Research on a Fuzzy Adaptive PID Control Method for Four Rotor UAV Control System

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Abstract. Research on A Fuzzy Adaptive PID Control Method for Four Rotor UAV Control System With the continuous improvement of national living standards, people have higher and higher requirements for the reliability of power supply. The emergence of unmanned aerial vehicle inspection technology provides a new idea to solve the contradiction between the increasing equipment scale and the increasing inspection requirements. However, at present, the stability of the traditional proportion integration differentiation (PID) control system of the four rotor unmanned aerial vehicle (UAV) is not high enough. During the inspection, there are accidents of drones hitting power equipment from time to time. In view of the above problems, this paper studies the fuzzy adaptive PID control method to support the stable flight of four rotor UAV. The principle of fuzzy control is analyzed. The fuzzy control method and PID control method are deeply integrated. A fuzzy adaptive PID control system is designed. The universe and membership function of the relevant control parameters of the system are formulated. The tuning rules of fuzzy adaptive PID control system are formulated. Finally, the improved control system is simulated. The simulation results show that the fuzzy adaptive PID control algorithm can effectively improve the stability, reliability and emergency ability of UAV. This method can effectively improve the adaptability of UAV to perform complex missions in complex environments. The research results have guiding significance for expanding the application field of UAV.

Keywords: Four Rotor Unmanned Aerial Vehicle · Fuzzy Control · Proportion Integration Differentiation

1 Introduction

Four rotor UAV has the characteristics of light and compact, rich flight posture, simple operation and so on [1]. At present, it has been widely used in many fields. Especially in the power industry, the application scale of four rotor UAV is growing [2]. However,

H. Yang et al. (Eds.): SmartGIFT 2022, LNICST 483, pp. 455–465, 2023.
https://doi.org/10.1007/978-3-031-31733-0_39

with the large number of UAV patrol inspection of power equipment, accidents of UAV impacting power equipment occur from time to time [3]. This is mainly because the four rotor UAV is a strongly coupled underactuated system. At present, the commonly used traditional UAV PID control system has low control accuracy and slow response speed [4]. When the UAV performs a simple flight mission, the defect of low stability of the control system has not been shown. When unmanned aerial vehicles perform complex flight tasks or deal with complex application scenarios, the defects of low stability of the control system are undoubtedly exposed [5]. At present, the state has very strict requirements on power supply reliability. Once a foreign object touches the power equipment, it is very likely to cause a power failure. Therefore, the stability of UAV control system must be improved to adapt the needs of power inspection application scenarios [3].

Aim at the above-mentioned problems, this paper improves the traditional proportion integration differentiation control method. Fuzzy control method is deeply integrated into the control system of four rotor UAV. On this basis, incomplete differential and anti integral saturation modules are introduced. Finally, the simulation experiment of the improved fuzzy adaptive PID control system of four rotor UAV is carried out. The research results have guiding significance for improving the stability of UAV control system.

2 Principle of Fuzzy Control

Fuzzy control logic can use simple language to describe the specified intelligent logic algorithm. Although the fuzzy control method has nonlinear characteristics, it can fully integrate the advantages of the two by introducing the fuzzy control theory into the traditional proportion integration differentiation control system. After the deep integration of fuzzy control theory, the safety and reliability of proportion integration differentiation control system will be greatly improved.

The input of fuzzy control needs to meet the needs of system design. Many factors such as external input, system output and UAV system status will affect the effect of fuzzy control. So the input information should be within a reasonable range. Then, the input signal is transformed into fuzzy vector by using proportional conversion.

Database and rule base together constitute the knowledge base of fuzzy control. The input signals, Output information and all fuzzy subsets are stored in the database. These fuzzy control rules come from the long-term experience of experts.

In short, fuzzy theory is to use the corresponding fuzzification rules and logic summarized by experts to constantly modify the system parameters.

In the process of fuzzy control, the fuzzy set is obtained by fuzzy reasoning. Fuzzy sets cannot be used directly. Only accurate values can be applied to the control system. Defuzzification is the process of solving fuzzy sets into exact values.

