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Design and Development of a Smart Pesticide-Spraying Agricultural VTOL Drone

Sameer John¹, M Ismail Yousaf¹, Nazo Haroon¹, Habiba Rani¹, Usman Ahmed¹

¹Department of Mechatronics Engineering, University of Wah

¹johsameer35@gmail.com

²ismaeeljhq@gmail.com

³nazo.haroon@wecuw.edu.pk

⁴habibarani0802@gmail.com

⁵usmankonosuba@gmail.com

Abstract

This project presents the design and development of a smart Vertical Takeoff and Landing (VTOL) drone optimized for pesticide spraying in large-scale agricultural fields. The system is engineered to reduce manual labor, minimize chemical waste, and enhance application precision contributing safer and more efficient farming practices. Through initial research, two primary limitations in conventional agricultural quadcopters were identified: limited flight time due to high energy consumption during hover, and restricted payload capacity. To overcome these constraints, a VTOL configuration was implemented. Its forward flight mode, similar to that of a fixed-wing aircraft, reduces power usage and extends flight time, while the aerodynamic structure increases payload efficiency without sacrificing stability. The drone features a lightweight PETG 3D-printed frame and a hybrid propulsion system comprising four vertical lift motors and one pusher motor. Spraying is carried out using an air pump and precision nozzles, ensuring controlled chemical delivery. The system integrates a GPS module, airspeed sensor, and HD Wi-Fi FPV camera for field navigation and monitoring. Internal sensors from the Speedy Bee Wing F405 flight controller such as IMU, gyroscope, barometer, and yaw provide real-time feedback, allowing mission planning and performance tuning via Mission Planner software. Although full autonomous spraying was not implemented, the drone is capable of semi-automated missions guided by GPS and onboard sensor data. The modular design supports easy maintenance and future system upgrades. By combining a VTOL platform with sensor-driven functionality and mission planning capabilities, this drone offers a practical and scalable solution for modern agricultural spraying applications.

Keywords: VTOL drone, precision agriculture, UAV, pesticide spraying, smart farming, sensor feedback.

Introduction

Agriculture is one of the simplest industries that can be used to sustain the lives of human beings and it still faces threats in terms of efficiency, labor shortage [1], and the environmental sustainability [2]. Within this category of challenges, spraying of pesticides has been very labor intensive, time consuming and may be a health hazard to the human being. Manual method of

spraying pesticides causes unequal distribution of pesticides used, excessive use of chemicals, and direct exposure of workers to toxic chemicals. The restrictions introduce new solutions to achieve the accuracy, efficiency and safety. Uncrewed aerial vehicles (UAVs)[3] are a potentially useful technology in precision agriculture, and spraying drones are becoming increasingly important in crop protection. Multirotor drones can vertically take off and land (VTOL), but usually have a smaller flight-capacity and payload-capacity. The fixed-wing drones are also more productive and have a greater range but cannot work in a vertical landing because they are not designed to operate in small-scale agricultural fields. The purpose of the presented research project is to design and construct a VTOL drone that will have the capacity to spray pesticides to address these problems. The vertical lift of the multirotor design is integrated with the fixed wing flight efficiency. It has also been designed with a three-dimensional printed PETG 3D printed plastic frame [4], carbon fiber-based landing gear, an air pump-powered onboard spray system. A flight controller was selected also to ensure that it was steady and had reliable maneuverability during spraying. The study will help in equipping the farmers with a drone that will, in addition to offering precision during spraying, minimize the wastes of the chemicals; it will also make sure that the farming fields are well covered by the drone. This scholarly article can be considered an addition to the fast-expanding industry of smart farming and precision agriculture, which have transcended the drawbacks of manual technology and primitive drones. Another invention that was done and designed in a systematic way embracing the designing of the drone to be less in weight, an integration and application of electronic circuitries and application of spray mechanism was the pesticide spray VTOL [5] drone. The subsystem was to support the objectives of payload carrying capacity, flight stability and efficient delivery of pesticides. Some of the important aspects and methods adopted in this research are as stated below. VTOL Frame Design: This drone structural frame is designed in such a way that it is strong and weight effective. To accomplish it, the body has been 3D-printed in PETG, the material of choice because of its durability and flexibility compared to PLA or ABS, which are either brittle or readily deform under pressure. The modular printing strategy enabled the drone frame to be printed in distinct components and subsequently assembled afterwards, which is easier when producing and also the replacement when damaged.

