Research on Attitude Control System of Quadrotor Unmanned Aerial Vehicle based on Fuzzy PID Control Algorithm

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Abstract. The control of quadrotor aircraft mainly includes attitude control and position control. Because the change of position is caused by the change of attitude, it is most important to control the attitude of quadrotor aircraft. PID control principle is simple, easy to master, convenient to use, strong adaptability and good robustness, and its control quality is insensitive to the change of the controlled object, so it is most widely used. Quadrotor UAV is a strongly coupled underactuated system, and its stability is easily affected by system uncertainty and external interference during flight. Therefore, an improved fuzzy PID control method is proposed. In this article, the significance and ideas of constructing the attitude control system of quadrotor UAV based on fuzzy PID control algorithm are analyzed. This control strategy not only keeps the advantages of fuzzy control algorithm, which is independent of accurate model, and flexible and fast control, but also combines the advantages of PID control algorithm with small static error, and can achieve good control of nonlinear complex system.

Keywords: Fuzzy PID Control; Quadrotor Unmanned Aerial Vehicle; Attitude Control.

1. Introduction

UAV is an unmanned aircraft that uses aerodynamic force to offset its own weight, and is controlled by radio remote control equipment and microcontroller's own program. It can realize remote control flight and autonomous flight. Attitude control is the basis of quadrotor aircraft research, the core part of stable flight, and a hot issue at home and abroad. The quadrotor UAV has six degrees of freedom in space, and the power provided by the aircraft is at the end of four axes. It is a strongly coupled, nonlinear, underactuated and multivariable system. Four-rotor UAV, as the representative of micro UAV, has small structural complexity, low cost and certain load capacity. Changing the rotating speed of four rotors can realize different attitude flight, oblique flight, lateral flight and vertical take-off and landing [2]. However, it is still a typical underactuated coupled nonlinear system, and it is difficult to obtain its accurate mathematical model, which is vulnerable to external disturbance and weak in resistance to disturbance. The control of quadrotor aircraft mainly includes attitude control and position control. Because the change of position is caused by the change of attitude, controlling the attitude of quadrotor aircraft is the most important [3]. In order to realize the attitude control of quadrotor aircraft, people usually use a mature PID controller.

The control of quadrotor aircraft mainly includes position control and attitude control. Attitude control not only affects the attitude angle of the aircraft, but also affects its position control, so attitude control is the premise and foundation of flight control of quadrotor aircraft [4]. The backstepping control proposed by Wang et al. can adapt to the nonlinear system of quadrotor UAV, but the calculation process of backstepping control is complicated, which reduces the processing speed of quadrotor UAV [5]. Although the synovial control proposed by Liu et al. has simple algorithm, strong robustness and strong ability to deal with external uncertainties, the synovial control needs to switch fuzzy control and use fuzzy language to make the control rough, but it has strong robustness and is suitable for nonlinear systems [6]. Fuzzy PID is a combination of the two, and variable universe fuzzy PID is a further optimization which inherits the advantages of fuzzy PID. Control logic can easily lead to chattering in the running process of control system [7]. Song et al. put forward K-Means algorithm, which can deal with the attitude deviation of UAV in time and is easy to implement, but it may converge to the local minimum, and it will converge slowly on large-scale data sets when multi-

sensors are needed to collect data [8]. In this article, the significance and ideas of constructing the attitude control system of quadrotor UAV based on fuzzy PID control algorithm are analyzed. This control strategy not only keeps the advantages of flexible and fast control of fuzzy control algorithm, but also combines the advantages of small static error of PID control algorithm, which can achieve good control of nonlinear complex system.

2. Dynamic Analysis and Model Establishment of Quadrotor UAV

How to establish an accurate mathematical model is very important for the research of the controlled object, and the accurate model can ensure the effectiveness and control performance of the designed controller. The rotors of quadrotor UAV will drift when rotating at high speed. Therefore, by designing the structure of quadrotor, the adjacent rotors rotate in opposite directions, and the alternate rotors rotate in the same direction [9]. The reaction torque generated by each rotor counteracts each other, thus to a certain extent, the quadrotor UAV keeps a fixed course and weakens the influence of drift. The control system of quadrotor UAV is complex, and it is easy to be disturbed by external conditions during flight, so the modeling is difficult. It is very important to establish an accurate dynamic model of quadrotor UAV, and the accurate mathematical model of the controlled object can ensure the effectiveness and control performance of the designed quadrotor UAV controller [10]. The attitude of quadrotor UAV during flight includes pitching motion of forward flight and backward flight, rolling motion of left flight and right flight, yaw motion of changing motion direction, and vertical ascending and descending motion.

