Design of a solar-powered agricultural drone for pesticide application

Mahmood Sail[1], Ali Daimah[1], Ahed Hassan[1], Mohamed Bashanfar[1], Bassam G.N. Muthanna[1*], Hemza Saidi[2]

(1. Department of Mechatronics Engineering, Faculty of Engineering and Computing, University of Science and Technology, Aden, 00967, Yemen;

2. Electrical Engineering Department, Faculty of Technology, Hassiba Benbouali University of Chlef, Chlef, 02000, Algeria)

Abstract: Technological innovations serve as a fundamental pillar in the development of the agricultural sector, contributing to improved productivity and environmental sustainability. The agricultural sector in our country faces increasing challenges, including rising operational costs, environmental pollution, and reduced efficiency in pesticide application. This project presents the design and manufacturing of an innovative solar-powered drone equipped with an autonomous guidance system and an integrated surveillance camera. The system aims to enhance pesticide application, reduce operational costs, and improve coverage accuracy, leading to minimized environmental impact and increased agricultural production efficiency. The system integrates a lightweight hexacopter frame, high-efficiency propulsion units, a 10-liter spraying tank with mist nozzles, a Pixhawk 2.4.8 autonomous flight controller, and flexible photovoltaic panels connected through a voltage booster to extend endurance. The drone was designed using SolidWorks for structural followed by fabrication with 3D-printed polymer components and composite materials for the tank. Field trials demonstrated stable flight performance, uniform spraying coverage over 500 m² per mission, and an average endurance of 14 minutes with full payload, partially supported by solar power. The results highlight the potential of solar-assisted UAVs to improve spraying efficiency, reduce labor and chemical exposure, and promote sustainable agriculture.

Keywords: smart agriculture, drone, solar energy, pesticide spraying, environmental sustainability.

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1 Introduction

The global demand for food is steadily increasing, placing significant pressure on the agricultural sector to enhance productivity while minimizing environmental impact. Conventional pesticide application methods, such as manual spraying and tractor-mounted systems, are often inefficient, labor-intensive, and hazardous to farmers. These practices frequently lead to excessive pesticide use, uneven coverage, and environmental contamination, particularly in areas with irregular farmland or difficult terrain (Yu and Wu, 2018; Garre and Harish, 2018). Consequently, the development of innovative technologies that improve efficiency, reduce risk, and support sustainable farming has become a priority.

Unmanned aerial vehicles (UAVs) have recently emerged as promising tools for agricultural spraying, offering higher accuracy, reduced labor requirements, and lower operational costs (Mogili and Deepak, 2018;

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***Corresponding author: Bassam G.N. Muthanna.** Department of Mechatronics Engineering, Faculty of Engineering and Computing, University of Science and Technology, Aden, Yemen. Emai: bas.muthanna@gmail.com; b.muthanna@ust.edu.

Hafeez et al., 2023). Studies report that UAV-based spraying reduces chemical waste, improves application uniformity, and minimizes worker exposure (Garre and Harish, 2018; Yallappa et al., 2024). However, most battery-powered drones are limited to 15–30 minutes of flight per charge, constraining their scalability for large-scale operations. To overcome this limitation, researchers have explored renewable energy solutions such as solar-assisted and hybrid UAV systems to extend flight endurance (Borikar et al., 2022; García-Munguía et al., 2024). Advances in autonomous navigation, artificial intelligence, and sensor-based path planning have further enhanced spraying precision and pesticide optimization (Anam et al., 2024). Specialized prototypes, such as vineyard-specific drones, have shown improved efficiency compared to traditional ground-based methods (Ezin and Sessiz, 2023). Despite these advances, most studies remain limited to simulations or conceptual designs, with relatively few reporting full-scale field implementation and validation.

