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QUADCOPTER PROTOTYPE STABILITY ANALYSIS USING MATLAB SIMSCAPE LIBRARY

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Abstract. ***Nowadays, the use of quadcopters in daily life has become important due to its capabilities and ability to carry out many tasks in many fields like civil, military, industrial, and agricultural fields. The modelling of the quadcopter and deeply understanding its movements is very important to ensure that the simulations of its behaviour are as close as possible to reality and also helps us to design a flight controller. In this work, we used a modern technique on MATLAB (Simscape) to simulate a quadcopter in real-time. At first, we build a quadcopter using Simscape multibody then we simulated the PID regulator, the command algorithms, and the motor model with the applied forces on the body to achieve the global model that we can use to study the movement of the quadcopter on the three-axis which ensure a stable functioning. The results obtained show the stability of the four movements of the quadcopter (roll, pitch, yaw, and altitude).***

Keywords: Quadcopter, Electrical model, PID regulator, Simscape, Stability.

1. INTRODUCTION

Nowadays, with the incredible development of technology, especially electronics and computer science, which led to appear powerful microcontrollers and powerful software, this is what helped people to increase the performance of drones from both sides: software, and hardware. Some important applications of this aircraft are that it can be used in the army, entertainment, surveillance, aerial photography, agriculture, and transportation, where individual goods can be transported too anywhere. The irrigation has become more efficient when using drones to be watering, monitoring fields and detects water pooling or leaks using thermal cameras.

Quadcopters have a different behaviour from other planes, as they have four movements resulting from the rotation of four engines in diverse ways. To obtain a vertical movement, all the engines must rotate at the same speed. As for the other movements there are two types of quadcopters (+ and x), and each type has its own way of controlling [1].

The control of the quadcopter depends mainly on its stability [2-3]. Where a special control unit is designed based on the basic movements made by the aircraft during flight. These movements are controlled by special propellers that produce forces and this shows that the aerodynamic properties of the aircraft are very important as many researchers have studied these properties in depth [4]. In addition to the mechanical vibration characteristics of the propellers which help the quadcopter to fly safely in optimal conditions [5].

Ensuring drone stability is an important task for ensure a safety flying. So, to stabilize a quadcopter there are many different regulators used. The most important and widely used regulators in the field of drones are: PID and LQR [6-7]. In addition, other different hybrid regulators can be used (P-LQR, PD-LQR and PD2-LQR) [8]. However, the PID has the ability to correct the error and apply accurate and optimal control using three control terms: proportional, integral and derivative. As for the LQR is a method that used to find the optimal control action that ensure a high stability and performance to the system by reducing the cost J value using two matrices Q and R, where Q is a square matrix with rows equal the number of states, and R is square matrix with rows equal to the number of inputs. Also, many artificial intelligent techniques based on Artificial Neural Networks (ANN) are used for improving the response of the PID regulator and make the system more reliable [9-10].

To develop a quadcopter model under MATLAB (Simulink), it is important to understand the quadcopter behaviour and its movements (Altitude, Roll, Pitch, and Yaw). In addition to understand the relation between the different equations, there are different ways to simulate a quadcopter model on MATLAB. The different mathematical equations of a quadcopter can be used to create a Simulink model in several ways [11-12]. A mechanical model can be developed based on Simscape Multibody library with the help of an electric library to simulate the motors [13].

In this work, we studied the x-type, where in this type we can control the three movements (roll, pitch, yaw) through pairs of motors. Firstly, to achieve a roll movement, the speed of the two motors on the left must be increased, and the speed of the two motors on the right must be decreased. This applies torque around the x-axis to obtain a rotational

movement this movement is coupled with a translational movement along the y-axis. Secondly, to achieve a pitch movement, the speed of the two motors on the front must be increased, and the speed of the two motors on the back must be decreased. This applies torque around the y-axis to obtain a rotational movement this movement is coupled with a translational movement along the x-axis. Finally, the yaw movement can be produced when the two diagonal motors rotate clockwise while the other two diagonal motors rotate counter clock wise. The main objective of the simulation in MATLAB using Simscape library is to study the aircraft performance in a better efficiency, where we can achieve and control the aircraft stability in its four basic movements.

