial in countries like Sri Lanka, because it supplies food and work. However, farmers confront several problems, such as a lack of workers, limited resources, and environmental harm. One of the primary challenges is the overuse of pesticides, which not only wastes chemicals but also affects the environment and human health. Farmers often use significant amounts of pesticides to safeguard their crops, leading to chemical residues on food, soil contamination, and health problems for workers.

Pesticides are chemicals used to kill pests, but excessive usage can be hazardous. Many people, especially youngsters, suffer from pesticide exposure annually. In many countries, farmers spray pesticides manually, which is time-consuming, inefficient, and exposes them to health risks [1].

To solve these difficulties, farmers are adopting precision agriculture—a strategy that uses advanced technology to enhance farming processes. Drones, also known as unmanned aerial vehicles (UAVs), play a crucial role in this paradigm change. These drones can fly over fields, assess crop health, and spray pesticides. By integrating artificial intelligence (AI) and computer vision, drones can detect pests in real time, enabling tailored pesticide treatment. This strategy reduces pesticide usage, minimizes environmental impacts, and promotes sustainable farming[2], [3].

Fig. 1. A Drone applied to agriculture

One popular type of agricultural drone is a quadcopter, defined by its four rotors that provide stability and maneuverability. Quadcopter drones are substantially faster and more efficient than previous approaches, capable of covering huge areas quickly while lowering pesticide consumption by 30%–40% and water usage by up to 90% [1], [2]. By employing AI and computer vision technology, these drones can detect pests in real time and apply pesticides with precision, targeting just damaged regions. This strategy minimises chemical wastage, lowers environmental impact, and promotes the safety of operators by reducing direct exposure to dangerous chemicals [2].

Beyond pesticide application, drones are crucial in precision agriculture, gathering data on soil parameters, monitoring crop health through multi spectral or hyper spectral imaging, and generating precise field maps to optimize planting patterns.

These capabilities help farmers to make informed decisions, leading to better resource management, increased efficiency, and sustainable farming methods.

By solving the limitations of traditional farming methods, agricultural drones, particularly quadcopters, are transforming modern agriculture, resulting in a healthier environment, safer practices, and superior crop management.

II. Literature Review

A. *Applications of drones in agriculture*

In agriculture, drones as UAVs are also on the rise in their pursuit of sustainability, efficiency, and precision. They have plenty of applications that are actively changing the traditional approach toward farming. As noted in [4], [5], drones are outfitted with sophisticated cameras and sensors that can take high-definition images of crops, and with the use of vegetation indices, they are able to locate areas that may be infested by pests, experiencing plant stress, or diseased at an early stage. In [5], UAVs make it possible for targeted spraying of pesticides and fertilisers at the right place, in the right quantity, and at the right time, thus minimising the use of chemicals. This ensures effective use of resources. In [6], [7], UAVs allow for precision spraying of pesticides and fertilisers, ensuring that the right amount is applied in the right place, which reduces chemical use. This ensures resources are utilised most effectively.

Drones can carry out in-depth field and soil analysis, providing information on moisture content and fertility [8]. This information helps improve fertilization and irrigation techniques. Drones help in effective water management by tracking water levels and distribution, which is essential for preserving water supplies and guaranteeing ideal agricultural growth [9]. By monitoring cows, UAVs can provide valuable information about their behavior and health, which can enhance productivity and management techniques. The use of drones integrated with AI, big data, and IoT is becoming increasingly prevalent to enhance the capacity for data collection and analysis that drones have [10].

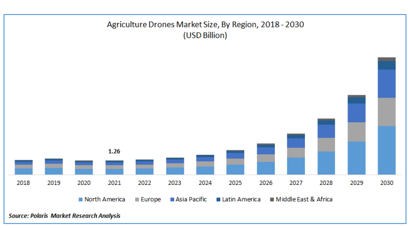

Fig. 2. Agriculture Drones Market Share [11]

Advanced technology and demand for sustainable farming solutions are some of the reasons the agricultural drone market is growing at such a fast rate [9]. Realizing the full potential of drones in agriculture, on the other hand, would require small-scale farmers to be technologically savvy and overcome high initial costs, strict regulations, and specialized skills. Although drones are transforming agriculture and bringing better ways of managing crops and resources, it appears that costs and regulatory issues have to be resolved first for them to be used on a wide scale.