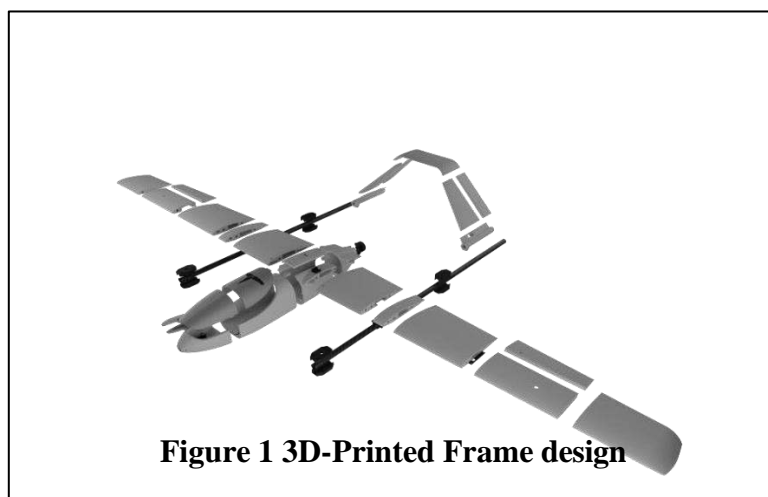


Figure 1 3D-Printed Frame design

The frame design was purchased to ensure stability and aerodynamic suitability, reducing the risk of imbalance during flight. PETG parts were reinforced with **carbon fiber rods**[7] to provide additional strength at stress points, especially at the arms and landing gear attachment areas. The use of PETG combined with carbon fiber allowed for a lightweight yet rigid design capable of carrying the spraying payload.

Flight Controller and Electronics

The drone used the SpeedyBee F405 as the main control unit. This controller was characterized by advanced stabilization, the ability to work with various sensors and autonomous flight modes. The flight controller was packaged with electronic speed controllers (ESCs), brushless DC motors, and payload appropriate-sized propellers. A lithium polymer [8] (Li-Po) battery provided power, chosen regarding the present current requirements of the propulsion system and spraying mechanism. Interconnecting wires were well-laid to reduce noise disturbances and to be safe. The controller was calibrated to maximize the operation of the VTOL including vertical take-off, hovering and spraying operations.

