Preliminary Study on Unmanned Aerial Vehicle (UAV) Quadcopter Using PID Controller

Muhammad Arifudin Lukmana (*Author*)
Dept. of Mechanical Engineering
Univeritas Pembangunan Nasional Veteran Jakarta, Indonesia
arifudin@upnvj.ac.id

Hendro Nurhadi (*Author*, *IEEE member*)
Dept. of Mechanical Engineering
Institut Teknologi Sepuluh Nopember, ITS
Surabaya, Indonesia
hdnurhadi@me.its.ac.id

***Abstract*—Unmanned Aerial Vehicle (UAV) commonly used for various missions, such as aerial surveillance, remote sensing, transport or search and rescue. UAV with four propeller, known as Quadcopter, is one of UAV known for high flexibility and mobility in narrow area. This paper will study response of a quadcopter with internal disturbance for rolling, pitching, yawing and altitude. The attitude data of quadcopter are numerically simulated. After integrating PID controllers into the systems, quadcopter settling time of roll and pitch systems are 1.419 seconds, yaw system is 2.327 seconds and altitude hold system is 6.339 seconds.**

Keywords—UAV; quadcopter; stability; simulation.

I. INTRODUCTION

Most Unmanned Aerial Vehicle (UAV) used in dangerous missions, such as aerial surveillance, remote sensing, transport or search and rescue. UAV system consist of aircraft, payload and control station. Fig. 1 shows the classification of aircraft (UAV).

Compared with the other flying principles, Vertical Take-off & Landing (VTOL) systems have advantage which allow it move instantly for any direction at low speed. The blimp system also have this advantage. In blimp the key for levitating is the "autolift" and the simplicity of control which can be essential for critical applications such as space exploration [3]. However, VTOL vehicles requires more power in order to levitate and hovering. But it have more speed and most promising flying concept in terms of small size. It is essential for indoor or narrow area missions.

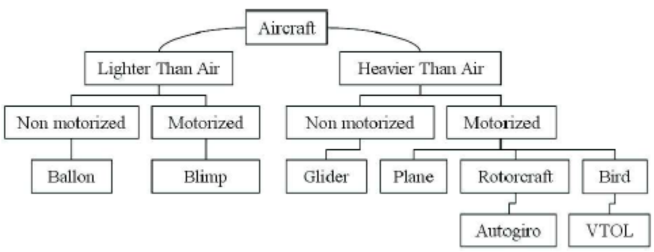

Fig. 1 Aircraft general classification depending on the flying principle and the propulsion mode[1]

II. DESIGN OF QUACOPTER

A. Quadcopter Configuration

The Quadcopter concept has been known for a long time. The variation is plus (+) or x configuration. Plus configuration movement described in figure 2, the aircraft have four propellers. The different rotational speed of two pairs of propellers (1,3) resulting pitch rotation coupled with lateral motion and it moving backward or onward (fig. 2 a-b). In the same manner, different rotational speed in propellers (2,3) make it to roll and moving to left or right (fig. 2 c-d). Fig. 2 e-f show for taking quarotor up and down. In case for yawing, propeller pair 1-3 rotate faster and 2-3 slower, causing quadcopter yawing in CCW direction (fig. 2 g).

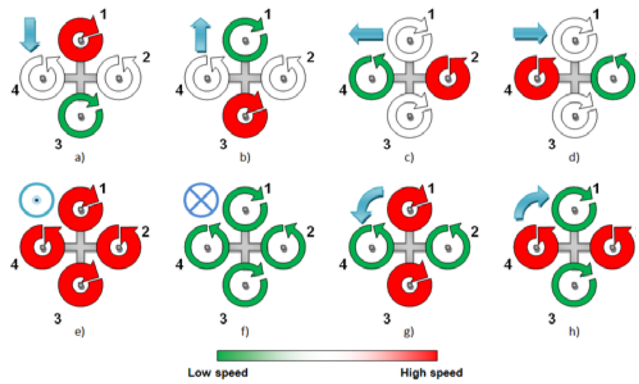

Fig. 2 Scheme of motor speed for maneuvering in plus (+) configuration

B. Physical Effect Acting on Quadcopter

- **Aerodynamic Force**

Aerodynamic forces are caused by rotational speed of propellers. The airfoil shape of spinning propeller is causing differential pressure between upper and lower. And give a lift force. The formulation of aerodynamic force is $C\Omega^2$. The force direction is parallel with propeller's shaft.

C=Constant; Ω = rotational speed of propeller

- **Inertial**

Newton's second law states the net force on an object is equal to the rate of change. Not only for linear change, but also rotational change. The formulation are $F_{inertial} = M.a$ for linear and $T = J.\alpha$ for rotational system.

