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Comparison of PID control, Backstepping, Backstepping PDPI on Take-off and Hover Quadcopter Positions

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Abstract- Quadcopter is one of the best types of Unmanned Aerial Vehicle (UAV), which is currently growing rapidly in the mechatronics research area. Take-off and hover are a very important fly phase that has to be owned by quadcopter. So, the quadcopter can be utilized optimally, where altitude and angle are fixed. In addition, quadcopter is a complex system that is unstable and can be difficult to fly without any control system, so it is needed the right method to keep the stability in phase of take-off and hover. This paper investigates the comparison method between a proportional-integral-derivative (PID), backstepping and combining backstepping PD PI methods as its control. Non-linier model was used to simulate the quadcopter with physical modeling. The results show that the methods are able to set the height and angle of quadcopter with a very small height errors 0.0804, 0.0156 and 0.0132 m, while the angle is always zero as desired.

Keywords: *quadcopter*; PID controller, *backstepping*; *take-off* and *hover*

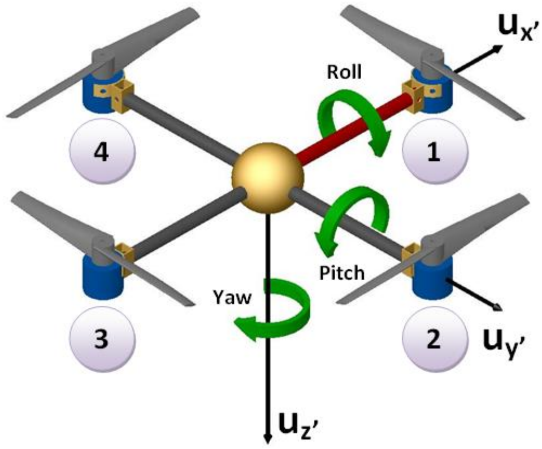

Figure 1. *Quadcopter*

I. Introduction

Quadcopter is an unmanned vehicle that has the potential to take off, hover, maneuver fly and landed in accordance with development of modern technology. Hover controller is a top priority in any efforts to control quadcopter. Any small errors, in terms of angles or altitudes can cause moving either the x, y, or z-axis. Additionally, quadcopter is a complex system that is unstable and can be difficult to fly without any control system, so that is needed an algorithm controller to maintain the conditions that can fly at heights and angles fixed. Quadcopter is a type of aircraft consisting of four motors located at the edge of the main body. The middle section is used for battery storage, control systems, and qaudcopter sensors. The control system is used to provide a signal to the motor driver for controlling the speed of each motor according to desired movement. Rotation speed of each motor (4-motor) is independent, but it must be noted the effect of the motor movement one of the other motors. By controlling the rotation speed of all the motors, then thrust, pitch, yaw, and roll of the quadcopter can be controlled..

Some researches on *quadcopter* controller such as Luukkonen [1] entitled *modelling and control of quadcopter*, Bresciani [7] on *modelling, identification and control of a quadcopter helicopter*. In his paper [1] presents mathematical method of a *quadcopter* using *Newton-Euler* equation and implemented in PD controller. Salvador Gonz´alez-V´azquez, et al. [2] develop a *quadcopter* model using PI to control horizontal position, while PID algorithm for vertical one. The controllers show the resilience of the system, such as Coriolis force and aerodynamic drag by gravity compensate.

A. Martinez, et al. [3] discusses research on the modeling and control of a miniature quadcopter, with particular emphasis on behavior of the control backstepping method and Frenet Serret Theory (FST). FST is a complete control system that consists of a cascade conection, controlling altitude and position. Controller designs to improve posture and stabilization. Sofiane Seghour, et al. [4] proposes control system for an autonomous quadcopter. Where two control algorithms are implemented in real time on embedded systems for stability attitude, using the integral controller and integral backstepping sliding mode with the aim of improving the tracking error.

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L. Derafa,et al. [5] develop design and implement of super twisting algorithm controller for tracking behavior of the quadcopter. The algorithm is based on 2 orde sliding mode tehnique to ensure resilience in case of modeling errors and external disturbances to reduce chattering caused by orde1 sliding control mode. Mu Huang, et al. [6] discusses the issue of control for UAV systems underactuated quadcopter model with uncertain parameters. Backstepping-based techniques used to design nonlinear adaptive controller which can compensate for the uncertainty of the system.