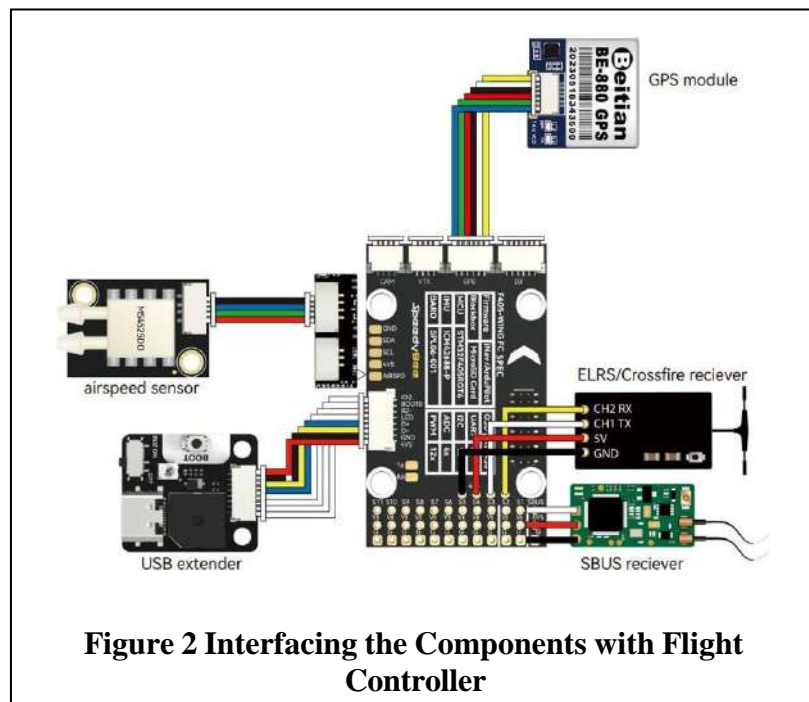
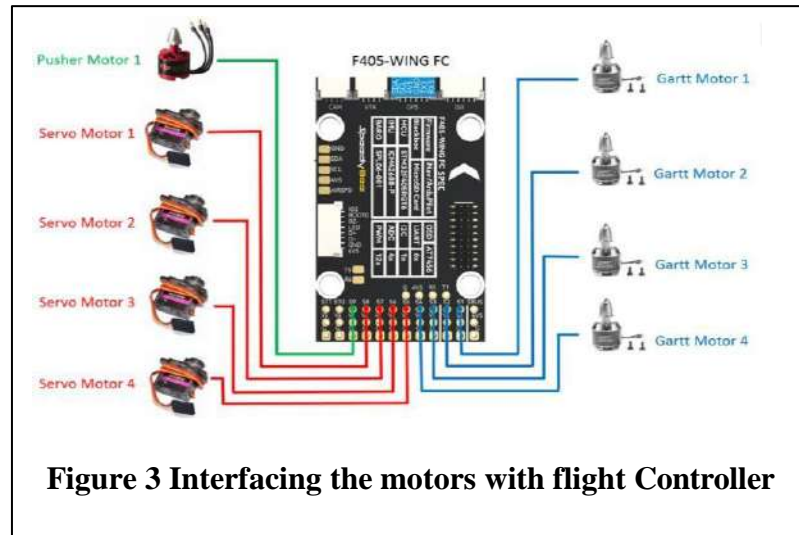


Figure 2 Interfacing the Components with Flight Controller



Spraying Mechanism

The pesticide spraying system worked on the principle of an air pump mechanism[9] that had the capability of pumping liquid pesticide out of an onboard tank and through nozzles. The drone used had the tank placed on the main body so that the weight was evenly distributed. The pump was enough to create enough pressure to atomize the liquid pesticide into fine particles so that it could

cover the crops uniformly. A lot of attention was paid to the weight of the spraying system. Nozzles and lightweight tubing were employed to keep the extra load at a minimum, but offer durability in use. This was made possible by integration of spraying mechanism with flight controller in such a manner that the spraying mechanism could be manually activated during flight thereby enabling the operator to determine the time when to release pesticides and the amount of pesticides to release.

Landing Gear

The drone landing gear was made with an 3D-printed PETG joint with carbon fiber rod bonding. This mixture provided a balance of rigidity and shock absorbing in the landing and take-off. The shape provided adequate ground clearance to the spraying devise avoiding the destruction of the nozzles and disturbance on the land. The light but robust landing gear[10] helped in the overall structural effectiveness of the drone.



Figure 4 Final Assembled Drone

Analysis and simulation through Mission Planner software: An important part of this research is analysis, simulation and flight planning of the Smart Agricultural Pesticide Spraying VTOL Drone using the Mission Planner, an advanced Ground Control Station (GCS) software for arduPilot which runs on drones , Using this software, we could configure, monitor and simulate the drone's performance before its actual deployment to stay safe, reliable and mission successful.

