Research on Control Method of Four Rotor UAV Based on Classical PID Control System

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Abstract. In recent years, four rotor unmanned aerial vehicle (UAV) has been widely used in the field of power inspection. The four rotor UAV has the characteristics of small size, low manufacturing cost, fast moving speed and so on. It is very convenient to use in various complex and inaccessible places. With the increasing strength of related control technology, the stability, functionality and safety performance of four rotor UAV have been significantly improved. In order to further verify the adaptability of the four rotor UAV to the field of power inspection. In this paper, the flight state control method of multi rotor UAV is studied. The principle of proportion integration differentiation (PID) control is analyzed. The position controller and attitude controller in the PID control system are designed. On this basis, a four rotor UAV Control System based on classical PID control method is constructed. Finally, the designed control system is simulated. The results show that the position control parameters and attitude angle control parameters in the PID control system are the key to ensure the stable operation of the system. The classical PID control system can meet the needs of UAV for simple flight tasks. However, for the application scenarios that require UAV to perform complex actions, the control method of four rotor UAV needs to be further improved. The research results play a guiding role in expanding the application field of UAV.

Keywords: Four Rotor Unmanned Aerial Vehicle · Proportional Integral Derivative · Attitude Control · Position Control

1 Introduction

In recent years, with the rapid development of UAV technology, UAV inspection mode is becoming more and more popular, and its application is also becoming more and more extensive [1]. There are many kinds of power equipment, which are scattered all over the country. Especially in the distribution network, most of the rural distribution network equipment is located in remote areas, and the operating conditions are poor

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[2]. The length of overhead distribution lines in Hunan power grid is more than 200000 km, and the scale of equipment is still growing rapidly every year. At present, the distribution network inspection of Hunan power grid mainly adopts manual inspection, that is, relying on the operation and maintenance personnel to find the line defects and hidden dangers through ground inspection, pole climbing inspection and other methods. With the rapid growth of the scale of distribution network equipment, the timeliness and accuracy of distribution network inspection requirements continue to improve. The traditional manual inspection mode can no longer meet the current operation inspection requirements [3].

Compared with the traditional manual inspection method, UAV inspection has the characteristics of high efficiency, high quality and high security. It is an important means for the development of distribution network line management in a more safe, efficient, refined and economic direction [1]. At present, four rotor UAV is widely used to carry out the inspection of distribution line UAV. Because the operating environment of distribution lines is very complex and harsh. In order to make the UAV fly safely and reliably in a space full of obstacles, scholars at home and abroad have carried out a lot of research in the field of four rotor UAV flight control technology [4, 5]. This paper focuses on the four rotor UAV, and designs a multi rotor UAV Control System Based on classical PID controller. The designed control system is simulated and analyzed. The results of this paper have a guiding role in expanding the application field of UAV.

2 Analysis of PID System Control Structure

Classical PID control system is divided into inner loop control system and outer loop control system. The inner loop control system is the attitude control system. The attitude control system has the characteristics of fast response and wide frequency band. The outer loop control system is a position control system. The position control system mainly realizes the position control of the aircraft on the X, y and Z axes by changing the size of U. Make certain changes to the control variables according to the real-time feedback parameters and the desired attitude angle of the aircraft, and enable the aircraft to fly to the desired place and fly along the preset route [6]. The whole system has four inputs: X, Y, Z and an angle, and the output is three position coordinates and three Euler angles. Figure 2 below shows the simulation diagram of the whole system, and Table 1 shows the parameters used in the simulation of four rotor UAV (Fig. 1).