II. MODELING [7]

Mathematics modeling of the *quadcopter* is using physical modeling as classified complex, therefore the assumptions used to simplify the model as follows:

1. The quadcopter is rigid
2. The quadcopter is simetric
3. The propeller is rigid
4. The thrust and drag force is proportional to the square of the propeller speed
5. Model state when is hovering

Quadcopter has 6 degree of freedom (DOF). To describe the motion of 6-DOF rigid body used two inertial reference frames, namely earth (E-frame) and the body fixed reference (B-frame).

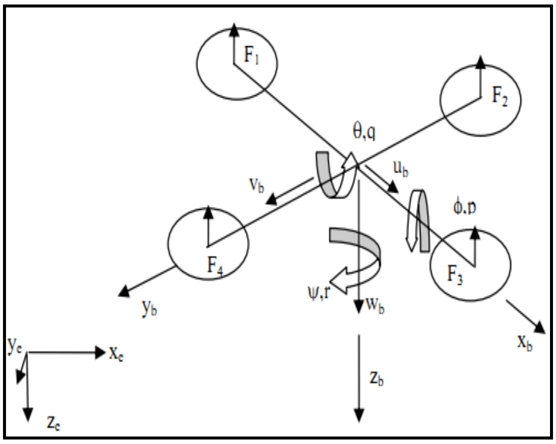

Figure 2. Dynamic model of a *quadcopter*

The dynamics equations of translational motion and rotation can be written:

$$\ddot{x} = \left(\cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi\right)\frac{U_1}{m} \quad (1)$$

$$\ddot{y} = \left(\cos\phi\sin\theta\cos\psi - \sin\phi\sin\psi\right)\frac{U_1}{m} \quad (2)$$

$$\ddot{z} = -g + \left(\cos\phi\cos\theta\right)\frac{U_1}{m} \quad (3)$$

$$\ddot{\phi} = \frac{I_{yy} - I_{zz}}{I_{xx}} qr + \frac{Jr}{I_{xx}} q\Omega + \frac{U_2}{I_{xx}} \quad (4)$$

$$\ddot{\theta} = \frac{I_{zz} - I_{xx}}{I_{yy}} pr - \frac{Jr}{I_{yy}} p\Omega + \frac{U_3}{I_{yy}} \quad (5)$$

$$\ddot{\psi} = \frac{I_{xx} - I_{yy}}{I_{zz}} pq + \frac{U_4}{I_{zz}} \quad (6)$$

Torque equations of roll, pitch and yaw can be determined based on forces that happened within each motor of the quadcopter.

$$U_1 = F_1 + F_2 + F_3 + F_4 = b\left(\Omega_1^2 + \Omega_2^2 + \Omega_3^2 + \Omega_4^2\right) \quad (7)$$

$$U_2 = bl\left(-\Omega_2^2 + \Omega_4^2\right) \quad (8)$$

$$U_3 = bl\left(\Omega_1^2 - \Omega_3^2\right) \quad (9)$$

$$U_4 = d\left(-\Omega_1^2 + \Omega_2^2 - \Omega_3^2 + \Omega_4^2\right) \quad (10)$$

Table 1. Parameters of *Quadcopter*. [8][9]

Parameter	Value (SI)
g	9.81 [m/s^2]
b	2.2478e-6;
d	2.5e-7;
m	1.2; [kg]
Ixx	0.0023; [kg.m^2]
Iyy	0.0023; [kg.m^2]
Izz	0.0015; [kg.m^2]
Jr	3.3750e-5; [kg.m^2]
l	0.254; [m]
Alpha	> 0

III. DESIGN OF QAUDCOPTER SYSTEM

In designing quadcopter system for stability of take-off and hover, this study implemented control ratio of PID, backstepping and backstepping PD PI.

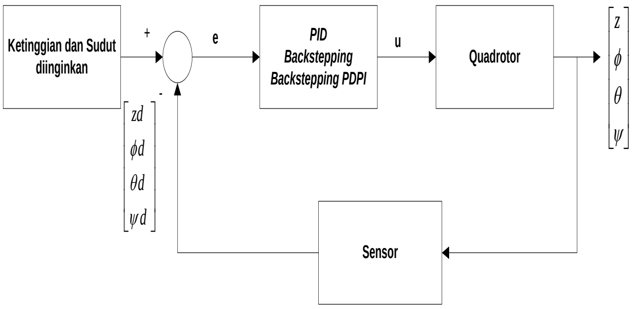

Figure 3. Block diagram of quadcopter system

A. PID Control [10][11]

In designing quadcopter stability system on take-off and hover by using the conventional method; PID control to seek elevation, the angle of roll, and yaw can be seen in the block diagram of figure 3.