Firmware Installation and Configuration:

We successfully flashed the ArduPilot firmware (VTOL and fixed wing mode supported) onto our Speedy Bee Wing F405 flight controller in order to make it interface with Mission Planner. The control architecture necessary for autonomous navigation and integration of various aspects of onboard sensors and actuators were all contained in this firmware. The firmware was then used to configure the essential flight parameters, sensor calibration and control outputs, such as the pesticide spraying mechanism needed via Mission Planner.

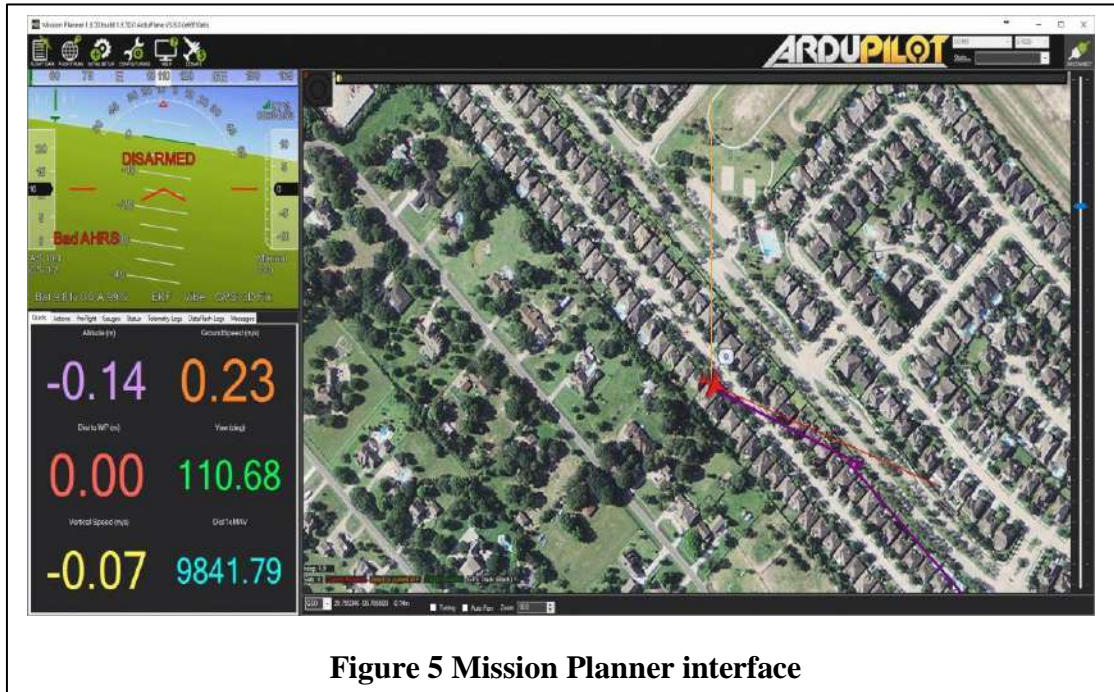


Figure 5 Mission Planner interface

Results and Discussion

The design and development of the pesticide spraying VTOL drone was evaluated in terms of flight stability, payload handling capability, and effectiveness of pesticide spraying. The results demonstrate the feasibility of integrating spraying systems into a VTOL platform for agricultural applications.

Flight Stability

During flight testing, the VTOL drone exhibited **stable hovering and maneuverability**[11]. The SpeedyBee F405 flight controller successfully maintained attitude stabilization and corrected for minor disturbances caused by wind or payload vibrations. The modular PETG frame, reinforced with carbon fiber rods, contributed to structural rigidity and minimized oscillations during hovering.

Take-off and landing sequences were executed reliably, confirming that the combination of lightweight materials and a robust control system provided sufficient stability. Overall, the drone achieved consistent vertical lift and sustained hovering, which is essential for targeted pesticide spraying over crops.