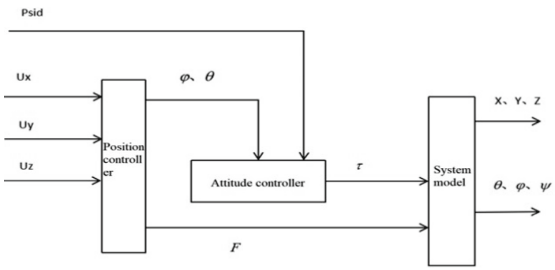

Fig. 1. Schematic diagram of classical PID control system

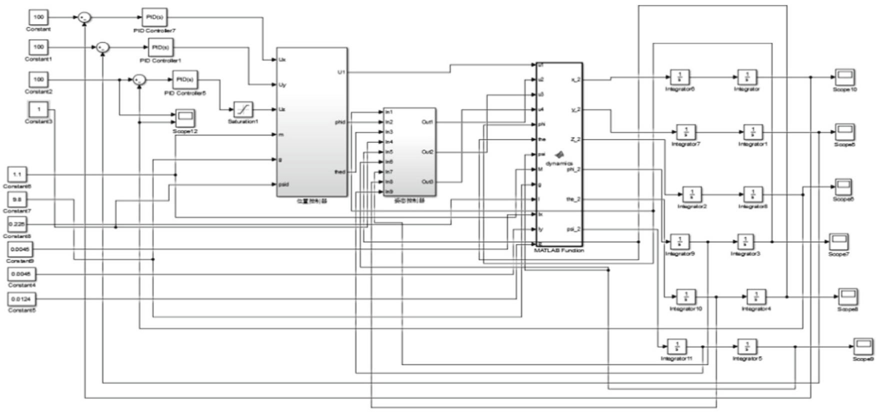

Fig. 2. Simulation diagram of classical PID control system

Table 1. Parameters of four rotor UAV

Parameters	value
m/kg	1.1
L/m	0.225
K	0.75
τ	0.1
$I_x/(\mathrm{kg} \cdot \mathrm{m}^2)$	0.0045
$I_y/(\mathrm{kg} \cdot \mathrm{m}^2)$	0.0045
$I_z/(\mathrm{kg} \cdot \mathrm{m}^2)$	0.0124

3 PID Control Principle

The PID system structure is shown in Fig. 3. The three parameters of proportion, integral and differential can be adjusted respectively, and one or two control laws can also be used. In short, the functions of each unit of the PID controller are as follows.

The proportional control unit can respond to the deviation quickly and timely, and adjust the deviation according to the proportion to eliminate the error to a certain extent, which can effectively improve the sensitivity of control, but the relative control accuracy is low. It has the characteristics that the smaller the proportion parameter is, the stronger the proportion effect is, the faster the dynamic response speed is, and the stronger the ability to eliminate errors is. In addition, the role of proportion should not be too strong. If the role of proportion is too strong, it will cause instability of system vibration. Therefore, it is necessary to select appropriate proportional parameters while maintaining the stability and dynamic performance of the system.

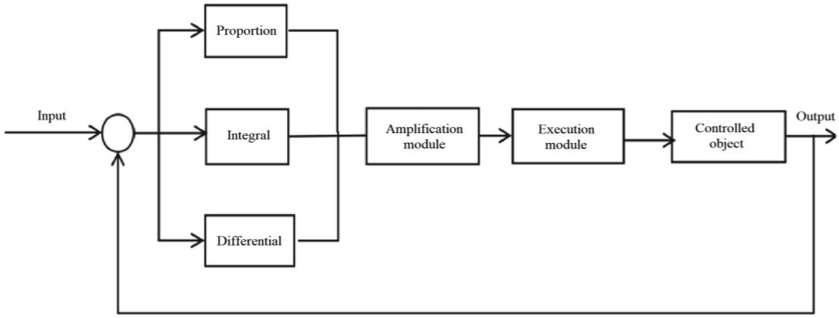

Fig. 3. PID system structure

The main function of the integrating element is to eliminate the steady-state error. The strength of the integration link depends on the size of the time constant. If the integral action is too strong, the phenomenon of superharmonic oscillation will occur.

The function of the differential link is to prevent the deviation signal from becoming too large. If the deviation signal produces large fluctuations, the differential link is equivalent to an early correction signal to avoid oscillation of the system. In short, the differential function is to find the trend of error before the system produces error, and make certain adjustment actions to solve the adverse consequences of error.

