Research on Temperature Control of Plant Factory Based on Fuzzy Control

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Abstract: *Because plant factory temperature system is a complex closed-loop control system with multiple inputs and multi outputs, the traditional PID control is ineffective. Therefore, this study designs a plant factory temperature control system based on fuzzy PID control, expounds the working principle of the controller, designs the controller parameters, and compares the system performance with the traditional PID control and fuzzy control system. The simulation results show that the plant factory temperature control system with fuzzy PID control has faster response speed, smaller overshoot, higher control precision and higher practicability.*

Keywords: Plant Factory; PID Control; Fuzzy Control; Fuzzy PID Control

1. Introduction

With the change of the world agricultural production situation, the traditional agricultural planting has been unable to meet the needs of social development, thus the agricultural facilities came into being, the traditional agricultural production mode is gradually replaced by the engineering technology means, so that the traditional agriculture get rid of the external ecological environment influence, raise the land utilization rate, increase the output ratio and economic efficiency[1]. Plant factory as the advanced stage of the development of facility agriculture, it can control the temperature, humidity, CO2 concentration, illumination intensity and other environmental parameters of plant factory in real time[2], and provide the most suitable growth environment for crop growth. At the same time, it usually adopts closed, multi-layer solid cultivation, saving space, planting density is high. It can make up to a certain extent the shortage of greenhouse.

Air temperature is an important factor affecting the growth of crops, the extreme high and low temperature have a great influence on plant growth [3-7]. Considering that it is a complex multi-input and multi-output closed-loop control system for plant factory temperature system, its environmental parameters are nonlinear, hysteresis, time-varying and strong coupling. The traditional PID control method has been difficult to meet the control requirements. Fuzzy control using the experience of human expert control, which has the advantage of good robustness and high control performance for nonlinear and complex object control [8]. Therefore, this study adopts the fuzzy PID control method and combines the advantages of fuzzy control and PID control, which greatly improves the overall performance of the temperature control system.

2. The Principle of Fuzzy PID Control

2.1 Fuzzy Controller Structure

As a result of combining the traditional rules-based expert system, fuzzy set theory and control theory, fuzzy control is very different from the traditional control theory based on the controlled process mathematical model. The fuzzy controller is mainly composed of 4 parts [8]: fuzzification, knowledge base, fuzzy reasoning and clarity, and its control structure is shown in Figure2-1.
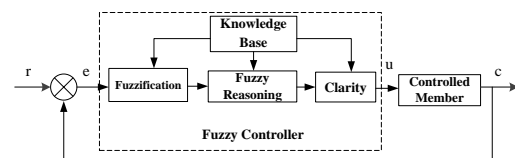

Figure 2.1: The structure of fuzzy control system

The function of fuzziness is to convert the exact amount of input into the fuzzy quantity, the input quantity may include the external reference input, the system output or the state, etc. The knowledge base contains the control objectives with knowledge and requirements in the application field, and composed of the database and the fuzzy control rule base. Fuzzy reasoning is the core of fuzzy controller, and has the ability to simulating human's fuzzy concept. Clarity is to convert the control quantity (fuzzy quantity) obtained by fuzzy reasoning into the clear quantity actually used for control.

2.2 Fuzzy PID Controller

In conventional control, PID control is the simplest and most practical control method, which can not only depend on the mathematical model through the analytical method design, but also can be determined by experience and trial and error without relying on the model. Fuzzy control is proposed and used in people's daily life based on practical experience, so fuzzy control does not need accurate model objects.

Fuzzy control generally assumes that error e and error reciprocal ec are used as input of fuzzy control, so it essentially equivalent to a nonlinear PD control with low steady-state accuracy. In order to eliminate the error, it is necessary to join the integral link，Therefore, this paper uses the method of fuzzy self-tuning PID parameters to complement each other to achieve the purpose of control, the control block diagram is shown in Figure 2-2. After fuzzy

