MODELLING OF QUADCOPTER FOR PRECISION AGRICULTURE AND SURVEILLANCE PURPOSES

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Abstract

This article presents the modelling of a quadcopter with a payload of 7 kg and the general overview of its use for precision crop spraying. The paper reviews the current state of the art in precision crop spraying and provides a comprehensive overview of the various types of unmanned aerial vehicles (UAVs) available, their capabilities, and their potential applications in precision crop spraying. It also provides a detailed analysis of the challenges and opportunities associated with the use of UAVs for precision crop spraying. The UAV used in the study was integrated with a liquid payload and a sprayer system that is controlled remotely by a flight controller radio. The objective was achieved by developing a mathematics-based model for the quadcopter. Subsequently, the quadcopter was physically fabricated in accordance with the computer model, tested, and evaluated. The modeling outcome gives a quadcopter with dimensions of 1140.28 mm by 767.11 mm by 267.37 mm and with each of the four propellers having a length of 457.2 mm. This was simulated, and the results show a stable trajectory flight and a uniformly distributed pattern of discharge of its content.

Keywords: Quadcopter, simulation and modelling

1. Introduction

Precision spraying with unmanned aerial vehicles (UAVs), also known as drones, is becoming increasingly popular in the agriculture industry. This technology allows farmers to spray crops with precision, reducing the amount of chemicals used and increasing crop yield. Part of the benefits of these systems is the increased safety for both the operators and the environment. By reducing the amount of chemicals used, there is less risk of chemical exposure for the operators, and less potential for chemical runoff into the environment.

The importance of developing sustainable agricultural practices cannot be overstated, particularly in recent years with the global population exceeding the 7 billion mark as population growth has become a very real and pressing issue. As a result, humanity's output of agricultural products must be significantly increased (Pederi, 2015).

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Although recent advances in science have resulted in several innovations engineered towards sustainable agricultural practices, these innovations are, however, not widely adopted in most countries of the world due to a myriad of challenges ranging from scarcity of family land, high labour cost, climate constraints, activities of pests and rodents, lack of quality seedlings, and agricultural resources.

Precision agriculture (PA) makes use of data sets in combination with economic crops and ecological analytical tools in assisting farmers to make positive decisions and manage their fields more accurately (at the right rates, at the right times, and in the right places) to meet both economic and environmental goals (Pierce & Nowak 1999; Raj *et al.,* 2020). Recently, there has been a surge of interest in PA around the world as a viable way to meet an enormous demand for higher-quality food and energy more sustainably by reducing externalization (Carolan, 2017). PA practices have changed dramatically in recent years, with the global market expected to reach $43.4 billion in 2025 (Delavarpour *et al.,* 2021). In order to meet up with this, therefore, this paper aimed to evaluate the stability and effectiveness of a UAV with a dynamic payload and crop sprayer system for precision crop spraying.

Precision Agriculture Cycle

The precision farming cycle begins with the acquisition of photos or data to build maps of yields, weeds, and terrain, followed by the application of herbicides or fertilizers, water (irrigation), and, lastly, the results for implementation. Before beginning the process of precision farming, an agriculturist must have a comprehensive awareness of the farm's soil types, hydrology, microclimates, and aerial photography, as well as the changeable aspects within the fields that affect a yield map. The yield map confirms the data that the farmers have, which is normally done by taking an aerial photograph of the property (Davis *et al.,* 2007). Platforms such as satellites, aircraft, balloons, and helicopters are utilized to apply the technology, as well as a variety of sensors such as optical and near-infrared, as well as RADAR (Radio Detection and Ranging), deployed on these platforms for its applications. Crop management, yield forecasting, and environmental protection can all benefit from diagnostic information obtained from images acquired from these onboard sensors, such as biomass, Leaf Area Index (LAI), disease, water stress, and lodging (Zhang & Kovacs, 2012). Figure 1 depicts the precision agricultural application cycle:

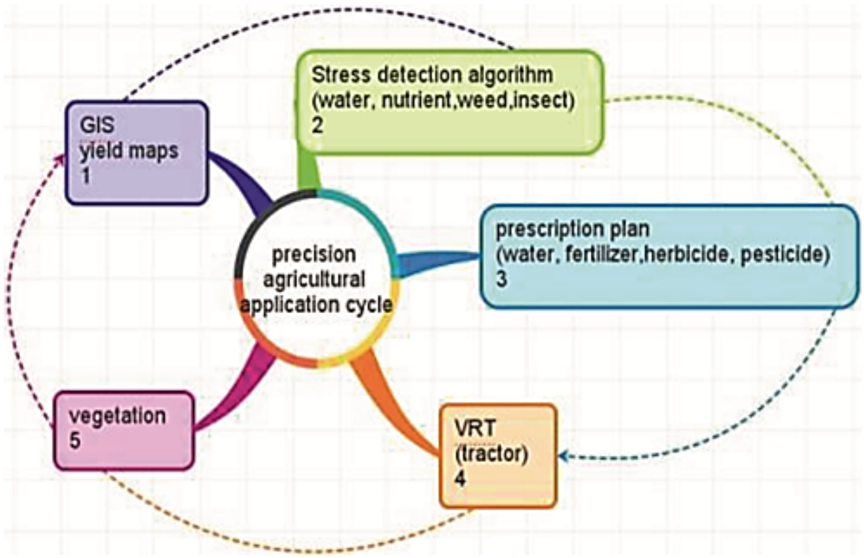


Figure 1: The cycle of precision agriculture (Abdullahi *et al*., 2015)

Precision agriculture has over the years evolved to leverage technological innovations such as the usage of drones and IoT sensors, as well as trending fields such as data science, machine learning, etc., to optimize agricultural operations such as surveillance, application of agricultural inputs, harvesting, and a plethora of other agricultural operations.