Figure 1 is the schematic of One dimensional fuzzy proportion integration differentiation control system. First, fuzzy inference is carried out on the initial data. Convert the input signal into fuzzy quantity. Then the fuzzy set is deduced according to the fuzzy rules of experts. Finally, the precise output value is calculated through the anti fuzzification operation. The following is the structure introduction of three fuzzy control systems with different dimensions.

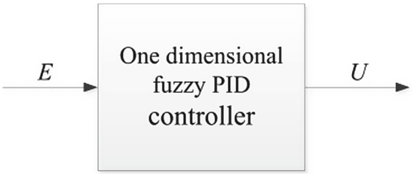


Fig. 1. One dimensional fuzzy proportion integration differentiation controller

The structure of this control system is very simple. Because the system only uses error as input, it is often difficult to reflect the real dynamic characteristics of the controlled object, and the control effect is not ideal. One dimensional fuzzy control system is rarely used in engineering applications. In the figure, e is the error. U is the error value fed back by the control structure.

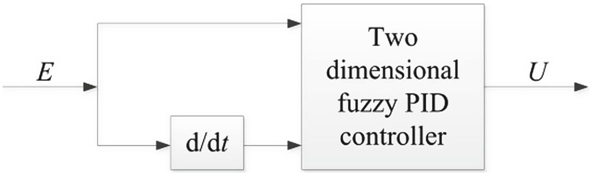


Fig. 2. Second order fuzzy optimal proportion integration differentiation controller

Figure 2 is Second order fuzzy optimal proportion integration differentiation control system. The input signal of two-dimensional control system includes error and error rate after differential processing. The two-dimensional control system can accurately image the output dynamic performance of the controlled object in the controlled process. In practical engineering applications, two-dimensional control system is widely used.

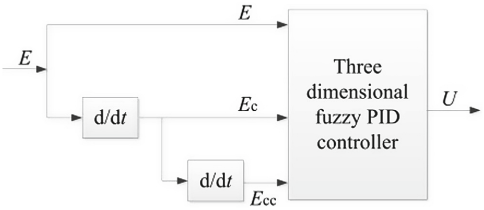


Fig. 3. Three dimensional fuzzy optimal proportion integration differentiation controller

Figure 3 is three-dimensional fuzzy optimal proportion integration differentiation controller. There are three inputs of three-dimensional fuzzy optimal proportion integration differentiation controller, which are error, the variety rate of error and change rate of error change. The structure of three-dimensional fuzzy optimal proportion integration differentiation controller is very complex. This kind of controller is generally only used in the field where the control accuracy is very high.

3 Proportion Integration Differentiation Adaptive Optimal Control Method Based on Fuzzy Theory

This paper introduces the proportion integration differentiation adaptive optimal control method based on fuzzy theory. By constructing a fuzzy optimal proportion integration differentiation controller, the defects of the traditional proportion integration differentiation control system are made up. The proportion integration differentiation adaptive optimal control method based on fuzzy theory can enhance the accuracy, timeliness and robustness of the control system. In theory, the fuzzy optimal proportion integration differentiation controller is far better than that of traditional proportion integration differentiation controller.

The fuzzy optimal proportion integration differentiation controller has two important components. They are fuzzy inference and proportion integration differentiation controller respectively.

The optimization system can adjust proportion integration differentiation parameters online in real time. This method greatly improves the adaptive ability of the controller. Figure 4 is the logic framework of proportion integration differentiation adaptive optimal controller based on fuzzy theory.

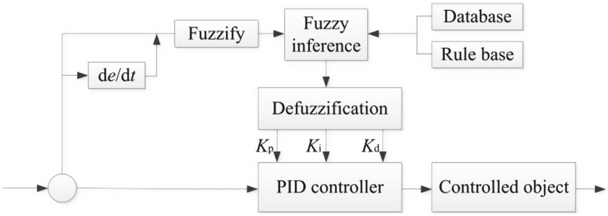


Fig. 4. The logic framework of proportion integration differentiation adaptive optimal controller based on fuzzy theory

3.1 Design of Proportion Integration Differentiation Adaptive Optimal Controller Based on Fuzzy Theory

This research adopts two-dimensional proportion integration differentiation adaptive optimal controller based on fuzzy theory. Taking the pitch angle channel as an example, the input signal of the controller system is the angle error obtained by feedback and the error rate after differential processing. Firstly, the input quantity is subjected to fuzzy reasoning, and the fuzzy vector is output. Then, according to the logic rules and membership function in the knowledge base, the fuzzy vector is calculated, and the fuzzy set is output. Finally, the fuzzy combination is defuzzified. Finally, the control variation of the three arguments, namely ΔK_{p}, ΔK_{i} and ΔK_{d}, can be obtained. Figure 5 is the fuzzy adaptive control system simulation model (Fig. 6).