reasoning of input amount *e* and *ec*, the fuzzy controller will output the precise PID control parameters, such as K_p, K_i and K_d, and then control the plant growth cabinet environment by PID controller.
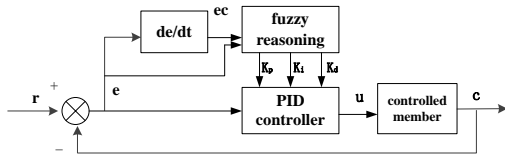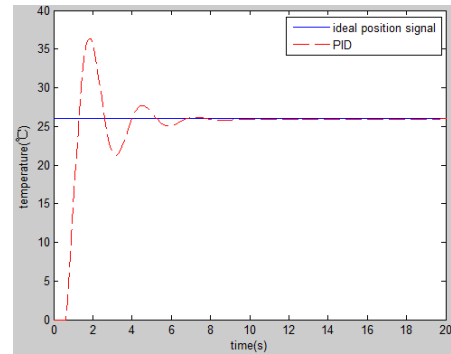

Figure 2.2: Fuzzy PID control block diagram

3. Controller Design

3.1 Design of Initial Parameter Control

Plant factory temperature control system is a complex system, and plant growth cabinet as a primary product of the plant factory, in a relatively small space, the environmental parameters are easier to control and facilitate scientific experiments. According to expert's experience, it can be concluded that plant factory temperature controlled object can be approximated as first-order inertial systems time-delay with disturbance, whose transfer function is: Plant factory temperature control system is a complex system, and plant growth cabinet as a primary product of the plant factory, in a relatively small space, the environmental parameters are easier to control and facilitate scientific experiments. According to expert's experience, it can be concluded that plant factory temperature controlled object can be approximated as first-order inertial systems time-delay with disturbance, whose transfer function is:

$$G(S) = \frac{K e^{-\tau S}}{Ts+1} \qquad (1)$$

Where: K represents the static gain of the object; T represents the time constant of the object; s represents a time variable; τ represents the pure lag time of the object. Take parameters K = 0.29, T = 6.4, τ = 0.64 [9].

The discrete PID controller expressions are as follows:

$$u(t) = K_p \left\{ e(t) + \frac{T_0}{T_i} \sum_i^t e(i) + \frac{T_d}{T_0} \left[e(t) - e(t-1) \right] \right\} \quad (2)$$

or

$$u(t) = K_p e(t) + K_i \sum_i^t e(i) + K_d \left[e(t) - e(t-1) \right] \qquad (3)$$

Take the above theory K_P, K_i, K_d value, combined with MATLAB simulation tuning, the final parameters K_p=35,K_i=4,Kd=4, set plant factory temperature 26 ℃, simulation results as shown in Figure 3-1.

Figure 3-1: PID control simulation results

3.2 Design of Fuzzy Controller

In fuzzy control, the output error *e* and the error derivative which is expressed by *ec* of the system are used as input of the fuzzy control, the output of the fuzzy controller is:

$$u(t) = K_u Fuzzy(K_e e, K_d \frac{de}{dt}) \qquad (4)$$

In the formula, K_u, K_e and K_d are the quantization factors of the output signal *u*, the input signal error *e* and the input error reciprocal *ec*. The input signal error $e \in [-6, 6]$,the error derivative $ec \in [-6, 6]$ and the output signal $u \in [-3, 3]$ of the fuzzy controller are all blurred into seven levels: negative big NB, negative middle NM, negative small NS, zero ZR, positive small PS, positive median PM and positive big PB. The membership functions of the input-output fuzzy subset are all triangular in distribution, and the membership function is set as shown in Figure 3-2.
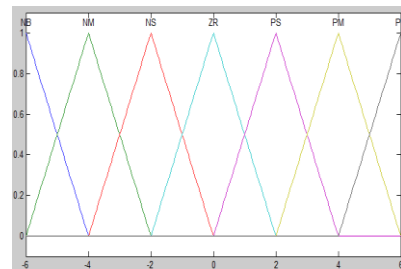
(a) e, ec membership function curve
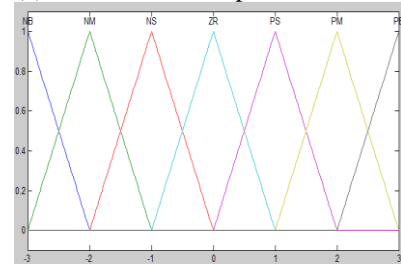
(b) u membership function curve

Figure 3.2: Membership function curve

For the relationship between the input and output variables, the fuzzy control rules are established, and the rules of rule *i* is:
IF e is X_i and ec is Y_i ,THEN u is Z_i
Among them, *Xi, Yi* and Z_i are the fuzzy subset of input and output variables in their respective domain. We can establish 7*7=49 "IF-THEN" statements like above and choose centroid method to defuzzification[10]. The fuzzy rules are

like Table1, and the final input / output feature surface is shown in Figure 3-3.