Advent of Drones in the Agricultural Industry

Drones have over the years gained diverse applications in the agricultural industry. The rate of adoption has been greatly affected by the emergence of technologies such as the Internet of Things (IoT), Big Data, and Artificial Intelligence that have historically been one of the most effective ways that farmers have used or applied to meet and overcome the constant changes and challenges that accompany this sector and meet growing food demands (Meivel *et al.,* 2016). The use of these technologies has led to the improvement of new and, in some cases, existing farming practices and tools already in use on farms. For example, one of the most popular new technologies now being employed in the farming sector to boost yields is the usage of linked tractors.

Drones are currently regarded as relatively young, and even less developed tools in comparison to other new technologies being utilized in smart or precision agriculture. In the agricultural industry, there are two types of drones now in use:

i. Medium-sized drones: which are primarily used for analysis applications
ii. Larger-sized drones: which are used for planting and spraying pesticides in the field.

In the 1980s, the first UAS in the agricultural industry were created for crop dusting. The accurate airborne administration of pesticides and fertilizers over agricultural fields, as well as aerial photography to support both crop field mapping and growth monitoring, has been the key areas of technological innovation in the agricultural sector over the years (Mone *et al.,* 2017). Micro Air Vehicles (MAVs), fixed-wing or rotary-winged helicopters with a low cost, low speed, low ceiling altitude, lightweight, and a low payload weight with a short endurance duration, make up the majority of agricultural UAS. Because the majority of farming applications only require low-to-medium endurance, the majority of UAS are either gasoline- or methanol-fueled or electric-powered, requiring rechargeable batteries or solar power.

It is crucial to note that while UAS (which use rechargeable batteries) are primarily used for short endurance runs, solar-powered UAS can last for extended periods. For example, a UAS that has been modified for pesticide spraying has a greater payload weight requirement, allowing it to support longer flight endurance (Pathak *et al.,* 2018). The airborne application of water, fertilizer, and pesticides for small-scale farms is a less investigated field in the agricultural uses of UAS. Farmers who want to boost their agricultural yields must use water, fertilizers, and pesticides properly. While the aerial application has been demonstrated to be beneficial for large-scale farmers, it can be ineffectual and time-consuming in small-scale production systems like those found in the majority of poor countries, such as Africa. It's worth noting, however, that the UAS's benefits over existing technologies are based on their maneuverability, cheap operating costs, safety, and precision.

With the invention of the Remote-Controlled Aerial Spraying System (RCASS) by Yamaha Motor Corporation in 1983, Japan became the first country to attempt to employ drones for aerial fertilizer application. It helped enhance the yields of Japan's rice, soybean, and wheat crops by allowing them to successfully utilize drones to eliminate pests that could have harmed total production. Yamaha created the R50 UAS helicopter in 1990, with a payload capacity of 44 pounds. The R-MAX (unmanned helicopter) was developed after that in 1997, and by 2000, it had been equipped with an azimuth and Differential Global Positioning System (DGPS) sensor system (Sadeghi *et al.,* 2015). Currently, 90% of crop protection in Japan is performed through the use of drones, which has made pest control easier in the country. Drones can be utilized efficiently for pesticide spraying and fertilizer application for the majority of African farms, as demonstrated by the instance of Japanese farms. The reason for this is that the farm size per farmer in the two regions is comparable. The average farm size in Japan is 3.7 acres, while it is 2 acres in Africa. In farms with narrow rows of crops and relatively hilly terrain, the aerial application of water, fertilizers, and pesticides is seen as highly beneficial, as these can be obstacles for tractors. The UAS can be used for aerial spraying in insect-infested areas, especially for eradicating mosquitoes and tsetse flies.

Drones in Precision Agriculture

Precision agriculture is essentially a data-driven agricultural management and productivity optimization approach. Precision agriculture enables farmers to leverage data to better target inputs and avoid wastage. As such, precision agriculture involves the following:

i. Measuring and determining variability and levels of variability in farms
ii. Applying controlled inputs to different sections of the farm due to variability
iii. Measuring results and returns

Each of the aforementioned steps involves activities in which drones have found vast applications over the years. Drones are now retrofitted with several measurements and testing probes as well as a camera for surveying and mapping and extracting relevant information about the soil or crops. Daponte et al., (2019), stated that multispectral cameras are often fitted to drones for monitoring the state of vegetation. The researcher noted that the parameters measured included the following:

i. Chlorophyll content
ii. Leaf water content
iii. Leaf area index (LAI)
iv. Normalized Difference Vegetation Index (NDVI).

Daponte et al., (2019), also noted that RGB cameras and LiDAR systems are usually fitted on drones to digitize the terrain surface and provide a Digital Terrain Model (DTM).

Huuskonen & Oksanen, (2018), discussed the adoption of drones in soil sampling, noting that it is imperative to gather information for making proper decisions regarding the fertilization of fields. The researchers also noted that augmented reality (AR) has been integrated into several drones' solutions to ease the collection of soil samples; wearable augmented reality glasses and headsets are gradually becoming quite popular, and they help farmers add visual marks to GPS points for the correct collection of samples as illustrated in Figure 2.

