Design and Flight Dynamics of an Agricultural Pesticide-Spraying Hexacopter: Revolutionizing Crop Protection in Agricultural Fields

Lovely Faith P. Cantor[1], Disney M. Otoman[1], Dale Mark N. Bristol[2], Jeanelyn R. Tominez[2]
[1]*Student, Department of Mechanical Engineering, Nueva Vizcaya State University - Bambang Campus, 3702 Bambang, Nueva Vizcaya, Philippines*
[2]*Faculty, Department of Mechanical Engineering, Nueva Vizcaya State University - Bambang Campus, 3702 Bambang, Nueva Vizcaya, Philippines*
Corresponding Author: dalemarkbristol@gmail.com

Abstract*: The study focuses on the design of six-rotor agricultural pesticide spraying drone or also known as hexacopter with the maximum savings potential and develop effective agricultural device that will benefit the farmers. As the agricultural industry continues to grow due to the improvement of crop production and technology, more challenges now come up in terms of improving the existing level of development and agricultural transformation. Thus, pesticide drone sprayer is designed to enable substantial energy savings. The drone sprayer is powered by 22000 mAh Lithium polymer battery with 6 motors and propellers that can last up to for about 24 minutes for a maximum payload capacity of 24.6 kg. The designed drone uses 6 standard flat fan nozzles, 70 mm diameter with an average spraying heigh of 3.5 meters. Simulation process is presented to determine the performance of spraying system and efficiency of drone sprayer using virtual model and mathematical computations. Drone sprayer has better performance compared to conventional sprayer by maximizing the time, energy and volume of liquid consumed pert hour of operation. Drone spraying reduces operator exposure to chemicals, direct sun light and other crops disturbances. However, the test will provide a baseline profile for further modifications to improve the efficiency of the drone system.

***Keywords*: agricultural pesticide spraying drone, crop protection, hexacopter, flight dynamics.**

1. Introduction

Traditional spraying techniques, which use either manual labor or pieces of machinery to apply fertilizer and insecticides to fields, have been the mainstay of agricultural pest control. But frequently, these techniques lead to chemical drift, uneven application, and over-spraying, which seriously contaminates the environment and endangers the health of farmworkers. Due to inefficiencies in coverage and droplet deposition, studies show that conventional systems, including tractor-mounted sprayers, can waste up to 60% of chemicals, causing damage to non-target organisms and soil and water contamination [1]. Additionally, traditional spraying is less sustainable in contemporary agriculture due to the high costs of labor, fuel, and machinery maintenance.

The switch to drone-assisted spraying represents a major development in farming methods. Precision technologies like GPS, sensors, and autonomous navigation systems allow drones to apply pesticides and nutrients precisely, limiting waste and decreasing environmental harm. According to research, drones can reduce pesticide use by up to 30% when compared to conventional methods while optimizing spray parameters including height, droplet size, and flow rate to achieve even coverage [2, 3]. Furthermore, drones improve operational efficiency by traversing difficult terrain and inaccessible locations, which makes them indispensable for extensive farming operations. By carefully customizing treatments according to crop requirements, they increase the effectiveness of pest management while protecting nearby ecosystems [2].

Additionally, the use of drones solves important issues with traditional spraying techniques. Drone systems that are outfitted with electrostatic spray technology, for example, have been proven to have better droplet deposition rates and homogeneity than conventional methods. Research shows that electrostatic spraying improves pesticide use and lowers pollution by more than 160% by increasing deposition density [4]. Additionally, during spraying operations, drones lessen human exposure to hazardous chemicals, lowering health hazards for farm workers. Drone technology may be expensive initially, but over time, the advantages of lower chemical usage and higher crop yields make it a viable option for sustainable agriculture [2].

