Greenhouse temperature controller design based on the fuzzy PID

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Abstract

Greenhouse temperature system is a system featuring big time lag and huge inertial. Its typical control methods generally fail to achieve good control effect. Therefore, based on the fuzzy PID control method, this paper conducts real-time adjustment of PID parameters through the temperature difference and the temperature deviation variation rate. The numerical simulation result with MATLAB Simulink suggests that to control greenhouse temperature based on the fuzzy PID control method can achieve great control effect. The controller designed is characterized with fast dynamic response good robustness, high stability precision, low overshoot, and strong anti-jamming capability.

Keywords: Temperature System; Conventional PID; Fuzzy PID

1 Introduction

In 2004, China's intelligent greenhouse area reached 588.0hm2, of which 403.0hm2 were developed by China and 185.4hm2 were imported [1-3]. Since China's computer technology development was quite background earlier, it was not until in the 1970s that a computer for the purpose of agriculture was invented. In the 1980s, computers were adopted for agricultural control. After 1990s, computer applications in agriculture entered in a rapid development period. In particular, some institutions and companies represented by National Engineering Research Center of Information and Technology of Agriculture (NERCITA) and Agricultural Engineering Technique Co., Ltd. affiliated to China Agricultural University have achieved remarkable achievements in intelligent greenhouse research and applications. NERCITA and its subsidiary production bases such as the one in Xiaotangshan Town are a batch of research centers integrating multiple departments, including software engineering, network engineering, intelligent system, environment control, precision agriculture, remote sensing and geographical information. They stand for the advanced agricultural techniques of China. In terms of intelligent techniques, they have made great strides. More importantly, they boast a set of self-developed critical techniques for intelligent greenhouse control system, including sensor, PC monitoring system, PLC control system and audio and video monitoring system. The experimental applications of these techniques in multiple production bases lead to sound economic benefits. Agricultural Engineering Technique affiliated to China Agricultural University is a company specializing in smart greenhouses construction, automatic fertigation and control system design. The control system researched by it stands for the advanced technical level in the field in China in that it can achieve testing and automatic control of the environmental factors, including irrigation, temperature and humidity, lighting, CO_2, dormant window, inside and outside sunshade, temperature supplement, audio, video and supplementary lighting.

The greenhouse temperature control is a very complex system characterized by big time lag, huge inertial and multivariable coupling. If it just adopts the traditional control method, satisfying control effect is hard to achieve. With a simple structure and strong function, PID controllers have found wide applications in the industrial control [4, 5]. The conventional intelligent PID controller of changeable gain is usually conducted by experienced experts to work out a group of fixed parameters according to certain control performance indexes. Greenhouse temperature control is often confronted with time-varying and time-lagging objects, which are complex to control, and the conventional PID control cannot immediately trace the changing characteristics of the objects. The control method based on the fuzzy PID controller can adjust the greenhouse temperature. The fuzzy PID control method is summarized according to the work experiences. It is a control strategy expressed through language. No precise mathematical model is required to be established to solve the nonlinear system problems [6-10].

The simulation result suggests that the greenhouse temperature control system based on the fuzzy PID designed in this paper boasts high control precision and strong robustness, and greatly improve the self-adaptability of the system, thus achieving good control effect.

2 Greenhouse environmental control factors

Temperature is one of the most environmental factors in the whole disaster-hit growth period, which may influence the physiological changes of all crops. Different crops in different growth period have different requirements of temperature. If the temperature is lower than the minimum or higher than the maximum, crops may suffer hazards or even death. At the same time, influenced by geography, topography, altitude and time, temperature difference is very large. Moreover, since China is in the eastern part of Eurasia, the typical climate characteristic of torrid summer

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and cold winter has posed great challenges to the temperature conditions of the greenhouse environment. Therefore, all these environmental factors should be considered in the automatic control system of the greenhouse environment. Due to radiation effect of the sunlight, the temperature within the greenhouse rises significantly making cooling measures a necessity. In winter, the greenhouse effect can be utilized to improve the temperature within the greenhouse to maximally meet the demand of the crops and achieve the goal of high yield.

Temperature is one of the major environmental factors influencing the yield and quality of melons. In different growth periods, melons have different requirements of temperature. They sprout at the temperature of 25～35℃; seedlings grow at the temperature of 20～25℃; fruits are yielded at the temperature of 30～35℃. When temperature falls to 13℃, the growth of the melons will be stagnated. Under 10℃, the growth stops totally and the melon plants may even die if there is frost. However, melons can adapt themselves to high temperature. They can growth well at 35 ℃ . Even at the high temperature of 40 ℃ , their photosynthesis is still very strong.

