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-linear 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

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 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 quadcopter 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.

Figure 1. Quadcopter

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 González-Vázquez, 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 connection, 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.
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 ordre sliding mode technique 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 symmetric
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).

\[
\ddot{x} = -g + \left( \cos \phi \cos \theta \cos \psi + \sin \phi \sin \psi \right) \frac{U_1}{m} \\
\ddot{y} = \left( \cos \phi \cos \theta \cos \psi - \sin \phi \sin \psi \right) \frac{U_1}{m} \\
\ddot{z} = \left( \cos \phi \sin \theta \cos \psi + \sin \phi \sin \psi \right) \frac{U_1}{m} \\
\ddot{\phi} = \frac{I_{yy} - I_{zz}}{I_{xx}} q^r + \frac{Jr}{I_{xx}} q \Omega + \frac{U_2}{I_{xx}} \\
\ddot{\theta} = \frac{I_{zz} - I_{xx}}{I_{yy}} p r^r - \frac{Jr}{I_{yy}} p \Omega + \frac{U_3}{I_{yy}} \\
\ddot{\psi} = \frac{I_{xx} - I_{yy}}{I_{zz}} p q + \frac{U_4}{I_{zz}}
\]

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

\[
U_1 = F_1 + F_2 + F_3 + F_4 = b \left( \Omega_1^2 + \Omega_2^2 + \Omega_3^2 + \Omega_4^2 \right) \\
U_2 = bl \left( -\Omega_2^2 + \Omega_4^2 \right) \\
U_3 = bl \left( -\Omega_3^2 + \Omega_4^2 \right) \\
U_4 = d \left( -\Omega_1^2 + \Omega_2^2 - \Omega_3^2 + \Omega_4^2 \right)
\]

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

| Parameter | Value (SI) |
|-----------|------------|
| $g$       | 9.81 [m/s²] |
| $b$       | 2.2478e-6; |
| $d$       | 2.5e-7;    |
| $m$       | 1.2; [kg]  |
| $I_{xx}$  | 0.0023; [kg.m²] |
| $I_{yy}$  | 0.0023; [kg.m²] |
| $I_{zz}$  | 0.0015; [kg.m²] |
| $J_r$     | 3.3750e-5; [kg.m²] |
| $l$       | 0.254; [m] |
| Alpha     | > 0        |

III. DESIGN OF QUADCOPPER SYSTEM

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

![Block diagram of quadcopter system](image)

**Figure 3.** Block diagram of quadcopter system

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

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

1. **Step 1.** Setting **tracking error**
   
   \( e_1 = Pds - x_7 \)  \( \text{(11)} \)

2. **Step 2.** Using Lyapunov function
   
   \( V(e_1) = \frac{1}{2} e_1^2 \) \( \text{(12)} \)

Derivative of equation (25)

\[ \dot{V}(e_1) = e_1 (Pds - x_7) \] \( \text{(13)} \)

Virtual input

\[ e_2 = x_8 - \dot{Pds} - \alpha_1 e_1 \] \( \text{(14)} \)

\[ V(e_1, e_2) = \frac{1}{2} (e_1^2 + e_2^2) \] \( \text{(15)} \)

III. RESULTS AND DISCUSSION

A. Open Loop Quadcopter Testing

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

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 the 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 system was using backstepping control with output disturbances. Quadcopter 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 of 6.2 s.

B. Quadcopter testing with PID controller

Figure 9. Height response, roll, pitch and yaw angle using backstepping controller with disturbance output
D. Quadcopter testing using backstepping PD PI control

3D simulation of the quadcopter movement

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

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.

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.

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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