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Research on Cabin Temperature Control of UAV Based on Fuzzy PID Controller

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Abstract: This research paper discusses a strategy to achieve a steady temperature control of the cabin of an unmanned aerial vehicle (UAV) by means of fuzzy PID control. By making the cabin move alternately in low temperature (-10°C) and room temperature (25°C) environments, the motion of the vehicle between clouds of different temperatures is simulated. The experiments show that the improvement of the PID control algorithm by combining the fuzzy control technology can effectively improve the adaptivity and stability of the system. The method has a good application prospect in the anti-deicing technology of UAVs and improving the stability of UAVs in low-temperature environments.

Keywords: Fuzzy PID, UAV, Temperature control system.

1. Introduction

Multi-rotor UAVs with small size, light weight, and the ability to take off and land vertically have been widely used in the fields of aerial photography, surveying and mapping, electric power inspection, and meteorological monitoring [1]. In the existing meteorological monitoring field, multi-rotor UAVs are mainly used for real-time monitoring of air pollution index in the low-altitude environment below 1000m [2-4]. Because drones operating in higher clouds are prone to icing up and causing flight accidents [5-7]. In freezing weather, the icing conditions of the UAV shell have an important relationship with the ambient temperature and humidity and the temperature of the UAV shell[8-11]. Specifically embodied in the same temperature, the higher the humidity the shorter the ice nucleation molding time; the same humidity, the lower the temperature the shorter the ice nucleation time; the higher the medium surface temperature, the longer the nucleation time. When the surface temperature of the medium is higher than 10 °C, it will be difficult to form ice crystals.

The UAV nacelle contains gyroscope, crystal, GPS and other electronic modules that are extremely sensitive to temperature, and when the temperature inside the nacelle changes significantly, it is easy to generate large errors due to temperature drift phenomenon, which has a greater impact on the reliable operation of the system [12]. On the other hand, in a low-temperature environment, the discharge capacity of lithium polymer batteries of existing UAV batteries is significantly reduced [13]. Specifically, when the temperature drops to -20°C, the battery may enter the hibernation mode and cannot work normally.

In summary, this paper discusses a strategy for controlling the cabin temperature of a UAV using active heating to ensure that the battery and electronic systems can operate reliably while ensuring that the shell does not freeze. The application of this scheme will broaden the scope of UAV use in the field of weather monitoring.

2. Cabin Temperature Control Strategy

Based on the previous analysis, this system sets the target temperature in the cabin at 15°C. Since the cabin wall has the role of heat conduction, by controlling the selection of materials for the cabin wall, as well as the thickness and construction process, the heat conduction coefficient is controlled within a reasonable range, so as to ensure that when the temperature inside the cabin is appropriate, the internal equipment can be used normally, and the shell of the UAV will not freeze.

This meteorological observation UAV needs to move flexibly between different cloud layers, and its external environment temperature changes rapidly, while the temperature control system itself has large delay and large inertia characteristics [14]. This temperature control system creatively uses a dual temperature sensing design, i.e., temperature and humidity sensors are installed inside the nacelle and on the surface of the shell for system control to reduce system inertia and speed up the response rate. When entering a low temperature environment from a high temperature environment, the heat generation module is quickly opened, which can effectively shorten the adjustment time.

3. Fuzzy PID Control Design

The core of the UAV temperature control system lies in how to reasonably adjust the heating module according to the internal temperature of the cabin and the external ambient temperature, so as to keep the temperature of the cabin in the neighborhood of the optimal state and ensure that the aircraft shell does not freeze.

3.1. Fuzzy control

Fuzzy control is widely used in various automated control systems such as temperature control, flow control, pressure control and so on [15]. Fuzzy control is a control method based on fuzzy logic, which is mainly used for systems that are difficult to be accurately defined and modeled. Compared with the traditional precise control methods, fuzzy control is more suitable for nonlinear and complex systems, and to a certain extent, it can deal with fuzzy and uncertainty problems. The fuzzy control system is mainly composed of three parts: fuzzification, inference and defuzzification. The control principle is shown in Figure 1.