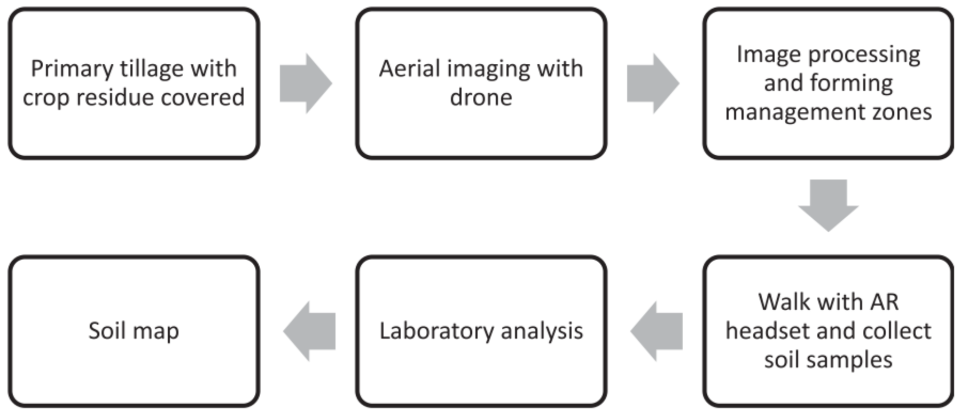


Figure 2*:* Block diagram of Soil Sampling with drones and Augmented Reality
Source: Huuskonen & Oksanen, (2018)

In a similar application, Fanigliulo et al., (2020), discussed the usage of drones in assessing soil tillage parameters, such as cloddiness and surface roughness produced by the tillage tool, to obtain precise information on the quality of the soil.

Sugiura et al. (2003) created maps of field information such as crop status and land topographical features using an image sensor and laser range finder placed on an unmanned helicopter. Even in the presence of vegetative coverings, Archer *et al*. (2004) constructed a microwave autonomous copter system for detecting the temporal changes of soil moisture as a function of depth. Khan et al. (2012) showed how UAV sensors may be utilized for satellite validation in the atmospheric boundary layer, horizontal and vertical mapping of local contaminants and greenhouse gases, and understanding carbon uptake in a forest canopy. Patel *et al*., (2013), created a unique quadcopter that uses an infrared camera to survey an agricultural farm and illustrate the difference between sick or diseased crops and matured crops as shown in Figure 3.

In outdoor conditions, Verbeke *et al*. (2014) tested a unique compound multi-copter for checking fruit orchards and vineyards while flying in between the trees. Researchers have conducted several studies and research applications involving multi-copter modelling, design, and control, and various solutions have been presented in the literature (Saha *et al.,* 2018). Only two highly intriguing studies are mentioned. Achtelik et al. (2011) demonstrated the indefinite flight time of a quadcopter using a technique based on an infrared laser system that converts the laser beam back to electrical energy. The multiple processes of designing and testing a quadcopter are described by (Raza, 2010). They devised and implemented a fuzzy logic controller as part of their research.

Figure 3: Rotary Copter Drone and Fixed Wing Drone being operated on the Field
Source:(Puri *et al.,* 2017)

Murugan *et al.,* 2016 proposed a method for monitoring precision agriculture. Using data from the satellite and the drone, it can discern between a sparse and crowded area. This method uses image statistics from a region to help reduce drone activity.

The popularity of drones in agriculture was highlighted by Paolo *et al.*, 2015. Various ploughing techniques can be recognized using an RGB-D sensor linked to the drone. To distinguish between the ploughed fields, two separate algorithms are applied.

Rodrigo *et a*l., (2017) discussed an Internet of Things (IoT) device that is used to track several agricultural metrics. The gadget measures soil temperature, humidity, and wetness using a network of sensors. The experiment was conducted in Sao Paulo, Brazil. Reference climatic data was gathered to inform various crop life and sustainability decisions.

Yallappa *et al.* (2017) proposed the creation of a drone that may be used to spray crops with essential chemicals. Pesticide application costs are reduced as a result of this. Six BLDC motors are supposed to be used in the planned sprayer. The insecticide solution was held in a conical chamber with a capacity of 5 litres. Four nozzles were employed to pressurize the solution into small droplets using a DC motor and a pump. A transmitter at ground level was used to regulate the entire process. The live spraying procedure was monitored via a camera.

Over the years, drones have proven to be quite invaluable in precision agricultural practices, and this has undoubtedly birthed a plethora of research on diverse opportunities and applications of drones in optimizing agricultural inputs and, consequently, yield. This research work focuses on the development of a quadcopter with an integrated fertilizer application unit and an integrated camera system for precision agricultural operations.

2. Materials and Methods

In order to understand the dynamics of the quadcopter to be deployed for precision agriculture purposes, the mathematical modelling needed for the development of the drone is as discussed in the following subsection.

2.1 CAD Modelling of the Quadcopter

CAD (Computer-Aided Design) modeling was employed to create a comprehensive digital representation of the quadcopter, enabling the design and visualization of its structure and components before physical assembly. This process facilitated meticulous planning and optimization, ensuring a precise fit and functionality.

The CAD model of the quadcopter commenced with the definition of its overall dimensions and shape. Considering the utilization of wood as the primary material, a 3D model of the frame structure was developed, incorporating essential supports, joints, and attachment points for other components.

Subsequently, each individual component was added to the model, strategically positioned within the frame structure. This encompassed the battery, pump, tank, flight controller, radio, power distribution board, cables, wires, connectors, electronic speed controllers, cameras, balance charger, three-axis gimbal, Android tablets, video transmitter and receiver, and other necessary elements.