One of the main benefits of drone spraying is its environmental sustainability. Drones help maintain ecosystem health and biodiversity by providing low-volume, precise applications and minimizing chemical runoff into soil and water systems. When compared to traditional approaches, research shows that profile variable rate spraying using drones can reduce spray flow rates by more than 30%, greatly reducing pesticide residues and ground deposition coverage [2]. Additionally, by enhancing crop stress resilience through optimal nutrient management, drones help climate-resilient agriculture [4]. This has led to the study's aim of drone integration into precision farming, which is anticipated to be crucial to reaching global sustainability objectives and increasing agricultural productivity as technology continues to improve drone capabilities and as well minimizing the risk in chemical contact and reducing the work of the farmers.

2. Materials and Methodology

A. Agricultural Pesticide Spraying Hexacopter Set-Up

The design of the hexacopter as shown in Fig.1 comprises of the main frame, which is made of carbon fiber-reinforced composite material with each arm length of 535 mm. At each free end of the arm, a motor is fixed, and propeller is mechanically coupled to the motor. The propeller has a diameter of 400 mm and an internal angle of 60˚ with each other. For all six motors the output side of an electronic speed controller is connected, and the input side is connected to the flight controller. The drone mounted sprayer mainly consists of motors, LiPo (Lithium polymer) batteries, pesticide tank, pump, and supporting frame. Six motors were mounted to hexa-copter frame to lift of 24.6 kg estimated payload capacity. A 22-liter capacity storage tank was used to hold the pesticide solution having greater capacity compared to 16-liter storage capacity of knapsack sprayer. Spraying tank is made of light weight plastic material which is mechanically coupled to the frame. Pump is powered from a power distribution board. The inlet of the pump is connected to the storage tank and the outlet is connected to the plastic tube or water hose where nozzles are fixed. The landing frame of 505 mm length is connected diagonally to the main frame so that the landing of the drone will be safe and the storage tank will not touch the ground.

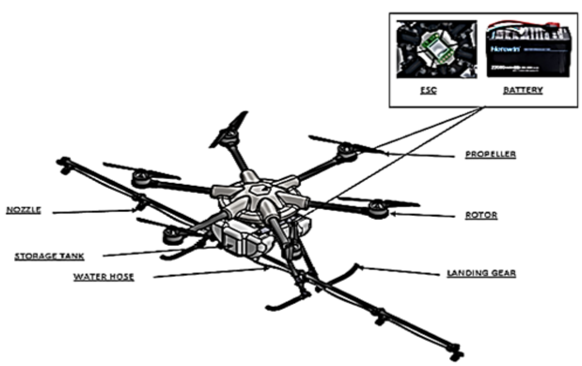

Fig. 1. Design of the hexacopter

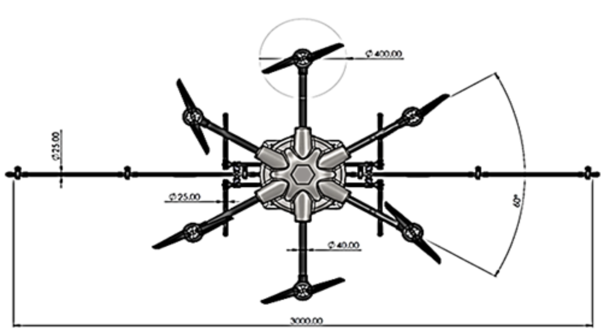

Fig. 2. Design of agricultural pesticide spraying hexacopter

B. Computer Animation of Hexacopter

The animation of the hexacopter prototype is programmed and created using solid works, cinema 4D and Arduino Integrated Development and Environment software. The design is generally composed of drone frame, propeller, motor section, power system and spraying performance. The values of several sensors are presented on the serial monitor. Then, using two ESP8266 devices, a Wi-Fi network is built, and the server-client idea is implemented. The various sensor data is then shown on the serial monitor on the client side. Finally, the hexacopter's calibration and setup are accomplished via the transmitter, as is the control of the motors at various speeds of rotation. This would reflect on the sequence of operation diagram found in Fig. 3.