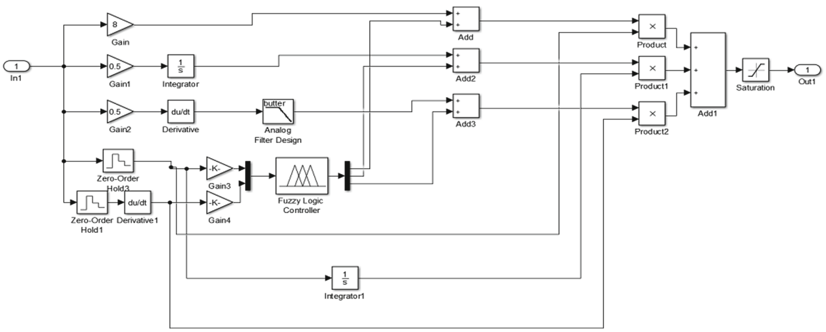


Fig. 5. Simulation model of proportion integration differentiation adaptive optimal controller based on fuzzy theory

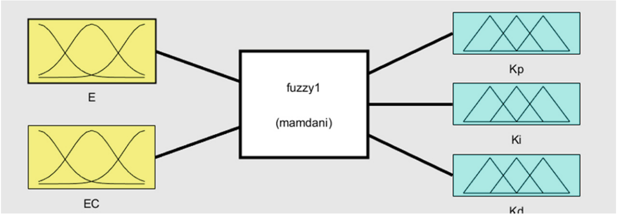
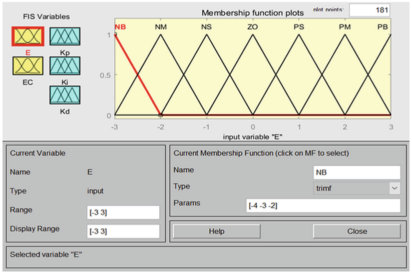


Fig. 6. Fuzzy reasoning structure diagram

3.2 The Choice of Universe and the Graph of Membership Function

The inputs of the two-dimensional proportion integration differentiation adaptive optimal controller based on fuzzy theory constructed in this paper are error e and error rate e_c. The output of two-dimensional proportion integration differentiation adaptive optimal controller based on fuzzy theory is the control variation of three parameters, namely ΔK_d, ΔK_i and ΔK_p. The whole process of fuzzy method such as fuzzy reasoning and anti fuzzy solution is carried out in the fuzzy module of MATLAB. The domain of input and change rate of Y is [−3, 3]. The domain of input variables and rate of change of attitude angle is [−3, 3]. The universe of the proportional coefficient between Y and attitude angle is [−1, 1]. The universe of the integral coefficient between Y and attitude angle is [−0.01, 0.01]. The universe of the differential coefficient between Y and attitude angle is [−1, 1]. The domain of the proportional coefficient of the body height Z is [−5, 5]. The domain of the differential coefficient of Z is [−0.01, 0.01]. The domain range of the integral coefficient of Z is [−5, 5]. In order to optimize the effect of proportion integration differentiation adaptive optimal controller based on fuzzy theory method, a large fuzzy universe is selected in this paper for the larger proportion coefficient and differential coefficient of Z channel.

Fuzzy sets are represented by [N-BS, N-MS, N-SS, Z-OS, P-SS, P-MS, P-BS]. Taking the output variable ΔK_p as an example, N-BS indicates that the negative error is large. N-MS indicates that the negative error is large. N-SS means small negative error. Z-OS means the error is 0. P-SS means that the positive error is small. P-MS indicates that the positive error is large. PB indicates large positive error. When carrying out fuzzy reasoning, it is necessary to transform the physical domain into a fuzzy domain. The transformation of discourse requires the use of quantitative factors. The quantization factor is equal to the fuzzy universe divided by the physical universe. The membership function diagram is obtained based on expert experience (Figs. 7, 8, 9, 10 and 11).