As the skeleton of the four-rotor UAV structure system, it includes the fuselage and landing gear, carrying all the components required by the system. The four rotors are mostly made of carbon fiber frame, which has the characteristics of light weight and strong plasticity, and can carry objects with large specific gravity. According to rigid body theory, quadrotor UAV can be regarded as a structure composed of a rigid body and four rotors. The four rotors are regarded as particles, and the force generated by each rotor through rotation can be decomposed into two quantities: the lift force of the vertical rotating surface and the reaction moment opposite to the rotating direction. The landing gear plays the role of supporting and protecting the fuselage, preventing the rotor from colliding with the ground when rotating, and at the same time, it plays the role of buffering and reducing the impact pressure of quadrotor UAV when landing through its structural characteristics. Force analysis of quadrotor UAV shows that the force acting on it includes vertical downward gravity. The lift generated by four rotors and four torques are shown in Figure 1.

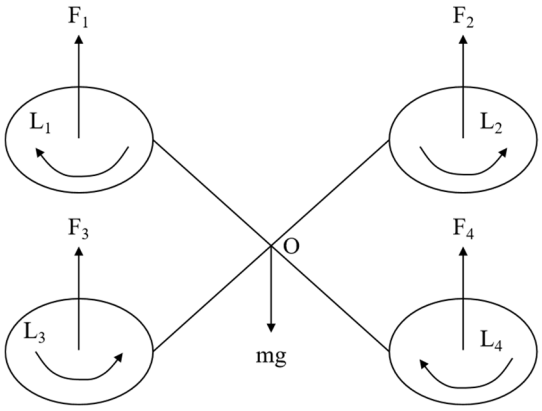

Figure 1. Force analysis of quadrotor UAV

Thrust is the resultant force of four motors, and the expression is:

$$F_i = b \cdot \omega_i^2 \tag{1}$$

Where b is the thrust coefficient; ω_i is the rotation speed of the motor i. Therefore, the resultant force of four rotors from four motors can be described by the following expression:

$$T = \sum_{i=1}^{4} |F_i| = b \cdot \sum_{i=1}^{4} \omega_i^2 \tag{2}$$

Now, the first set of differential equations of four-rotor acceleration can be described as:

$$\ddot{q} = \begin{bmatrix} \ddot{x} \\ \ddot{y} \\ \ddot{z} \end{bmatrix} = g \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} - R \frac{T}{m} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \tag{3}$$

Where g is the acceleration of gravity; m is the weight of the quadrotor. The vector M describes the torque applied to the quadrotor. The torque can be obtained by Equation (4), so the vector M is defined as:

$$M = FL \tag{4}$$

$$M = \begin{pmatrix} Lb\left(\omega_3^2 - \omega_4^2\right) \\ Lb\left(\omega_1^2 - \omega_2^2\right) \\ d\left(\omega_1^2 - \omega_2^2 - \omega_3^2 - \omega_4^2\right) \end{pmatrix} \tag{5}$$

Where F is the force generated by the propeller; L is the arm length of the quadrotor; b is the thrust coefficient; d is the tensile force coefficient. Using equation (5) and moment of inertia I, a second set of differential equations is obtained:

$$I \cdot \ddot{\Omega} = -\left(\dot{\Omega} \times I \cdot \ddot{\Omega}\right) - M_G + M \tag{6}$$

Where M_G is the torque produced by gyro effect. The rotation speed ω_i of the four motors is the real input variable of the four rotors, but for the convenience of research, it is reasonable to convert the input variable.

The quadrotor is a nonlinear, multivariable and strongly coupled controlled object. The design of its flight system is mainly aimed at its dynamic characteristics, such as strong coupling, instability, sensitivity to external disturbances, etc., so as to propose a suitable algorithm to achieve the purpose of stable flight control. Fuzzy control doesn't need to know the internal structure, working principle or mathematical model of the controlled object. It focuses on the control experience and strategy of the controlled object, which is written into fuzzy rules by fuzzy conditional language through analysis, induction and summary [11]. In the design process of fuzzy controller, it is most important to compile fuzzy rule base and fuzzy reasoning algorithm with expert experience and theoretical knowledge, and it is most important to determine the structure of modular controller, establish fuzzy rules and select approximate reasoning algorithm.