Choose the indoor temperature as the control factors of the greenhouse system, the aperture of cold and hot water mixing valve as the system entry and solar radiation and cloud radiation as disturbance variables. In the model building of the greenhouse system, it is hypothesized that the greenhouse area is $40m^2$ and the volume is $120m^2$. AD590 is chosen as the sensor.

3 The realization of the control strategy of the fuzzy PID

3.1 THE STRUCTURE OF THE FUZZY PID CONTROLLER

In the computer control, the controlled variable can only be calculated according to the deviation value at the sampling instant. Therefore, digital PID is usually adopted. Equation (1) is the digital form of the PID controlled variable.

$$u(t) = kpe(t) + ki\int_0^t e(t)dt + kd\frac{de(t)}{dt}, \quad (1)$$

where, kp stands for the coefficient of the proportional; ki for the coefficient of the integral term; kd for the coefficient of the differential term; and $e(t)$ for the deviation value between the set value and the actual measurement.

Based on the conventional PID adjustor, the fuzzy PID controller relies on the fuzzy set theory and automatically adjusts the kp , ki and kd according to the control deviation and the variation rate of the deviation [3]. During the application process, this paper conducts real-time correction of kp , ki and kd according to the value of e and ec , and based on the fuzzy control so as to meet e and ec 's different requirements of the controlled parameters and equip the controlled objects with good performance.

The control structure of the fuzzy PID controller is shown in Figure 1, in which r stands for the set value; u for the variables of the temperature control device (the position of the cold water and hot water valve); *kp*, *ki* and *kd* for the coefficient of the proportional, integral term and differential term modified by the fuzzy controller; and the fuzzy PID controller adopts two-dimensional entry (the deviation between the actual temperature and the set temperature is e and the variation rate of the deviation is ec).

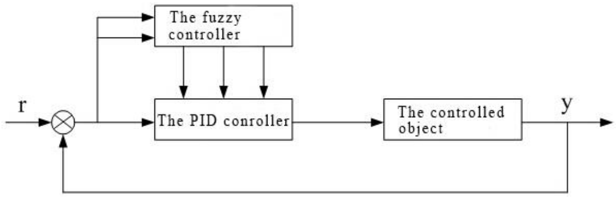

FIGURE 1 The control structure of the fuzzy PID controller

3.2 FUZZIFICATION

The fuzzy controller is two-input and three-output with *e* and *ec* as the input and *kp ki* and *kd* as the output. The fuzzy set of the linguistic value of theinput variables *e* and *ec* and the output variables *kp*, *ki* and *kd* corresponds to the fuzzy language of {NB, NM, NS, ZO, PS, PM, PB}. The fuzzy domain of *e* and *ec* is {-3.0, -2.0, -1.0, 0.0, l.0, 2.0, 3.0}; the fuzzy domain of *kp* is {-0.30, -0.20, -0.10, 0.0, 0.10, 0.20, 0.30}; the fuzzy domain of *ki* is {-0.06, -0.04, -0.02, 0.0, 0.02, 0.04, 0.06}; and the fuzzy domain of *kd* is {-3.0, -2.0, -1.0, 0.0, l.0, 2.0, 3.0}. Trigonometric function is chosen as the membership function of *e*, *ec*, *kp*, *ki* and *kd*. (See Figure 2 - Figure 5 below)