This study addresses these gaps by designing, fabricating, and testing a solar-powered hexacopter UAV equipped with a 10-liter pesticide spraying system, autonomous flight controller, and integrated photovoltaic panels to extend operational time. The drone was modeled in SolidWorks and fabricated from lightweight polymer and composite materials. Field testing was conducted to evaluate its endurance, spraying performance, and autonomous operation, demonstrating the feasibility of solar-assisted UAVs for sustainable agricultural applications, particularly in regions with challenging terrain, high operational costs, or limited access to advanced machinery.

2 Methods and materials

Figure 1 illustrates traditional pesticide spraying methods, which rely heavily on manual labor and often lead to significant resource wastage and high operational costs. To address these challenges, the development of the solar-powered agricultural hexacopter was organized into four main stages: (i) Mechanical Design and Fabrication, (ii) Propulsion and Power System Design, (iii) Electronic Integration and Programming, and (iv) Field Testing and Evaluation. This structured approach ensured a seamless transition from conceptual design to practical implementation and performance validation.

Figure 1 Real photos of the traditional pesticide spraying in Abiyan Governorate, Yemen. (Authors source)

2.1 Mechanical design and frame fabrication

The drone frame was designed using SolidWorks to achieve structural stability, lightweight construction, and high payload capacity. A hexacopter configuration was chosen to balance thrust, endurance, and fault tolerance. The minimum thrust per motor was calculated using:

$$T_{motor} \geq \frac{W_{total} \times SF}{N} \tag{1}$$

where W_{total} is the total weight in kilograms (drone + payload + battery), *N* is the number of motors (6), and *SF* is the safety factor (1.3–1.5).

The arms and central plate were fabricated using laser-cut acrylic and 3D-printed joints as shown in Figure 3(a), while the pesticide tank was built from composite material for strength and chemical resistance as shown in Figure 3(b). The final frame had a motor-to-motor span of 113.2 cm and an empty weight of 7.8 kg (Figure 2).

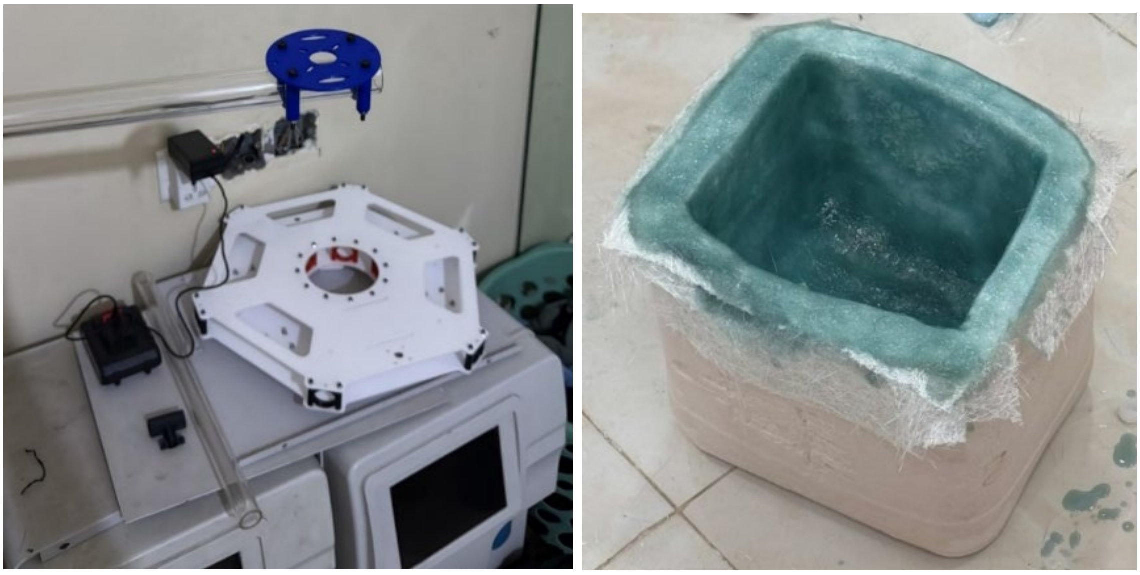
Figure 2 (a) and Table 1 present the dimensions of components. Special attention was given to the aerodynamics and weight distribution to optimize the performance of the drone during pesticide spraying operations. The design phase also included simulations to validate the structural integrity and functionality of the proposed assembly.