B. *Pesticide spraying techniques*

UAV technology in agriculture can be fully effective only if pesticide spraying systems address issues like drift and environmental impact. Inconsistent droplet size and changing weather conditions often reduce spray accuracy, requiring adaptive systems that adjust in real-time [12], [13].

New techniques, like variable-rate and electrostatic spraying, improve precision by reducing drift and optimizing deposition. Using advanced control systems and spray adjuvants also helps minimise pesticide use while targeting crops more effectively [14]. Despite challenges, these advancements promise more efficient and accurate pest control [15].

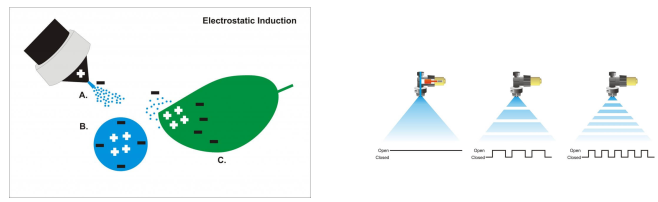

Fig. 3. Variable-rate and Electrostatic spraying

C. *AI and computer vision in pest detection*

AI and computer vision are revolutionizing agriculture by detecting pests accurately, automating tasks, and optimizing resources. Because deep-learning models, especially CNNs, can process large-size data with high accuracy, these have become very popular in the identification of pests. According to [16], some of the models that have been used in identifying crop pests include YOLO and its variants: YOLOv3, YOLOv4, and YOLOv8, with great mAP ratings. These networks can identify and classify the pests in real-time, which is important for timely response in the management of the pest. Coupled with the integration of AI with edge computing and IoT, some development of intelligent systems for agriculture has been found possible [17]. These devices allow real-time pest identification and environmental data analysis using environmental sensors and mobile applications, improving the accuracy of pest management methods [18].

In resource-constrained contexts, low-power embedded systems with neural accelerators allow for continuous pest monitoring and detection while extending their operational life through energy harvesting. Despite these developments, several challenges still exist that prevent the complete infiltration of AI and computer vision into pest detection [19]. Increased accuracy in detection requires more complicated algorithms due to factors like variations in lighting, object occlusion, big datasets, and similarities between pest and non-pest species

[20]. IoT sensor deployment inefficiently and computational resource demand limit scalability.

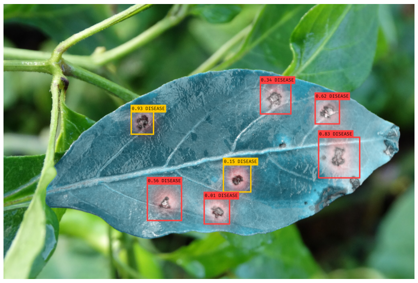

Fig. 4. Computer Vision for Monitoring and Enhancing Plant [21]

D. Case studies of precision agriculture using drones

Drones play a significant part in precision agriculture by giving useful data on vegetation, soil moisture, and crop health, helping increase sustainability and productivity. Equipped with optical, thermal, and multispectral cameras, they create detailed maps that assist farmers in managing crops and resources [22].

By sensing changes in leaf reflectance, drones enable early identification of pest outbreaks, allowing precise pesticide treatment or the release of natural predators [23]. With improvements in robotics, AI, and remote sensing, drones provide speedy and economical options for monitoring and maintaining crops. However, obstacles including high costs, connection with existing systems, and pilot training remain. Despite this, drones transform agriculture with efficient and accurate solutions [7].

