Research on Fuzzy PID Intelligent Agricultural Temperature Control System Based on PSO Optimization

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Abstract: Aiming at the problems of nonlinearity, large lag and difficulty in parameter tuning of traditional PID control in intelligent agricultural greenhouse environment, a Fuzzy PID control strategy based on Particle Swarm Optimization (PSO) is proposed. Firstly, the mathematical model of the greenhouse temperature control system is established, and the characteristics of large inertia and pure lag are analyzed. Secondly, a fuzzy PID controller is designed. A PSO optimization model with ITAE (Integral of Time-weighted Absolute Error) as the fitness function is constructed to globally optimize the quantization factors and scaling factors of the fuzzy controller, solving the defects of subjectivity and local optimum in manual parameter tuning. Finally, simulation models of traditional PID, fuzzy PID and PSO-fuzzy PID control systems are built in MATLAB/Simulink. The simulation results show that, compared with the traditional PID control, the overshoot of the fuzzy PID control system optimized by PSO has decreased from 4.5% to 0, and the regulation time has been shortened from 481 seconds to 326 seconds. This significantly improves the dynamic response speed and steady-state accuracy of the system. This research provides an effective technical path for solving the nonlinear and time-delay problems in the environmental control of agricultural greenhouses.

Keywords: Intelligent agriculture; Greenhouse temperature control; Fuzzy PID control; Particle Swarm Optimization; Parameter tuning

I Introduction

Modern agricultural production requires a controllable planting environment suitable for crop growth. Greenhouse temperature control systems generally have obvious nonlinearity, large inertia and severe time delay[1]. Conventional PID control is difficult to balance response speed and operation stability simultaneously. Although fuzzy PID control can dynamically adjust parameters based on fuzzy logic, its quantization factors and scaling factors are mostly set by artificial experience, which leads to strong subjectivity and unsatisfactory parameter optimization effect[2].

Aiming at the above practical problems, this paper adopts Particle Swarm Optimization algorithm to improve fuzzy PID control strategy. The proposed hybrid method combines the adaptive advantage of fuzzy control and global optimization ability of PSO[3], which effectively solves the parameter tuning difficulty of greenhouse temperature control system. Compared with traditional control methods, this strategy can realize online dynamic correction of PID parameters and optimize key parameters of fuzzy controller synchronously, so as to further improve the stability and dynamic performance of the temperature control system[4].

II System Principle Design

A. Mathematical Model of Greenhouse Temperature System

The greenhouse temperature control system belongs to a first-order inertial process with pure time delay. Its transfer function is expressed as:

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

where K is the system gain, T is the time constant, and τ is the pure time delay. According to parameter tuning results, the model parameters are set as $K=0.85$, $T=140$, $\tau=30$. This model can well reflect the temperature change rule and heat transfer delay in agricultural greenhouse scenarios[5].

B. Principle of Traditional PID Control

Traditional PID control is a classic control method widely used in industrial fields. Its control quantity is calculated by linear combination of proportional, integral and differential of system deviation e(t)[6]. The control formula is as follows:

$$u(t)=K_p\left[e(t)+\frac{1}{T_i}\int_0^t e(t)\,dt+T_d\frac{de(t)}{dt}\right] \tag{2}$$

where Kp denotes proportional coefficient, Ti denotes integral time constant, and Td denotes differential time constant.For greenhouse temperature system with strong nonlinearity, large inertia and pure time delay, traditional PID control has obvious limitations. Once the parameters Kp,Ki,Kd are determined, they will remain fixed and cannot adapt to the changes of external temperature, light intensity and other environmental factors[7]. If parameters are set for steady-state performance, the dynamic response will be slow; if parameters are adjusted for rapid response, system oscillation and overshoot will easily occur. Therefore, an intelligent control strategy with online parameter adjustment function is necessary[8].