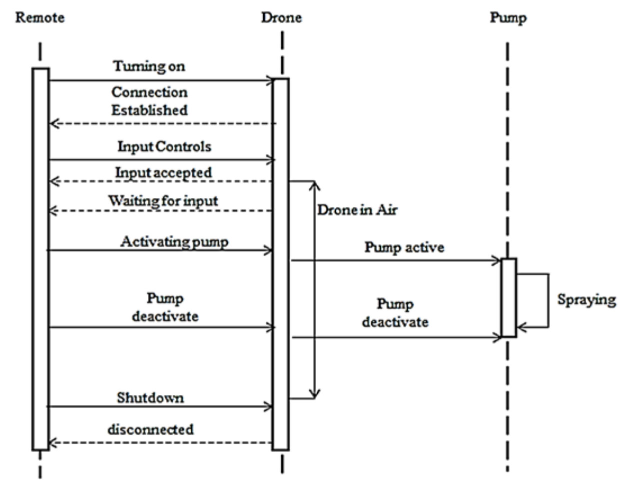

Fig. 3. Sequence of operation on agricultural pesticide spraying hexacopter

3. Results and Discussion

A. Efficiency of Agricultural Pesticide Spraying Drone

Determining the efficiency of drone pesticide sprayers would be of significant value to find out their potential use in the crop protection industry. Drone applicator has apparent advantages and attractive characteristics over ground air-blast sprayer to cover field at the higher position, low spray volumes associated with a small payload raises questions of adequate spray penetration, deposition and coverage of crop produced in a high-density canopy and the resulting level of pest control. Such constraints require characterization of the drone application performance throughout multiple spraying events relevant to the complexity of hull-splitting stages [5]. Drone sprayer was tested through simulation process in which the lift, capacity and spraying discharge were programmed and ran. Virtual field was created for spraying performance. The results were recorded, evaluated and examined for further development. Efficiency is the ratio of the output divided by the input. Here, the propellers convert mechanical energy to thrust [6].

Data based on the available specs of propeller, pump and motor:

Mechanical power (produced by the propeller) = Thrust x velocity

Velocity = max. speed (based on the specifications of drone) = 16 m/s

Mechanical power (from the previous calculation) = 121.81 N (16 m/s) = 1948.96 W

Max. Power input of the motor = 2423 W

$$e = \frac{Power\ produced}{Power\ of\ the\ motor} = \frac{1948.96\ W}{2423\ W} \text{ x } 100\% = 80\%$$

Efficiency calculation of existing drone based on the catalogue:

Power produced by propeller = 100 to 2500 W

Power of the motor = 500 to 3500

At maximum:

$$e = \frac{Power\ produced}{Power\ of\ the\ motor} = \frac{2500\ W}{3500\ W} \text{ x } 100\% = 71.42\%$$

B. Flight Dynamics of Hexacopter

1) Thrust-to-Weight Ratio

Thrust developed at 100% rpm can be 3-5 times larger than the total weight of the drone so that the drone has better maneuverability, and the drone can climb higher altitudes with a higher rate of climb. Considering maximum thrust by one motor:

$$\text{Thrust} = 13.9 \text{ kg}$$

$$\text{Total thrust produced} = 6 \text{ x } 13.9 \text{ kg} = 83.40 \text{ kg}$$

$$\text{Thrust to weight ratio} = \frac{83.40}{35.138} = 2.37 \text{ or } 2.37{:}1$$

$$\text{Battery capacity} = (488 \text{ W} - \text{h})(2) = 976 \text{ W} - \text{h}$$

$$\text{Spraying flow rate} = 1.8 \text{ to } 3.2 \text{ L/min}$$

$$\text{Average spraying flow rate} = \frac{1.8 + 3.2}{2} = 2.5 \frac{\text{L}}{\text{min}}$$

$$\text{Flight time (hr) x Power (W)} = E_{\text{battery}} \text{ (W} - \text{h)}$$

$$\text{FlightTime} = \frac{E_{\text{battery}}}{\text{Power}} = \frac{976}{2423} = 0.4028 \text{ hr x } 60 \text{ min}$$

$$= \text{FlightTime} = 24.168 \text{ min}$$

$$\text{Flight Speed} = \frac{\text{distance}}{\text{time}} = \frac{2900 \text{ m}}{24.168 \text{ min}} = 2 \text{ m/s or } 7.2 \text{ kph}$$

with 13.9 kg maximum thrust is good for hexacopter design for greater thrust to weight ratio considering the overall weight of the drone was only estimated. Further information is presented in Table 1.