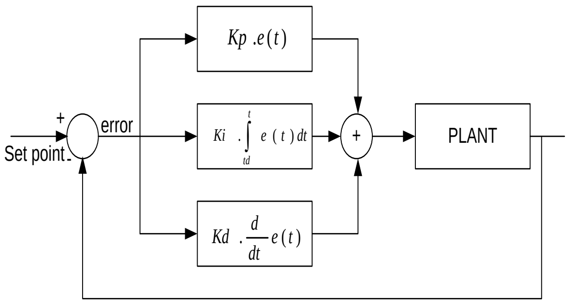

Figure 4. Block diagram of PID control

A. Backstepping Control [12] [13][14]

To determine elevation, the angle of roll, pitch and yaw with backstepping controller, the steps are as follows:

step 1. setting *tracking error*

$$e_1 = Pds - x_7 \tag{11}$$

step 2. using Lyapunov function

$$V(e_1) = \frac{1}{2} e_1^{\,2} \tag{12}$$

Derivative of equation (25)

$$\dot{V}(e_1) = e_1(Pds - x7) \tag{13}$$

Virtual input

$$e_2 = x_8 - \dot{P}ds - \alpha_1 e_1 \tag{14}$$

$$V(e_1 e_2) = \frac{1}{2}(e_1^{\,2} + e_2^{\,2}) \tag{15}$$

Sehingga di dapat sinyal kontrol sebagai berikut:

$$U_2(Roll) = \frac{1}{b_1}(e_1 - a_1 x_{10} x_{12} - a_2 x_{10}\Omega - \alpha_1(e_2 + \alpha_1 e_1) - \alpha_2 e_2) \tag{16}$$

$$U_3(Pitch) = \frac{1}{b_2}(e_3 - a_3 x_8 x_{12} - a_4 x_8 \Omega - \alpha_3(e_4 + \alpha_3 e_3) - \alpha_4 e_4) \tag{17}$$

$$U_4(Yaw) = \frac{1}{b_3}(e_5 - a_5 x_8 x_{10} - \alpha_5(e_6 + \alpha_5 e_5) - \alpha_6 e_6) \tag{18}$$

$$U_1 = \frac{m}{\cos x_7 + \cos x_9}(e_7 + g - \alpha_7(e_8 + \alpha_7 e_7) - \alpha_8 e_8) \tag{19}$$

where :

$$e_3 = qds - x_9$$
$$e_4 = x_{10} - \dot{q}ds - \alpha_3 e_3$$
$$e_5 = rds - x_{11}$$
$$e_6 = x_{12} - \dot{r}ds - \alpha_5 e_5 \tag{20}$$
$$e_7 = zds - x_5$$
$$e_8 = x_6 - \dot{z}ds - \alpha_7 e_7 \tag{21}$$

III. RESULTS AND DISCUSSION

A. Open Loop Quadcopter Testng

In quadcopter can occur hover when visually the quadcopter was flying and idle not stick to the ground or an upward force was equal to the force experienced quadcopter weight. Figure 5 shows the current rotational speed w nominal or equal to zero.

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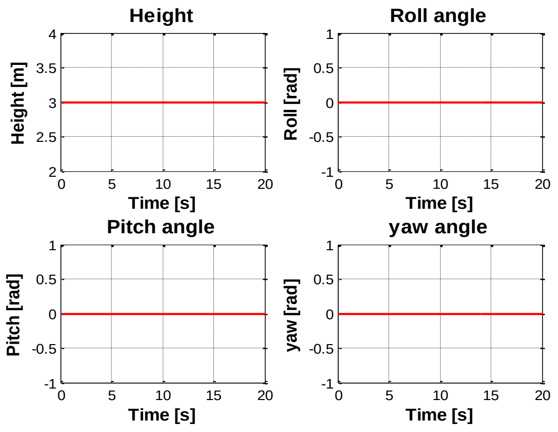

Figure 5. Height response (z), roll, pitch and yaw angle

Quadcopter system simulation testing at open shown in figure 6 with disruption of pulses with math equations at z = 0.3m (10%) in the second of 10, roll angle = 0.1 rad / s in the second 12, the pitch angle = 0,0001 rad / s at the second of 14, and the yaw angle = 0.1 rad / s in the second of 16, indicated that the system was not able to overcome the interference that can be seen in the graph in which the value of elevation (z) started to fall at the second of 12 in the amount of about 0.6 m. Time constanta was τ = 1.55 s and time setting of 6.2 s.

