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OPTIMAL DESIGN OF PID CONTROLLER FOR TEMPERATURE IN GREENHOUSE SYSTEM

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Abstract. *This work presents a black-box modeling method based on structure identification and parameter estimation to obtain the temperature model of the greenhouse system. The traditional PID controller can achieve stabilization of greenhouse temperature, but its performance is not satisfactory. Therefore, the fuzzy and genetic algorithms are introduced to optimize the PID control parameters. Numerical results show that both fuzzy control algorithm and genetic algorithm can optimize the PID controller, and the dynamic performance of the system has been improved. However, in terms of the speed and stability of the system, the optimization effect of genetic algorithm is better.*
Keywords: PID, Intelligent greenhouse, Temperature control, Fuzzy algorithm, Genetic algorithm

1. **Introduction.** In order to improve the survival rate and yield of crops, the temperature control within the greenhouse system becomes more and more important. However, the greenhouse temperature system is considered as a nonlinear, non-deterministic, strongly coupled dynamic system with intensive multi-disturbance from surroundings, such as physical factors and plant physiological phenomena.

In previous research, the PID (proportional, integral, and derivative) controller is currently the most widely used controller for greenhouse temperature control [1]. The results show that the system performance has been greatly improved after PID control, but there is still room for improvement. Therefore, other algorithms are introduced to optimize the PID control parameters. Both genetic algorithm and fuzzy algorithm can greatly optimize the PID controller, but there is few research on which optimization algorithm in the greenhouse temperature model can achieve better control performance.

In this paper, a black-box modeling method based on structure identification and parameter estimation is proposed for the greenhouse temperature model [2]. Then we use the genetic algorithm and fuzzy algorithm to optimize the conventional PID controller, and compare the performance criteria like overshoot, settling time, peak time and rise time. The simulation shows that both fuzzy control algorithm and genetic algorithm can improve the dynamic performance of the system: for the control object in this paper, the optimization effect of genetic algorithm is better.

The remainder of the paper is organized as follows. In Section 2, we give the simplified control object and describe the research question. In Section 3, the fuzzy algorithm and genetic algorithm are introduced to optimize the traditional PID controller. The simulation results are given in Section 4. In Section 5, we give the conclusion of the paper.

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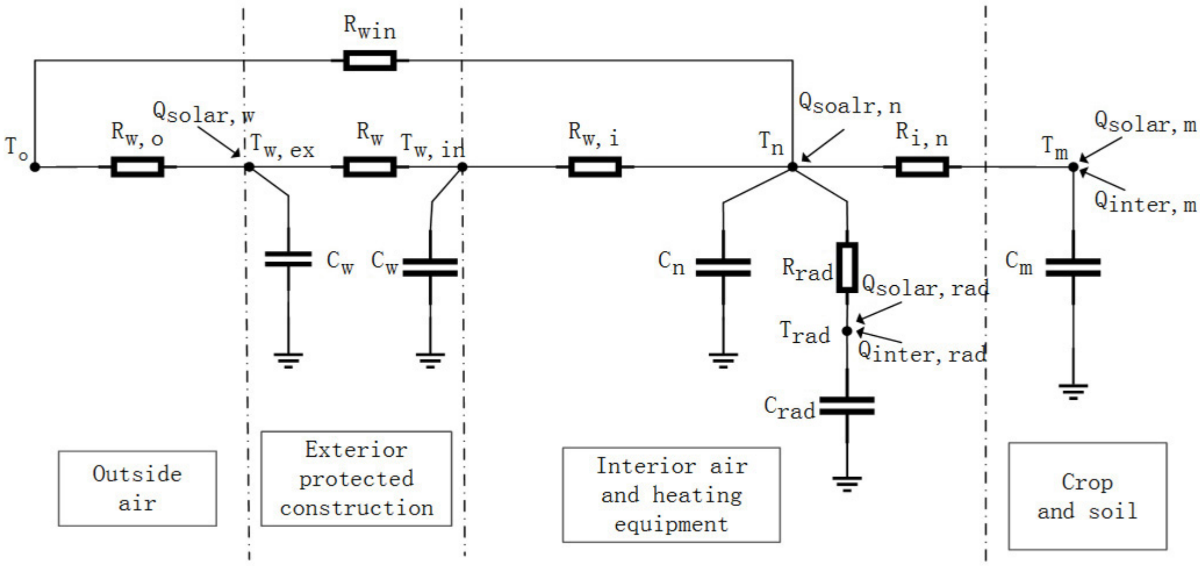