The accurate modeling of each component was considered with its physical dimensions, shape, and placement within the quadcopter. The CAD software facilitated virtual manipulation and assembly, ensuring proper integration without any interferences.

2.2 Design Model

The design model was based on the conceptual design of the 5 kg quadcopter frame, which is as shown in Figure 4.

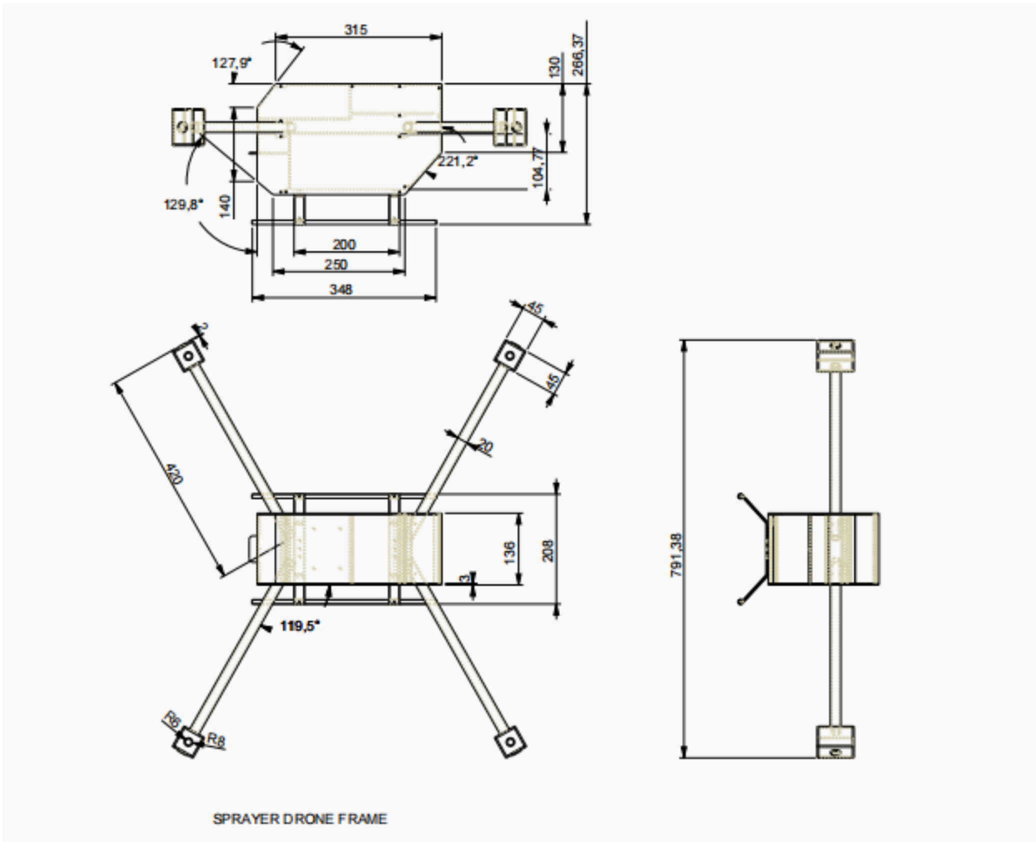


Figure 4. CAD concept of the quadcopter frame

2.2.1 Mathematical Model

The modelling of the quadcopter was majorly on the consideration of its structural frame and the degree of freedom determination needed for the effective functionality.

a. Absolute linear position of the inertia frame, (ξ) is as expressed in equation (1)

$$(\xi) = x, y, z$$

$$\xi = \begin{bmatrix} x \\ y \\ z \end{bmatrix} \qquad (1)$$

The altitude, i.e., angular position, is defined in the inertia frame using 3 Euler angles

$(\eta) = \phi, \theta, \varphi$ as expressed in equation (2).

Where θ= Pitch angle <rotation around y-axis>

ϕ= Roll angle <rotation around x-axis>

φ= yaw angle <rotation around z-axis>

$$\eta = \begin{bmatrix} \phi \\ \theta \\ \varphi \end{bmatrix} \qquad (2)$$

Considering the linear and angular positioning of the quadcopter, the vector (q), resulting from the combination of equations (1) and (2), gives equation (3)

$$\Sigma = \begin{bmatrix} x \\ y \\ z \end{bmatrix} \; ; \; \eta = \begin{bmatrix} \phi \\ \theta \\ \varphi \end{bmatrix} \; ; q = \begin{bmatrix} \xi \\ \eta \end{bmatrix} \qquad (3)$$

Assuming the body frame is at the quadcopter center of mass, this implies that the body frame linear velocity (V_b) and the frame angular velocity (V) are modeled as equations (4) and (5) respectively.

$$(V_b) = \begin{bmatrix} V_x, B \\ V_y, B \\ V_z, B \end{bmatrix} \qquad (4)$$

$$(V) = \begin{bmatrix} p \\ q \\ r \end{bmatrix} \qquad (5)$$

b. Quadcopter Degree of Freedom

The quadcopter degree of freedom, which is the number of independent quantities that uniquely specify the system location, is determined using Figure 5.