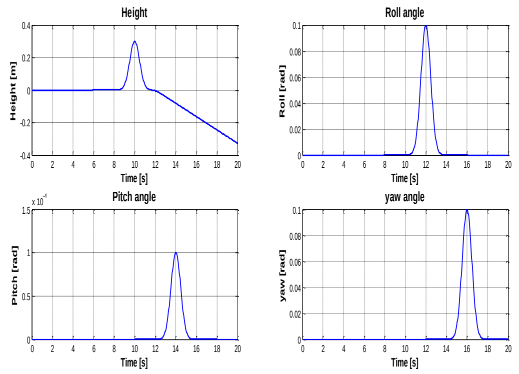

Figure 6. Height response (Z), roll, pitch and yaw angle at *Open Loop*

B. *Quadcopter* testing with PID controller

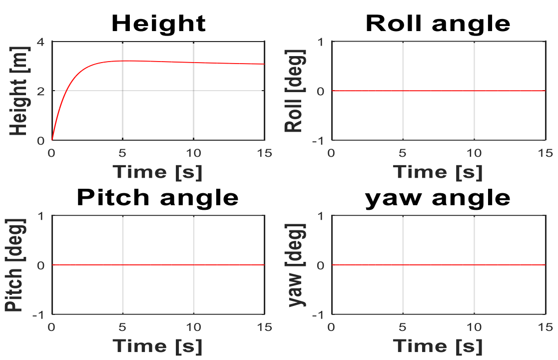

Figure 7. Height response, roll, pitch and yaw angle using PID controller

Figure 7 shows height response, roll, pitch, and yaw angle using PID control, indicating there was an error of 0.804m.

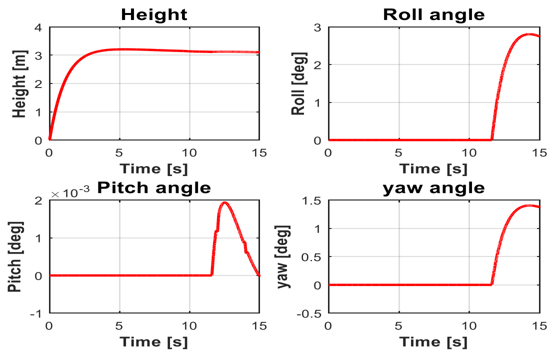

Figure 8. Height response, roll, pitch and yaw angle usinga PID control with disturbance of the output

Figure 8 shows simulation testing of a quadrotor at the output with impaired at z = 0.3 (10%) at the second of 10, roll angle = 0.1 rad / s at the second of 12, the pitch angle = 0.0001 rad / s at the second of 14, and yaw angle = 0.1 rad / s at the second of 16, indicating that the PID controller was able to improve the response even though the interference with the steady state error of 0.1056m.

C. Quadcopter testing using backstepping control

Testing quadcopter sytem was using backstepping control with output disturbances. Qadcopter system simulation quadcopter was the output with interference pulses with math equations, pulse width = 2 at z = 0.3 (10%) in the second of 10, the roll angle = 0.1 rad/s at the second of 12, the pitch angle = 0.0001 rad/s in the second of 14, and the yaw angle = 0.1 rad/s at the second of 16, showed that the backstepping controller was able to improve the response so that the results were closer to the setpoint. Although there was still a steady state error of 0.0156m and stable conditions with time constant τ = 0.4791 s and time setting by 1.92 s. The response can be seen in figure 9.

