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PID based controller design for attitude stabilization of Quad-rotor

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ABSTRACT

This article presents a PID based control approach for stabilizing the attitude of quad-rotor UAV during flying. To solve the stability problem of quad-rotor UAV, some suitable and easy feedback control algorithm can be used. In the standard Quad-rotor type UAV systems, controlling of attitude is one of the most critical tasks and appropriate controller for stabilization of attitude is essential and necessary. So, in order to validate the unwanted disturbance rejection operation, a robust PID controller with feedback compensation is derived in this research artical. The results proved the effectiveness of control method for stabilizing attitude of quad-rotor.

INTRODUCTION

One of the prominent rotorcrafts, a UAV has been the area of interest among the researchers in recent years. The quad-rotor is an unmanned aerial vehicle (UAV) which has four propellers attached to four motors placed on a fixed body (Senkul, 2013). A quad-rotor UAV has exceptional advantages with its size, weight and its simple mechanical arrangement (Lee, 2011). This is the main reason that, nowadays these UAVs are wide used in various applications at minimal cost and without endangering any risk to human life (Burkle, 2011). UAVs are inherently suitable for military applications such as border patrolling, security intelligence, cartography, surveillance, cost guards, acquisition of targets (Hsu, 2010) and (Chao, 2010). UAVs have also penetrated in civilian applications such as search & rescue missions (Krerngkamjornkit, 2013), explorations (Caldeira, 2013), security & surveying of oil pipe lines (Zhang, 2013), forests on fire (Ferrell, 2013). As a result the research community has seen substantial improvements in the design of controllers for these types of vehicles (Stowers, 2011).

Plenty of technical & distinctive issues are associated to quad-rotor that opened a way to a massive research work. A quad-rotor system is a simple structure but nonlinear in nature which makes the controls very complex and difficult. Researchers have been facing issues with controlling the attitude and tackling to the air disturbances while flying which is the main concern in this article.

The contribution is organized as follows: the modeling of the quad-rotor and controller design is done in section 2. Simulations and experimental results for the system in closed-loop with the PID technique is presented in section 3. Concluding remarks are given in Section 4.

MATERIAL AND METHODS

Equation 1 is the overall dynamic system representation and orientation of quad-rotor UAV which is extracted from Newton-Eular method and discussed comprehensively in my previous article (M. Hassan Tanveer, 2013).

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$$\begin{aligned}
\ddot{X} &= (\sin\psi\sin\phi + \cos\psi\sin\theta\cos\phi)\frac{U_1}{m} \\
\ddot{Y} &= (-\cos\psi\sin\phi + \sin\psi\sin\theta\cos\phi)\frac{U_1}{m} \\
\ddot{Z} &= -g + (\cos\theta\cos\phi)\frac{U_1}{m} \\
\dot{\phi} &= \frac{I_{YY} - I_{ZZ}}{I_{XX}}\,\theta\,\psi - \frac{J_{TP}}{I_{XX}}\,\theta\,\omega + \frac{U_2}{I_{XX}} \\
\dot{\theta} &= \frac{I_{ZZ} - I_{XX}}{I_{YY}}\,\theta\,\psi - \frac{J_{TP}}{I_{YY}}\,\theta\,\omega + \frac{U_3}{I_{YY}} \\
\dot{\psi} &= \frac{I_{XX} - I_{YY}}{I_{ZZ}}\,\theta\,\psi - \frac{U_4}{I_{ZZ}}
\end{aligned} \tag{1}$$

In this article under the disturbance condition, PID controller technique is proposed for appropriate attitude controlling of quad-rotor. The plant dynamics are presented in equation (2) which are chosen from equation (1). For controlling of quad-rotor's attitude, all three angles which are roll, pitch and yaw are used for controller desiging.

$$\begin{aligned}
\ddot{\phi} &= \frac{I_{YY} - I_{ZZ}}{I_{XX}}\,\theta\,\psi - \frac{J_{TP}}{I_{XX}}\,\theta\,\Omega + l\frac{U_2}{I_{XX}} \\
\ddot{\theta} &= \frac{I_{ZZ} - I_{XX}}{I_{YY}}\,\theta\,\psi - \frac{J_{TP}}{I_{YY}}\,\theta\,\Omega + l\frac{U_3}{I_{YY}} \\
\ddot{\psi} &= \frac{I_{XX} - I_{YY}}{I_{ZZ}}\,\theta\,\psi - l\frac{U_4}{I_{ZZ}}
\end{aligned} \tag{2}$$

The main objective of this research is to design Controller which makes quad-rotor stable under the circumstances of disturbance. In order to deal with this major issue an appropriate PID Controller is presented in this paper for making the system stabilize under the distubance condition. The PID control is tuned by auto-tuning method and its range between 0 to 1 for all parameters.