2. EQUATIONS AND METRICS

2.1 The equations used in the model.

To calculate the forces on the three axes generated by each motor, the following equations are used:

$$F_{xx} = TF * \sin(y) \quad (1)$$

$$F_{yy} = TF * \sin(x) \quad (2)$$

$$F_z = \sqrt{((TF * \cos(x))^2 + ((TF * \cos(y))^2} \quad (3)$$

To calculate the thrust force the equation (4) is used:

$$Thrust = D^3 * Pitch * RPM^2 * 10^{-10} \quad (4)$$

2.2 Command Algorithms

$$MM_{11} = TT + RR + PP - YY \quad (5)$$
$$MM_{22} = TT - RR + PP + YY \quad (6)$$
$$MM_{33} = TT - RR - PP - YY \quad (7)$$
$$MM_{44} = TT + RR - PP + YY \quad (8)$$

2.3 PID Equation

The PID regulator, also called PID corrector (proportional, integral, derivative) is a control system that improves the systems performance.

The following equation shows the PID command:

$$KK_{yy}(tt) = KK_{pp}\, ee(tt) + KK_{ii} \int ee(tt)\,ddtt + KK_{dd} \frac{dddd}{dddd} \quad (9)$$

After studying and improving the system, we were able to obtain the constants shown in (Table 1), which are the right values for the stability of the system.

Table 1. PID coefficients

PID	Coefficients		
	K_p	K_i	K_d
Roll	0.5	0.4	0.5
Pitch	0.5	0.4	0.5
Yaw	1	0.5	0.9
Altitude	0.2	0.2	0.1

In Table 2, mechanics parameters and metrics are presented.

Table 2. Mechanics parameters and metrics

Parameters	Value / Units
Weight of drone (m)	0.49 (kg)
Speed of motor	(RPM)
Propellers size	D/Pitch –08/4.5 (inches)
Thrust-ForceTF, Fx, Fy, and Fz	one force(Oz), and Newton (N)
x, y, z	Meter (m)
Ix, Iy, Iz	[0.00266, 0.00266, 0.0027] ($kg.m^2$)
Angles (roll, pitch, yaw)	(rad)
Speed	(m/s)
Mi	motors
T, R, P, Y	(Thrust, Roll, Pitch, Yaw)

3. SIMULATION

Computer or digital simulation refers to executing a computer program to simulate a real and complex physical phenomenon. So, a built in Simscape library under MATLAB used to simulate a prototype of quadcopter. The figures below show the important blocks and the global model.

To study the stability of the quadcopter, the regulator PID is used with the model. Each movement has a specific regulator (Figure 1).

- Roll PID regulator.
- Pitch PID regulator
- Yaw PID regulator
- Altitude PID regulator

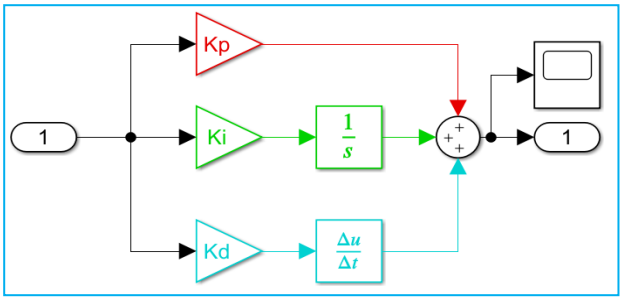


Figure 1. PID regulator model for each movement

Each motor must have a model (electrical model) using electrical tools under Simscape library as shown in the (Figure 2).