FIGURE 1. Schematic diagram of the greenhouse heat balance model

2. **Research Questions.** As shown in Figure 1, w, ex, in subscripts represent greenhouse exterior wall, exterior surfaces and internal surfaces, o, n represent the outside air and inside air, $solar$ is the solar heat radiation, win is the windows, m is the heating equipment, and rad is the radiators. T, C, R represent the temperature, heat capacity and the heat resistance. The greenhouse temperature system has five parts that transfer heat to each other: the external environment of the greenhouse, the greenhouse envelope, the indoor air, the internal heating equipment and the radiator. After we ignore the heats released by the crops, we can get the energy heat balance formula of the above five part. Then the state space equation for the greenhouse temperature model can obtain

$$\begin{aligned} dx/dt &= Ax + Bu \\ y &= Cx + Du \end{aligned} \tag{1}$$

The system state $x = [T_{w,ex}\, T_{w,in}\, T_n\, T_{rad}\, T_m]$, the input vector is $u = Q$ and the output vector $y = T_n$, the parameter matrix A, B, C, D is

$$A = \begin{bmatrix} -\frac{1}{C_wR_{w,o}} - \frac{1}{C_wR_w} & \frac{1}{C_wR_w} & 0 & 0 & 0 \\ \frac{1}{C_wR_w} & -\frac{1}{C_wR_w} - \frac{1}{C_wR_{w,i}} & \frac{1}{C_wR_{w,i}} & 0 & 0 \\ 0 & \frac{1}{C_nR_{w,i}} & -\frac{1}{C_nR_{w,i}} - \frac{1}{C_nR_{win}} - \frac{1}{C_nR_{i,m}} - \frac{1}{C_nR_{rad}} & \frac{1}{C_nR_{rad}} & \frac{1}{C_nR_{i,m}} \\ 0 & 0 & \frac{1}{C_{rad}R_{rad}} & -\frac{1}{C_{rad}R_{rad}} & 0 \\ 0 & 0 & \frac{1}{C_mR_{i,m}} & 0 & -\frac{1}{C_mR_{i,m}} \end{bmatrix}$$

$$\begin{aligned} B &= \begin{bmatrix} 0 & 0 & 0 & \frac{c(t_g - t_h)}{C_{rad}} & 0 \end{bmatrix}^T \\ C &= \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \end{bmatrix} \\ D &= \begin{bmatrix} 0 & 0 & 0 & 0 \end{bmatrix} \end{aligned} \tag{2}$$

In this paper, we simulate the meteorological parameters such as outdoor temperature and solar radiation intensity [3]. Then we use the data on temperature and heat dissipation within the greenhouse to estimate the system coefficients in Equation (2). The identification results of the parameters are as follows:

$$A_d = \begin{bmatrix} 0.9967 & 0.0186 & 0.0136 & -0.0048 & -0.0237 \\ 0.0081 & 0.3152 & -0.8526 & -0.1103 & -0.1066 \\ -0.1245 & 0.0486 & 0.3961 & -0.5395 & -0.3960 \\ -0.0347 & -0.1809 & -0.0172 & 0.7492 & -0.6833 \\ 0.0361 & 0.0040 & 0.1017 & 0.2913 & 0.9002 \end{bmatrix}$$
$$B_d = \begin{bmatrix} 0.011410 & 0.000470 & 0.000327 & -0.002102 & -0.000346 \end{bmatrix}^T$$
$$C_d = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$
$$D_d = 0 \tag{3}$$

When we use the conventional PID controller to stabilize the system (1), the control law of the controller is

$$u_i(t) = k_p \left[e_i(t) + \frac{1}{k_i} \int e_i(t)dt + k_d \frac{de_i(t)}{dt} \right] \tag{4}$$

e_i is the deviation between set value and output value; k_p, k_i, k_d are parameters to be designed. Then the system can finally stabilize at the temperature set value of about 20, but it still has a large overshoot and a long adjustment time, so it is still necessary to further improve the PID controller.

