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Simulation of Pilot Helicopter Control System Based on PID Control

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Abstract

Helicopter piloting has gradually become a way of transporting pilots in various ports. However the helicopter is a high-order, multi-variable, strongly coupled and unstable system that requires reliable and effective control methods for flight control. Based on the analysis of the 3-DOF helicopter system, a simplified system model of the 3-DOF helicopter is obtained.The PID controller is designed by using the conventional PID control method and a fast and effective simulation debugging GUI is designed to simulate the designed controller.The simulation results show that the simulation curves are stable at the expected values, which proves the controllability of the helicopter system and the effectiveness of PID control.

Keywords

3-DOF helicopter, PID control, simulation debugging GUI.

1. Introduction

The pilot boat has always been the means of transport and departure of pilots from various ports in China. This traditional mode of operation is slow, inefficient and costly. The high frequency of the wind and the weather and the harsh working environment have greatly restricted the operation mode of the pilots who used the pilot boats to transport the boats to the dinghy [1]. The pilot boat cannot go to sea normally, which affects the port production efficiency. Compared with traditional methods of operation, helicopters are characterized by fast, flexible, efficient and wide range of activities. When the helicopter is working, it can hover in the air, not directly contact with the hull, and get rid of the impact of the sea waves. The helicopter has strong wind resistance and high working efficiency. It can work normally under the conditions of strong winds, and the port piloting capacity is greatly improved. Under the complicated meteorological conditions, helicopters have considerable advantages in providing pilotage services for ships compared with traditional methods [2]. Helicopter flight control system is a typical multi-input and multi-output system. It has nonlinear, high-order and multi-variable characteristics. It is a relatively complex controlled object in control system engineering [3-5], which is designed to be effective and low-cost. Helicopter flight control systems are receiving increasing attention.

In view of the characteristics of the three-degree-of-freedom helicopter system, as an excellent research platform for control theory, it has been favored by relevant scholars in recent years [6]. In Ref. [7], a self-tuning PID controller is designed. A discrete second-order sliding mode observer is used in Ref. [8] to discuss state and unknown input estimation. n adaptive fuzzy PID controller is designed in Ref. [9]. The nonlinear state feedback linearization method proposed in Ref. [10] can realize the linearization and decoupling control of the nonlinearly coupled three-degree-of-freedom helicopter system. The main drawback of the above mentioned methods is that some nonlinear parts are neglected in the process of establishing a three-degree-of-freedom helicopter mathematical model,

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which has not strict basis. In the simulation experiment, there are also constant adjustments and modifications of the controller, and the debugging process is complicated and inconvenient.

the model of high-order, multivariable, strongly coupled and unstable three-degree-of-freedom helicopter systems is analyzed in this paper. The traditional PID control method is chosen and the controller is designed to control the flight of the system. Finally, the simulation debugging interface of the three-degree-of-freedom helicopter system is designed by combining MATLAB/Simulink and GUI tools. The simulation of the control system is carried out by the quick and convenient operation of the interface to verify the effectiveness of the designed control method.

2. Three-degree-of-freedom helicopter system modeling

2.1 Introduction to the system model

The three-degree-of-freedom helicopter model is shown in Figure 1, where A is the balance block, C and D are the two propellers that power the system, AB is the balance bar, and E is the base. The model uses the balance bar to simulate the flight motion with the point O as the fulcrum. The force generated by the rotation of the two propellers can make the balance bar perform the pitching motion with the O point. By using the speed difference between the two propellers, the balance bar can be rotated by the O point. At the same time, due to the speed difference, the CD will be side-shifted with point B. The corresponding encoder is installed on the pitch axis, the rotation axis and the lateral axis of the model, and the data of the pitch angle ε, the rotation angle w and the lateral angle p can be collected during the movement of the model, so that the flight state of the model can be observed. [11].