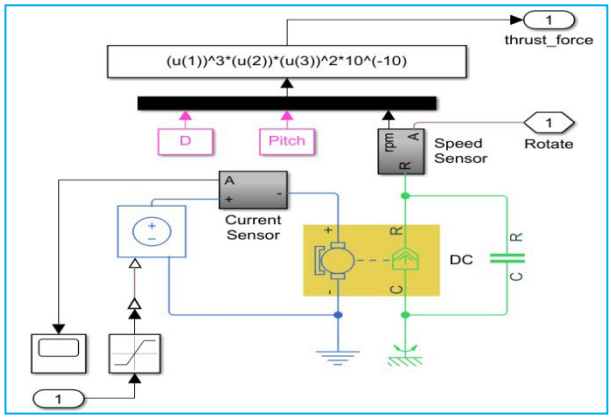


Figure 2. Brushless Direct Current motor (BLDC) motor model

Figure 3 shows how the control commands are linked to control the four movements of the quadcopter, each character for a specific motor (U, L, D, R).

After we calculate the thrust of each motor, we must calculate the force along of each axis. From Figure 4, we see how the forces along of the three axes can be calculated.

The software SolidWorks is used to design the quadcopter structure. At first, the base plate is simulated, arms to support motors then the propellers blades and motors. After that the model is uploaded on MATLAB as shown in the (Figure 5).

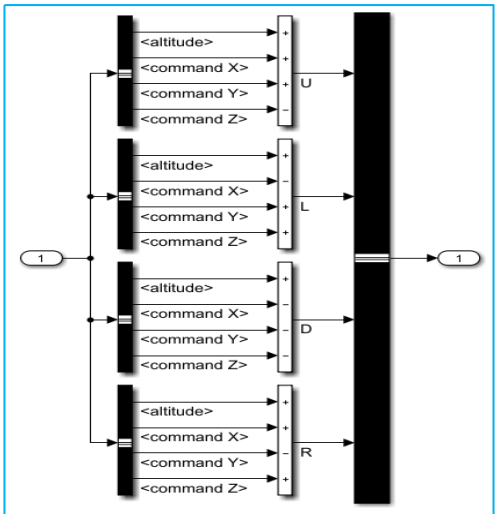


Figure 3. Command Algorithms model

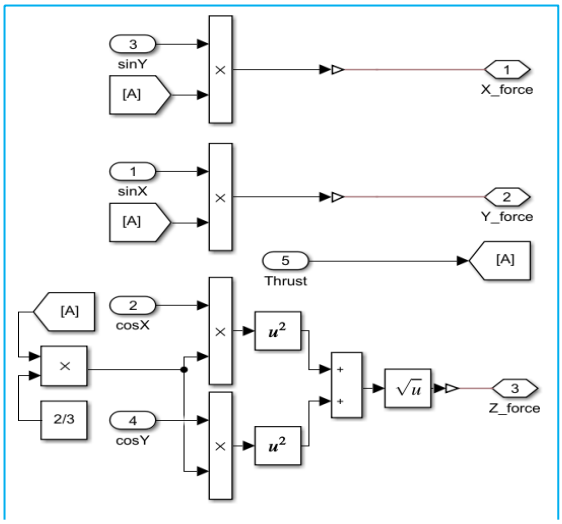


Figure 4. Forces along of the three axes (x, y, and z)

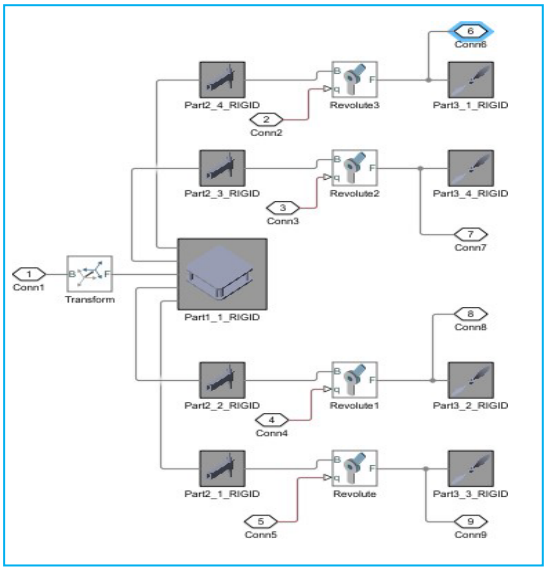


Figure 5. Quadcopter structure model using Simscape multibody.

