IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 6, November 2026
Impact Factor: 8.2

Design and Development of a Cost-Effective Multifunctional Agricultural Drone for Pesticide Spraying, Fruit Harvesting, and AI-based Crop Monitoring

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Abstract : *The proposed project focuses on the design and development of a 450 mm quadcopter drone for various aerial applications. The drone is designed using a 450 mm frame size, which provides a stable and balanced platform for flight operations. The main objective of this project is to develop a cost-effective, lightweight, and efficient unmanned aerial vehicle (UAV). The drone consists of four brushless DC (BLDC) motors mounted at equal distances on the frame. Each motor is connected to an Electronic Speed Controller (ESC) to regulate its speed and rotation. Four propellers generate the required thrust to lift and control the drone during flight. A flight controller is used as the main control unit to maintain stability and balance. The flight controller receives information from sensors such as gyroscopes and accelerometers. These sensors help the drone maintain its orientation and provide stable flight performance. A suitable lithium-polymer (Li-Po) battery is used as the primary power source. The power distribution board distributes electrical power to the motors, ESCs, and flight control system. A radio transmitter and receiver are used for wireless communication and manual control of the drone. The drone is designed to perform take-off, landing, hovering, forward movement, backward movement, and directional movement. The 450 mm frame provides sufficient space for mounting additional electronic components and accessories. The system can also be integrated with a GPS module for position tracking and autonomous navigation. A camera can be mounted on the drone for aerial photography, surveillance, and monitoring applications. The overall design considers important factors such as payload capacity, flight time, thrust-to-weight ratio, and power consumption. Proper motor selection and propeller configuration help improve lifting capacity and flight efficiency. The project also focuses on reducing vibration and improving the mechanical strength of the frame. The developed drone can be used in agricultural monitoring, land surveying, security surveillance, and educational research. The modular design makes maintenance, component replacement, and future upgrades easier. Overall, this project demonstrates the practical application of aerodynamics, electronics, mechanical design, and control systems in UAV development. The proposed 450 mm quadcopter aims to provide a reliable, stable, and economical aerial platform for multiple applications.*

Keywords: Agricultural Drone, Pesticide Spraying, Fruit Harvesting, AI-Based Crop Monitoring, Multifunctional Drone, UAV Technology, Precision Agriculture, Autonomous Flight, Cost-Effective Design, Smart Farming, Airframe Design, Payload Optimization

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DOI: 10.48175/IJARSCT-41157

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I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs), commonly known as drones, are rapidly developing technologies used in various fields such as agriculture, defence, surveillance, photography, surveying, and industrial applications. Drones are aircraft that operate without a human pilot onboard and can be controlled remotely or through autonomous flight systems. Due to their flexibility, low operating cost, and ability to access difficult locations, drones have become an important part of modern engineering and technology.

This project focuses on the design and development of a 450 mm quadcopter drone, which is a four-rotor aerial vehicle designed to achieve stable flight and efficient performance. The term 450 mm refers to the approximate diagonal distance between the centres of two opposite motors on the drone frame. This frame size provides sufficient space for mounting motors, electronic speed controllers, a flight controller, a battery, and other essential components.

The flight controller acts as the brain of the drone by processing sensor information and controlling the speed of the motors. It generally uses sensors such as gyroscopes and accelerometers to maintain stability, balance, and orientation during flight. By adjusting the rotational speed of individual motors, the drone can perform different movements such as ascending, descending, hovering, moving forward, moving backward, and turning left or right.

The 450 mm quadcopter is designed by considering important engineering parameters such as frame strength, total weight, motor thrust, propeller size, battery capacity, power consumption, payload capacity, and flight duration. Proper selection of these components is essential to achieve reliable flight performance and efficient energy utilization.

The main purpose of this project is to understand the working principles of multirotor aircraft and gain practical knowledge of mechanical design, electrical connections, electronic control systems, and aerodynamic principles. The project also provides an opportunity to study the integration of hardware and software required for controlling an unmanned aerial vehicle.

The developed 450 mm drone can be further enhanced by integrating additional technologies such as GPS navigation, camera systems, obstacle detection sensors, and autonomous flight capabilities. These features can expand its applications in agricultural monitoring, aerial photography, land surveying, infrastructure inspection, and surveillance.

In conclusion, the design and development of a 450 mm quadcopter drone provides a practical platform for understanding modern UAV technology. The project aims to develop a cost-effective, stable, reliable, and easily maintainable drone that can be used for educational, experimental, and various practical applications.