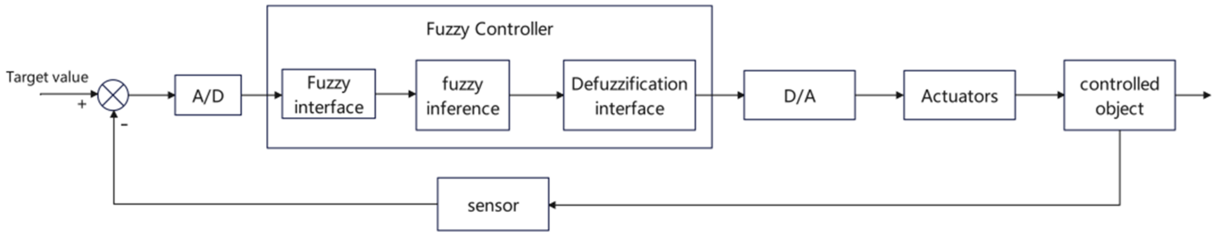

Figure 1. Fuzzy control schematic

3.2. PID control

PID control is a classical control method, is composed of proportional, integral and differential negative feedback control system. Proportional unit to the size of the deviation as the control object, the control volume will increase with the increase in deviation, the system's response speed is also accelerated; Integral unit using the cumulative deviation as the control volume, to achieve the effective suppression of the system's steady-state error, especially in the presence of the normal deviation of the role of the obvious; differential unit is the use of the rate of change of the deviation to adjust the system, you can accelerate or inhibit the system's response rate to reduce the amount of overshooting. The principle of the PID control system shown in Figure 2, the system through the proportional, integral, differential unit, the output will be transmitted to the controlled object [16].

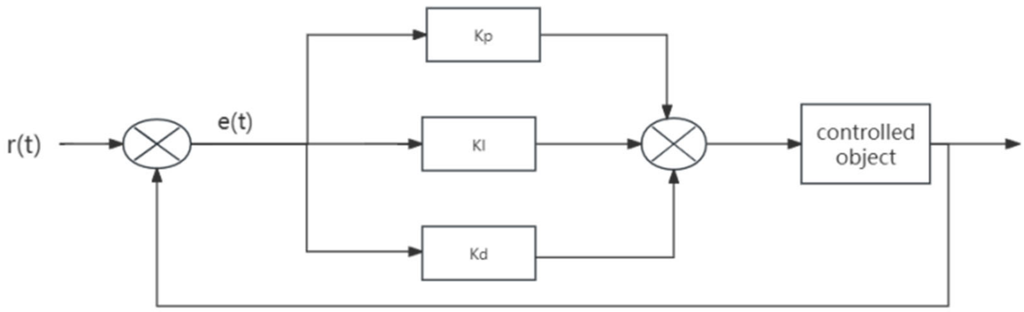

Figure 2. Schematic diagram of PID control system

PID control according to the temperature sensor feedback signal, through the real-time monitoring of the temperature and the target value for comparison, dynamic adjustment of the heating module power, in order to achieve accurate temperature control.

3.3. Fuzzy PID control

Fuzzy PID control is a new control method combining PID control and fuzzy control [17-18]. It introduces fuzzy logic on the basis of the traditional PID control, through fuzzification, fuzzy reasoning and defuzzification steps, to better adapt to nonlinear, time-varying or uncertain systems. Fuzzy PID control system principle shown in Figure 3. Fuzzy PID control is based on the combination of fuzzy logic and traditional PID control strategy, which can effectively control a variety of controlled objects precisely. By adjusting the proportional gain, integral gain and differential gain, the performance of the system can be improved. This control strategy has the advantages of wide applicability, simple parameter selection, etc. It realizes precise control and ensures that the temperature in the cabin is always in the best state.

In order to improve the adaptability and stability of the temperature control system, this paper adopts the fuzzy control technology to improve the PID control algorithm. Firstly, a set of fuzzy risk model is established through the fuzzification of system input and output. Secondly, the output of the fuzzy PID controller is calculated through fuzzy inference and fuzzy rule base. Finally, the output of the fuzzy PID controller is transformed into the control signal of the system through the defuzzification process.

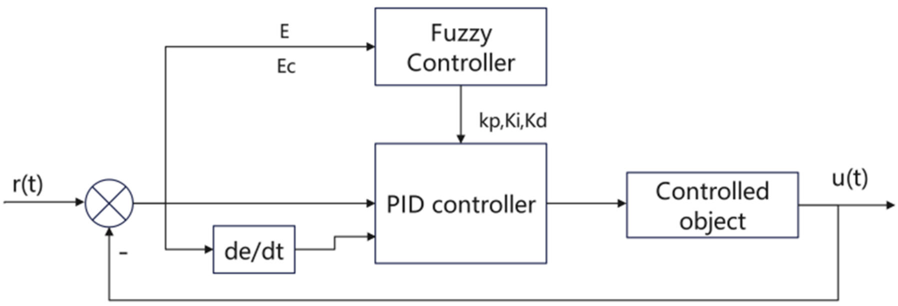

Figure 3. Schematic diagram of fuzzy PID control system

The system considers the deviation E and the deviation change rate Ec as two input variables, and the PID control parameters ΔKp, ΔKi, ΔKd as three output variables. By using the PID control parameters, real-time regulation can be realized, and the formula of the specific operation steps is as follows.

$$\mathrm{Kp} = Kp0 + Gp \cdot \Delta Kp \tag{1}$$

$$\mathrm{Ki} = Ki0 + Gi \cdot \Delta Ki \tag{2}$$

$$\mathrm{Kd} = Kd0 + Gd \cdot \Delta Kd \tag{3}$$

In the above three equations, Kp0, Ki0 and Kd0 are the initial values of the proportional, differential and integral links, respectively. In addition, ΔKp, ΔKi and ΔKd are the three adjusted values of the output of the fuzzy controller, and the proportionality coefficients corresponding to them are Gp, Gi and Gd, respectively.