Figure 6 shows the quadcopter structure in the mechanics explorer under MATLAB environment:

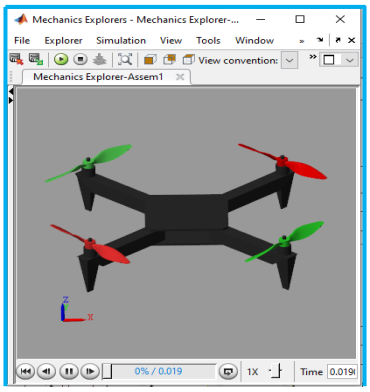


Figure 6. Quadcopter in Mechanics Explorer

To develop the global model, it is necessary to understand the behaviour of the quadcopter and its movements. It is known that the plane has six (6) degrees of freedom, but only four basic movements. So, it is easy to choose the variables that cause the quadcopter to move in different directions.

- Control the altitude along the vertical z-axis: Altitude.
- Control of rotation around the x-axis: Roll.
- Control of rotation around the y-axis: Pitch.
- Control of rotation around the z-axis: Yaw

And know the relationships between the different blocks and models of the quadcopters (regulator, motors model, command algorithms model, and forces model).

Figure 7 shows the global model of the quadcopter:

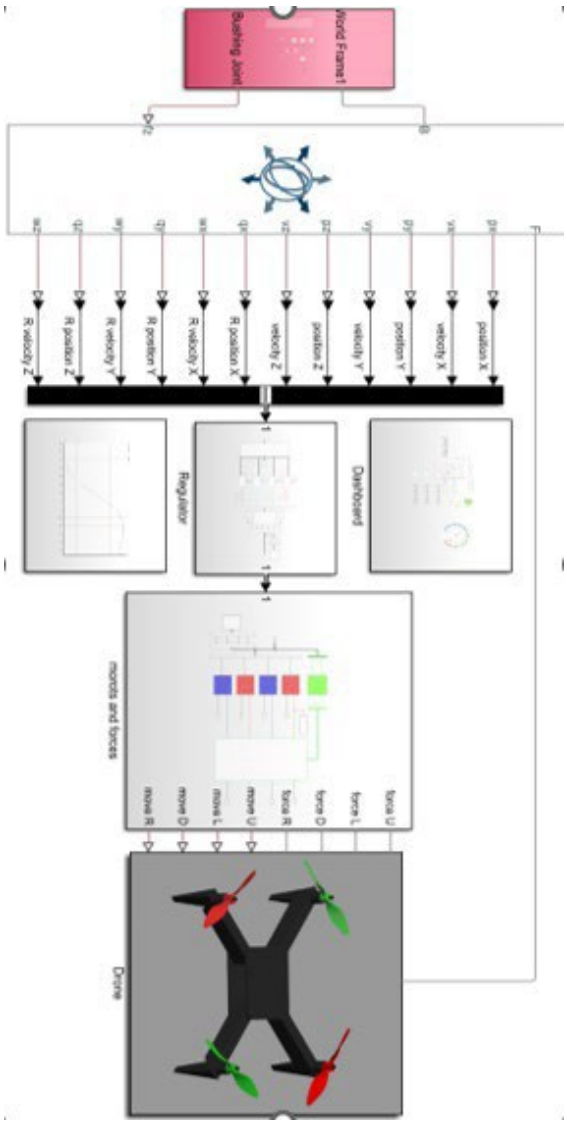


Figure 7. The quadcopter global model

4. RESULTS AND DISCUSSION

After developing the quadcopter model, the most important parameter to be studied is the aircraft stability during the performance of its four basic movements avoiding any external perturbations.

Then, the PID regulators must be tuned and adjusted. There are four movements, so we have four PID regulators. Each regulator has three constants (k_p, k_i, k_d). All these constants are adjusted until optimal stability is gotten (Table 1).

4.1 Altitude results

In order to obtain a vertical movement, it is necessary that all the lifting force is opposed to the force of gravity along the z-axis. On the other hand, the lifting force created by each motor must be the same to prevent overturning of the quadcopter. For this, the thrust produced by motors must be identical.