(a) schematic design (b) CAD design from different faces (c) CAD design from different faces

Figure 2 Hexacopter agricultural drone

Table 1 The dimensions of the arms

Parameter	Dimension (cm)
Outer motor-to-motor diameter	113.21
Inner base diameter (central plate)	39.51
Motor arm length (from center to motor)	54
Number of arms	6
Leg height (landing gear)	12
Spray bar length	100
Spray bar diameter	1.2
Motor mount shaft diameter	2.5



(a) Outer frame manufactured by 3D printer, (b) tank manufactured manually

Figure 3 Outer frame and tank manufacturing methods

The final step involved the assembly and integration of electronic devices sourced from commercial markets. These components included the flight controller, GPS module, spraying system controller, motors, and battery management system. Careful wiring, calibration, and testing procedures were performed to ensure proper communication between the devices and the structural components, resulting in a fully functional agricultural spraying drone ready for operational testing. Figure 4 shows the final prototype of agricultural drone.

Figure 4 Final prototype for the agriculture drone.

Table 3 Spraying specifications

Parameter	Value
Tank Capacity	10 L
Pump Flow Rate	2.5 L min^{-1}
Droplet Diameter	100 µm
Spray Bar Width	1 m
Area per Mission	400–600 m^2

Table 4 Power consumption estimates

Component	Voltage	Current	Power	Duty cycle	Energy use
6 Motors	22.2 V	10 A	1332 W	70%	932.4 Wh
Flight Controller	5 V	0.5 A	2.5 W	100%	2.5 Wh
GPS & Telemetry	5 V	0.3 A	1.5 W	100%	1.5 Wh
Spraying System	12 V	2 A	24 W	50%	12 Wh

2.2 Propulsion system

The propulsion system consisted of six AX3115 470 KV brushless motors paired with tri-blade HQ 9x5x3 propellers and 60A ESCs.

2.2.1 Design Criteria

(1) Total takeoff weight (drone + payload + tank + battery + solar panels): 13.5 kg;

(2) Required thrust-to-weight ratio: ≥ 2.0;

(3) Power requirement per motor estimated using:

$$P = \frac{T \times \upsilon}{\eta} \tag{2}$$

Where,

T is thrust (N);

υ is induced velocity (m/s);

η is propeller efficiency.

2.2.2 Solar integration

Flexible photovoltaic panels were mounted on the top surface, providing ~25% of daily energy demand under clear conditions. Energy flow was stabilized using a DC-DC booster circuit.

2.3 Electronic integration

The drone’s navigation is handled by the Pixhawk 2.4.8 flight controller. Integration includes:

(1) FS-i6B Flysky receiver;

(2) 433 MHz telemetry;

(3) High-precision GPS module;

(4) QGroundControl software for mission planning.

A 10-liter tank and Sari-brand electric pump control the pesticide release via a 1-meter-wide spray bar with mist-type nozzles.

Flexible solar panels are mounted on the drone's top surface to supply supplemental power. They are connected to a voltage booster circuit for efficient energy flow.