3. **Methodologies.** Firstly, fuzzy control algorithm is introduced to optimize the controller. As shown in Figure 2, the temperature deviation and its deviation rate of change are used as two input variables, and the output value of the fuzzy controller is set as the fuzzy correction value, which is added with the ordinary PID parameters to obtain the final optimized PID parameter value. The greenhouse temperature can be adjusted so that it can reach the set value.

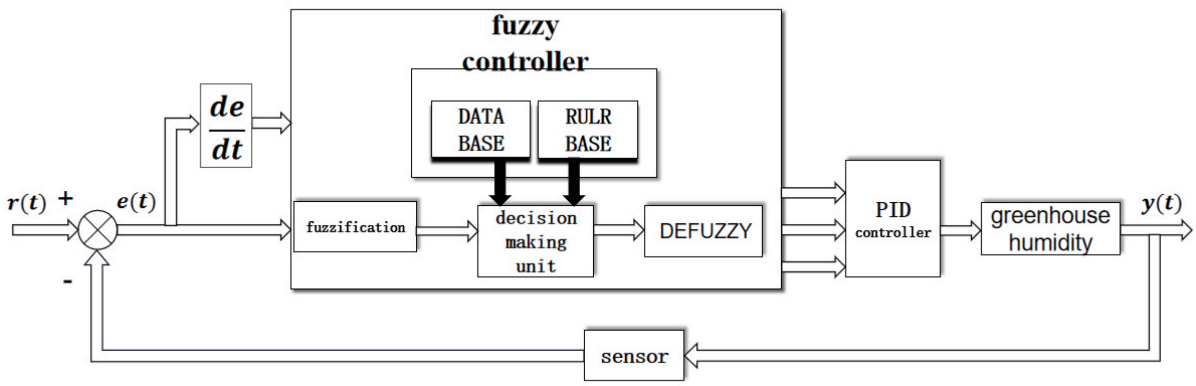

FIGURE 2. Fuzzy PID controller structure diagram

In the system, the input variable (e, de) and the output variable Δk_p, Δk_i, Δk_d are divided into 7 level, and the value of input sets 2 and the output sets 4. Following this rule, the fuzzy set is defined as $E_k = \{\text{NB, NM, NS, ZO, PS, PM, PB}\}$. The selection of the fuzzy membership function of the input quantity is shown in Table 1 [4]. The routine form of fuzzy condition and fuzzy relation "IF A and B THEN C" is introduced to construct fuzzy rule. Decision-making part of the system uses Madani fuzzy inference arithmetic and we use the centre-of-gravity method to defuzzy. As shown in Equation (5), the center of gravity method is to take the center of gravity of the area enclosed by the membership function curve and the abscissa as the final output value of fuzzy reasoning.

$$v_0 = \frac{\int_V v\mu_v(v)dv}{\int_V \mu_v(v)dv} \tag{5}$$

TABLE 1. Fuzzy membership function

	NB	NM	NS	ZO	PS	PM	PB
E	Gaussian	Triangle	Triangle	Triangle	Triangle	Triangle	Gaussian
EC	Gaussian	Triangle	Triangle	Triangle	Triangle	Triangle	Gaussian
k_p	Gaussian	Triangle	Triangle	Triangle	Triangle	Triangle	Gaussian
k_i	Gaussian	Triangle	Triangle	Triangle	Triangle	Triangle	Gaussian
k_d	Gaussian	Triangle	Triangle	Triangle	Triangle	Triangle	Gaussian

Then, the genetic algorithm is introduced to optimize PID parameters. As shown in Figure 3, the parameter optimization process is that the input and output of the system are used as the input of the genetic algorithm, after the genetic iterate operation (selective crossover and mutation [5]), the optimized parameters k_p, k_i, k_d with the largest fitness are found as the output of the controller and finally input to the controlled object to adjust the system and observe the output effect of the system.