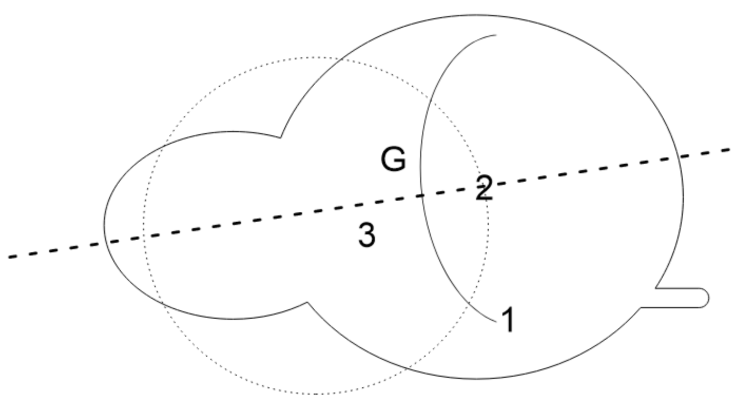


Figure 5*:* Rigid Body

With the notations in Figure 4, the degree of freedom is computed thus:

The fixed space x, y, z has 3 degrees of freedom (DOF);

The imagined sphere, which is free with its radius starting at point 3, has 2 DOF, which are ϕ, φ;

Then, the observed round circular shape is assigned 1 DOF, which is θ.

Therefore, the total DOF equals six (6)

2.2.2 Euler Angles and their Determination

Euler angles are used to describe the orientation of a rigid body. Hence, they form the generalized coordinates for a rigid body motion with course path orientation changes as sketched in Figure 6.

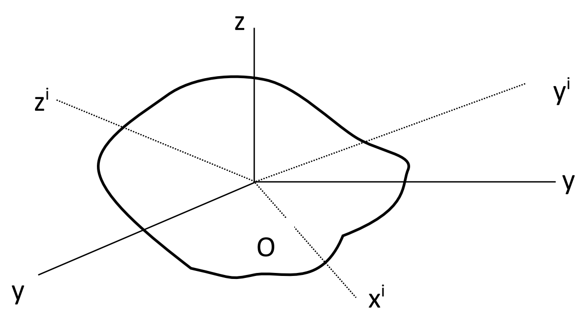


Figure 6: Rigid Body Coordinate

With reference to Figure 6, The sketch *is defined to have the following attributes:*

Point 0 = Fixed

Space coordinates = x y z

Body coordinates based on rotation = $x'\ y'\ z'$

Subsequently, x-y plane and $x' - y'$ plane will intersect, and the plane of intersection is known as the <u>Line of nodes.</u>

To determine the Euler angles for the drone system, the procedures involved are as follows:

i. Drawing of the x-y plane and $x'\ y'$plane with a dot. This is as shown in **Figure 7**

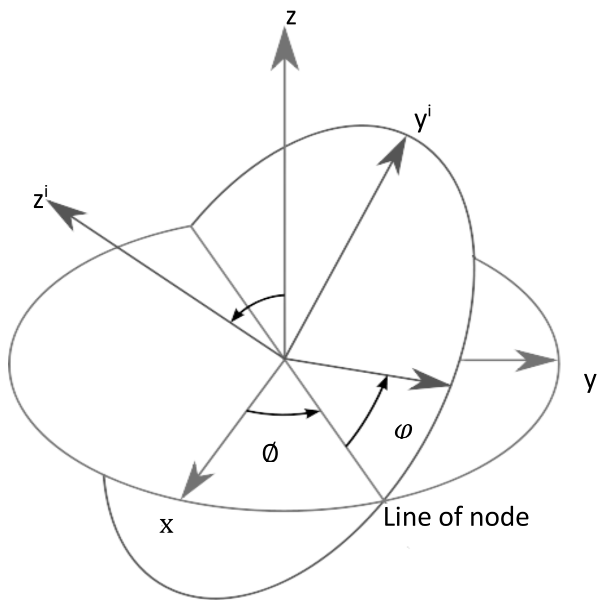


Figure 7. Rigid body plane

ii. Mapping of x, y, and z is contained in equation (6), while the actions involved in the analysis are explained subsequently with reference to Figure 7.

$$\textit{The task is to bring} \quad \begin{matrix} x \to x' \\ y \to y' \\ z \to z' \end{matrix} \qquad (6)$$

1) Moving of x → x'; this is done by taking $x \to line$ of node through rotating the z-axis by ϕ amount. By so doing, <line of node & x> ⊥ to the Z rotation about Z
2) Moving of z to z' is achieved by rotating the system about the line of the node, because the node's line is in the x-z plane at an angle θ

   Note: z & z' are ⊥to the line of the node, hence rotating about it.
3) Taking x from the line of the node to x' by φ, x is now positioned @ x', y also will arrive @ y' due to the angular rotation. This rotation is above z', because it is in the x' y' z' plane and making it (perpendicular to) ⊥ y' & x'>

Hence, $\phi, \theta, \varphi = Euler\ angles$

Once these three are specified, the drone's location or orientation could be specified.

2.2.3. **Orientation of a rigid body description using Euler angles**

To construct the matrix A, which takes the system orientation to $t = 0 \rightarrow t = t$, the following computational case study of the assumption of having a fixed point at: $\phi\ rotation\ z_{axis}$; $\theta\ about\ x_{axis}$; and $\varphi\ rotation\ z_{axis}$ was used.

Using the matrix formulation, with A being the rotation matrix which takes the quadcopter from the body frame to the inertia frame as $x'\ y'\ z'$, assumes to be the position / body orientation, the equations (7) and (8) were thus established.