Note:
M= mass; a = linear acceleration; J=inertial momentum; α = rotational acceleration

- **Gravity**

Gravity is a force caused by earth gravitational acceleration. The direction always pointing earth core. Or in this paper is downward (Z axis). The formulation is $F_{gravity} = m.g$

Note: g = Earth's gravity (9,81 m/s^2)

- **Gyroscopic effect**

Gyroscopic effect or precession is a change in the orientation of the rotational axis of a rotating body.

There are Quadcopter's equations of motion in 4 Degree of Freedom (DoF). Figure 3 shows the earth axis, frame body system axis and quadcopter configuration. The symbolic note or nomenclature are described in Table I.

$$\ddot{z} = -g + (\cos\phi\cos\theta)\frac{1}{m}U_1$$

$$\ddot{\phi} = \dot{\theta}\dot{\psi}\left(\frac{I_y - I_z}{I_x}\right) - \frac{J_r}{I_x}\dot{\theta}\Omega + \frac{l}{I_x}U_2$$

$$\ddot{\theta} = \dot{\phi}\dot{\psi}\left(\frac{I_z - I_x}{I_y}\right) + \frac{J_r}{I_y}\dot{\phi}\Omega + \frac{l}{I_y}U_3$$

$$\ddot{\psi} = \dot{\phi}\dot{\theta}\left(\frac{I_x - I_y}{I_z}\right) + \frac{1}{I_z}U_4$$

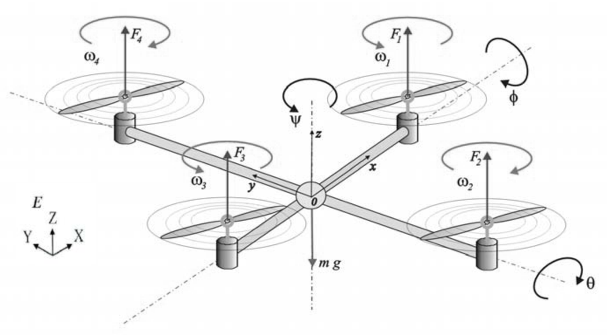

Fig. 3 Quadcopter configuration, frame body system is in x,y,z axis. And Earth axis E (X,Y,Z).

TABLE I. NOMENCLATURE

Symbol	*Definition*
Φ	Roll angle
θ	Pitch angle
Ψ	Yaw angle
Ω	rotor rotational speed
$I_{x,y,z}$	Inertial body
J_r	Inertia rotor
τ_a	Torque on airframe body
b	Thrust factor
d	drag factor
l	Arm length

Controller input for the four DoF system there are U1 for altitude, U2 for rolling, U3 for pitching and U4 for yawing. Ω is differential value of rotor rotational speed.

$$U_1 = b(\Omega_1^2 + \Omega_2^2 + \Omega_3^2 + \Omega_4^2)$$
$$U_2 = b(\Omega_4^2 - \Omega_2^2)$$
$$U_3 = b(\Omega_3^2 - \Omega_1^2)$$
$$U_4 = d(\Omega_2^2 + \Omega_4^2 - \Omega_1^2 - \Omega_3^2)$$
$$\Omega = \Omega_2 + \Omega_4 - \Omega_1 - \Omega_3$$

Quadrotor data are obtained from existing quadrotor. The quadrotor designed for disaster mitigation, so it must carry camera as payload and its can carry up to 500 grams of cargo.

III. RESEARCH METHODOLOGY

A. *UAV Concept Phase*

Firstly, quadrotor's mission requirement is for disaster mitigation and surveillance. The complete quadrotor system is shown in Figure 4 below. Several sensors are present, there are GPS, IMU (Inertial Measurement Unit), Barometric, Compass and SONAR. There are two ways for controlling the Quadrotor, using Remote Control (RC) or using Control Station. If the Control Station is used then Autopilot and GPS navigation tracking can be activated.