The up and down movement is obtained by changing the speed of motors rotation. If the thrust force is greater than the weight of the quadcopter, the movement is upward, and if it is less than the weight of the quadcopter, the movement is downward.

In the (Figure 8) we can see the stability on the z-axis. When, we give a command to the drone to climb a height of five meters, the PID regulator adjust the velocity of the quadcopter to stabilize at the given height command after about six seconds, which represent a good result compared with the literature.

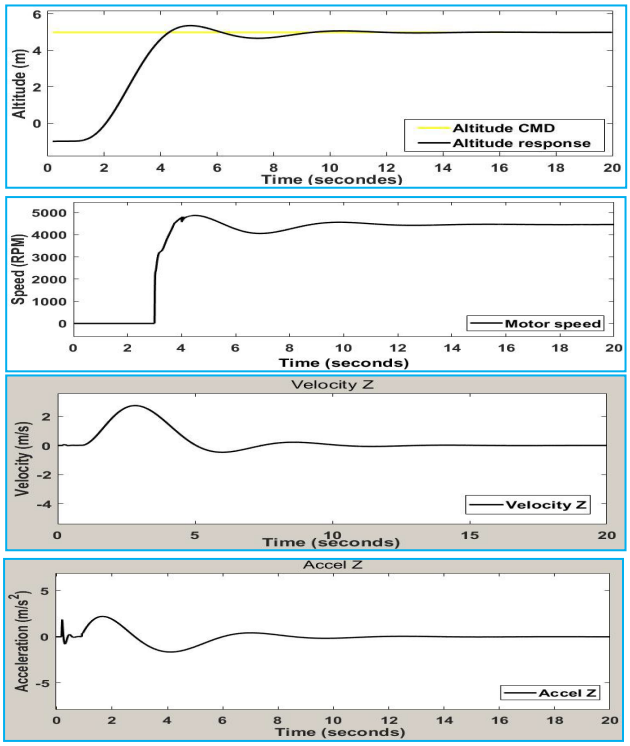
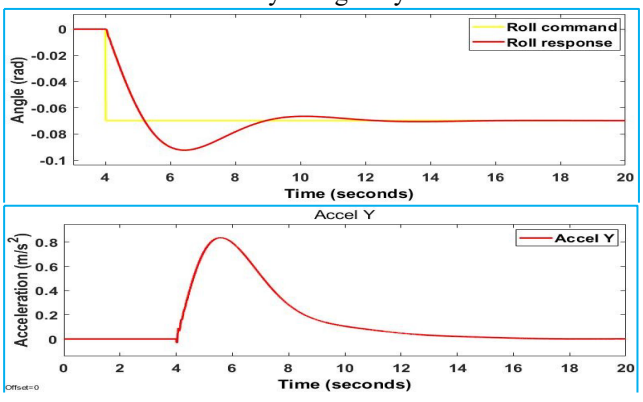


Figure 8. Altitude command and response (Altitude, Motor speed, velocity, and acceleration)

4.2 Roll results

The roll movement is done when a torque is given around the x-axis. This torque rotates the plane at a specific angle. This movement produces another movement along the y-axis. This allows the drone to go left or right.

To stabilize the movement along the y-axis, the PID parameters are tuned for the roll movement. Figure 9 shows the drone's stability along the y-axis.



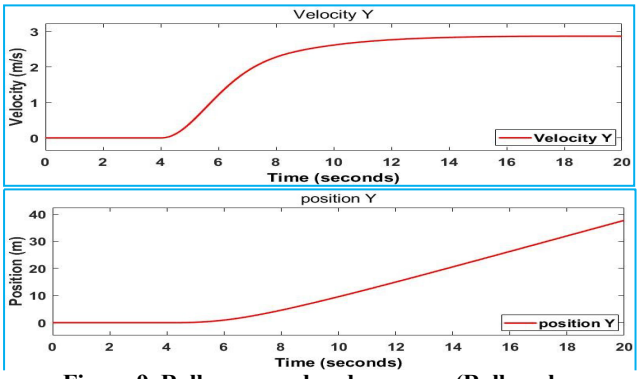


Figure 9. Roll command and response (Roll angle, acceleration, velocity, and position)

4.3 Pitch movement

This movement is similar to that of rolling. When a torque is given around the y-axis, it rotates the plane at a specific angle. This movement produces another movement along the x-axis. This allows the drone to go forward or backward. To stabilize the movement along the x-axis, the PID parameters are tuned for the Pitch movement. Figure 10 shows the drone's stability along the x-axis.