Table1: Fuzzy rules

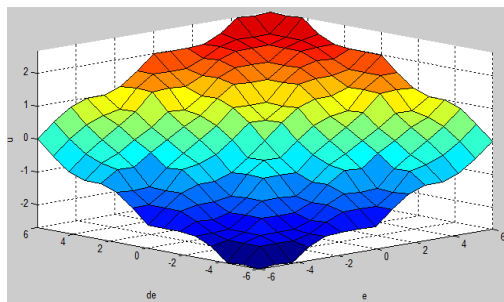| ec	e						
	NB	NM	NS	ZR	PS	PM	PB
NB	NB	NB	NM	NM	NS	NS	ZR
NM	NB	NM	NM	NS	NS	ZR	PS
NS	NM	NM	NS	NS	ZR	PS	PS
ZR	NM	NS	NS	ZR	PS	PS	PM
PS	NS	NS	ZR	PS	PS	PM	PM
PM	NS	ZR	PS	PS	PM	PM	PB
PB	ZR	PS	PS	PM	PM	PB	PB

Figure 3.3: Input / Output feature surface

Set K_u=11*26, K_e=6/26 and K_d=1/26, input plant factory temperature is also 26 ℃, simulation results such as Figure 3-4, red dotted line and black solid line are the system without pure delay and pure delay curve respectively. It can be seen from the figure, when the system without pure delay, fuzzy control is fast response, no overshoot, good dynamic performance, but the existence of the steady error caused by "fuzzification"; when a delay in the system, the simple fuzzy control effect is not very good, the adjusting time is long, have not overshoot but the steady-state error, while haven't integral part of its elimination, steady state performance is poor.
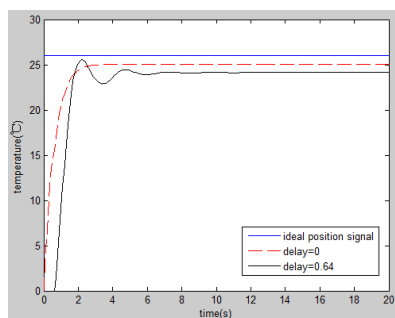

Figure 3.4: Simulation results of fuzzy control

3.3 Design of Fuzzy PID Controller

Fuzzy PID control relations:

$$u(t) = (K_{p0} + \Delta K_p) \cdot e + (K_{i0} + \Delta K_i) \cdot \int e dt + (K_{d0} + \Delta K_d) \cdot \frac{de}{dt} \quad (5)$$

In the formula, K_{p0}, K_{i0} and K_{d0} represent the initial gain parameters of the PID controller; e, de/dt also represent the input error and the input error reciprocal, and the $\triangle K_p$, $\triangle K_i$ and $\triangle K_d$ represent the tuning parameters of the output of the fuzzy PID controller.

The input and output domain and the fuzzification level are the same as 3.2 sections. The membership functions of e and ec

with high sensitivity of the triangular distribution; $\triangle K_p$, $\triangle K_i$ and $\triangle K_d$ are Gauss distribution; the membership function of e is irregular, and the sensitivity of e near 0 is increased [11], such setting can ensure the control system has good stability performance. The setting of membership function is shown in Figure 3-5.
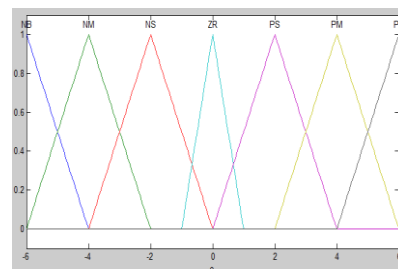
(a)e Membership Function Curve
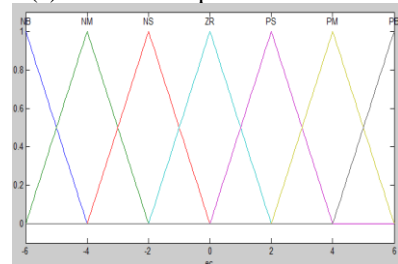
(b)ec Membership Function Curve
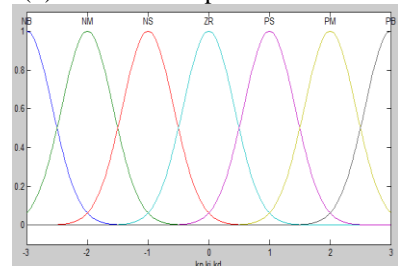
(c)$\triangle K_p$, $\triangle K_i$, $\triangle K_d$ Membership Function Curve
Figure 3.5: Membership Function Curve