The function of traditional PID controller is based on the difference of feedback, and K_P, K_i and K_D are used to eliminate errors and reduce errors, so as to stabilize the system and reduce interference. Therefore, in order to make the stability of the whole system better and make the whole system reach the best state, it is necessary to properly adjust and optimize K_P, K_i and K_D. By constantly adjusting the parameters and judging by the effect, whether the parameters at this time meet the requirements. There are many methods to adjust the parameters of PID controller, including two examples. One is to calculate the most appropriate parameters according to the theoretical formula. The other is to constantly carry out experiments and modify them according to the experimental results, and finally find the most suitable K_P, K_i and K_D. The second method is more commonly used.

4 Position Controller Design

Due to the input of attitude controller φ_d and θ_d and other parameters need to be determined according to the output of the position controller. Therefore, it is necessary to establish a position controller. According to the control variables of three positions of U_x, U_y and U_z fed back by the position control loop. Then, the desired attitude angle is calculated, and the command is issued to establish a corresponding relationship between the input of the attitude controller and the output of the position controller. Finally, the attitude controller constantly modifies the feedback attitude angle according to our preset position, and finally realizes the real-time control of the aircraft. Set $[x_d\ y_d\ z_d]$ to the desired position. $[x\ y\ z]$ is the actual position of the aircraft. $\left[\dot{x}d\ \dot{y}d\ \dot{z}d\right]$ is the expected linear velocity signal. $\left[\dot{x}\ \dot{y}\ \dot{z}\right]$ is the linear velocity of the aircraft. $\left[\ddot{x}\ \ddot{y}\ \ddot{z}\right]$ is the acceleration of the aircraft. The given quantity input by the position controller is as follows.

$$
\begin{aligned}
U_x &= K_{px}(x_d - x) + K_{dx}(\dot{x}_d - \dot{x}) + \ddot{x} \\
U_y &= K_{py}(y_d - y) + K_{dy}(\dot{y}_d - \dot{y}) + \ddot{y} \\
U_z &= K_{pz}(z_d - z) + K_{dz}(\dot{z}_d - \dot{z}) + \ddot{z}
\end{aligned} \tag{1}
$$

where K_{PX}, K_{PY} and K_{PZ} are the proportional adjustment coefficients of the position control of the UAV in the three axes of *xyz*. K_{dx}, K_{dy} and K_{dz} are the differential adjustment coefficients of *xyz*'s three axial up position control. Figure 4 is the simulation diagram of the position controller of the whole system.

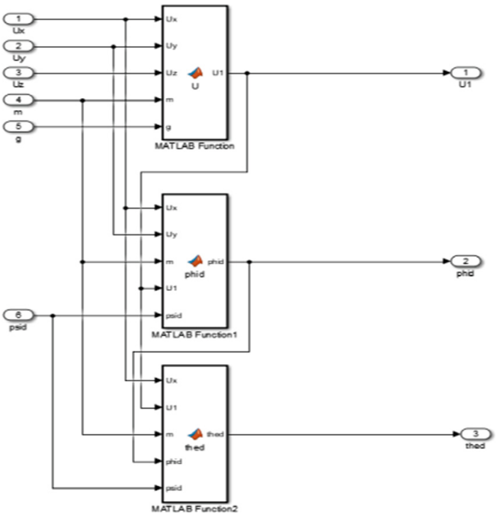

Fig. 4. Simulation diagram of position controller

The altitude channel control quantity U_1 is defined as T_{x}, T_{y} and T_{z} based on the triaxial components of the ground coordinate system.

$$
\begin{aligned}
T_x &= (\cos\,\varphi\,\sin\,\theta\,\cos\,\psi + \sin\,\varphi\,\sin\,\psi)U_1 \\
T_y &= (\cos\,\varphi\,\sin\,\theta\,\sin\,\psi - \sin\,\varphi\,\cos\,\psi)U_1 \\
T_z &= (\cos\,\varphi\,\cos\theta)U_1
\end{aligned} \tag{2}
$$