Table 1
Spraying system of drone pesticide sprayer

Parameters	Values
Spraying Flight Time (min)	24.17
Container Volume (L)	22
Flight Speed (m/s)	2
Spray Droplet Diameter (mm)	70
Spray Height (m)	2 – 5
Spray Width (m)	3 – 6
Operating Frequency (GHz)	2.4
Charged Time (hr)	1 - 2

2) Lift Force

The drone moves forward at a constant speed. Drone force calculation is based on the given formula according to Newton's second law of motion. The lift force is illustrated in Figure 3, which is represented by the free body diagram.

F= ma

Mass of the drone = Overall weight of the drone (at full load)

F= ma = (35.14 kg) (9.81 m/s2) = 344.72 N

Force = Lift = 344.72 N

The hexacopter's computed lift force, such as 344.72 N, is obtained by optimizing rotor configuration, motor performance, and structural design. In heavy lift hexacopter applications, the overall lift must offset the weight of the drone and its payload. This is consistent with the study published by Ismael et al. (2020) built a hexacopter with a total load capacity of 350 N (20 kg payload + 10 kg drone weight), which is nearly identical to the 344.72 N figure. This lift is generated by six brushless DC motors, each delivering up to 3.4 kg (33.35 N) of thrust at 1,500 rpm, with counter-rotating tri-blade propellers minimizing torque effects and increasing stability [7].

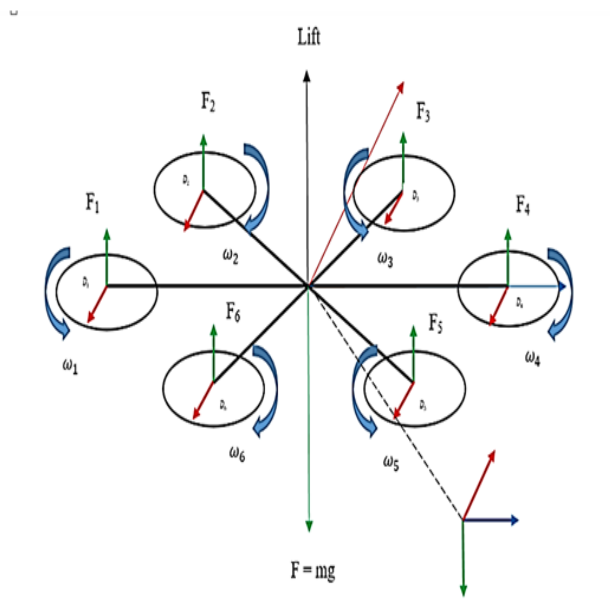

Fig. 4. Free body diagram of forces on hexacopter

3) Spray Angle

The container tank is made of rigid plastic with a volume of 22 liters. It consists of 6 standard flat fan nozzles with spray droplet diameter of 70 mm. A tiny transducer on the drone sprayer displays pressure on the ground station, allowing the system's pressure to be monitored. Pump flow rate is 1.8 to 3.2 L/min with a spray width of 3 to 6 meters and height of 2 to 5 meters based on the available pump and nozzle specifications having an average spray angle of 65.47 degrees. Six nozzles are used based on the design measurement of the drone's bottom length. The average spray width of each nozzle (according to the given specifications of nozzle and pump)

$$W_{ave} = \frac{3\ m + 6\ m}{2} = 4.5 \text{ m}$$

For an average spray width of 4.5 m, the angle required is calculated as shown in Figure 5.