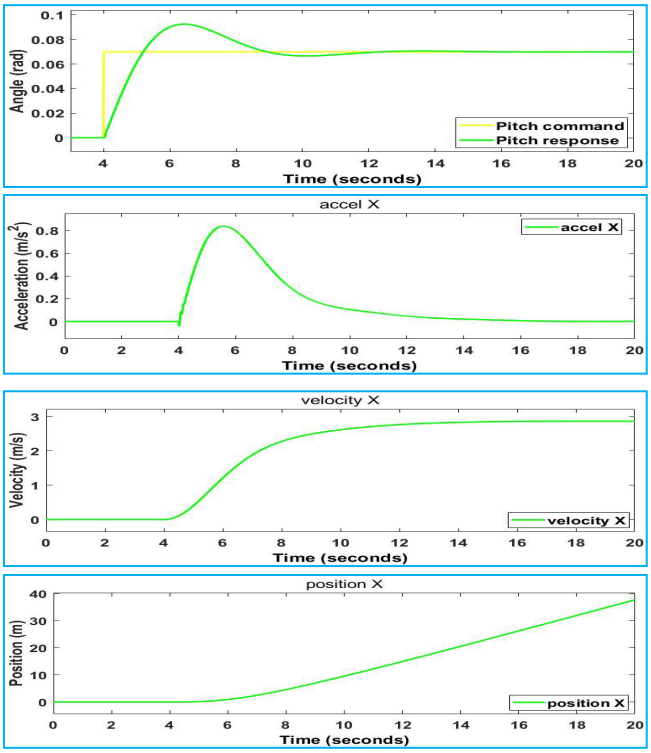


Figure 10. Pitch command and response(Pitch angle, acceleration, velocity, and position)

4.4 Yaw results

The yaw movement makes the drone change her direction. When a torque is given around the z-axis using the

diagonals motors, the torque rotates the plane at a specific angle around the z-axis. To stabilize the Yaw movement around the z-axis we have tuned the PID parameters to ensure the stabilization.

Figure 11 shows the drone's stability around the z- axis.

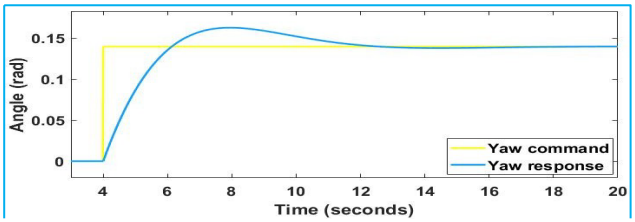


Figure 11. Yaw command and response

5. CONCLUSIONS

The Simulink quadcopter model was introduced using the Simscape library under MATLAB and a PID controller to study the stability of a quadcopter in real time. After giving the motion command and measuring the output, the output error was calculated and then adjusted the error using a PID controller. The results were transmitted through the control algorithms to the kinetic model in the form of electrical energy, which rotates the motors, the latter produces a lift force, and this force can move the quadcopter.

When we ordered the quadcopter to climb to a height of three meters, it stabilized at this height in about seven seconds which is a good result according to the proposed system in this paper and compared to the literature. Also when the quadcopter is ordered to go left or right by giving the Roll angle about six or –six degrees, it stabilized in about eight seconds which also represent a nice result. The third result of this study is when the quadcopter is ordered to go forward or backward by giving the Pitch angle about six or -six degrees, the quadcopter stabilized in about eight seconds. Finally, the quadcopter too stabilized in the yaw movement in about eight second on the one hand and in the other hand the period of time for the drone stability of was so close due to the fact that the design of the quadcopter is symmetric.

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