Attitude Stabilization Controller:

The feedback signal combined with reference signal and produces error signal which goes to PID control block as shown in fig.(1). For Quad-rotor attitude controlling only orientation angles i.e pith, roll and yaw are controlled. The quad-rotor dynamics must be simplified. There are some of the terms that can be neglected which are gyroscopic torque and Coriolis-centripetal as mentioned in (Bresciani, 2008).

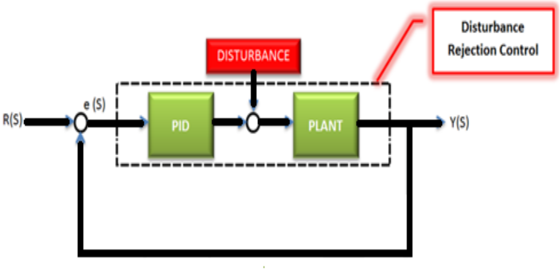

Fig. 1: Control System

After neglecting the terms in equation (2), the equation becomes:

$$\begin{bmatrix} \ddot{\phi} \\ \ddot{\theta} \\ \ddot{\psi} \end{bmatrix} = \begin{bmatrix} \frac{L}{I_{xx}} u_2 \\ \frac{L}{I_{yy}} u_3 \\ \frac{1}{I_{zz}} u_4 \end{bmatrix} \tag{3}$$

By applying Laplace Transform on equation (3), the transfer function of quad-rotor plant's attitude which are roll, pitch and yaw obtained separately as equation (4).

$$\left.\begin{array}{l} \frac{\phi(s)}{u_2(s)} = \frac{L}{I_{xx} s^2} \\ \frac{\theta(s)}{u_3(s)} = \frac{L}{I_{yy} s^2} \\ \frac{\psi(s)}{u_4(s)} = \frac{1}{I_{zz} s^2} \end{array}\right\} \tag{3}$$

So for its controller designing, the error signals $e_\phi, e_{\theta,} e_\psi$ will be:

$$\begin{array}{l} e_\phi = \phi_{ref} - \phi \\ e_\theta = \theta_{ref} - \theta \\ e_\psi = \psi_{ref - \psi} \end{array} \tag{4}$$

For Roll angle controlling, following equation will be take in account.

$$\phi(S) = \frac{lU_2}{I_{xx} S^2} \tag{5}$$

After evaluating roll with rotor dynamics K_1 given in equation (5) the above eq becomes:

$$\phi(S) = \frac{K_1{}^2)l}{I_{xx}\ S^2(S+1)^2} U \tag{6}$$

$$\phi(S) = \frac{K_1}{S^4 + S^3 + S^2} U$$

The PID equation is

$$PID = K_p e(S) + \frac{K_i}{S} e(S) + SK_d e(S) \tag{7}$$

After applying PID to the system the eq for attitude stabilization of roll becomes

$$\phi = e(S) \left. \frac{S^2 K_d K_1 + SK_p K_1 + K_i K_1}{S^5 + S^4 + S^3 + S^2 K_d K_1 + SK_p 1 + K_i K_1} \right] U \tag{8}$$

Similarly for other angles of attitude (i.e: pitch and yaw), can obtain by same above mentioned proposed method.

RESULT AND DISCUSSION

The simulation result presented in this section expose the effectiveness of controller to stabilize the quad-rotor attitude and altitude under disturbance conditions. The closed loop system behaviors are analyzed while hovering in the presence of unknown disturbance injected on attitude of quad-rotor.

During simulation in proposed PID controller, 0° set points is set for each attitude angle (Yaw, Pitch and Roll) for maintaining Quad-rotor attitude under disturbance conditions.

A comparison is being done for evaluating the effectiveness of proposed controller. Fig. 2 and Fig. 3 demonstrates, that disturbance is added on Roll angle among different interval of time with the controller effect of PD and PID respectively. Table 1 shows the response results of both controller for complete attitude stabilization of quad-rotor. These results proved that, the proposed PID controller work very well and easily handled the disturbance condition and quickly stabilized the quad-rotor attitude. The auto-tuned chosen PID Parameters for attitude controller are Kp = 0.1198, Ki = 0.0009, Kd = 0.1382.