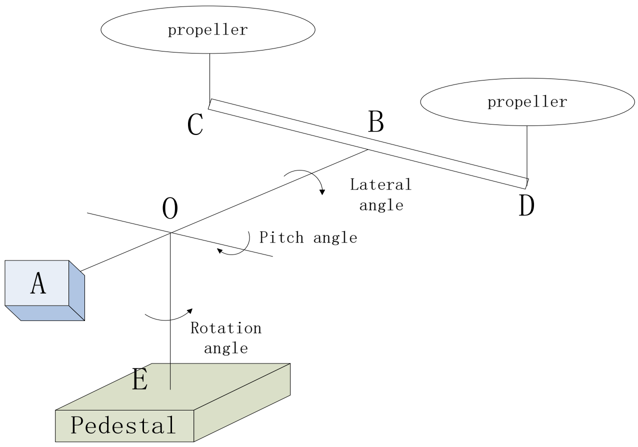

Figure 1. Three-degree-of-freedom helicopter model

2.2 System modeling

Based on the characteristics of the above three-degree-of-freedom helicopter system, the model will be modeled from the pitch axis, the lateral axis and the rotation axis of the model.

Pitch axis

The pitch axis model is shown in Figure 2. The motion of the pitch axis is obtained with the same rotational speed of the two propellers of the model. The lift generated by the two propellers is f_1 and f_2, then the lift of the model propeller is $F_h = f_1 + f_2$. Let the gravity be G, when the $F_h > G$, the helicopter model will rise; when $F_h < G$, the helicopter model will fall, and when $F_h = G$, the helicopter will be balanced and hovering in the air. It can be seen that the torque of the model pitch axis is controlled by the lift generated by the rotation of the two propellers.

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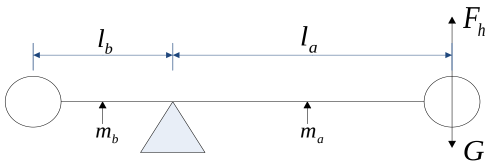

Figure 2. Pitch axis model

The model is selected to be hovering and the elevation angle $\varepsilon = 0$ is analyzed [12]:

$$\begin{aligned} J_e\ddot{\varepsilon} &= l_aF_h - l_aG = l_a(f_1 + f_2) - l_aG \\ &= l_aK_c(V_1 + V_2) - T_g = l_aK_cV_s - T_g \end{aligned} \tag{1}$$

Where, J_e is the moment of inertia of the pitch angle, $J_e = m_al_a^2 + m_bl_b^2$; $\ddot{\varepsilon}$ is the rotational acceleration of the pitch axis; K_c is the lift constant of the model propeller; V_1 and V_2 are the voltages of the two propeller motors and generate lifts f_1 and f_2, respectively. T_g is the effective weight torque generated by the pitch axis, $T_g = m_bgl_b - m_agl_b$.

If you ignore the effective weight torque T_g, you get:

$$J_e\ddot{\varepsilon} = l_aK_cV_s \tag{2}$$

Furthermore, the open-loop transfer function of the pitch axis can be derived:

$$\frac{\varepsilon(s)}{V_s(s)} = \frac{l_aK_c / J_e}{s^2} \tag{3}$$

Lateral axis

The lateral axis model is shown in Figure 3. The motion of the lateral axis is obtained with different rotational speeds of the two propellers of the model. The different rotation speeds of the propellers cause the f_1 and f_2 to be different. When $f_1 > f_2$ or $f_1 < f_2$, the propeller body is inclined, and the angle of inclination is the cross-angle p, and a lateral force is formed, so that the helicopter model has an O point. The pivot is rotated.

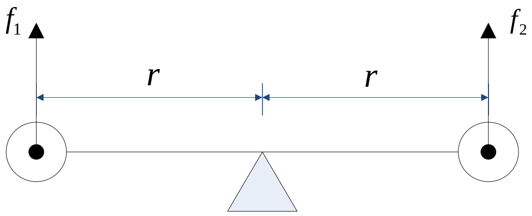

Figure 3. lateral axis model

The kinetic equation is obtained through system dynamics analysis [12]:

$$J_p\ddot{p} = f_1r - f_2r = K_c(V_1 - V_2)r = K_crV_d \tag{4}$$

Where, J_p is the moment of inertia of the lateral axis; $\ddot{p}$ is the rotational acceleration of the lateral axis; r is the distance between the two motors to the lateral axis.