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III. Problem Statement

Agriculture is a significant aspect of Sri Lanka's economy. However, there are various challenges in the agriculture sector that need to be addressed, especially when it comes to managing pests and utilising pesticides.Farmers often use a lot of insecticides to manage pests. While pesticides are essential in safeguarding crops, even employing too many can be hazardous. Overusing pesticides can affect the ecosystem by polluting the soil and water, and it can also cause health concerns for farmers who handle these chemicals [1].

The World Health Organization (WHO) claims that many individuals get sick each year from exposure to pesticides. Another challenge in agriculture is the shortage of workers. Spraying pesticides manually takes a lot of time and requires many workers. Since there are not enough workers available, this process is slow and inefficient. Additionally, spraying by hand is also not as accurate, resulting in wastage of pesticides and increased costs for farmers.

Using too many pesticides in farming harms the environment. Pesticides not only kill pests but can also harm other important creatures like bees and pollinators. They can mix with water and cause pollution. As a result, the balance of nature is disrupted, making farming less sustainable in the long term [24].

Currently, pest detection in agriculture is not particularly accurate. Farmers normally monitor crops by hand, but this can miss pests or identify them too late, which means farmers use pesticides in areas where they are not needed. This results in more insecticide being used than necessary, leading to wasted chemicals and increased harm to the environment [3].

Using drones, also known as Unmanned Aerial Vehicles (UAVs), can assist in tackling these challenges. They employ sensors and AI to detect pests more quickly and precisely. These drones can spray pesticides only where they are needed, decreasing wastage and the amount of chemicals consumed. This will not only save money for farmers but also safeguard the environment and reduce health hazards.This project will assist in alleviating the challenges of pesticide misuse, labor shortages, and environmental harm by providing a smarter and more sustainable way to manage pests in agriculture [25].

IV. System Overview

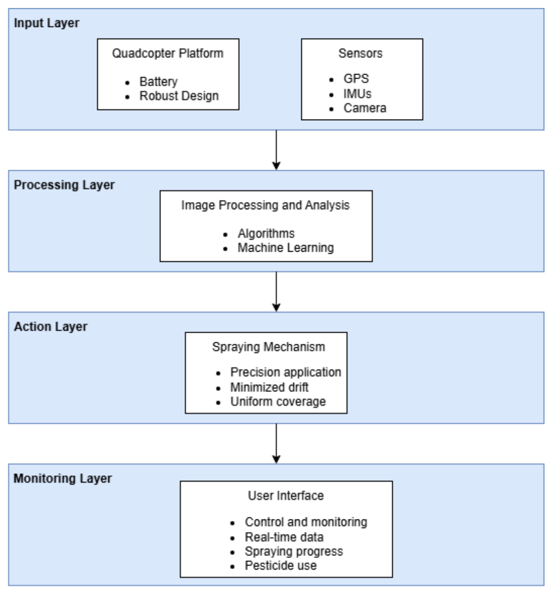

Fig. 5. Layeres of Precision Agriculture Quadcopter

Traditional methods of pesticide application, such as manual spraying or the use of big, manned aircraft, often lead to inefficiencies, increased costs, and environmental harm. These approaches typically result in over-application, producing wasting of chemicals, increased expenses for farmers, and severe consequences on human health and ecosystems.

This study intends to overcome these difficulties by building a quadcopter-based system for precision agriculture.

The method begins with data collecting and field mapping to understand the geography, crop distribution, and field layout. This data can be gathered via remote sensing techniques such as satellite imaging or aerial photography. The next step is to process and analyse this data to develop precise maps of the agricultural area, which will be used to plan the UAV flight paths. Accurate field mapping is critical to optimizing UAV flight routes for efficient data collection, insect identification, and targeted spraying.

The quadcopter will then be programmed to fly over these regions and spray insecticide only where necessary. This will help reduce the quantity of pesticide needed, saving farmers money and lowering their environmental impact. Additionally, the quadcopter will be equipped with a camera to capture photographs of the crops. These photos can then be used to identify pests and illnesses.