If the temperature deviation in the cabin is set as E and the deviation rate of change is EC, then the temperature deviation E, the temperature deviation rate of change EC and the values of the Kp, Ki and Kd domain levels are {-6 ,-5 ,-4 ,-3 ,-2 ,-1 ,0 ,1 ,1 ,2 ,3 ,4 ,5 ,6}; and the fuzzy subset of the fuzzy domains is {NB ,NM ,NS ,Z ,PS ,PM ,PB}, and its subset is {negative large, negative medium , negative small, zero, positive small, positive medium ,positive large}. is {negative large, negative medium, negative small, zero, positive small, positive medium, positive large}. The fuzzy rules of Kp, Ki and Kd parameters for fuzzy PID control are designed using Simulink module as shown in Table 1 to Table 3.

Table 1. Fuzzy rules of Kp

E	EC						
	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PM	PM	PM	PM	Z
NM	PB	PB	PB	PB	PM	Z	Z
NS	PM	PM	PM	PS	Z	PS	PS
Z	PM	PM	PS	Z	NS	NS	NM
PS	PS	PS	Z	PS	NM	NM	NM
PM	PS	Z	NS	NM	NM	PB	NB
PB	Z	Z	NM	NM	NM	NB	NB

Table 2. Fuzzy rules of Ki

E	EC						
	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NM	NM	NS	Z	Z
NM	PB	PB	PB	PB	PM	Z	Z
NS	PM	PM	PM	PS	Z	PS	PS
Z	NM	NM	NS	Z	PS	PM	PM
PS	NM	NS	Z	NS	PS	PM	PB
PM	Z	Z	PS	NM	NM	PS	PB
PB	Z	PS	PS	PM	PM	PB	PB

Table 3. Fuzzy rules of Kd

E	EC						
	NB	NM	NS	Z	PS	PM	PB
NB	PS	NS	NB	NB	NB	NM	PS
NM	PS	NS	NB	NM	NM	NS	Z
NS	Z	NS	NM	NS	NS	NS	Z
Z	Z	NS	NS	NS	Z	Z	Z
PS	Z	Z	Z	Z	Z	Z	Z
PM	Z	PS	PS	PS	PS	PS	PB
PB	PB	PM	PM	PM	PS	PB	PB

4. Control System Testing and Analysis

The temperature control system based on the fuzzy PID control algorithm proposed in this paper was compared with the traditional PID control algorithm for experiments. Through the refrigeration cabinet to build a test platform, so that the cabin in the low temperature (-10 ℃) and room temperature (20 ℃) environment alternating movement, simulating the aircraft in different temperatures between the clouds movement. When the target temperature in the nacelle is set to 15 ℃ , the operation results of PID control and fuzzy PID control are compared (Figure 4).

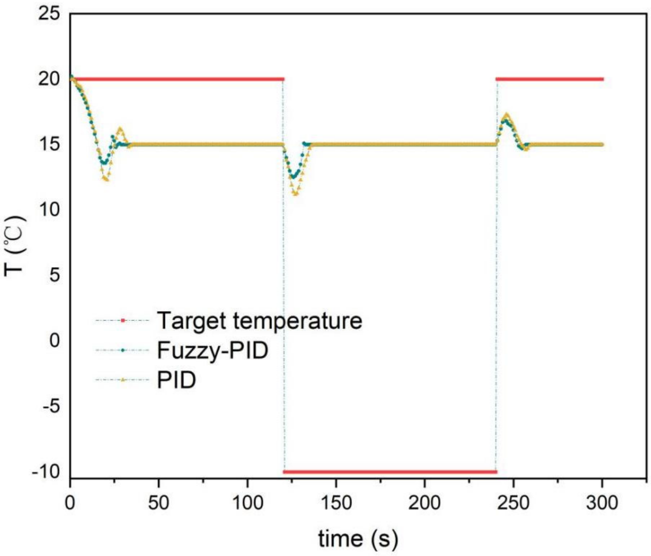

Figure 4. Comparison of temperature control effect

Through the comparison of the effect of temperature control, it can be seen that the fuzzy PID control system has strong stability, fast response speed, vibration amplitude is small, obviously better than the traditional PID control effect, has very good practicality.

5. Conclusion

In this paper, a temperature control system based on fuzzy PID control is designed to improve the adaptability and stability of the system by combining the fuzzy control technology with the PID control algorithm. The experimental results show that the method has a better application prospect in the anti-deicing technology of UAVs and improving the stability of UAVs in low-temperature environments. Further research can consider combining other intelligent algorithms with the PID algorithm to improve the performance and robustness of the system.

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