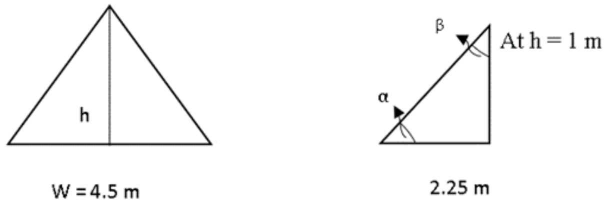

Fig. 5. Spraying angle of hexacopter using trigonometric relation

$\alpha = \tan^{-1}\frac{1}{2.25} = 23.96°$

$\beta = 180° – 90° – 23.96° = 66.04°$

Spray angle (θ) = 66.04° x 2 = 132.08°

According to some studies, flat-fan nozzles are available in several spray angles. The most common spray angles are 65, 73, 80, and 110 degrees [8] for the proper distribution of pesticides. The spray pattern will be uneven if nozzles are not aligned properly on the spray boom.

4. Conclusion

In conclusion the design is composed of lightweight carbon fiber material and a heavy-duty brushless motor with a thrust to weight ratio of 2.37:1. It is composed of frame, motor, propeller, pump, nozzles, electronic board and cables, water hose, battery and HD camera. The size of the drone is 1200 x 3000 x 580 mm consist of six-rotor system, six nozzles and two pieces of 22000. mAh Li-po battery. The capacity of the storage tank is 22 L and maximum takeoff capacity of 40 kg. Aside from having an average number of rotors, the six-rotor drone system was chosen over other multi-rotors because the design was easy to maintain and developed a higher thrust-to-weight ratio. Basic Arduino codes for spraying system were programmed to transmit and receive signals for spray mechanism. The estimated calculated efficiency, thrust to weight ratio, flight time and flight speed based on the given drone's specifications are 80%, 2.37 or 2.37:1, 24.17 min and 2 m/s respectively.

5. Acknowledgement

The authors would like to acknowledge the efforts made by the following team members in this research study namely Nathalie Grace Costales, Chedie Natividad, Jerry Tabelisma II, Mark Jaylord Lacquias, Ryan Bendillo, and Lea Tidang.

References

[1] V.M. Pathak, V.K. Verma, B.S. Rawat, et al. "Current status of pesticide effects on environment, human health and it's eco-friendly management as bioremediation: A comprehensive review." *Front. Microbiol.* 2022. https://doi.org/10.3389/fmicb.2022.962619.

[2] D. Yallapa, R. Kavitha, A. Surendrakumar, et al. "Improving agricultural spraying with multi-rotor drones: a technical study on operational parameter optimization." *Front. Nutr*. Vol. 11. 2024. https://doi. org/ 10.3389/fnut.2024.1487074.

[3] Y. Nan, H. Zhang, J. Zheng, K. Yang, Y. Ge. "Low-volume precision spray for plant pest control using profile variable rate spraying and ultrasonic detection." *Front. Plant Sci*, Vol. 13. 2023. https://doi. org/10.3389/fpls.2022.1042769.

[4] Z. Lin, J. Xie, S. Tian, et al. "Research and experiment of electrostatic spraying system for agricultural plant protection unmanned vehicle." *Front. Ecol. Evol*. Vol. 11. 2023. https://doi.org/10.3389/fevo.2023. 1138180.

[5] X. Li. "Evaluation of an unmanned aerial vehicle as a new method of pesticide application for almond crop protection." 2020. Wiley Online Library. https://doi.org/10.1002/ps.6052.

[6] C. Blouin. "How to increase a drone's flight time and lift capacity." Retrieved October 10, 2020, from https://www.aliexpress.com/ item/32804167552.html.

[7] B. Ismail, A.H.A, Rahim, F. Zawawi. "Design And Development of Heavy-Lift Hexacopter for Heavy Payload*." Journal of Transport System Engineering.* 7(2): 53-63, 2020. https://jtse.utm.my/index. php/jtse/article/view/165.

[8] S. Li, C. Chen, Y. Wang, et al. "Study on the Atomization Characteristics of Flat Fan Nozzles for Pesticide Application at Low Pressures." *Agriculture* 2021, 11(4), 309; https://doi.org/10.3390/ agriculture11040309.