The project's ultimate goal is to produce a practical, cost-effective, and ecologically friendly solution that benefits both farmers and the environment. This new method to precision agriculture has the potential to greatly boost crop yields, cut pesticide use, and contribute to a more sustainable future for agriculture.

V. System Design

Building upon the system overview, this section details the design considerations for each of the quadcopter's key components. The design will ensure functionality, adaptability, and efficiency in navigating farms and executing targeted pesticide applications.

A. ***Quadcopter Platform***

1) Frame: The quadcopter includes a sturdy yet lightweight frame built for durability and portability. Carbon fibre, recognised for its strength and low weight, is used to construct the arms, bottom, and top plates, ensuring the frame can survive field conditions while holding the spraying and detection modules. The design allows for simple assembly, with sufficient space for mounting the battery, motor, and payload components.

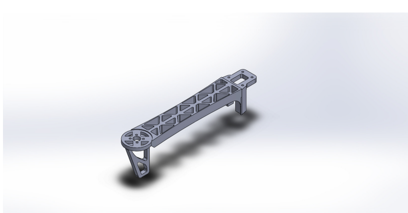

Fig. 6. Quadcopter arm

2) Motors: The quadcopter is powered by four brushless DC motors, chosen for their efficiency, reliability, and quiet operation—perfect for precision agricultural tasks. These motors provide the necessary thrust to carry the drone's payload, including the pesticide tank, spraying system, and detection modules. They're carefully selected to match the drone's weight and performance needs, ensuring smooth and stable flight.

Each motor is securely mounted on the drone's arms, which are designed to minimise vibrations and keep the quadcopter steady during operation. They work seamlessly with electronic speed controllers (ESCs), which precisely adjust the motor speed for quick and accurate movement, even in tough conditions.

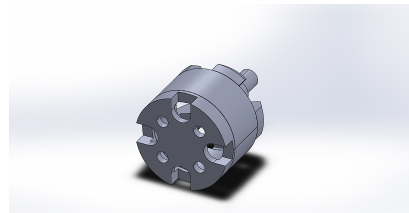

Fig. 7. Quadcopter motor

3) Propellers: The motors are paired with lightweight, carbon-reinforced propellers. These propellers are strong and durable, designed to maximize thrust while remaining energy-efficient to help extend flight time. Their aerodynamic shape reduces drag and noise, making the drone operate more smoothly.

The propeller size and pitch are carefully chosen to match the drone's load and performance requirements. If needed, they can be swapped or upgraded to handle specific obstacles like high winds or heavier payloads.

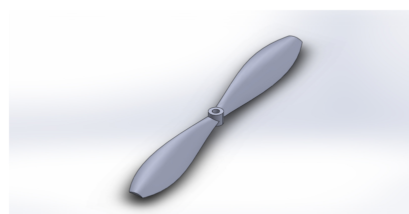

Fig. 8. Quadcopter propeller

B. ***Pest Detection System***

1) Cameras: The integration of a high-resolution RGB camera on the quadcopter enables the capture of detailed photos of crops, helping the identification of pest-affected areas. These photos, tagged with exact geographical data through RTK technology, give accurate location information for targeted treatments. Optionally, a multispectral camera can be integrated to boost pest detection capabilities. Multi-spectral cameras collect images across several spectral bands, including near-infrared (NIR), allowing greater insights into plant health and enabling the analysis of vegetation indices. These indicators, such as the NDVI (Normalized Difference Vegetation Index), can indicate small differences in plant health, highlighting areas that may be affected by pests or diseases.

2) Image Processing: Captured photos are processed utilising advanced algorithms and machine learning models, such as Convolutional Neural Networks (CNNs), to identify pest-infested areas. CNNs are highly effective in image identification applications due to their capacity to learn complicated patterns and features from big datasets. The analysed data is then utilised to build precise spraying maps, guiding the quadcopter to administer pesticides just where needed. This targeted strategy minimizes pesticide usage by lowering environmental impacts and health hazards associated with excessive or needless spraying.