Further derivation of the open-loop transfer function of the lateral axis is:

$$\frac{p(s)}{V_d(s)} = \frac{K_cr / J_p}{s^2} \tag{5}$$

Rotary axis

The rotating shaft model is shown in Fig. 4. The movement of the rotating shaft is caused by the rotation of the lateral shaft causing the lift of the propeller to become a lateral force and forming a

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component in the horizontal direction to generate a moment. This moment is the source of the rotational acceleration generated by the rotating shaft. The component of the lateral force in the vertical direction maintains the balance of the model in the air, and the size is equal to G .

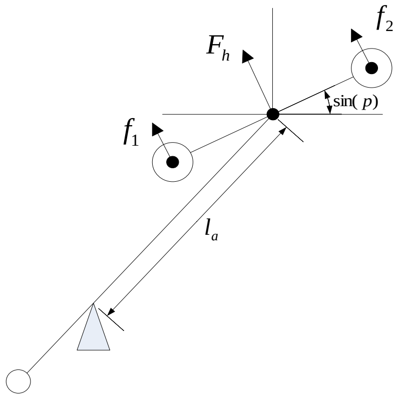

Figure 4. Rotary Axis Model

The kinetic equation is obtained through system dynamics analysis [12]:

$$J_w \dot{w} = G \sin(p) l_a \tag{6}$$

Where, J_w is the moment of inertia of the rotating shaft; $\dot{w}$ is the rotational acceleration, the unit is $rad/\sec$; $\sin(p)$ is the sine value of the transverse angle p, and when the cross angle is 0, the rotation axis has no torque. When the cross angle is small, the acceleration of the rotary axis is proportional to the cross angle. The system open loop transfer function is:

$$\frac{w(s)}{p(s)} = \frac{Gl_a / J_w}{s} \tag{7}$$

3. PID controller design

Since its inception in the 1940s, PID controllers have been widely used in industrial process control such as metallurgy, chemical, electric power, light industry, aviation and machinery because of their simple structure, robustness to error and easy operation. Although the application field of control technology will become wider and wider in the future, the controlled objects will become more and more complex, and the corresponding control technology will become more and more sophisticated. However, various controllers based on PID will not be in process control. Or basic control unit [13].

The PID is named after its three corrective methods. The controlled variable is the result of adding the three control quantities (proportional, integral and differential), ie its output, the input is the error value (the result after the set value minus the measured value) or is derived from the error value. signal. If the definition $u(t)$ is the control output, the PID algorithm can be expressed by the following formula [14]:

$$u(t) = K_P e(t) + K_I \int_0^t e(\tau) d\tau + K_D \frac{d}{dt} e(t) \tag{8}$$

The block diagram of the control system is shown in Figure 5. Three control loops are designed. Since the rotary axis controller is controlled according to the lateral side shaft angle, the response time of the lateral shaft closed loop system is faster than that of the rotary shaft closed loop system. Response time.

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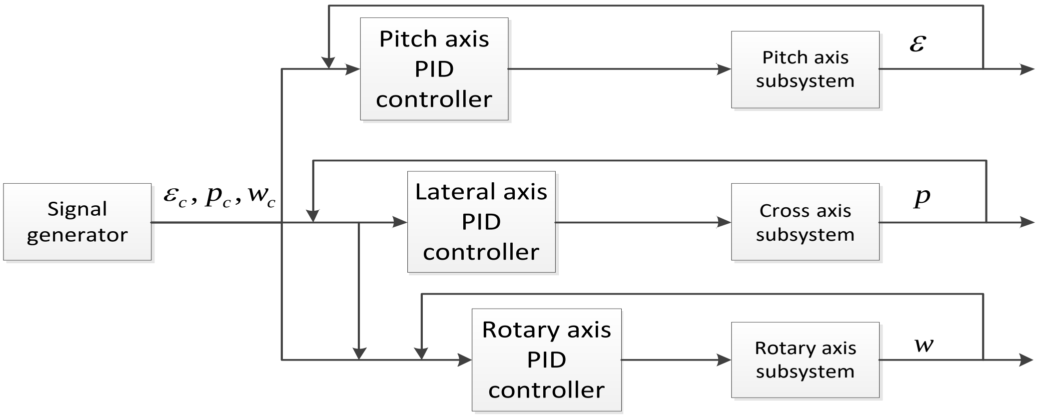

Figure 5. Block diagram of a three-degree-of-freedom helicopter control system

3.1 Pitch axis controller

The pitch axis PID controller obtained by (2) is as follows:

$$V_s = K_p(\varepsilon - \varepsilon_c) + K_i\int(\varepsilon - \varepsilon_c)dt + K_d\dot{\varepsilon} \tag{9}$$

Where, V_s is the sum of the voltages of the two propeller motors, $V_s = V_1 + V_2$; ε is the actual pitch angle; ε_c is the desired pitch angle.