It can be seen from the above formula that the inputs U_{x}, U_{y} and U_{z} of the position controller are approximately equal to the component of the acceleration of the aircraft decomposed into the ground coordinate system. Ignoring the effect of aerodynamic force, the following relationship can be obtained.

$$
\begin{aligned}
U_x &= \frac{1}{\text{m}} T_x \\
U_y &= \frac{1}{\text{m}} T_y
\end{aligned}
$$

$$U_z = \frac{1}{\mathrm{m}} T_z - g \tag{3}$$

Input signal of attitude control loop ψ_{d} is the given value of the system. φ_{d} and θ_{d} can be obtained by formula.

$$\begin{aligned} U_1 &= m\sqrt{U_x^2 + U_y^2 + (U_z + g)^2} \\ \varphi_d &= \arcsin\left(\left(U_x sin\psi_d - U_y \cos\psi_d\right)\frac{m}{U_1}\right) \\ \theta_d &= \frac{\arcsin(U_x m - U_1 \sin\psi_d \sin\varphi_d)}{(U_1 \cos\psi_d \cos\varphi_d)} \end{aligned} \tag{4}$$

From the above formula, the input of the aircraft attitude controller can be calculated φ_{d} and θ_{d}.

5 Attitude Controller Design

If you want the UAV to reach the specified position and form the specified attitude, you need to constantly adjust the attitude angle. The input of the attitude controller is three attitude angles. After passing through the cascade PID controller, the angular acceleration is obtained, and then multiplied by the corresponding kinematic inertia to obtain three torques, which are used as the input of the system model. Finally, through the feedback of attitude angle sensor, the feedback adjustment is carried out to realize the dynamic adjustment of pitch angle, roll angle and yaw angle. Figure 5 is the schematic diagram of the attitude controller.

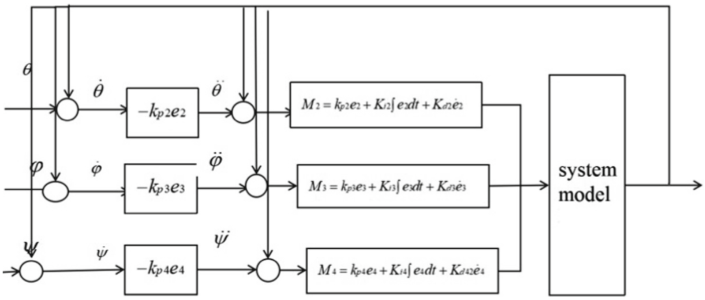

Fig. 5. Loop structure diagram of attitude control

Considering that the coupling and nonlinear relationship are ignored when the attitude angle is small, the control torque and angular acceleration have the following relationship.

$$\begin{aligned} U_2 &= J\ddot{\theta} \\ U_3 &= J\ddot{\varphi} \end{aligned}$$

$$U_4 = J\ddot{\psi} \tag{5}$$

Set the given attitude angle signal as [θ φ ψ]. The actual attitude angle signal is [θ_3 φ_3 ψ_3]. The expression of the control quantity is as follows.

$$\begin{aligned} M_2 &= k_{p2}e_2 + K_{i2}\int e_2 dt + K_{d2}\dot{e}_2 \\ M_3 &= k_{p3}e_3 + K_{i3}\int e_3 dt + K_{d3}\dot{e}_3 \\ M_4 &= k_{p4}e_4 + K_{i4}\int e_4 dt + K_{d42}\dot{e}_4 \end{aligned} \tag{6}$$

where:

$$\begin{aligned} e_2 &= \theta_3 - \theta, \quad \dot{e}_3 = \dot{\varphi}_3 - \dot{\varphi} \\ e_3 &= \varphi_3 - \varphi, \quad \dot{e}_2 = \dot{\theta}_3 - \dot{\theta} \\ e_4 &= \psi_3 - \psi, \quad \dot{e}_4 = \dot{\psi}_3 - \dot{\psi} \end{aligned} \tag{7}$$

Based on PID controller control, the following expression can be obtained.

$$\begin{aligned} U_2 &= JM_2 \\ U_3 &= JM_3 \\ U_4 &= JM_4 \end{aligned} \tag{8}$$

The simulation diagram of attitude control is shown in Fig. 6.