Current Variable

Name: E

Type: input

Range: [-3 3]

Display Range: [-3 3]

Current Membership Function (click on MF to select)

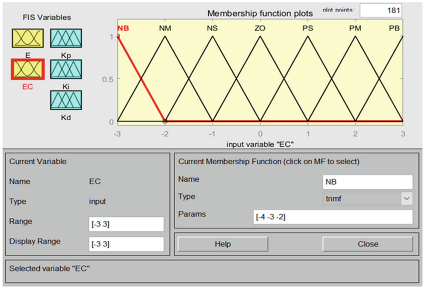
Name: NB

Type: trimf

Params: [-4 -3 -2]

Selected variable "E"

Fig. 7. Plot of membership function for *e*



Current Variable

Name: EC

Type: input

Range: [-3 3]

Display Range: [-3 3]

Current Membership Function (click on MF to select)

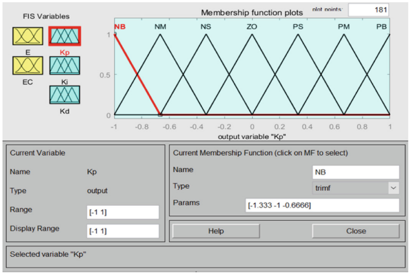
Name: NB

Type: trimf

Params: [-4 -3 -2]

Selected variable "EC"

Fig. 8. Plot of membership function for e_c



Current Variable

Name: Kp

Type: output

Range: [-1 1]

Display Range: [-1 1]

Current Membership Function (click on MF to select)

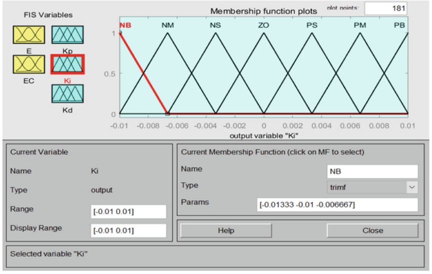
Name: NB

Type: trimf

Params: [-1.333 -1 -0.6666]

Selected variable "Kp"

Fig. 9. Plot of membership function for ΔK_p



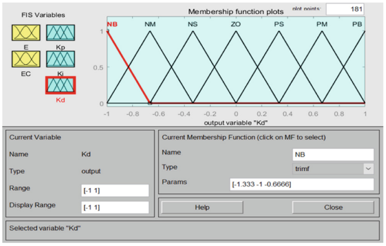
plot points: 181

Current Variable
Name Ki
Type output
Range [-0.01 0.01]
Display Range [-0.01 0.01]

Current Membership Function (click on MF to select)
Name NB
Type trimf
Params [-0.01333 -0.01 -0.006667]

Selected variable "Ki"

Fig. 10. Plot of membership function for ΔK_{i}



plot points: 181

Current Variable
Name Kd
Type output
Range [-1 1]
Display Range [-1 1]

Current Membership Function (click on MF to select)
Name NB
Type trimf
Params [-1.333 -1 -0.6666]

Selected variable "Kd"

Fig. 11. Plot of membership function for ΔK_{d}

3.3 Confirm Fuzzy Rules

The proportion integration differentiation adaptive optimal controller based on fuzzy theory can modify the parameters of the UAV control system in real time according to the feedback error e and error change rate e_{c}.

The proportion integration differentiation adaptive optimal control method based on fuzzy theory can enhance the dynamic response performance and make the UAV fly smoothly all the time. The tuning rules are as follows.

(1) When the deviation is large, the system needs to quickly adjust the deviation. First, you should increase the value of the scale parameter. However, the value of error change rate will increase under the action of proportional link. Larger error will cause integral saturation. Therefore, smaller integration parameters should be selected.

(2) When the values of error and error rate are moderate. If the scale coefficient is too large, the system will have overshoot. Therefore, we should reduce the size of the proportional parameter and choose a smaller integral coefficient. In addition, in order to improve the stability and the system response speed, appropriate differential coefficients should be selected.