II. LITERATURE SURVEY

Literature related to agricultural robotics indicates that combining multiple farming operations into a single platform can improve resource utilization and reduce the need for separate machines. However, most existing agricultural drone systems are developed for individual applications, such as spraying or monitoring [1–3, 5], while fruit harvesting generally requires additional robotic mechanisms [4]. Integrating spraying, fruit harvesting, and AI-based crop monitoring into one affordable drone presents an opportunity for further development.

Based on the literature survey, the major research gap identified is the need to investigate an integrated, lightweight, multifunctional, and cost-effective agricultural drone capable of performing different farming activities. Therefore, the proposed project focuses on developing a multifunctional agricultural drone that combines mechanical design, propulsion systems, pesticide spraying technology, fruit harvesting mechanisms, and AI-based crop monitoring. The proposed system aims to improve farming efficiency, reduce labour dependency, save time, and support precision agriculture.

III. PROJECT OBJECTIVES

- Assemble and characterize a stable F450 quadcopter platform with a compatible propulsion and flight-control stack.
- Design a low-volume water-only spraying unit and measure its discharge, mass and power demand.
- Fabricate a three-finger soft gripper actuated by an MG996R-class servo and Arduino UNO to detach 40–60

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mm artificial fruit from a low-force fixture.

- Capture crop images and demonstrate a reproducible AI classification pipeline on a laptop.
- Measure subsystem performance, cost, power consumption and mass; report limitations without overstating field capability.

IV. SCOPE OF THE PROJECT

The fruit harvesting mechanism aims to assist in identifying and collecting fruits using a suitable robotic gripping mechanism. The system is designed to minimize fruit damage during harvesting operations. The AI-based crop monitoring system uses cameras and image-processing techniques to observe crop conditions, identify possible diseases, and monitor plant health.

The project also includes the integration of different mechanical and electronic components to ensure proper coordination between the drone and its multifunctional operations. Special attention is given to cost reduction, ease of operation, safety, payload capacity, energy efficiency, and maintenance.

The proposed system has the potential to support small and medium-scale farmers by reducing labour dependency, saving time, improving crop management, and increasing agricultural productivity. In the future, the project can be further developed by incorporating advanced AI algorithms, GPS-based autonomous navigation, obstacle detection, improved harvesting mechanisms, and larger-capacity spraying systems.

V. METHODOLOGY AND DESIGN

The methodology of this project involves the design, development, and integration of a cost-effective multifunctional agricultural drone capable of performing pesticide spraying, fruit harvesting, and AI-based crop monitoring. The project follows a systematic approach, starting from requirement analysis and conceptual design to component selection, fabrication, assembly, and testing. The main focus is to develop a lightweight, stable, reliable, and affordable drone that can perform multiple agricultural operations efficiently.

1. Requirement Analysis and Conceptual Design

Initially, the requirements of the agricultural drone are identified based on its three major functions: pesticide spraying, fruit harvesting, and crop monitoring. The overall design is planned by considering drone dimensions, payload capacity, flight stability, motor thrust, battery capacity, and operating time. A multifunctional configuration is selected to accommodate all the required mechanisms.

2. Airframe Design and Fabrication

The drone airframe is designed using suitable lightweight and strong materials to provide structural stability and support all the components. A 450 mm quadcopter frame configuration is considered for the prototype. The frame is designed to accommodate four motors, propellers, electronic components, spraying equipment, and harvesting mechanisms. CAD software is used for designing and dimensional analysis.

3. Propulsion and Flight Control System

The propulsion system consists of four brushless DC motors, electronic speed controllers (ESCs), and propellers. These components generate the required thrust for lifting and controlling the drone. A flight controller is integrated to maintain stability, balance, and direction during flight. A rechargeable Li-Po battery supplies electrical power to the propulsion and control systems.

4. Pesticide Spraying System

The water-only prototype spraying system consists of a liquid storage tank, DC pump, connecting pipes, and spraying nozzles. The pump supplies liquid from the tank to the nozzles, which distribute it over the crops. The spraying mechanism is designed to provide controlled and uniform application while minimizing liquid wastage.

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5. Fruit Harvesting Mechanism

A suitable robotic harvesting mechanism is proposed for integration into the drone structure. It consists of a lightweight gripping mechanism, actuator, and control system. The gripper is intended to hold and collect fruits carefully without causing physical damage. The mechanism is designed to minimize additional weight and maintain drone stability.

6. AI-Based Crop Monitoring System

A camera-based monitoring system is proposed to capture images of agricultural fields. Image-processing and AI techniques can be used to analyse crop conditions, identify visible disease symptoms, and monitor plant health. The collected information can help farmers understand crop conditions and take appropriate agricultural decisions.