C. Spraying Mechanism

1) Pesticide Tank: A lightweight, durable tank is essential for storing the pesticide solution. The tank's capacity should be optimised considering the quadcopter's flight range and coverage area, ensuring sufficient payload for effective spraying operations. Lightweight materials, such as magnesium-based alloys, can be used to construct the tank while maintaining durability.

2) Pump & Nozzles: The spraying system comprises a compact, efficient pump and adjustable nozzles, crucial for uniform pesticide distribution. The pump's size and power should be carefully chosen to match the tank's capacity and the desired spray rate. Adjustable nozzles enable fine-tuning of spray angles and flow rates to suit various field conditions. Factors such as droplet size and coverage consistency are critical for effective pest control and minimizing drift. Larger droplets are generally preferred for herbicides to reduce drift, while smaller droplets may be more effective for fungicides.

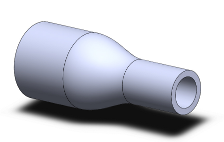

Fig. 9. Spraying nozzle

3) Flow Control System: A significant feature of the spraying mechanism is the flow control system, which ensures that pesticide is discharged only when the quadcopter is over the selected target region. This device, combined with the GPS and image processing data, operates the pump and nozzles precisely, limiting waste and lowering environmental effect. Real-time monitoring of tank levels through sensors can further boost efficiency, enabling the drone to cease spraying and return to the base for replenishment when needed.

VI. MATLAB MODELS AND SIMULATION RESULTS

A. Model and Simulation

The MATLAB simulations provide a comprehensive look into the quadcopter's performance, validating its design for precision agricultural applications. The simulation focuses on stability, control accuracy, and system responsiveness under realistic operating conditions.

The quadcopter system is modelled in Simulink using interconnected subsystems. The model comprises:

- Input signal generation
- Error calculation
- PID controller implementation
- 3D quadcopter model
- Output visualisation system

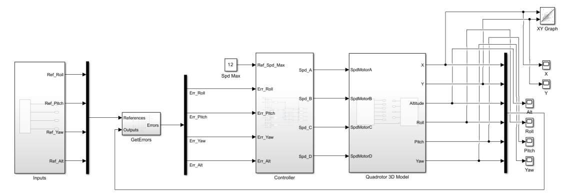

Fig. 10. Simulink Blocks

The control system utilises a cascaded PID architecture including four principal control loops:

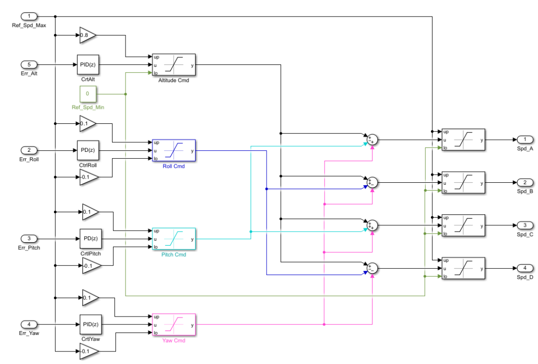

Fig. 11. Controller Subsystem

1) Altitude Control: Regulates vertical position by adjusting thrust. This loop ensures the quadcopter maintains the desired altitude for effective data collection and spraying.
2) Roll Control stabilizes lateral tilt, compensates for disturbances, and ensures a level flight path. This loop maintains the drone's stability during lateral movements.
3) Pitch Control: Governs forward/backward tilt, controlling the drone's movement in those directions. This loop enables the quadcopter to follow the planned flight path for comprehensive field coverage.
4) Pitch Control: Governs forward/backward tilt, controlling the drone's movement in those directions. This loop enables the quadcopter to follow the planned flight path for comprehensive field coverage.
5) Yaw Control: Manages heading orientation, directing the drone towards the intended target for accurate spraying. This loop ensures the quadcopter is pointing in the right direction.

Each control loop processes its corresponding error signal and produces suitable motor commands. The cascaded PID structure ensures robust control, enabling the quadcopter to achieve and maintain desired flight parameters.