3 System testing and programming

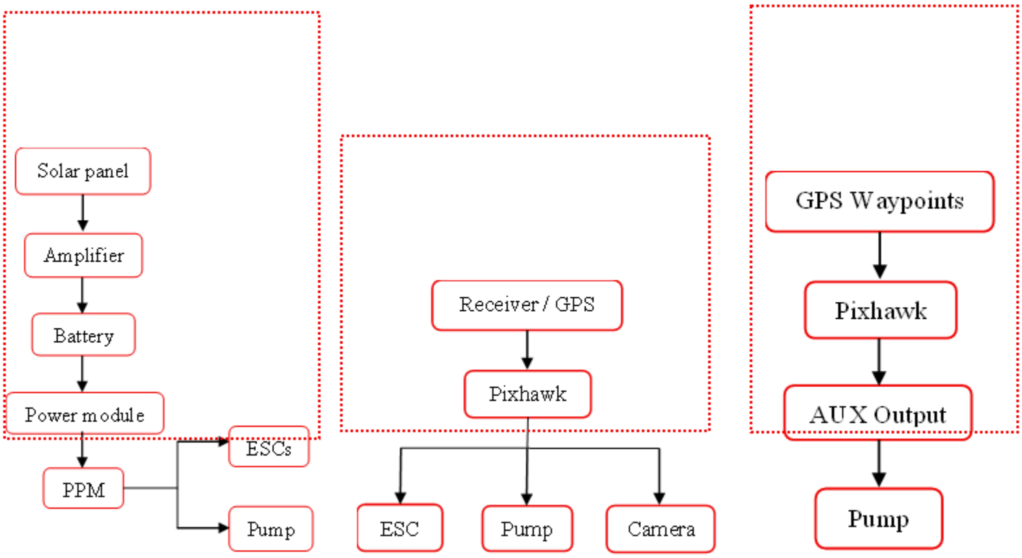
Flight tests were performed without payload and then with full load to assess stability and power usage. Spraying was tested with water across a test field, evaluating coverage and droplet uniformity. Low voltage simulated; drone successfully returned and began wireless recharging.

Table 5 Summary of system performance metrics

Metric	Value
Flight Time (No Load)	23 minutes
Flight Time (Full Load)	14 minutes
Spraying Area per Mission	500 m²
RTL Accuracy	±1.2 m
Daily Solar Energy Efficiency	~25% of total need

Figure 5 shows the overall system architecture of the solar-powered agricultural drone. It shows the interaction between the power subsystem, the flight control subsystem, and the spraying mechanism. Electrical power is supplied by the Li-Po battery, supplemented by flexible solar panels through a DC–DC booster circuit. This power is distributed to the motors, flight controller, GPS module, telemetry unit, and spraying system.

Control signals originate from the Pixhawk flight controller, which processes navigation data from the GPS, telemetry feedback, and remote-control inputs. The Pixhawk generates commands that regulate the Electronic Speed Controllers (ESCs) for motor operation and activate the servo-controlled spraying pump. The telemetry module provides two-way communication with the ground station, enabling real-time monitoring and mission updates.

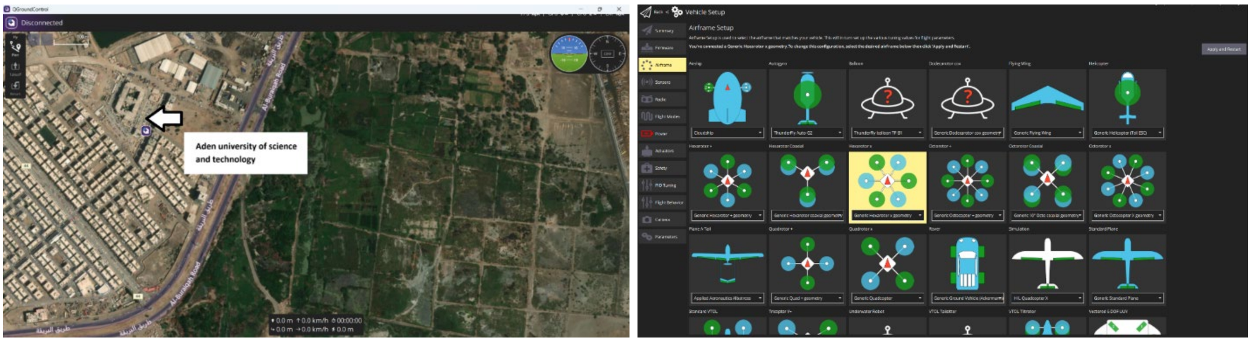


(a) work flow (b) signal communication between manual user input and the drone's autonomous response systems (c) spraying domain

Figure 5 System block diagram description

Programming the flight controller was a fundamental step in ensuring safe and autonomous operation of our agricultural hexacopter. For this purpose, we selected the Pixhawk flight controller running the PX4 open-source firmware. We carried out the configuration and mission planning using QGroundControl, a ground station software chosen for its intuitive graphical interface and rich feature set.