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = \begin{pmatrix} C\varphi & S\varphi & 0 \\ -S\varphi & C\varphi & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & C\theta & S\theta \\ 0 & -S\theta & C\theta \end{pmatrix} \begin{pmatrix} C\phi & S\varphi & 0 \\ -S\varphi & C\phi & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} \quad (7)$$

$$A = \begin{pmatrix} C\varphi C\phi - C\theta S\phi S\varphi & C\varphi S\varphi + C\theta C\varphi S\varphi & S\varphi S\theta \\ -S\varphi C\phi - C\theta S\phi C\varphi & -S\varphi S\varphi + C\theta C\varphi C\varphi & C\varphi S\theta \\ S\theta S\phi & -S\theta C\phi & C\theta \end{pmatrix} \quad (8)$$

To check equation 8, all angles were assumed to be zero, thus resulting in the unit matrix of equations (9) and (10).

$$A = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} = \text{Unit matrix} \quad (9)$$

$\sin\theta, \sin\theta = 0, \cos\theta = 0$

Which infers that <Given $\theta\varphi\phi = 0$>

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix}\ i.e \begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} x \\ y \\ z \end{pmatrix} \quad (10)$$

But with Euler angles, the new orientation $x'y'z'$ will not be different, nor will its unit matrix.

Since the system body is symmetrical along the x and y axes, the inertia matrix of equation (11) is thus arrived at.

$$I = \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \quad (11)$$

where $I_{xx} = I_{yy}$

Similarly, the modelling of its force and torque components is as derived using the principal formula of equation (12).

$$F_i = kw_i^2 \quad (12)$$

Where Force F_i is directly proportional to angular velocity, w and K is the lift constant.

The combined rotor force, T, is as expressed in equation (13)

$$T_B = \begin{bmatrix} 0 \\ 0 \\ T \end{bmatrix} \quad (13)$$

Also, if T_B is the combination of all the torques at $T\phi, T\theta, T\varphi,$ then equation (14) subsists

$$T_B = \begin{bmatrix} T\phi \\ T\theta \\ T\varphi \end{bmatrix} = \begin{bmatrix} lk(-w_2^2 + w_4^2) \\ lk(-w_1^2 + w_3^2) \\ b(w_1^2 - w_2^2 + w_3^2 - w_4^2) \end{bmatrix} \quad (14)$$

Where b is the drag constant, l is the distance between the rotation and $w_n\eta$ is the angular velocity.

2.2.4. Design for Drone's Altitude of Flight and Angular Acceleration

To define the altitude of flight, the angular position is used as the basis, which is factored on the inertia positions of the 3 Euler angles, ϕ, θ, and φ, which are relatively connected as expressed in equation (15)

$$\eta = \begin{bmatrix} \phi \\ \theta \\ \varphi \end{bmatrix} \quad (15)$$

Simplifying equation (15) further gives equation (16)

$$\eta = w_n^{-1}v; \begin{bmatrix} \phi \\ \theta \\ \varphi \end{bmatrix} = \begin{bmatrix} 1 & S\phi T\theta & C\phi T\theta \\ 0 & C\phi & -S\phi \\ 0 & S\varphi C\theta & C\phi C\theta \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} \quad (14)$$

Therefore,the body frame velocity, which is the angular velocity (v), is as expressed in equation (15)

$$\text{v} = w_n\eta; \begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} 1 & 0 & -S\theta \\ 0 & C\phi & C\theta S\phi \\ 0 & -S\phi & C\theta C\phi \end{bmatrix} \begin{bmatrix} \phi \\ \theta \\ \varphi \end{bmatrix} \quad (15)$$

For the acceleration of the drone to be determined, the rotational matrix, R, the body frame torque, T_B, and the gravitational force, G, were modeled based on the generic equation (16) to give equation (17).

$$m\Sigma = G + RT_B \quad (16)$$

$$\Sigma = \begin{bmatrix} \ddot{x} \\ \ddot{y} \\ \ddot{z} \end{bmatrix} = -g \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} + \frac{T}{M} \begin{bmatrix} C\varphi S\theta C\varphi + S\varphi S\phi \\ S\varphi S\theta C\varphi - C\varphi S\varphi \\ C\theta C\theta \end{bmatrix} \quad (17)$$

By differentiating equation (14), the resulting equation, which is the angular acceleration, is as expressed in equation (18).

$$\eta = \frac{d}{dt}(w_n^{-1}v) = \frac{d}{dt}(w_n^{-1})v + w_n^{-1}v$$

$$= \begin{bmatrix} 0 & \phi C\phi T\theta + \theta S\phi / C_\theta^2 & -\phi S\phi C\theta + \theta C\phi / C_\theta^2 \\ 0 & -\phi S\phi & -\phi C\phi \\ 0 & \phi C\phi / C\phi + S\varphi T\theta / C\theta & -\phi S\phi / C\theta + \theta C\phi T\theta / C\theta \end{bmatrix} V + w_n^{-1}v \qquad (18)$$

2.3 Simulation and Computer Modelling

MATLAB simulation was used to test the control system of the quadcopter and adjust the parameters accordingly. The quadcopter was modeled as a rigid body with six degrees of freedom, including three translational and three rotational motions.

In the next step, the parameters of the quadcopter were defined. These parameters, such as the mass of the quadcopter, moments of inertia around the body axes, distances of the rotors from the center of mass, and gravitational acceleration, were specified to accurately represent the quadcopter's mechanical system.