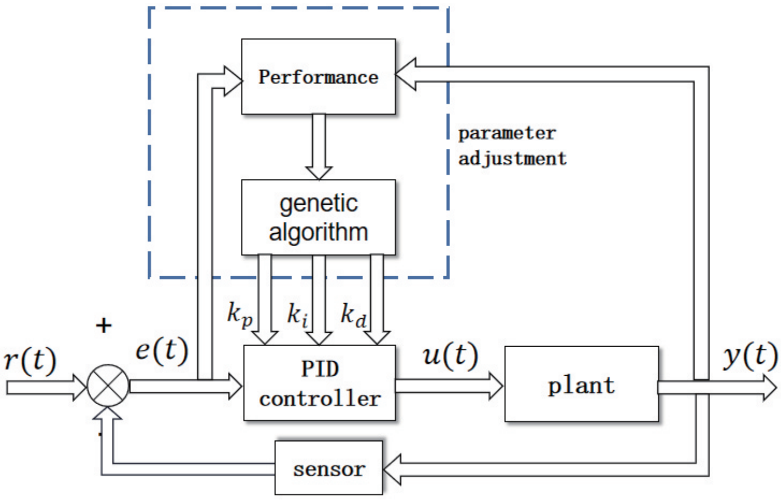

FIGURE 3. GA-PID controller structure diagram

Considering the transient performance and obtaining satisfactory performance, this paper uses the integral of the absolute value of the error and the square term of the control input as the objective function:

$$J = \int_0^{\infty} \left(k_{error}|e(t)| + k_{overshoot}pos + k_{rise}t_r\right) dt + k_{settle}t_s \tag{6}$$

In the function (6), the meaning of each symbol is as follows: k_{error} is the error weight, $k_{overshoot}$ is the overshoot weight, k_{rise} is the rise time weight, and k_{settle} is the adjustment time weight. $e(t)$ is the systematic error and pos is the overshoot. We set the fitness function as the inverse of the objective function.

4. **Results.** To verify the validity of the model and the optimized controller we proposed in this paper we use the Matlab simulation platform to conduct simulation experiments. Since there is no definite domain, the fuzzy control input here takes the general domain $[-6, 6]$. At the same time, in order to ensure the stable output of the controller, the domain is expanded to $[-12, 12]$, and we use the centre-of-gravity method to defuzzy. Fuzzy control rule of the system is referred to [6].

In the genetic algorithm, we select the binary characters 0 and 1 of 10 characters in length to represent the k_p, k_i, k_d, in order to ensure the optimization accuracy of the control strategy and improve the global optimization effect, the population size of 50 generations is selected here. The population value is randomly generated, 0 or 1.

Considering the global convergence and local search ability of the algorithm, the selection, crossover and mutation probabilities are selected as 0.2, 0.8, 0.1 [7].

For the stability and rapidity of the system and the prevention of excessive control, the weights in the fitness function is $k_{error} = 0.5$, $k_{overshoot} = 0.4$, $k_{rise} = 0.9$, $k_{settle} = 0.4$. Figure 4 and Figure 5 show the response curves for the three methods, respectively. The dynamic performance indicators under the three methods are also given in Table 2. We can