7. System Integration

All the mechanical, electrical, electronic, and monitoring components are intended to be integrated into a single drone platform. The spraying system, harvesting mechanism, camera, flight controller, and power supply are arranged to maintain proper weight distribution and balance. The integration process focuses on reliable operation and efficient utilization of available power.

8.Testing and Performance Evaluation

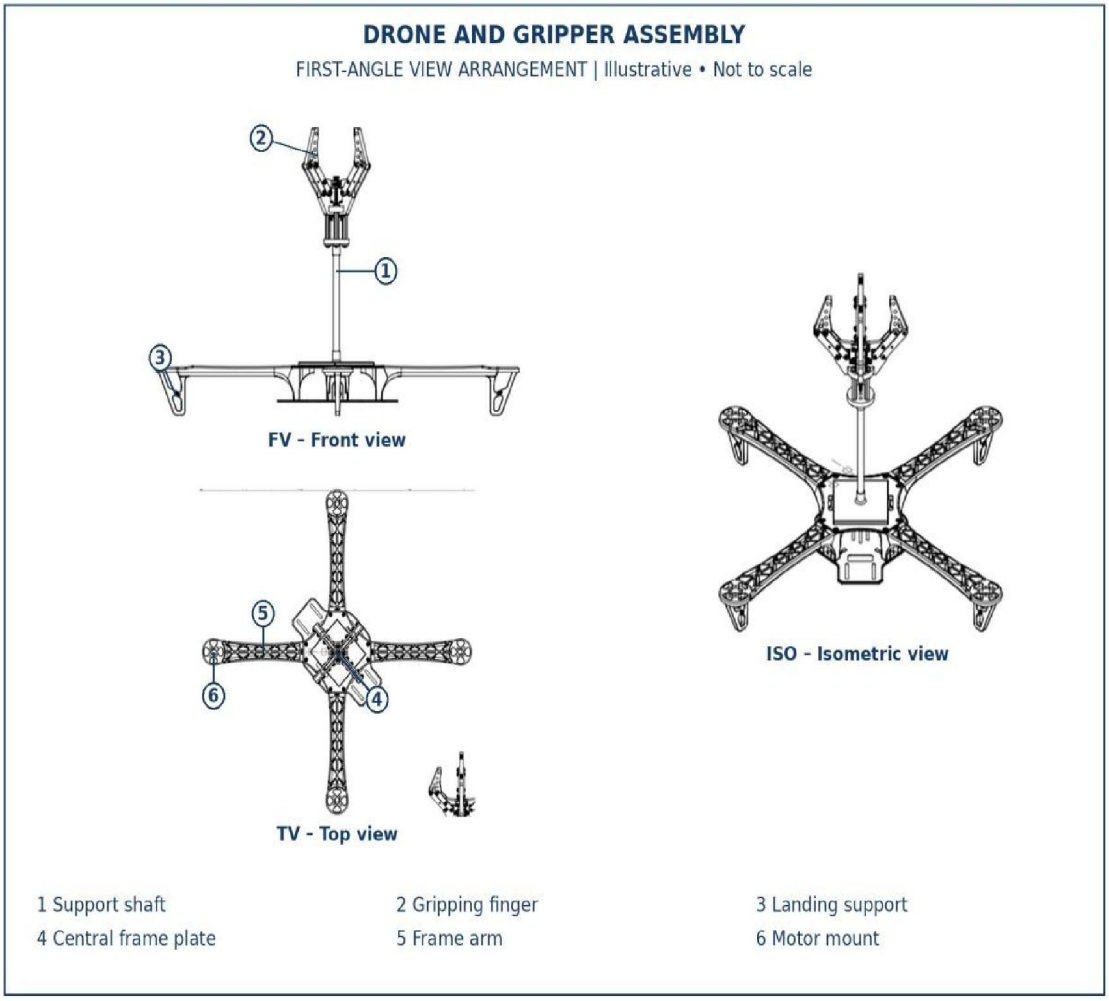
After completing the assembly, the drone will undergo different tests to evaluate its performance. The testing includes motor operation, flight stability, payload handling, spraying performance, harvesting mechanism operation, and camera functionality. The results will be analysed to identify limitations and make necessary improvements.

Design Considerations

The proposed drone design considers the following important parameters:

- Frame size: 450 mm quadcopter configuration.
- Structure: Lightweight and durable frame.
- Propulsion: Four brushless DC motors with suitable propellers.
- Flight control: Electronic flight controller for stability.
- Power supply: Rechargeable Li-Po battery.
- Spraying: Tank, DC pump, pipes, and spray nozzles.
- Harvesting: Lightweight robotic gripping mechanism.
- Monitoring: Camera with AI-based image processing.
- Safety: Proper weight distribution and controlled operation.
- Cost: Affordable components and simple fabrication methods.