The setting principle of K_p is that the increase of K_p can reduce the rise time correspondingly during the initial rising process of temperature response curve. When overshoot, reducing K_p can reduce overshoot. The role of K_i is to eliminate the system's steady-state error, the larger the Ki, the shorter the error elimination time, but when the value of the K_i is too large, it is easy to produce integral saturation phenomenon, while the K_i value is too small, a large steady-state error is easily caused. K_d is used to improve the dynamic performance of the system, and K_d can be predicted the deviation in advance when the deviation of the temperature response process will changes. However, when K_d is too large, the adjustment time of the temperature control system will be longer [12].

According to the setting principle, the fuzzy control rules are established, and the rules of rule i is:
IF e is X_i and ec is Y_i ,
THEN $\triangle K_p$ is A_i、 $\triangle K_i$ is B_i、 $\triangle K_d$ is C_i

Among them, X_i, Y_i and A_i,B_i,C_i are the fuzzy subset of input and output variables in their respective domain. We also can establish 7*7=49 "IF-THEN" statements like above and choose centroid method to defuzzification. The final input / output feature surface is shown in Figure 3-6.
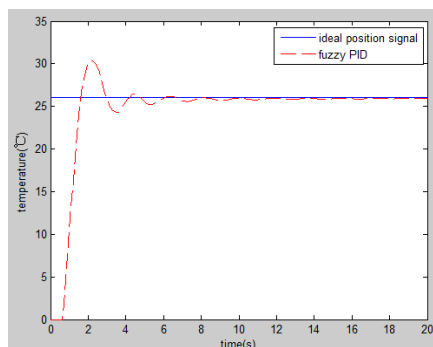
Figure 3.6: Simulation results of fuzzy PID control

4. Comparative Analysis

The plant factory temperature was set at $26℃$, compared with the traditional PID control, fuzzy control and fuzzy PID control, the simulation contrast results were shown in Figure 4-1. We can see from Figure 4-1, in the simulation condition, the dynamic response curve of the temperature system obtained by the fuzzy PID control is obviously better than the traditional PID control in the adjustment time and overshoot, the system response is faster and more stable than PID control; fuzzy PID control is also better than fuzzy control in the steady-state error, high control precision.
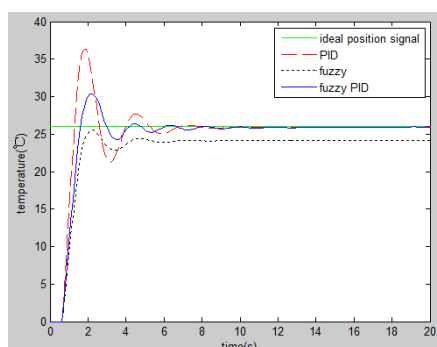

Figure 4.1: Simulation results

5. Conclusion

In this study, a fuzzy PID controller is designed for complex plant factory control system. The design process is given. At the same time, the controller is compared with traditional PID control and fuzzy control, and the simulation results show that:
1) The traditional PID structure is simple in principle, convenient in design and stable in performance, but with large overshoot and long adjustment time, it can be used when temperature control requirements are not particularly strict.
2) Fuzzy control has fewer fuzzy rules, shorter adjustment time and no overshoot, but there is a steady-state error. It can be used when temperature control accuracy does not need to be accurate.
3) Fuzzy PID control has more fuzzy rules and more complex design than fuzzy control, but compared with traditional PID control, it has faster response speed and shorter adjustment time. Compared with fuzzy control, it can eliminate steady-state error. It has the advantages of both the traditional PID control and the fuzzy control,

which is suitable for the temperature control requirements of plant factory.

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Author Profile

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