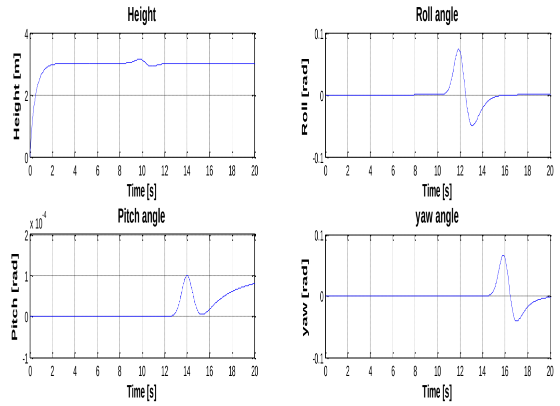

Figure 9. Height response, roll, pitch and yaw angle using backstepping controller with disturbance output

D. Quadcopter testing using backstepping PD PI control

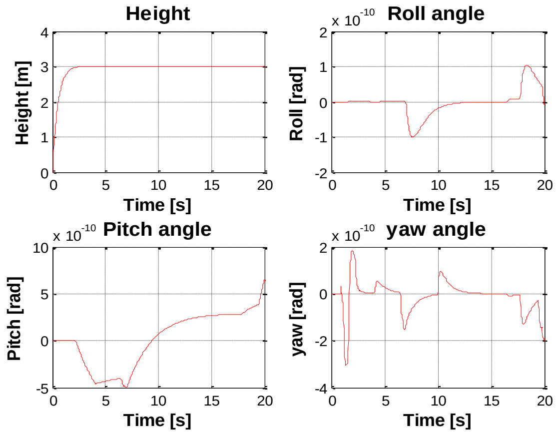

Figure 10. Simulation of quatrotor *close loop* with *backstepping* PD PI controller

In Figure 10 shows a graph of output response of the closed loop quadcopter with backstepping PD PI controller. Elevation response (z) was set in 3m, while roll, pitch and yaw angle were set to 0 rad/s. It takes only about 2s to reach stable steady state with 0.0132m error

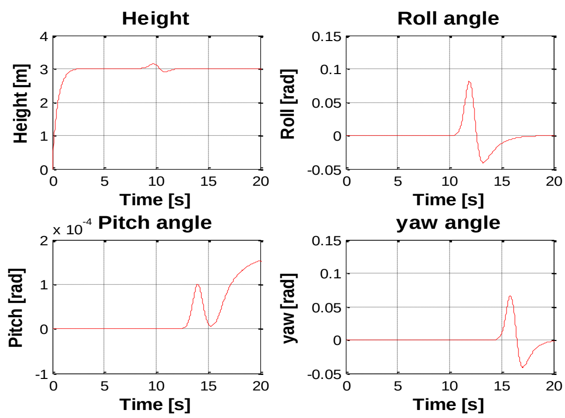

Figure 11. Quadrotor *close loop* simulations with *backstepping* PD PI controller and disturbance on output

Testing simulation system of the quadrotor on output with a disturbance at z = 0.3 (10%) in the second of 10, roll angle = 0.1 rad / s at the second of 12, the pitch angle = 0.0001rad / s in the second of 14, and the yaw angle = 0.1 rad / s in the second of 16, showed that backstepping PD PI controller was able to improve the response even though there was interference with a tiny steady-state error about 0.0131m.

3D simulation of the Quadcopter movement
Motion of the quadcopter was simulated in 3D simulation. It was carried out using a toolbox quadcopter form petercorke with slighty modifications, resulting 3D simulation as seen in figure 12.

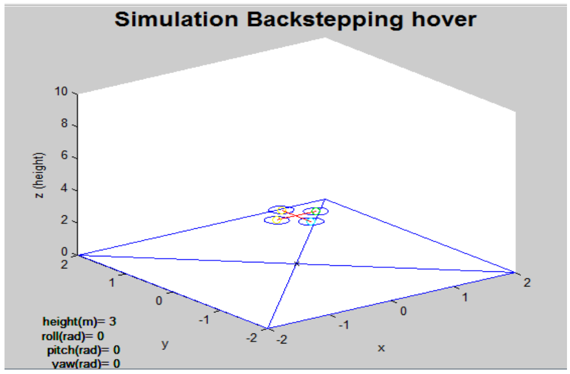

Figure 12. 3D quadcopter simulation

V. CONCLUSION

The simulation results comparison method PID control, backstepping, and backstepping PDPI shows the settings using the non-linear controller better its performance and sturdy compared to conventional methods. It can be seen from the graphs that output responses of height, roll angle (φ), pitch (Θ), yaw (ψ) are close to zero and small the elevation (z) error.

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