Table 1 Thrust and PWM signal Values

PWM Signal (μ s)	Thrust (N)	Current (A)	Power (W)
1100	0.5	1.8	20.0
1300	2.0	5.0	55.5



1500	4.0	9.2	102.0
1700	6.2	13.8	152.5
1900	8.0	17.5	194.5

Payload Handling

The drone was fitted with pesticide tank and spraying system without affecting the flight performance. Experiments showed that the structure was capable of lifting the spraying payload effectively [12], and that little of the stability was lost when full-tank operations were put into effect. The propulsion system thrust to weight ratio was adequate to counter the additional load and no significant imbalance was noted.

Table 2 Vertical to Horizontal Transition Values

Test No.	VTOL to Forward (s)	Forward to Hover (s)	Stability (/10)	Rating	Notes
1	4.5	5.2	8.5		Minor pitch dip
2	4.2	5.0	9.0		Smooth
3	4.7	5.5	8.0		Slight delay
Avg.	4.47	5.23	8.5		—

There was however slight degradation of overall flight endurance with the addition of the payload because the Li-Po battery emptied more quickly with the heavy load. In spite of this shortcoming, drone could complete spraying tasks within a reasonable operating time period applicable to small to medium-sized fields.

Table 3 Battery Discharge Rate

Time (min)	Voltage (V)	Current (A)	Power (W)	Remaining Capacity (%)
0	12.6	0	0	100
10	12.2	8.5	103.7	75
20	11.9	9.0	107.1	50
30	11.5	9.2	105.8	25
40	11.0	9.5	104.5	10



Spraying Effectiveness

Air pump spraying mechanism gave sufficient pressure to spray liquid pesticide via the nozzles, which produced fine and dispersed droplets [13]. In test runs, the spray pattern was evenly spread across the target area. The location of the tank made the weight distribution even during the spraying process, and it was not found that there were no nozzle blockages during the working process.

Table 4 Spray coverage and Flight speed

Speed (m/s)	Coverage Width (m)	Flow Rate (ml/min)	Uniformity Score (/10)
1.0	0.7	150	9.0
1.5	1.0	160	8.0
2.0	1.2	180	7.5
2.5	1.3	200	6.5

The spraying system made it possible to release pesticides under control, reducing wastage and making sure that only the necessary amount of chemicals was applied. This drone-based system greatly benefits the people operating it by eliminating the need to become exposed to toxic substances and ensures more accurate delivery than the traditional spraying methods used by the company.

Limitations

Despite the successful performance of the drone, a number of limitations were noted: Flight endurance: With the spraying payload added, the total air time was decreased, limiting the operational range of the drone.

- Payload capacity: The existing payload was within the limits of the system, but upgrading to larger tanks or higher-powered pumps would have necessitated structural and propulsion changes.
- Spraying coverage: The system is today more appropriate in small-scale farms. Extensive agricultural plots would need repeated flights or scaffolding of the design.

These limitations notwithstanding, the findings validate the claim that a VTOL spraying drone has the potential to present farmers with a safer and more efficient solution to traditional methods of spraying. The constraints can be overcome in future studies through the use of large capacity



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batteries, lightweight composite materials or streamlined spraying mechanisms

Conclusion

This study has been able to show how a pesticide spraying agricultural VTOL drone can be designed and built to integrate vertical take-off and landing with a built-in spraying system. PETG material with carbon fiber rods, 3D-printed material, was used to design lightweight yet strong frame, and the flight control board SpeedyBee F405 was used to provide stable flying capabilities. The findings verified that drone can carry and operate a payload of spraying successfully and provide fine and even spraying of pesticide and stay on the air. The system also minimized the risks of chemical exposure on the operators and provided better efficiency than the manual spraying. Although the drone achieved the targeted goals, some limitations were found, including the limited flight duration when carrying payload, small tank capacity, and small and medium-scale fields. These constraints, however, offer a good understanding as to how to improve the same in the future, including using larger capacity batteries, new lightweight materials or new more efficient spraying technologies. Finally, this paper discusses the promise of VTOL drones as a viable fix to precision agriculture. Such systems help to enhance modern ways of agriculture by enhancing safety, efficiency, and accuracy in the application of pesticides.

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