(3) When the error value is small, a larger proportion coefficient and integral coefficient should be selected. When the error change rate is small, a larger differential coefficient should be selected (Tables 1, 2 and 3).

Table 1. Control strategy of Kp

ΔK_p	e_c						
e	N-BS	N-MS	N-SS	Z-ES	P-SS	P-MS	P-BS
N-BS	P-BS	P-BS	P-MS	P-MS	P-SS	Z-ES	Z-ES
N-MS	P-BS	P-BS	P-MS	P-SS	P-SS	Z-ES	N-SS
N-SS	P-MS	P-MS	P-MS	P-SS	Z-ES	N-SS	N-SS
Z-ES	P-MS	P-MS	P-SS	P-SS	N-SS	N-MS	N-MS
P-SS	P-SS	P-SS	Z-ES	N-SS	N-SS	N-MS	N-MS
P-MS	P-SS	Z-ES	N-SS	N-MS	N-MS	N-MS	N-BS
P-BS	Z-ES	Z-ES	N-MS	N-MS	N-MS	N-MS	N-BS

Table 2. Control strategy of Ki

ΔK_i	e_c						
e	N-BS	N-MS	N-SS	Z-ES	P-SS	P-MS	P-BS
N-BS	N-BS	N-BS	N-MS	N-MS	N-SS	Z-ES	Z-ES
N-MS	N-BS	N-BS	N-MS	N-SS	N-SS	Z-ES	N-SS
N-SS	N-BS	N-SS	N-SS	N-SS	Z-ES	P-SS	P-SS
Z-ES	N-MS	N-SS	N-SS	Z-ES	P-SS	P-MS	P-MS
P-SS	N-MS	N-SS	Z-ES	P-SS	P-SS	P-MS	P-BS
P-MS	Z-ES	Z-ES	P-SS	P-SS	P-MS	P-BS	P-BS
P-BS	Z-ES	Z-ES	P-SS	P-MS	P-MS	P-BS	P-BS

Table 3. Control strategy of Kd

ΔK_d	e_c						
e	N-BS	N-MS	N-SS	Z-ES	P-SS	P-MS	P-BS
N-BS	P-SS	N-SS	N-BS	N-BS	N-BS	N-MS	P-SS
N-MS	P-SS	N-SS	N-BS	N-MS	N-MS	N-SS	Z-ES
N-SS	Z-ES	N-MS	N-MS	N-MS	N-SS	N-SS	Z-ES
Z-ES	Z-ES	N-SS	N-SS	N-SS	N-SS	N-SS	Z-ES
P-SS	Z-ES	Z-ES	Z-ES	Z-ES	Z-ES	Z-ES	Z-ES
P-MS	P-BS	N-SS	P-SS	P-SS	P-SS	P-SS	P-BS
P-BS	P-BS	P-MS	P-MS	P-MS	P-SS	P-SS	P-BS

3.4 Defuzzification Solution

After fuzzy reasoning, the subcollection can be achieved. An numerical value can be obtained by defuzzifying the fuzzy set. Using this value, the actuator can be accurately controlled. There are three ways to defuzzify.

The first method is the maximum membership method. This method has the advantages of simple operation and strong real-time performance. However, due to the need to choose the number with the largest membership as the control quantity, the accuracy of the results obtained by using this method is also very low.

The second method is the central number method. The disadvantage of this method is the large amount of calculation and poor real-time performance. However, because this method uses all the data in the fuzzy set, the result obtained has the highest accuracy.

The third method is the barycenter method. In this method, the center of the closed shape formed by the function curve and parameter coordinate axis in the fuzzy rule base is taken as the fuzzy output. After fuzzy reasoning, the changes of three parameters are obtained, namely ΔK_p, ΔK_i and ΔK_d.

4 Comparison and Analysis of Simulation Results

The sake of this paper is to improve the flight control effect of UAV, so we will improve the decoupled attitude control loop separately. The fuzzy control method is deeply integrated in the PID control system. Figure 12 is the simulation diagram of pitch angle. Figure 13 shows the simulation diagram of of rolling angle. The simulation diagram of z channel is shown in Fig. 14. Figure 15 is the simulation diagram of of yaw angle.