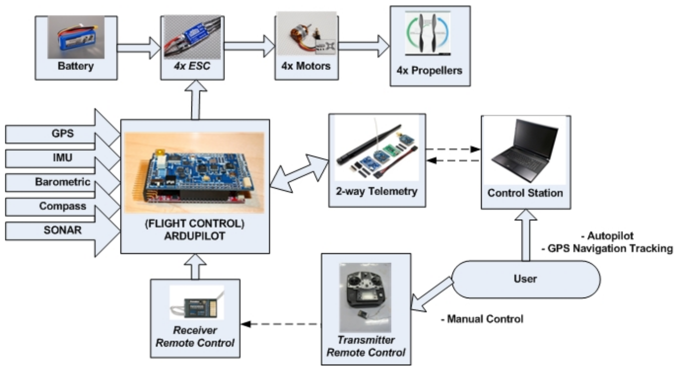

Fig. 4 Block diagram of UAV Quadrotor working concept

B. Design with 3D Modelling Software Phase

It much easier to get simulation parameter such as mass and moment of inertia (noted in I) from 3D modelling software. CATIA is used to obtain the parameters. Finished 3D model is shown in Figure 5. And the parameters are shown in Table II.

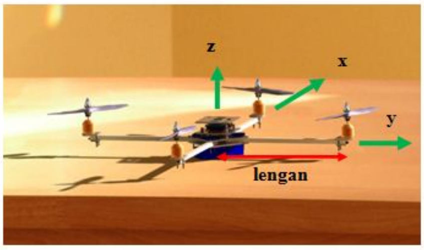

Fig. 5 Rendered picture of quadrotor from CATIA

TABLE II. SIMULATION PARAMETER FROM CATIA

Coefficient	***Value***	***Unit(s)***
Mass (M)	0.978	Kg(s)
Arm Length (L)	0.302	Meter(s)
(Moment of Inertia in x axis) Ix	0.022	Kg.m^2
(Moment of Inertia in y axis) Iy	0.022	Kg.m^2
(Moment of Inertia in z axis) Iz	0.043	Kg.m^2
(Moment of Inertia of propeller) J_r	3.139x10^{-5}	Kg.m^2

C. Stability Simulation of Roll, Pitch, Yaw and Altitude

Based on previous data for simulation, modelling the motor DC brushless with open-loop controller process comes first. Then continue to quadrotor rotational and translational system.

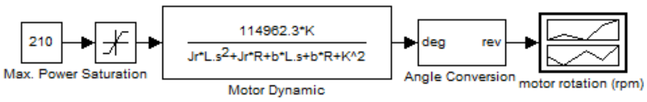

Fig. 6 Open-loop Motor DC brushless System

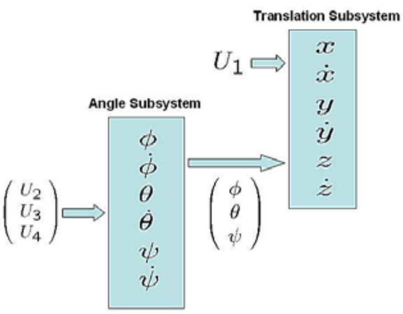

Fig. 7 Angle subsistem coupled to Translational system and controller Input given.

After modelling rotational and translational system of quadrotor, then develop the block diagram of closed-loop system with PID controller in each system. There are 4 systems need to be controlled (roll, pitch, yaw and altitude) so, there are 4 PID controllers. Simulation analysis based on input step response. For stability criteria, roll and pitch systems settling time less than 2 seconds, overshoot less than 10%. Yaw system settling less than 4 seconds, overshoot less than 5% and altitude hold error less than 5% and altitude hold works with less oscillation.

IV. SIMULATION ANALYSIS

Block Diagram in fig. 7 and 4 DoF equation of quadrotor simulated with numerical software, varying the input then we get these graphic shown below (Fig. 8 to 11).

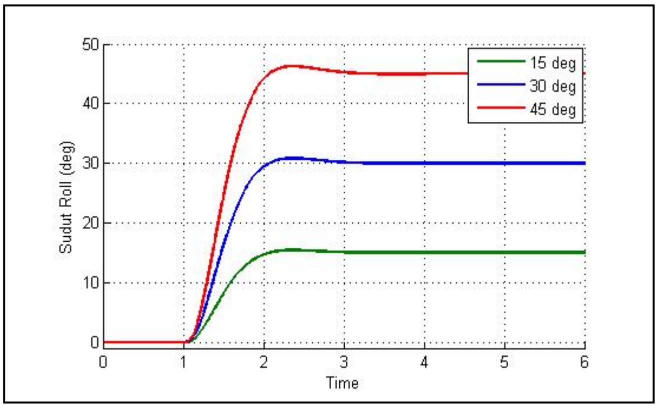

Fig. 8 Roll angle position response versus time with three variation of roll angle reference. (P=8.5; I=0; D=4)