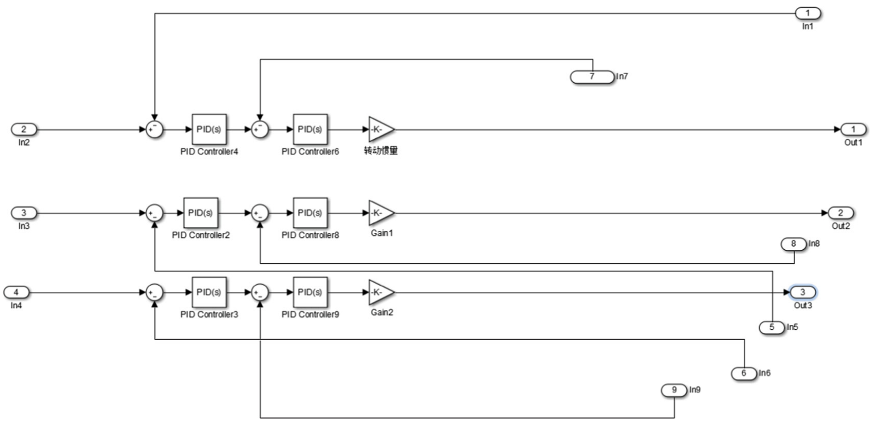

Fig. 6. Simulation diagram of attitude controller

6 Simulation Analysis of Control System Based on Classical PID

Based on the above research content, the classical PID control system is simulated and analyzed. The simulation results are shown in the figure below (Figs. 7, 8, 9, 10, 11 and 12).

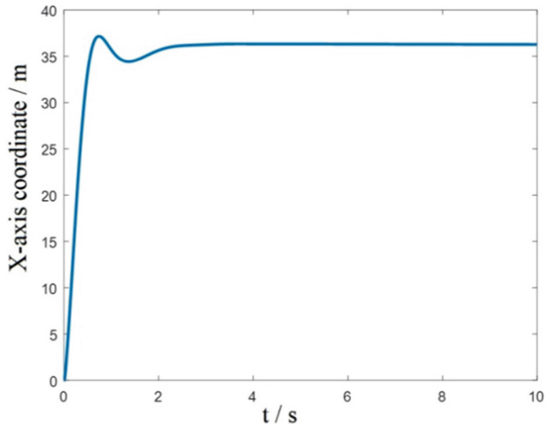

Fig. 7. Simulation results of X-axis coordinate

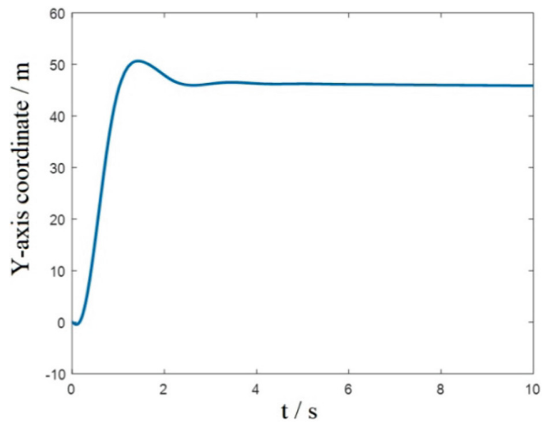

Fig. 8. Simulation results of Y-axis coordinate

The simulation results are shown in the figure above. It can be seen from the oscilloscope display graph that the oscilloscope display curve is relatively stable. However, there are certain overshoot and fluctuations, and the steady state can be reached in about 3S. In addition, the system has only four inputs, so the pitch angle and roll angle return to the origin after fluctuation.