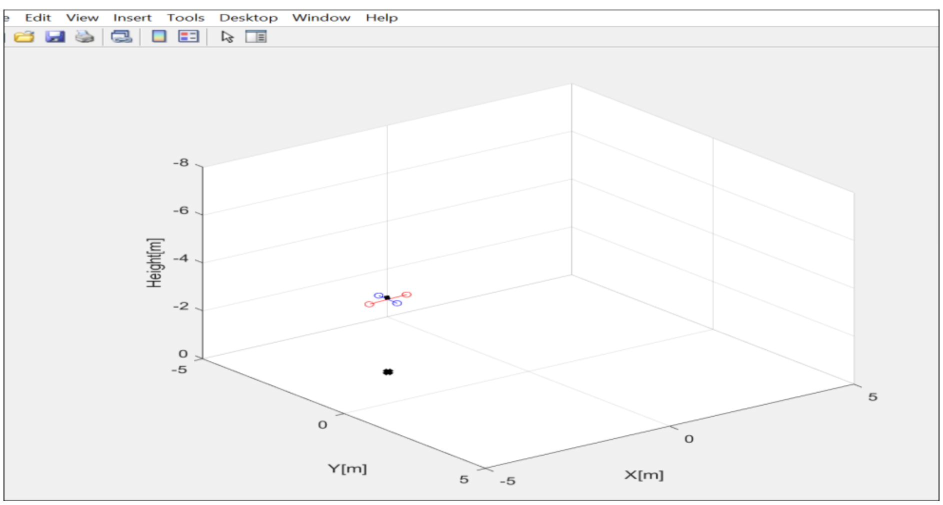


Figure 8: Simulated Quadcopter Trajectory

After defining the parameters, the quadcopter dynamics were implemented in the simulation. This involved incorporating the translational and rotational dynamics. The translational dynamics accounted for the forces exerted on the quadcopter due to the thrust generated by the rotors, while the rotational dynamics considered the torques produced by the rotors. These dynamics were essential for modeling the quadcopter's motion and behavior accurately.

3. Results and Discussion

After running the simulation, the results were analyzed to gain a deeper understanding of the quadcopter's behavior under various control inputs. The response of the quadcopter to different control inputs was observed and examined to assess its stability and performance. By studying the system's stability as shown in Figure 9, valuable insights were obtained regarding the quadcopter's ability to maintain its desired state or trajectory.

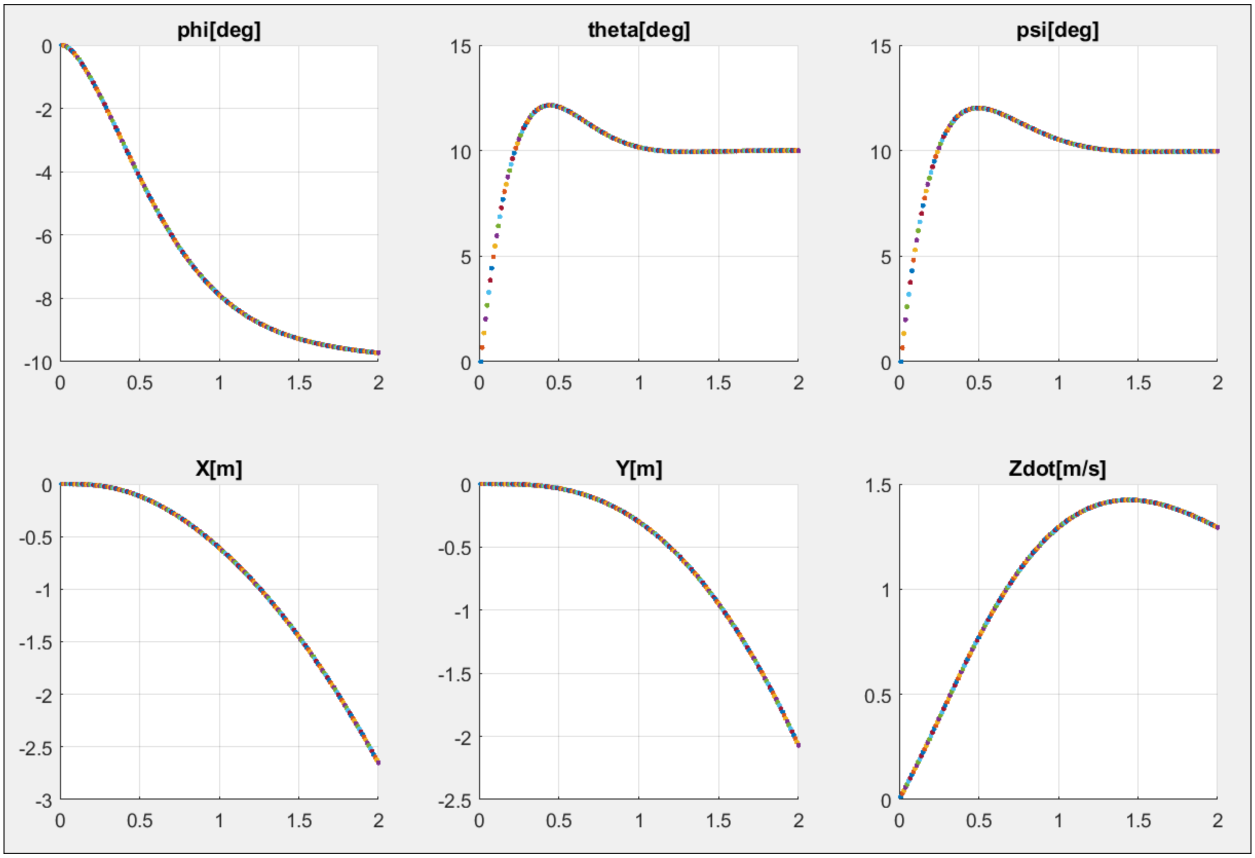


Figure 9: Simulated Body Frame Stability based on Encoded PID Values

Based on the findings from the analysis, improvements and modifications to the control system were identified to enhance the quadcopter's performance. These insights were used to fine-tune the control parameters, adjust the controller algorithms, or implement additional control mechanisms to overcome any limitations or shortcomings observed during the analysis. By iteratively refining the control system based on the analysis results, the overall performance of the quadcopter was improved, ensuring more precise and stable flight characteristics.