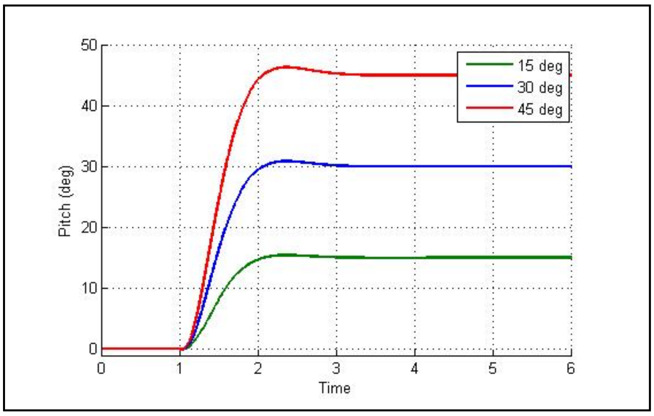

Fig. 9 Pitch angle position response versus time with three variation of pitch angle reference. Identical with roll angle system. (P=8.5; I=0; D=4)

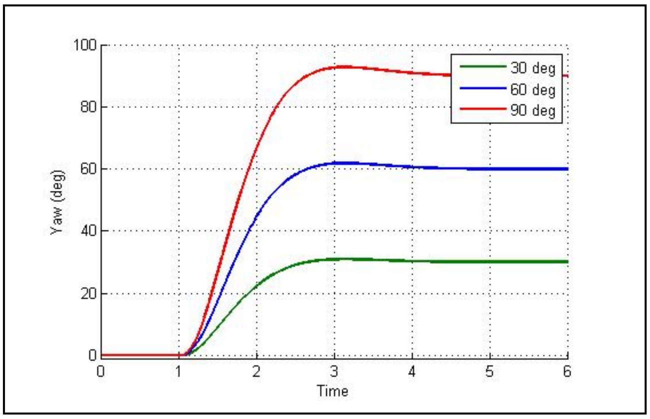

Fig. 10 Yaw angle position response versus time with three variation of yaw angle reference. (P=14; I=0;D=10)

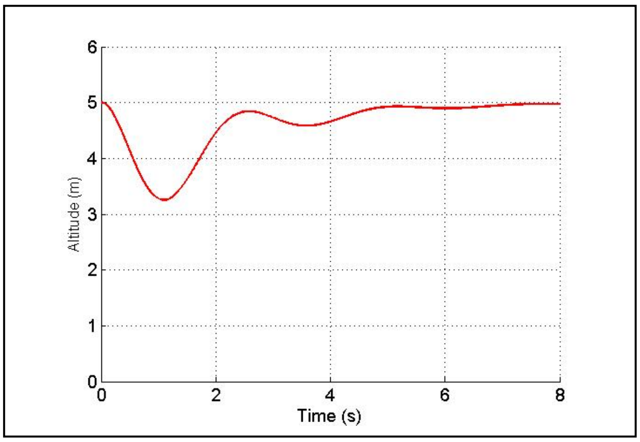

Fig. 11 Quadrotor's altitude response versus time. The altitude referece is 5 meters.

In Fig. 8 and Fig. 9, roll and pitch system has identical characteristic. It is identical because quadrotor has symmetric form in x and y axis. The both overshoot values are 2.8% and settling times are 1.419 seconds. The response result meet the control design requirements as mentioned before.

In yaw system, showing slower response than roll and pitch system. Because U4 control as input have smaller coefficient value of drag factor (d) than U1, U2, U3 thrust factor (b). The average settling time is 2.327 seconds. It is fair response result.

Altitude system in Fig. 11 shows that lowest point is 3,322 meters from ground. The graph shown that quadrotor can maintain altitude if it is dropped from 5 meters height from the ground. When quadrotor released from 5 meters, it will fall down into 3,322 meters from ground and response back to 5 meter reference. And this system settles in 6.339 seconds. The oscillation is small and slow, it should be enough and meet the requirement.

TABLE III. SIMULATION PARAMETER

System	Kp	Ki	Kd	Settling Time (s)	Over-shoot
Roll	8,5	0	4	1,419	2,8 %
Pitch	8,5	0	4	1,421	2,8 %
Yaw	14	0	10	2,327	1,03 %
Altitude	40	18	12	6,339	-

ACKNOWLEDGMENT

Thanks to

REFERENCES

[1] Bouabdallah, Samir et all. *Design and Control of an Indoor Micro Quadrotor*. Lausanne:Swiss Federal Institute of Technology. 2008

[2] Bresciani, Tomasso. *Modelling, Identification and Control of a Quadrotor Helicopter*. Lund University. 2008

[3] A. Elfes, S.S. Bueno and al, Robotic Airship for Exploration of planetary Bodies with an Atmosphere Autonomy Challenges. Autonomous Robots. Journal: Kluwer Academic Publishers, 2003.