3.2 Lateral axis controller

The lateral side axis PID controller obtained by (4) is as follows:

$$V_d = K_p(p - p_c) + K_i\int(p - p_c)dt + K_d\dot{p} \tag{10}$$

Where, V_d is the difference between the voltages of the two propeller motors, $V_d = V_1 - V_2$; p is the actual lateral side angle; p_c is the desired lateral side angle.

3.3 Rotary axis controller

If the cross angle p changes within a small angle, the equation (6) can be linearized as:

$$J_w\dot{w} = Gpr \tag{11}$$

Get the rotary axis PID controller as follows:

$$p_c = K_p(w - w_c) + K_i\int(w - w_c)dt + K_d\dot{w} \tag{12}$$

Where, w is the actual rotational angular velocity; w_c is the desired rotational angular velocity.

4. System Simulation GUI and Results Analysis

Simulation experiments were performed in the MATLAB/Simulink environment. Firstly, build a Simulink simulation block diagram of each degree of freedom PID control system. Taking the pitch axis as an example, first set an expected value, here select the pitch angle $\varepsilon = 5$, and implement it with a Step module with an amplitude of 5. Then set up the PID controller, which consists of proportional, integral, and differential links, corresponding to three PID parameters K_p, K_i and K_d.The comparison link consists of parameter K_p alone; the integral link consists of parameter K_i and the Integrator module; the differential link consists of parameter K_d and the Derivative module. In order to test the anti-jamming performance of the designed controller, some natural effects that may occur in the simulation reality are added. When the simulation time of the three axes is 5s, a step disturbance of amplitude 1 is added, and the disturbance signal is adjusted with the PID. The latter control signal is superimposed and transmitted to the controlled object, that is, the three degrees of

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freedom of the helicopter, and the output result is fed back to the input terminal to realize closed-loop control. Finally, pass the closed-loop output signal to the oscilloscope for easy observation. The Simulink simulation block diagram of the pitch axis PID control system is shown in Figure 6. The simulation block diagram of the lateral axis and rotary axis PID control system is the same as the pitch axis structure.

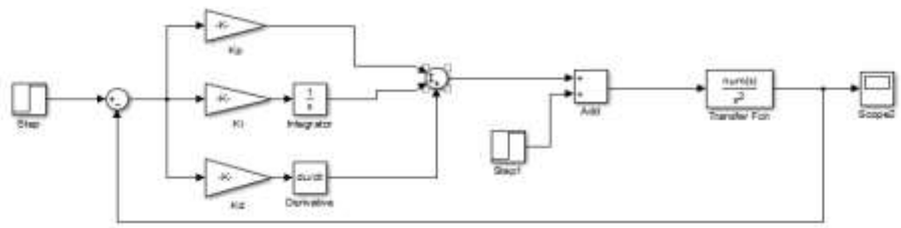

Figure 6. Simulation diagram of the pitch axis control system

The setting of the lateral axis and the rotating axis is expected to be the horizontal measurement angle $p=2$ and the rotational angular velocity $w=5$, wherein the PID parameters of the respective degrees are repeatedly debugged. In the process of actually debugging the PID control parameters, it is found that a large number of numerical combination tests are required to obtain better K_p, K_i and K_d, and each time value is modified to assign parameters to the corresponding modules in the built Simulink system block diagram. This process is very cumbersome. GUI is an intermediary for human-computer interaction, which can be used to input, process and output data [15]. So a GUI-based control simulation system is designed for three-degree-of-freedom helicopters in this paper.

First, the initial interface of the system is designed as shown in Figure 7. Three buttons are added to this interface, which correspond to the pitch axis, the lateral axis and the rotation axis.

Figure 7. Simulation GUI initial interface

When the system is running, click the corresponding button to enter the simulation interface corresponding to the degree of freedom, as shown in Figure 8-10.