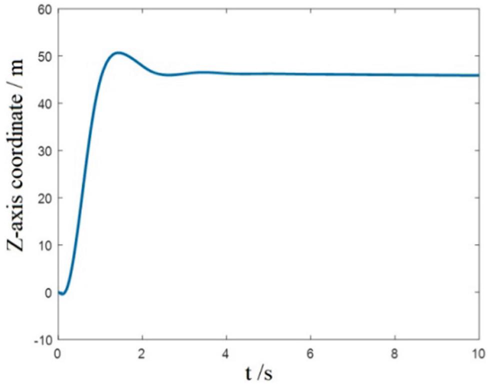

Fig. 9. Simulation results of Z-axis coordinate

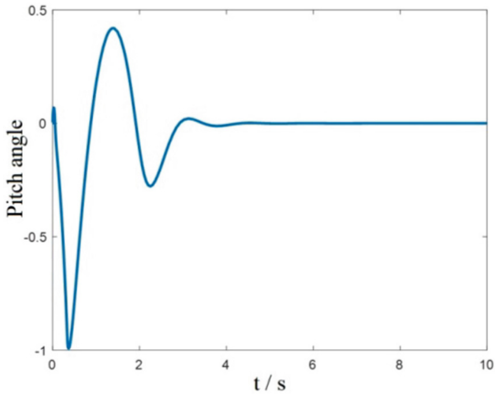

Fig. 10. Pitch angle simulation result

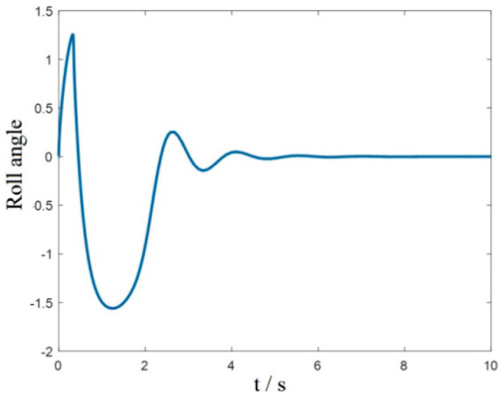

Fig. 11. Roll angle simulation result

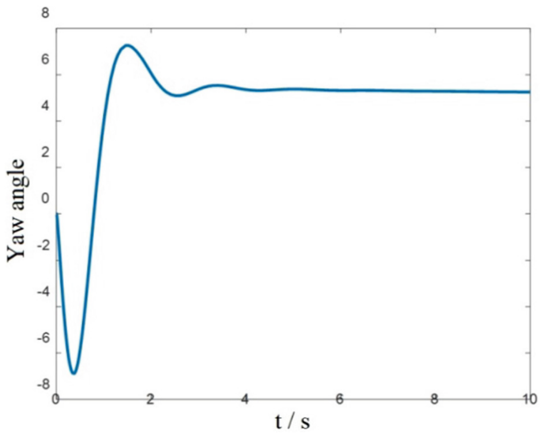

Fig. 12. Yaw angle simulation result

7 Conclusion

This paper takes the motion state control method of four rotor UAV as the research object. The control system of UAV running state based on classical PID controller is designed. The inner loop control model to realize the flight attitude control of UAV and the outer loop control model to realize the space position control of UAV are constructed. The simulation experiment of UAV operation state control system is carried out.

The research results show that the classical PID control system meets the needs of UAV for simple flight tasks. For example, in the daily inspection work scene of transmission lines, only drones need to fly and take photos at a constant speed along the smooth line channel. Classical PID control system can be used to perform such a simple task.

The working scenario of lean inspection of distribution lines requires that unmanned aerial vehicles can shuttle freely in rugged and complex line channels, and that unmanned aerial vehicles can quickly avoid obstacles. When performing such complex tasks, it is necessary to further improve the control method of four rotor UAV.

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