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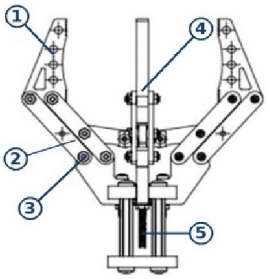


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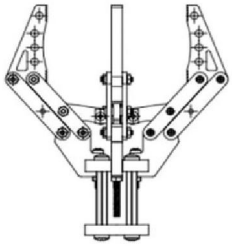
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FRUIT GRIPPER ASSEMBLY

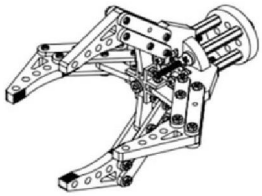
FIRST-ANGLE VIEW ARRANGEMENT | Illustrative • Not to scale



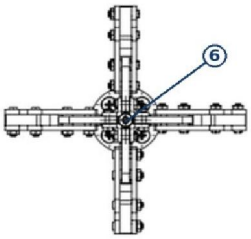
FV – Front view



SV – Side view*



ISO – Isometric view



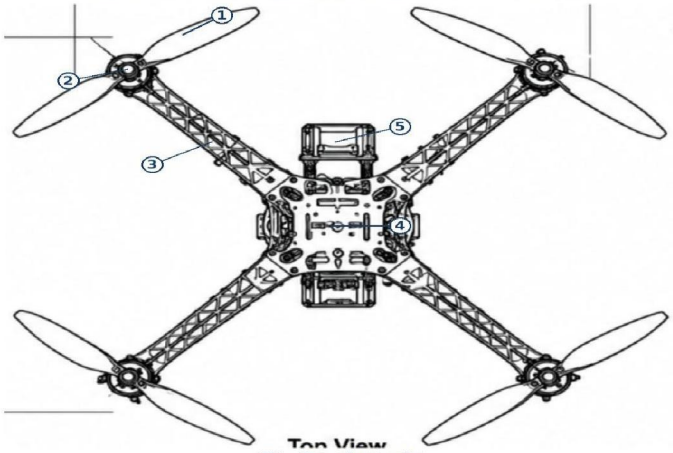
TV – Top view

*Side-view handedness must be confirmed from CAD; position is provisional.

1 Gripping finger
2 Finger linkage
3 Pivot joint
4 Central rod
5 Mounting flange
6 Linkage hub

F450 FRAME AND PROPULSION

FIRST-ANGLE VIEW ARRANGEMENT | Illustrative • Not to scale



Top View

TV – Top view only

Nominal opposite motor-centre spacing: 450 mm; verify against CAD.

1 Propeller
2 Motor / hub
3 Frame arm
4 Central plate
5 Mounting bracket

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Payload Calculation (F450 diagonal: 450 mm; adjacent motor spacing: 318.2 mm. Top-view dimension labels require correction.)

$P_L = W_{max} - W_e$

$P_L = 1.5 - 1.0$

$P_L = 0.5$ kg

Where: Assumed maximum all-up mass = 1.5 kg
Assumed empty drone mass = 1.0 kg. Payload includes all added modules and their contents.

Fruit Gripper

Assumed fruit mass = 0.2 kg Gravitational acceleration = 9.81 m/s² Friction coefficient = 0.5
Formula:
Gripping force per finger = (Fruit mass × Gravitational acceleration) / (3 × Friction coefficient) Calculation:
= (0.2 × 9.81) / (3 × 0.5)
Fg = 1.308 N per finger (ideal equal contacts; 2.616 N with safety factor 2). Detachment force requires separate testing.

Spray tank

Spraying duration = Tank capacity / Pump flow rate Calculation:
= 0.5 L / (0.5 L/min)
= 1 minute (theoretical; 0.5 L of water alone uses the entire payload allowance).

Thrust calculation

Estimated static thrust using ideal actuator-disc theory:

$Tm = [2\pi\rho air\ r^2\ (P\eta h)^2]^{(1/3)}$

Where: ηh = assumed hover power factor = 0.70

P= shaft power = current X voltage X motor efficiency
R = Propeller radius (meters)
ρair = Air density = 1.225 kg/m³

V= Voltage = 10 V
I = Current =16 A
Motor efficiency = 75% = 0.75

$P = 10 \times 16 \times 0.75 = 120$ W

$Tm = [2\pi \times 1.225 \times 0.125^2 \times (0.7 \times 120)^2]^{(1/3)}$ Tm = 9.467 N
Therefore, estimated thrust per motor = 9.467 N

Tm = 9.467/9.81 kgf Tm
≈ 0.965 kgf
Each motor is estimated to generate 0.965 kgf of static thrust.