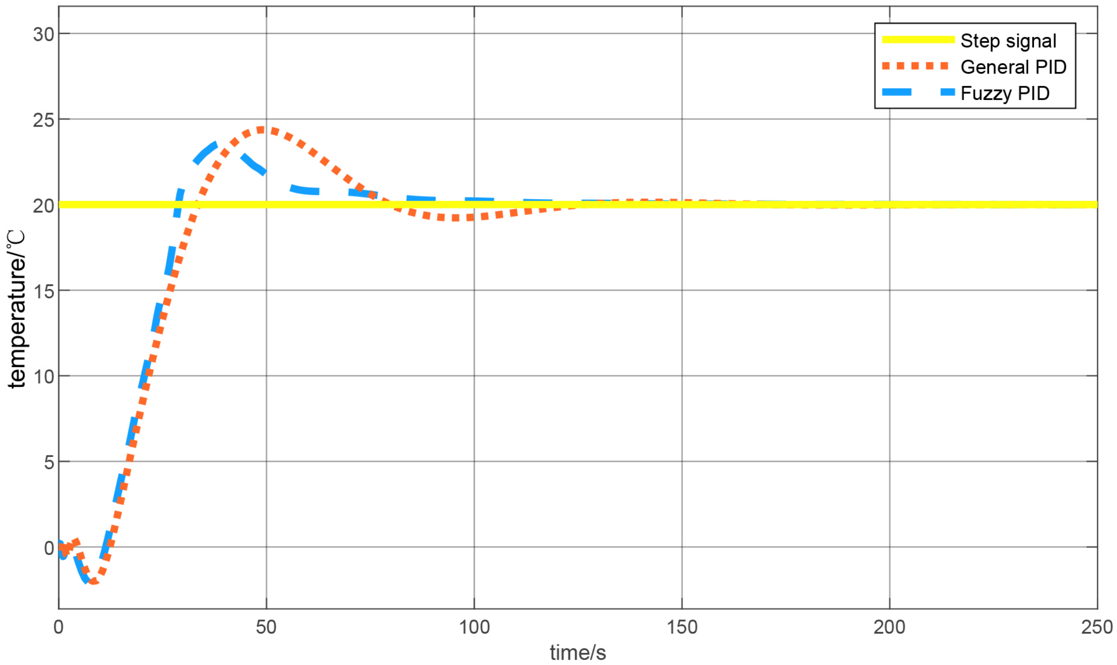

FIGURE 4. Fuzzy PID and PID step response curve

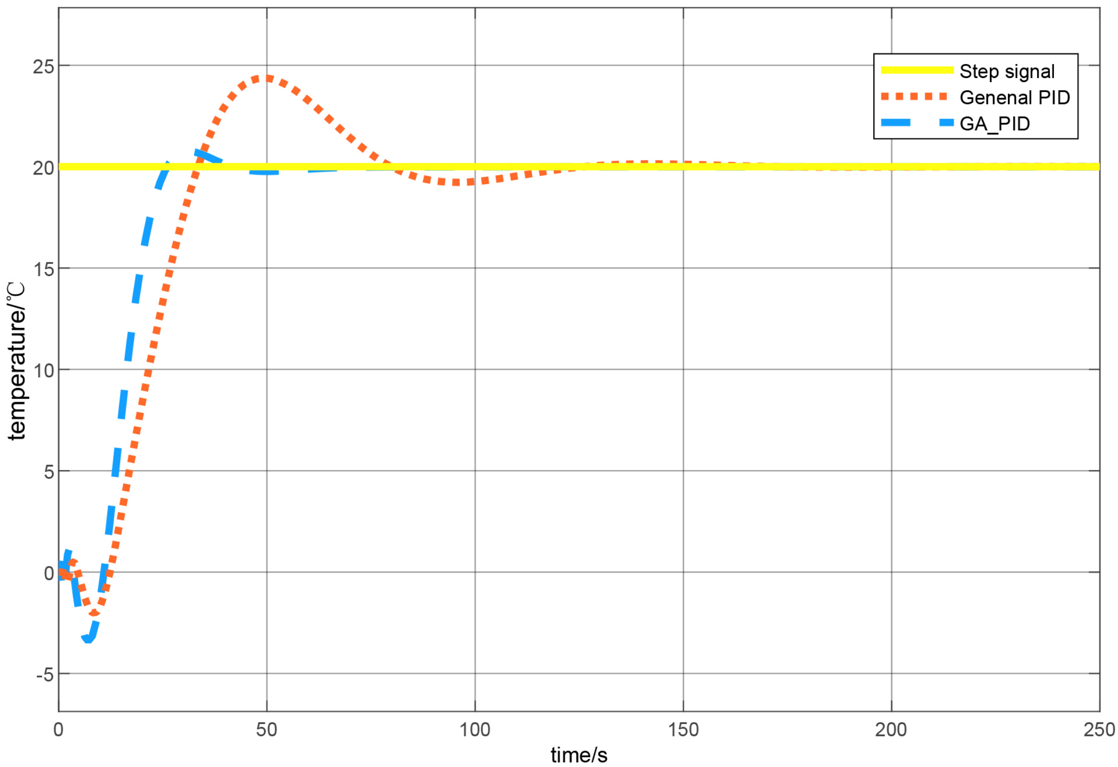

FIGURE 5. GA-PID and PID step response curve

Table 2. Dynamic performance under three controllers

	t_r/s	t_p/s	t_s/s	$h(t_p)$/°C	$h(\infty)$/°C	σ/%
PID	15.475	49.415	112.001	24.370	20	21.850
Fuzzy PID	13.667	38.862	81.353	23.570	20	17.850
GA-PID	10.571	32.429	37	20.760	20	3.800

see both fuzzy control algorithm and genetic algorithm can optimize the PID controller, and the dynamic performance of the system has been improved. However, in terms of the speed and stability of the system, the optimization effect of genetic algorithm is better.

5. **Conclusion.** From the system application result above, we can conclude that the general PID controller can greatly improve the dynamic performance of greenhouse temperature after being optimized by fuzzy algorithm and genetic algorithm, respectively. Comparing the two optimization results, the two algorithms have the same rapidity in terms of the rise time. In fact, the fuzzy PID controller can have better control effect in the presence of disturbance, while the GA-PID controller has faster response speed and stability. However, we only use a relatively general model in the greenhouse temperature system for optimization analysis, so the conclusions drawn in this paper have certain limitations. We can further optimize the algorithm and analyze the various models of greenhouse systems.