3. Result Analysis and Discussion

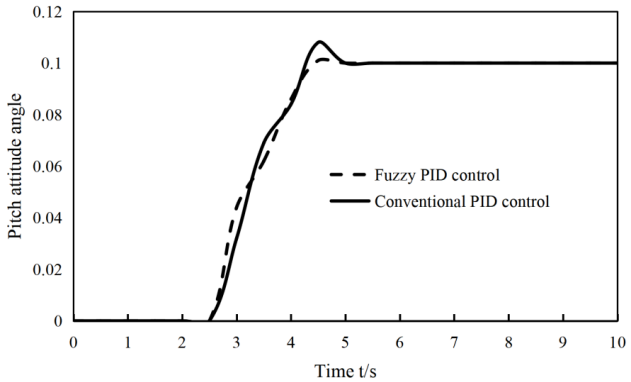

Figure 2. Simulation results of step response

Although the conventional PID controller has the advantages of simple design, reliable performance and good stability. However, there will be many disturbances in industrial control, so it is necessary to constantly adjust the PID parameters in order to achieve a more satisfactory control effect. Because the parameters are changeable and there is no accurate mathematical model and law, it is a simple and practical method to adopt fuzzy control adjustment. After determining the fuzzy rules of system control, the whole system is simulated. The pitching attitude angle of quadrotor UAV is selected as the simulation control object, and the simulation results under the step input condition are shown in Figure 2.

As can be seen from Figure 2, the static error of fuzzy PID controller and conventional PID controller is very small under step input. And the overshoot of the system under the action of fuzzy PID controller is obviously smaller than that under the action of conventional PID controller. Therefore, the dynamic performance of the system is better under the action of fuzzy PID controller. Establishing fuzzy control rules suitable for flight control system can not only improve the rapidity of control, but also ensure that the stability is not affected and avoid the control dead zone. After the circuit is reset, the circuit enters the working state, and the parameter configuration enable signal is given a high level to configure the parameters, including the upper and lower limits of amplitude limiting, the set value of proportional integral differential parameters, and the sampling time value. After the parameter configuration signal is lowered, the parameter configuration has been completed. The simulation results of the two controllers under sinusoidal input are shown in Figure 3.

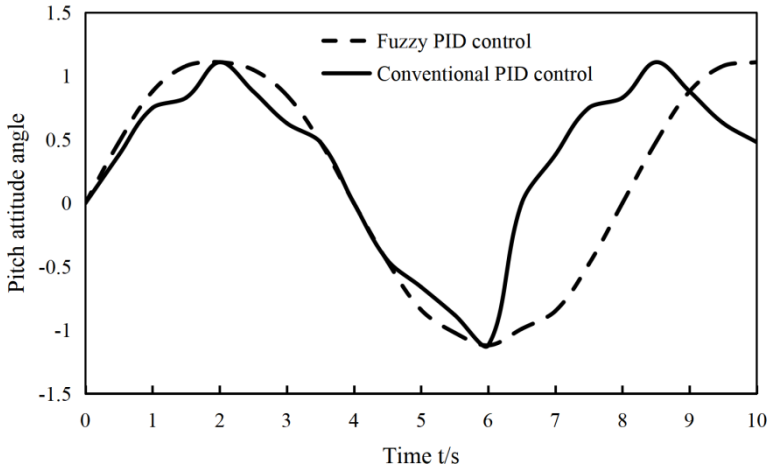

Figure 3. Simulation results of sinusoidal response

It can be seen from Figure 3 that the control accuracy of conventional PID controller is greater than 5%, while that of fuzzy PID controller is about 2%, and the latter is obviously higher than the former. Fuzzy controller has better steady-state performance. Because the control of flight attitude is the loop of displacement trajectory control, a good attitude controller design scheme can not only ensure the stable flight attitude of quadrotor aircraft in the air, but also control the flight displacement trajectory of quadrotor aircraft. The fuzzy controller has its own fuzzy rule base written by expert knowledge, which can make full use of the adjustment experience of fuzzy rule base to self-adjust the nonlinear system online, and cooperate with PID controller to give full play to their respective control advantages, so as to realize the optimal control of the system.

4. Conclusion

In the flight process of quadrotor UAV, excellent attitude control is the premise of stable flight. The control of quadrotor UAV mainly includes attitude control and position control. Because the change of position is caused by the change of attitude, it is most important to control the attitude of quadrotor UAV. In this article, the nonlinear model of quadrotor UAV is established in Matlab environment, the fuzzy PID controller model and the conventional PID controller model are designed

respectively, and the system control effects of the two controllers are simulated by software platform. The control accuracy of conventional PID controller is greater than 5%, while that of fuzzy PID controller is about 2%. Fuzzy PID controller is superior to conventional PID controller in dynamic performance and steady performance, and fuzzy PID controller can better control quadrotor UAV. This control strategy not only keeps the advantages of fuzzy control algorithm, which is independent of accurate model, and flexible and fast control, but also combines the advantages of PID control algorithm with small static error, and can achieve good control of nonlinear complex system.

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