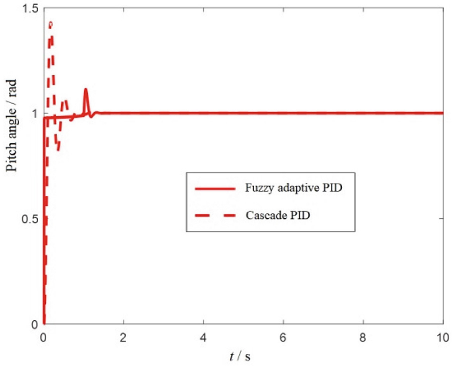


Fig. 12. Calculation and analysis result of pitch angle

In Figs. 12, 13, 14 and 15, the horizontal axis is the time axis. The vertical coordinate axis represents the radian of pitch angle, roll angle, yaw angle and the value of Z channel respectively. According to the simulation results, compared with the traditional cascade proportion integration differentiation controller the proportion integration differentiation adaptive optimal controller based on fuzzy theory completes the online tuning of four

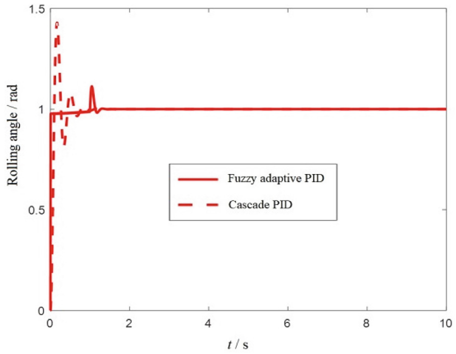


Fig. 13. Calculation and analysis result of rolling angle

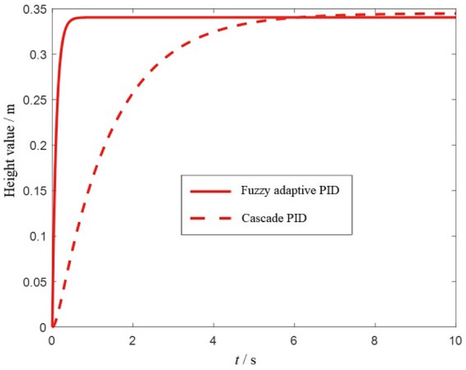


Fig. 14. Calculation and analysis result of z channel

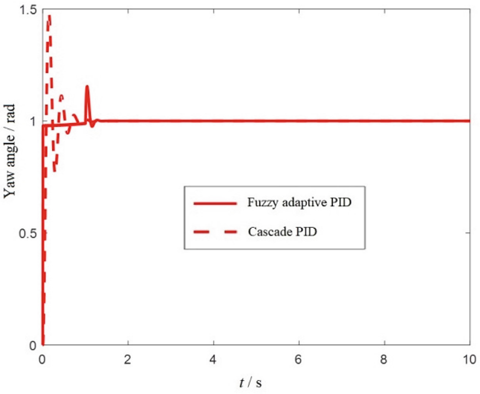


Fig. 15. Calculation and analysis result of yaw angle

control parameters in a very short time. The response curve of the parameters of the proportion integration differentiation adaptive optimal controller based on fuzzy theory is relatively smooth without violent fluctuations. In general, after the fuzzy adaptive improvement, the overshoot and oscillation of the system are greatly reduced, and the system response speed is greatly improved.

5 Conclusion

The proportion integration differentiation adaptive optimal control method based on fuzzy theory suitable for the control system of four rotor UAV is studied in this pape. The proportion integration differentiation adaptive optimal controller based on fuzzy theory is designed. The universe and membership function of the relevant control parameters of the system are formulated. The tuning rules of fuzzy adaptive PID control system are formulated. Through simulation analysis, it is found that the stability and the system response speed are greatly improved after the fuzzy adaptive improvement. Therefore, the fuzzy adaptive PID control algorithm can effectively improve the stability, reliability and emergency ability of UAV. This method can effectively improve the adaptability of UAV to perform complex missions in complex environments.

Acknowledgment. This research work is supported by State Grid Hunan Electric Power Company Limited. The number of the science and technology project is 5216A521001J.

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