Since there are 4 motors present in the following quadcopter, total thrust generated is given by Tm X 4.
Total thrust = 9.467 × 4 = 37.868 N
T ≈ 3.86 kgf

For an illustrative conservative thrust derating, assume a 30% reduction. Derating factor = 0.70 (not an additional motor efficiency).

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Thrust T is given by:

$T = 3.86 \times 0.70 = 2.702$ kgf

$T = 2.702$ kg

Derated thrust estimate = 2.702 kgf; actual thrust requires testing.

Final Design Summary

The project entitled "Design and Development of a Cost-Effective Multifunctional Agricultural Drone for Pesticide Spraying, Fruit Harvesting, and AI-Based Crop Monitoring" focuses on developing an efficient, affordable, and multifunctional agricultural drone with a 450 mm quadcopter frame.

The proposed drone is designed with four brushless DC motors, electronic speed controllers, propellers, a flight controller, and a rechargeable Li-Po battery to provide stable flight and sufficient lifting capability. The frame is designed to support the propulsion system, spraying equipment, fruit-harvesting mechanism, and crop-monitoring components. The pesticide spraying system consists of a liquid storage tank, DC pump, pipes, and spray nozzles to distribute pesticides uniformly over agricultural crops. The fruit-harvesting mechanism uses a mechanical gripper to hold and collect fruits carefully. An AI-based crop-monitoring system uses a camera and image-processing technology to observe crop conditions and identify visible signs of disease, pests, and other crop-related problems.

Based on the preliminary design calculations, the drone has an estimated maximum thrust of 3.86 kgf, a thrust-to-weight ratio of 2.57:1, and a nominal battery energy of 57.72 Wh. The estimated flight time is approximately 13.9 minutes assuming a 11.1 V, 5.2 Ah battery, 80% usable energy and 200 W average power ($57.72 \times 0.8 / 200 \times 60$). The proposed design also considers payload capacity, spraying duration, motor spacing, propeller clearance, and gripping force.

The main objective of this project is to integrate pesticide spraying, fruit harvesting, and intelligent crop monitoring into a single agricultural drone. This multifunctional approach can help reduce manual labour, save time, improve agricultural productivity, and minimize the effort required for conventional farming operations.

Overall, the proposed 450 mm agricultural drone provides a cost-effective design concept for modern precision agriculture. Future improvements can include autonomous navigation, GPS-based field mapping, obstacle detection, improved AI crop-disease identification, optimized battery performance, and increased payload capacity.

Final Outcome: The project presents a multifunctional agricultural drone concept that combines spraying, fruit harvesting, and AI-based crop monitoring in a single platform to support smart and efficient farming.

VI. CONCLUSION

The project entitled "Design and Development of a Cost-Effective Multifunctional Agricultural Drone for Pesticide Spraying, Fruit Harvesting, and AI-Based Crop Monitoring" aims to develop an innovative and affordable solution for modern agricultural applications. The proposed 450 mm quadcopter drone integrates three major agricultural functions: pesticide spraying, fruit harvesting, and AI-based crop monitoring into a single platform.

The designed drone uses four brushless DC motors, electronic speed controllers, a flight controller, a rechargeable Li-Po battery, and a lightweight frame to achieve stable flight and support the required agricultural equipment. The pesticide spraying system is designed to distribute pesticides through a pump and spray nozzles. The fruit-harvesting mechanism uses a mechanical gripper to collect fruits carefully, while the camera-based AI monitoring system helps observe crop conditions and identify possible signs of diseases and pest attacks.

The preliminary design calculations provide an estimated thrust-to-weight ratio of 2.57:1 and a flight time of approximately 13.9 minutes under the assumed operating conditions. These calculations support the initial design and component selection. However, actual performance must be confirmed through prototype development and experimental testing.

The proposed multifunctional agricultural drone has the potential to reduce manual labour, save time, improve spraying efficiency, and support better crop monitoring. By combining multiple agricultural operations into one system, the project aims to reduce the need for separate equipment and provide a practical approach to precision agriculture.

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In conclusion, this project demonstrates the concept and engineering design of a cost-effective multifunctional agricultural drone for smart farming applications. With further improvements in autonomous navigation, AI technology, payload capacity, battery performance, and harvesting accuracy, the system can be developed into a more advanced and reliable agricultural solution in the future.

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