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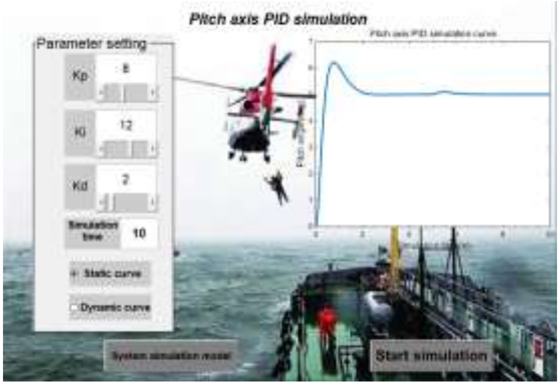

Figure 8. Pitch axis PID simulation interface

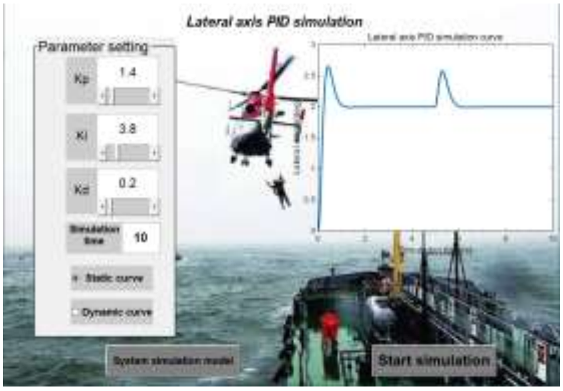

Figure 9. Lateral axis PID simulation interface

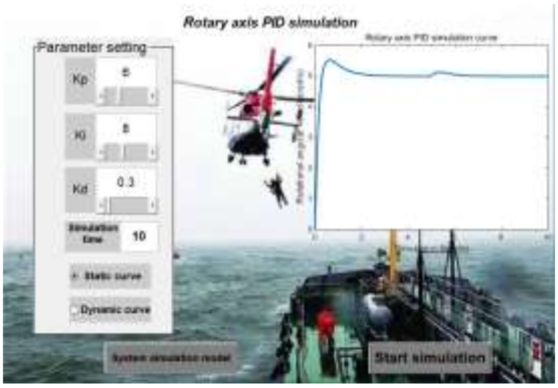

Figure 10. Rotary Axis PID Simulation Interface

In the simulation interface of each degree of freedom, a parameter setting panel is designed, which includes the modification of the simulation time value of K_p, K_i and K_d, and the three control parameters can not only input the desired value directly in the text box, but also Drag the slider to fine tune the value. In order to facilitate the observation and analysis of the simulation results, the system added static curve and dynamic curve mode selection buttons. The previous simulation can only get the result by observing the oscilloscope module after the simulation. When we select the dynamic curve button before the simulation, we can dynamically observe the change process of the simulation curve in the interface. For some turning points with large changes, Better observations to facilitate analysis of the results. At the same time, in order to quickly modify the corresponding Simulink block diagram, the system simulation model button is added to the interface. Pressing this button directly enters the Simulink editing interface and changes the block diagram as needed.

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After a large amount of data debugging, the pitch axes select K_p, K_i and K_d values of 8, 12 and 2, and the selected parameters are input into the built-up pitch axis Simulink block diagram, and the expected value of the pitch angle is simulated; The lateral axis selects K_p, K_i and K_d values of 1.4, 3.8 and 0.2, and the selected parameters are input into the built-in cross-section axis Simulink block diagram, and the expected value of the cross-angle is simulated. The rotation axes select the values of K_p, K_i and K_d as 6, 8, and 0.3. The selected parameters are input to the built-in rotating axis Simulink block diagram, and the expected values of the rotational angular velocity are simulated. The simulation results are shown in Figure 8-10. It can be seen from the obtained three sets of simulation curves that the pitch axis can be stabilized at the expected value of $\varepsilon = 5$ at approximately 2.5 s; the lateral axis can be stabilized at the expected value of $p = 2$ at approximately 1.2 s; the rotational axis can be approximately 2.2 s. Stable at the expected value of $w = 5$.In order to have a faster response speed, the three degrees of freedom have different degrees of overshoot, however there is no residual in each axis after stabilization. For step interference caused by artificial addition, it is found that each axis fluctuates, but will eventually stabilize at the desired value. From the above results, the controllability of the three-degree-of-freedom helicopter system has better steady-state performance and robust performance and the effectiveness of the designed PID controller.