To begin the environment setup, QGroundControl was downloaded from the official website and installed. The Pixhawk flight controller was then connected via USB, prompting automatic detection by the software. The PX4 firmware was successfully installed during this process. After rebooting, the software prompted the selection of a frame configuration. The Hexa-X configuration was chosen, which is ideal for six-motor drones arranged in an X-pattern, and this selection was automatically saved. Following the frame setup, essential configurations and calibrations were performed. Sensor calibration included the gyroscope, accelerometer, and compass, ensuring accurate flight data. Additionally, the FlySky receiver channels were mapped during the RC (remote control) calibration to enable proper communication between the transmitter and flight controller.



Airframe Setup

Airframe Setup is used to select the airframe that matches your vehicle. This will in turn set up the various tuning values for flight parameters.

You're connected a Generic Hexarotor x geometry. To change this configuration, select the desired airframe below then click 'Apply and Restart'.

(a) QGround control interface after detecting the Pixhawk controller (b) frame selection interface showing Hexa-X configuration

Figure 6 QGroundControl and Pixhawk Configuration

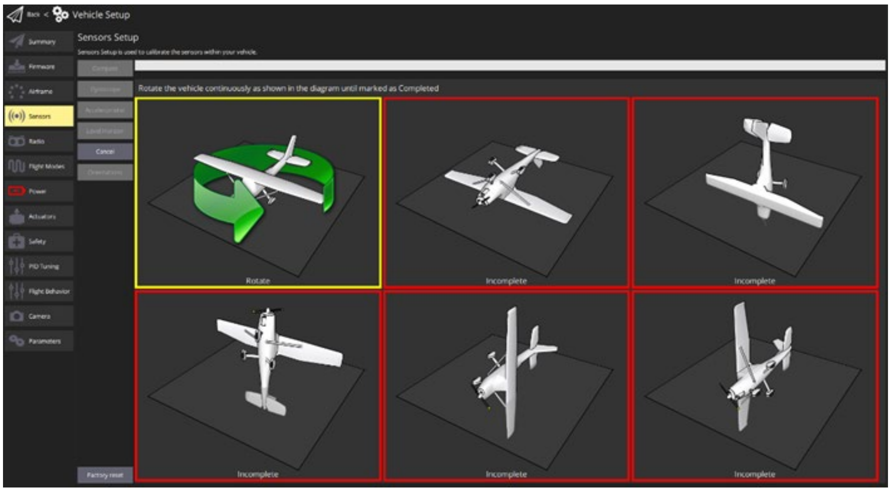
To ensure stable flight, we calibrated various onboard sensors using QGroundControl's guided interface:

(1) Gyroscope Calibration: We held the drone steady in six orientations as prompted.

(2) Accelerometer Calibration: We repeated similar positional movements to calibrate the accelerometer.

(3) Compass Calibration: We rotated the drone in all directions to calibrate the internal magnetometer, ensuring no metallic objects were nearby.

(4) Radio Control (RC) Calibration: We connected the Fly Sky fs-ia6b receiver and moved all sticks and switches to identify channel mappings.