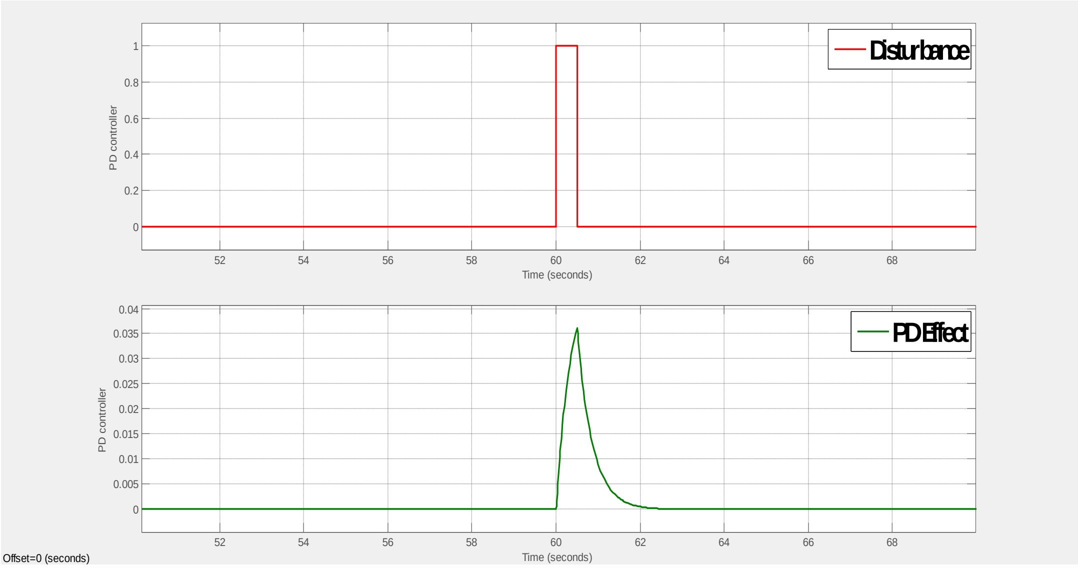

Fig. 2: Disturbance and Effect of PD controller on Roll angle

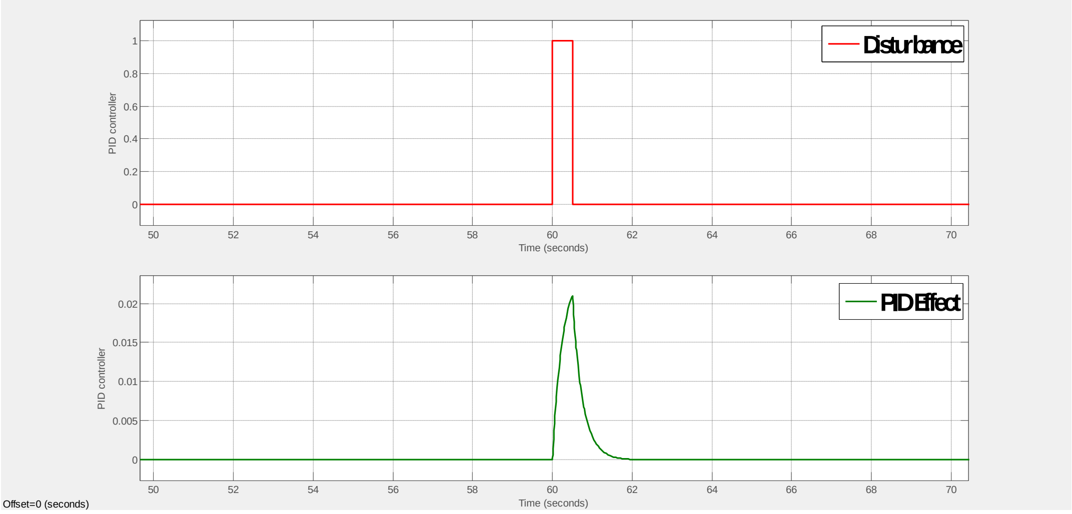

Fig. 3: Disturbance and its effect of PID controller on Roll angle

Table 1: Disturbance and its effect on PID and PD controller in Roll angle

Controller	Overshoot	Reference Settling Time
PD	3.25 %	2.2 sec
PID	2.20 %	1.6 sec

Conclusion:

The overall outcome of simulation shows the result of proposed PID controller for attitude stabilization of quad-rotor UAV system under disturbance condition. The parameters of PID controller are selected by auto-tune method. From the simulation results, it is proved that the effectiveness of the control method is verified and the controller has offered to return the entire system to stabilize the situation where there is any kind of disturbance imposed on quad-rotor.

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