3.2 Discussion of Results

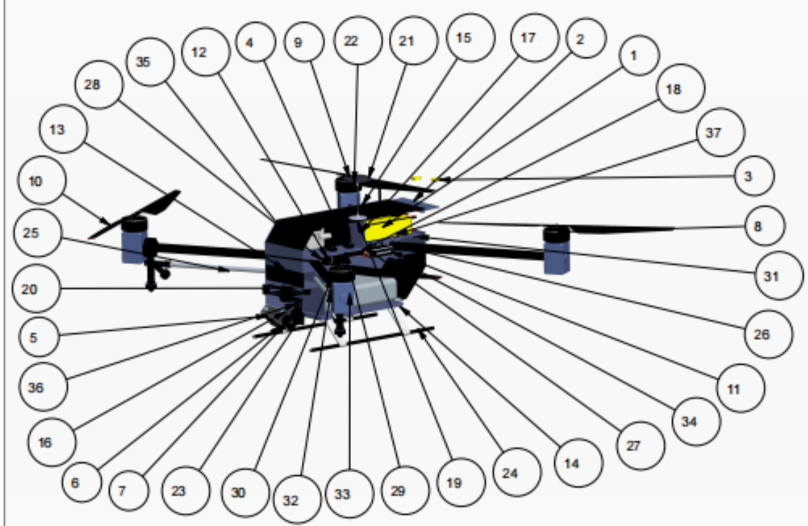
Following the initial round of testing and calibration of the assembled quadcopter, it was observed that the quadcopter was struggling to achieve lift-off. A number of potential issues were identified that could have led to this problem.

One of the primary challenges encountered was the issue of an imbalanced arm. The quadcopter's stability is significantly dependent on the symmetrical distribution of weight and equal arm dimensioning. Even a minor imbalance can affect the lift-off and stability of the quadcopter in flight. An error in arm dimensioning could have led to an imbalance plane and thus a struggle to achieve lift.

Furthermore, there were possible issues associated with the brushless motors. Brushless motors are an integral part of a quadcopter, providing the necessary thrust for lift-off and maintaining stable flight. However, a malfunctioning motor can significantly impact the quadcopter's performance. Problems such as inconsistent speed control, wear and tear, or overheating could potentially affect the motor's performance and, in turn, the quadcopter's ability to lift-off.

In addition to these, inadequate calibration could have also contributed to the problem. Calibration plays a crucial role in ensuring the quadcopter responds appropriately to control inputs. Incorrect calibration could lead to unstable or unexpected behaviors.

The resulting completed drone is as shown in Figure 10.



S/N	PART	QTY
1	ANTENNA	1
2	BATTERTTRAY_COVER	1
3	BATTERY_CONNECTOR_ASSEMBLY	1
4	BATTER_PACK_ASSEMBLY	1
5	CAMERA1	1
6	CAMERA2	1
7	CAMERA2_HOLDER	1
8	DRONE_PART_04_MOTOR	4
9	DRONE_PART_05_PROPELLER	2
10	DRONE_PART_05_PROPELLER_CW	2
11	ESC	4
12	FLIGHT_CONTROLLER	1
13	FRAME_FRONT_COVER	1
14	FRAME_PART1	1
15	FRAME_PART1B	1
16	FRAME_PART2_BASE_PLATE	1
17	FRAME_PART_BATTERY_PLATE	1
18	FRAME_PART_MID_PLATE	1
19	FRAME_PART_TOP_PLATE	1
20	GIMBAL_ASSEMBLY	1
21	GPS	1
22	GPS_STALK	1
23	LANDING_SKID	2
24	LANDING_SKID_2	2
25	PIPE	2
26	POWER_DB	1
27	POWER_MODULE	1
28	PUMP_CONTROLLER	1
29	RECEIVER	1
30	ROTOR_ARM	4
31	SAFTY_SWITCH	1
32	SPRAYER_NOZZLE	2
33	SPRAYER_NOZZLE2	2
34	SPRAYTANK_COVER	1
35	SPRAY_PUMP	1
36	TANK	1
37	VTX	1

Figure 10. The 3-D model of the 5 kg quadcopter

4. Conclusion

The modeling of a 7 kg quadcopter has been discussed. The quadcopter developed has dimensions of 1140.28 mm by 767.11 mm by 267.37 mm, and each of the four propellers has a length of 457.2 mm. The simulation result was quite encouraging as the discharging rate of fluid for agricultural application was even. However, some flaws such as the improper attachment of propellers or inaccurate motor alignment are observed in the assembly of the quadcopter, which led to the low efficiency of the operation of the quadcopter. Further work will leverage these flaws to improve its stability and lift-off.

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