B. Results

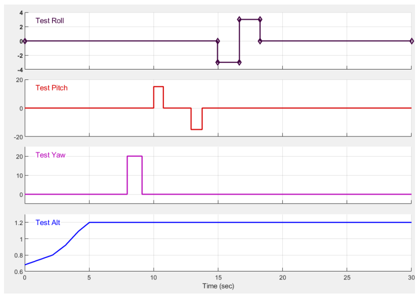

Fig. 12. Input signals

The quadcopter simulation necessitates four crucial input signals for comprehensive control: roll, pitch, yaw, and altitude. These signals are produced through the input subsystem. The test signals are engineered to assess the quadcopter's stability and responsiveness in scenarios pertinent to precision agriculture. This approach allows for an examination of the quadcopter's ability to maintain a stable flight path while executing maneuvers essential for effective crop monitoring and targeted spraying.

1) Roll Angle Input: Oscillates between -3° and +3° to evaluate lateral stability. This oscillation simulates the drone's response to minor disturbances and its ability to maintain a level flight path.

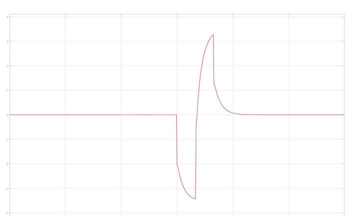

Fig. 13. Roll Output Scope

2) Pitch Angle Input: Fluctuates between -15° and +15° to simulate forward and backward motion. This range allows for testing the quadcopter's responsiveness to control inputs for directional movement.

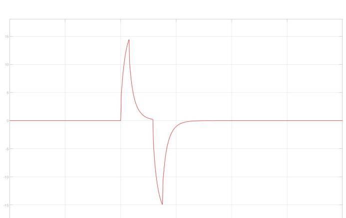

Fig. 14. Pitch Output Scope

3) Yaw Angle Input: Steps to 20° to examine orientation control. This step input assesses the drone's ability to adjust its heading and align itself with specific directions for targeted spraying.

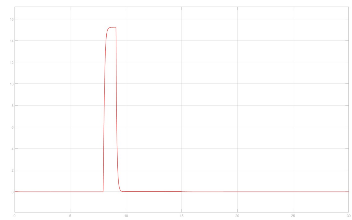

Fig. 15. Yaw Output Scope

4) Altitude Input: A gradual ramp to 1.2m followed by a steady-state hovering phase. This input profile tests the quadcopter's ability to reach and maintain a desired altitude for optimal sensor data acquisition and spraying operations.

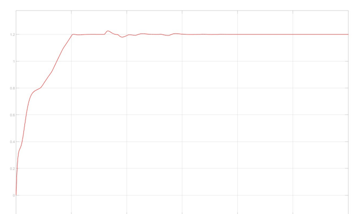

Fig. 16. Altitude Output Scope

VII. Conclusion

This project successfully designed and simulated a quadcopter model in Simulink for precision agriculture, with a focus on targeted pesticide spraying and pest detection. The simulation incorporated realistic input signals, a cascaded PID control system, and a 3D physical model to evaluate performance in a controlled environment.

Future study could focus on:

- Integrating real-world sensor data like multispectral images.
- Exploring improved control algorithms for greater performance in changing conditions.
- Incorporating AI and ML for autonomous decision-making, such as flight path planning based on pest detection and environmental considerations.

These developments will further boost quadcopters' potential in agriculture, producing a more sustainable and technologically advanced future for the industry. The integration of UAVs, robotics, AI, big data, the Internet of Things, and intelligent sensing can work together for a positive impact on agricultural methods.

VIII. Individual contribution

THAYALANESAN M. / THIRUVARANKAN M. - Designed the quadcopter's structure in SolidWorks, including the arms, frame, propellers and motors.

THENNAKOON T.M.T.S. / UDAKARA L.M.Y. - Developed the control system for stability and integrated the motor subsystems and input signals for smooth operation.

THRIMANNA K.D.D. - Integrated the SolidWorks model into Simulink and handled project documentation.

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