REFERENCES

[1] F. Gouadria, L. Sbita and N. Sigrimis, Comparison between self-tuning fuzzy PID and classic PID controllers for greenhouse system, *2017 International Conference on Green Energy Conversion Systems*, pp.1-6, 2017.

[2] J. B. Cunha, Greenhouse climate models: An overview, *EFITA 2003 Conference*, Debrecen, Hungary, pp.823-829, 2003.

[3] L. Y. Chiu, D. J. A. Rustia, Y. L. Chen and T. T. Lin, Modelling and forecasting of greenhouse whitefly incidence using time-series and ARIMAX analysis, *IFAC-PapersOnLine*, vol.52, no.30, pp.196-201, 2019.

[4] Y. Cheng, Research on intelligent control of an agricultural greenhouse based on fuzzy PID control, *Journal of Environmental Engineering and Science*, vol.15, no.3, pp.113-118, 2020.

[5] A. Altınten, F. Ketevanliolu, S. Erdoan, H. Hapolu and M. Alpbaz, Self-tuning PID control of jacketed batch polystyrene reactor using genetic algorithm, *Chemical Engineering Journal*, vol.138, nos.1-3, pp.490-497, 2008.

[6] S. W. Wang and J. F. Dong, Design and simulation of fuzzy self-tuning PID controller based on MATLAB, *Mechanical & Electrical Engineering Technology*, vol.35, no.2, pp.67-70, 2006.

[7] W. Zhang and L. Yuan, Research on greenhouse intelligent control system based on genetic algorithm and fuzzy PID algorithm, *Journal of Agricultural Mechanization Research*, vol.39, no.7, pp.209-213, 2017.