Sensors Setup

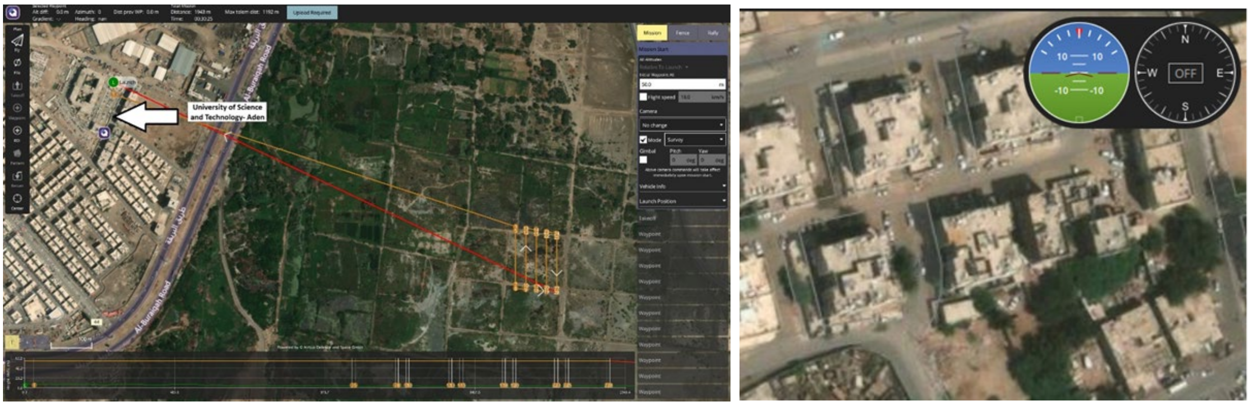
Sensors Setup is used to calibrate the sensors within your vehicle.

Rotate the vehicle continuously as shown in the diagram until marked as Completed

Figure 7 Gyroscope calibration interface.

After completing all configurations, a basic flight test was conducted to verify system functionality. The drone was placed in an open outdoor area, and the flight mode was set to Stabilized Mode to allow for manual control testing. Takeoff was initiated using the FlySky transmitter, and the drone successfully lifted off. During hovering, the drone demonstrated stable flight behavior and responsive control, confirming the effectiveness of the setup and calibration procedures.

A core feature of our project was enabling the drone to perform a fully autonomous spraying mission over a predefined agricultural field. This was accomplished using QGroundControl through a series of structured steps. First, we switched to the "Plan" view to access the mission planning interface. A takeoff waypoint was added to specify the drone's ascent location and altitude. Using the Survey tool, we designed the spray route by drawing a grid over the target field, which automatically generated waypoints based on the field's dimensions and the spray coverage width. To control the spraying mechanism, a "Do Set Servo" command was inserted at the start of the route to activate the pump and another at the end to deactivate it. Flight parameters were then adjusted, setting the altitude between 3 to 5 meters and the speed between 2 to 3 meters per second to ensure effective and uniform spraying. After finalizing the plan, the complete mission was uploaded to the Pixhawk flight controller using the "Upload" option. Finally, after confirming GPS lock and overall system readiness, the mission was executed via the "Start Mission" command, allowing the drone to autonomously complete the spraying operation.



(a) Survey grid created in the Plan tab for spraying mission (b) hexacopter during ground-level flight testing

Figure 8 Total survey grid overview

4 Conclusion

This study successfully designed and implemented a solar-powered agricultural hexacopter drone capable of performing autonomous pesticide spraying with enhanced efficiency and stability. The integrated system combined key technologies such as autonomous navigation via the Pixhawk controller, a solar voltage boost circuit, and a wireless self-charging mechanism. Field tests validated the system's effectiveness, demonstrating stable flight performance, reliable energy management, and accurate spraying coverage. The results highlight the drone's potential to support sustainable agriculture in Yemen by reducing operational costs, minimizing manual labor risks, and improving overall productivity.

Several challenges were encountered during the project, including load imbalance due to initial tank placement, solar charging inefficiencies under cloudy conditions, delayed pump activation, and difficulty aligning the wireless charging pad in windy environments. These issues were addressed through targeted solutions: repositioning the tank to improve the drone's center of gravity, refining spray commands in QGroundControl to reduce delays, using mist nozzles for more efficient coverage, and applying magnetic anchoring to align the charging pad more effectively.

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