5. Conculsion

For the fast-growing helicopter pilot project, the three-degree-of-freedom helicopter system is analyzed and modeled, and the simplified dynamic equations and open-loop transfer functions are obtained from the perspective of three degrees of freedom. The high-efficiency and stable PID control is introduced, and the conventional PID controller is designed for each degree. The simulation experiment of adding disturbance is carried out on MATLAB/Simulink. The simulation results verify that the PID controller has high steady-state accuracy and good robustness. In order to solve the complexity and cumbersome modification of the debugging process, a GUI-based control simulation system for a three-degree-of-freedom helicopter is designed. After testing, the system has good human-machine interaction performance, which makes the debugging process simple and clear, greatly improving the debugging efficiency. The further studies on combination intelligent control with PID control for the helicopter system are under investigation.

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References

[1] Fang Lizhi. Application of Dynamic Matrix Control in Three-DOF Helicopters[J].Science and technology,2019(22):14-15.

[2] Liu Yaqi, Guo Xinghua, Lin Xi. Operation and Safety Management of Helicopter in Pilots' Pick-up and Transfer[J]. World Shipping, 2018, 41(1): 16-19. DOI:10:16176/j.cnki.21-1284.2018.01.004

[3] Zhou Wei,Wang Xiaodong. Three-DOF Helicopter Control Based on PID Neural Network[J].Computer and Digital Engineering,2018,46(01):83-88.

[4] Ding Chunlong. Research on Modeling and Control Method of Three-DOF Helicopter[D]. Harbin: Harbin University of Science and Technology, 2014

[5] Yang Huiping, Gao Guanbin, Na Jing. Design of Three Degrees of Freedom Helicopter Experimental Platform and Attitude Tracking Controller[J]. Machinery & Electronics, 2015, (5): 69-72

[6] Li Yashuai, Shao Zongkai. Adaptive fuzzy H∞ mixed sensitivity robust control for three-degree-of-freedom helicopter system[J]. Sensors and Microsystems, 2018, 37(1): 74-78. DOI:10.13873/J.1000-978 7(2018) 01-0074-05

ISSN: 2414-1895 DOI: 10.6919/ICJE.201910_5(11).0014

[7] Ahsene Boubakir,Salim Labiod,Fares Boudjema,et al. Designand experimentation of a self-tuning PI D control applied to the 3DOF helicopter[J]. Archives of Control Sciences,2013,23(3): 311-331
[8] Madhumita Pal,Franck Plestan,Abdelhamid Chriette. Discrete-time second-order-sliding-mode observ er for state and unknown inputestimation: Application to a 3DOF helicopter[C]//2015 European Co ntrol Conference,Linz,Austria,2015:2914-2919
[9] Sun Yujia, Yan Guoqing. Adaptive fuzzy PID attitude control for three-degree-of-freedom helicopte rs[J]. Electronic Design Engineering, 2017, 25(11): 73-76. DOI:10.14022/j.cnki.dzsjgc.2017.11.018
[10] Zhou Wei, Wang Xiaodong. Three-degree-of-freedom helicopter control based on nonlinear output feedback[J]. Computer and Digital Engineering, 2017, 45(5): 917-922. DOI:10.3969/j.issn.1672-972 2.201 7.05.027
[11] Wang Hong,Lin Zijian,Wang Lingling.Study on Simulation of Three-DOF Helicopter System Based on Fuzzy Control[J].Electronic Measurement Technology,2017,40(10):113-117.
[12] Zhang Jingang. Research on Adaptive Modeling and Control of Three-DOF Helicopter System[D]. Yunnan: Kunming University of Science and Technology, 2016
[13] Liu Jinwei. Advanced PID Control MATLAB Simulation [M]. Publishing House of Electronics Ind ustry, 2011: 459-473.
[14] Wu Yong. Quadcopter DIY: Based on STM32 Microcontroller [M]. Beijing: Beijing University of Aeronautics and Astronautics Press, 2016:196-197
[15] Su Jinming, Wang Yongli. MATLAB 7.0 User Guide. Volume [M]. Beijing: Publishing House of Electronics Industry, 2004: 81-82