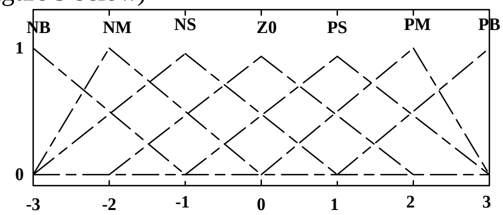

FIGURE 2 The membership function of e and *ec*

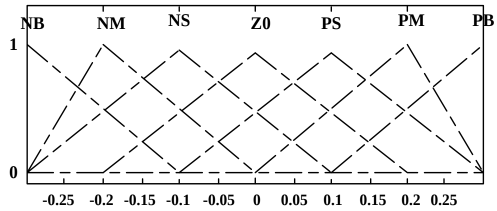

FIGURE 3 The membership function of *kp*

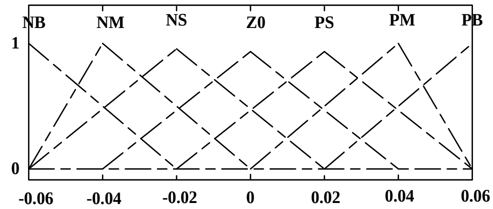

FIGURE 4 The membership function of *ki*

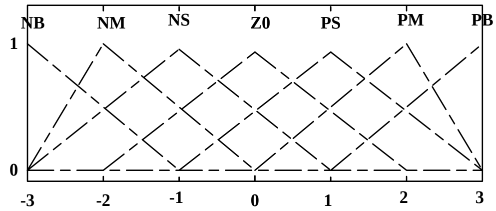

FIGURE 5 The membership function of *kd*

3.3 FUZZY RULE

According to the experiences of experts, the self-adjusting rule of PID's parameters of kp, ki and kd are gained. When the value of $|e|$ is larger, the value of kp should be larger and the value of kd should be smaller (shorten the response time of the system) and ensure $ki=0$ (avoid extremely large overshoot); when the value of $|e|$ is medium, the value of kp should be smaller (maintain the overshoot of the system response at a small value) and the value of ki and kd should be proper (the value of kd has a great influence on the system); when the value of $|e|$ is smaller, the value of kp and ki should be smaller (the steady-state performance of system is comparatively good) and the value of kd should be proper so as to avoid vibration around the balance point [7]. Based on the above stated rules, the rules are shown in Table1 to Table 3 below.

TABLE 1 The fuzzy rule table of *kp*

	ec						
	NB	NM	NS	0	PS	PM	PB
NB	PB	PB	PM	PM	PS	0	0
NM	PB	PB	PM	PS	PS	0	NS
NS	PM	PM	PM	PS	0	NS	NS
0	PM	PM	PS	0	NS	NM	NM
PS	PS	PS	0	NS	NS	NM	NM
PM	PS	0	NS	NM	NM	NM	NB
PB	0	0	NM	NM	NM	NB	NB

TABLE 2 The fuzzy rule table of *ki*

	ec						
	NB	NM	NS	0	PS	PM	PB
NB	NB	NB	NM	NM	NS	0	0
NM	NB	NB	NM	NS	NS	0	0
NS	NB	NM	NS	NS	0	PS	PS
0	NM	NM	NS	0	PS	PM	PM
PS	NM	NS	0	PS	PS	PM	PB
PM	0	0	PS	PS	PM	PB	PB
PB	0	0	PS	PM	PM	PB	PB

TABLE 3 The fuzzy rule table of *kd*

	ec						
	NB	NM	NS	0	PS	PM	PB
NB	PS	NS	NB	NB	NB	NM	0
NM	PS	NS	NB	NM	NM	NS	0
NS	0	NS	NM	NM	NS	NS	0
0	0	NS	NS	NS	NS	NS	0
PS	0	0	0	0	0	0	0
PM	PB	PS	PS	PS	PS	PS	PB
PB	PM	PM	PM	PM	PS	PS	PB

3.4 FUZZY SOLUTION

The fuzzy inference achieves a fuzzy set, but the controlled output signal gained through the actual control system must be a precise value in the fuzzy domain. Therefore, it is necessary to conduct fuzzy solution of the fuzzy set. Centroid method boasts smoother inference control. Even if the input signal has some slight changes, the output signal will be changed. Therefore, the system adopts the centroid method to prevent fuzzification [8]. The calculation expression is shown in (2).

$$u=\sum Xi\cdot\mu(Xi)/\sum\mu(Xi), \tag{2}$$

where, x_i is the membership degree of the No."i" fuzzy output value, $\mu(x_i)$.

4 System simulation

Since the greenhouse system is a nonlinear and large time-lagging system with huge inertial, it should be made into an appropriate linear system in the simulation. During the simulation process, the influence of the sun and the cloud should be treated as phase step load. Since the sunlight directly influences every part of the greenhouse, there is no need to consider the time lag or the thermal capacity a dn heat loss. This is a first-order model with the time lag. The model[6] is shown in expression (3).

$$G(s)\frac{e^{-s\tau}}{\alpha s+k}, \tag{3}$$

where, k stands for the heat loss; α for the thermal capacity of the internal air of the greenhouse, the greenhouse materials and the greenhouse floor; and τ for the total time required for the delay of valve movement and the time that the heat is conveyed from the valve to the pipeline and from the pipeline to the air. ($a=10.3J/m^2$, $k=0.0263w/m^2$ and $\tau=150s$)

Build PID and fuzzy PID control algorithm in Simulink. Set the delayed time in the TransportDelay as 150 seconds; and set the phase step value as 25 and simulation time as 5,000s.

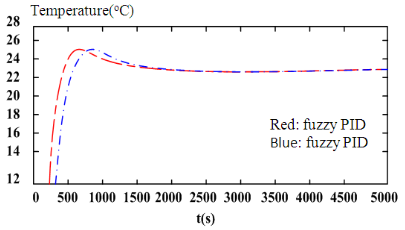

FIGURE 6 Simulation correlation curve

As is shown in Figure 6, the performance indexes of the conventional PID control are: the adjustment time $ts=2400s$, the overshoot is about16% and the steady-state error $ess=0$; the performance indexes of the fuzzy PID control are: the adjustment time $ts=1900s$, the overshoot is about 12%and the steady-state error $ess=0$. The simulation results suggest that the adjustment time of the fuzzy PID is significantly shorter than that of the conventional PID, the overshoot of the former is also smaller. Therefore, the fuzzy PID can achieve precise control of the system.

5 Conclusions

Considering the nonlinearity, big time lag and huge inertial of the greenhouse system, this paper controls the greenhouse temperature through the fuzzy PID control algorithm. Readers can self-study the control effect and improve the self-adaptability of system to set three PID parameters on the computer. In this way, this paper overcomes the previous problem of the conventional control's failure to adjust the parameters of the controlled objects and the conventional PID on-line. The simulation result suggests that the fuzzy PID control algorithm is effective and feasible and boasts good dynamic and static performance.

References

[1] MA, S. F., & WANG, Z. X. 2007 Optimization on Application Amount of Controlled Release N with P_2O_5 and K_2O in Tomato of Greenhouse *Acta Agriculturae Boreali-Occidentalis Sinica* **6**, 061.

[2] ZHANG, Y. L., & SONG, S. Y. 2008 Effects of Nitrogen Levels on Growth and Yield of Fruit in Greenhouse Tomato *Northern Horticulture* **2**, 010.

[3] JIAO, X. Y., WANG, L. G., ZHANG, D. L., ZHANG, J. S., & DONG, E. W. 2010 Present Situation of Fertilizer Application, Its Problems and Suggestions Concerning Vegetable Production under Conditions of Solar-greenhouse *Journal of Shanxi Agricultural Sciences* **4**, 013.

[4] Rivera, D. E., Morari, M., & Skogestad, S. 1986 Internal model control: PID controller design. *Industrial & engineering chemistry process design and development* **25**(1), 252-265.

[5] Tzafestas, S., & Papanikolopoulos, N. P. 1990 Incremental fuzzy expert PID control. Industrial Electronics *IEEE Transactions on* **37**(5), 365-371.

[6] Li, S. J., & Liu, Y. X. 2006 An improved approach to nonlinear dynamical system identification using PID neural networks. *International Journal of Nonlinear Sciences and Numerical Simulation* **7**(2), 177-182.

[7] De Wit, C. C., Olsson, H., Astrom, K. J., & Lischinsky, P. 1995 A new model for control of systems with friction. Automatic Control, *IEEE Transactions on* **40**(3), 419-425.

[8] Das, I., & Dennis, J. E. 1998 Normal-boundary intersection: A new method for generating the Pareto surface in nonlinear multicriteria optimization problems. *SIAM Journal on Optimization* **8**(3), 631-657.

[9] Chang, W. D. 2007 Nonlinear system identification and control using a real-coded genetic algorithm. *Applied Mathematical Modelling* **31**(3), 541-550.

[10] Chiang, T., & Zhang, Y. Q. 1997 A new rate control scheme using quadratic rate distortion model. Circuits and Systems for Video Technology, *IEEE Transactions on* **7**(1), 246-250.

[11] Geen, J. A., Sherman, S. J., Chang, J. F., & Lewis, S. R. 2002 Single-chip surface micromachined integrated gyroscope with 50/h Allan deviation. *IEEE Journal of Solid-State Circuits* **37**(12), 1860-1866.

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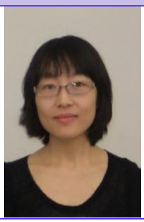

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