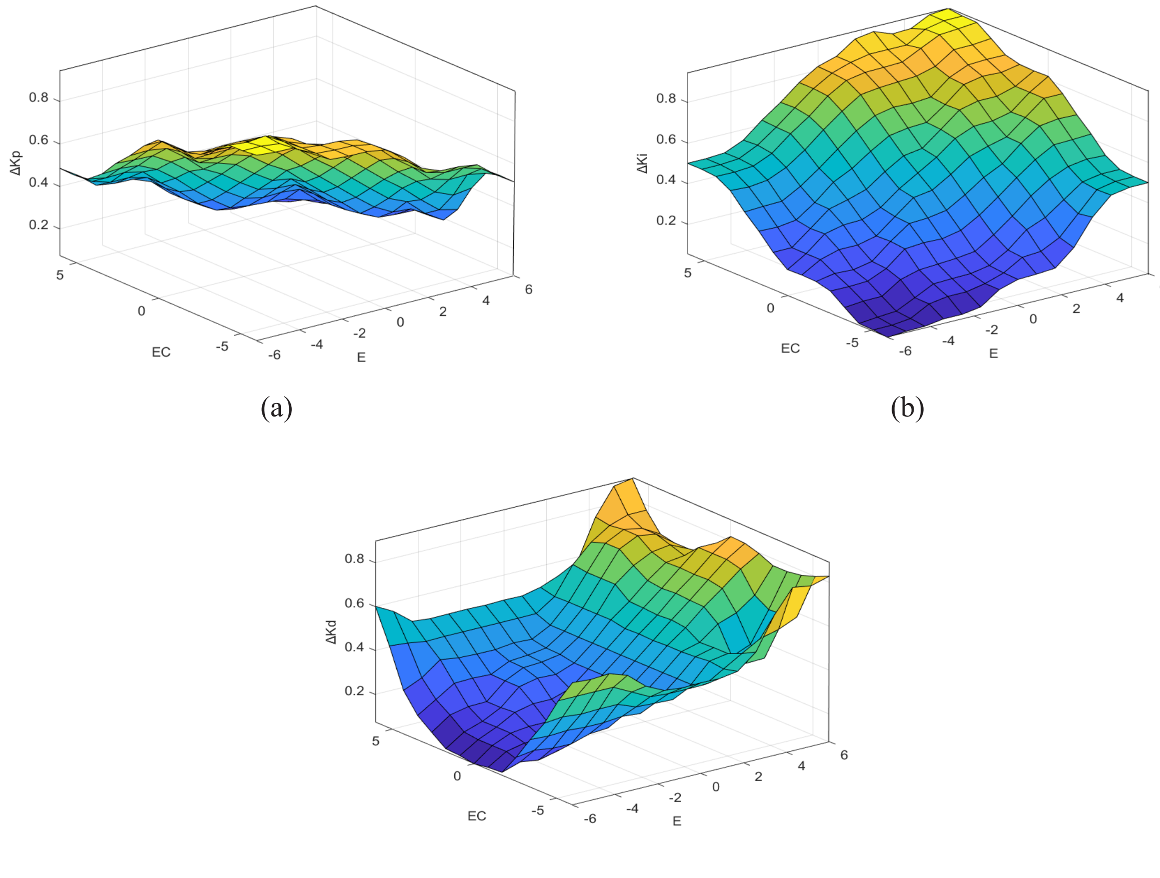
C. Principle of Fuzzy PID Control

Fuzzy control theory is introduced to solve the problem of fixed parameters in traditional PID control. The core of fuzzy PID control is to adjust three PID parameters Kp,Ki,Kd in real time by fuzzy inference according to temperature error e and error change rate ec.

Input variables are temperature error e and error change rate ec; output variables are parameter correction values ΔKp, ΔKi and ΔKd. The domain of all variables is defined as [−6,6]. The linguistic variables are divided into seven levels: *NB*, *NM*, *NS*, *ZO*, *PS*, *PM*, *PB*, representing Negative Big, Negative Medium, Negative Small, Zero, Positive Small, Positive Medium and Positive Big respectively[9].

In accordance with the principle of suppressing overshoot under large errors and improving precision under small errors, 49 fuzzy control rules are established. Gaussian membership functions are applied to input variables E and EC, and triangular membership functions are adopted for output variables ΔKp, ΔKi and ΔKd. After completing the configuration of variables, membership functions and control rules, the fuzzy PID controller is constructed. The output surfaces of three parameters are shown in Fig. 1.

Fuzzy PID control can adjust parameters dynamically according to the operating state of the system, so it has better adaptability than traditional PID control.



(a) (b) (c)

Figure 1. Fuzzy PID Controller Output Curve (a)ΔKp;(b)ΔKi;(c)ΔKd

III PSO-Optimized Fuzzy PID Control

PSO is a swarm intelligence-based stochastic optimization algorithm inspired by group behaviors including bird flocks foraging and fish schools migration. It converts the feasible solution space of an optimization problem into algorithm search space, where each candidate solution is defined as an individual particle, and all particles constitute a swarm. Each particle possesses position and velocity: the position corresponds to a candidate solution, and velocity decides its moving direction and step size in the next iteration[10].

PSO achieves optimization by iteratively updating particle velocity and position. In each iteration, every particle modifies its motion state relying on its personal best position (pbest) and the global best position of the whole swarm (gbest). Repeated iterations make particles continuously converge to the global optimal solution [11].

The particle velocity update formula is written as:

$$v_i^k = \omega \cdot v_i^{k-1} + c_1 \cdot r_1 \cdot \left(p_{besti} - x_i^{k-1}\right) + c_2 \cdot r_2 \cdot \left(g_{best} - x_i^{k-1}\right) \tag{3}$$

The particle position update formula is expressed as:

$$x_i^k = x_i^{k-1} + v_i^k \tag{4}$$

In Eqs. (3) and (4): v_i^k and x_i^k are the velocity and position of the i-th particle in the k-th iteration; ω is the inertia weight, which determines how much the particle retains its previous velocity; c1 and c2 are learning factors, reflecting the particle’s trust in individual experience and swarm experience; r1 and r2 are random values between 0 and 1 to increase search randomness; pbesti is the personal best position of the i-th particle; gbest is the global optimal position of the entire swarm.

A. Iterative Optimization Process of PSO

Particle Swarm Optimization simulates the foraging behavior of bird swarms to realize global optimal solution searching. In this system, PSO is used to optimize quantization factors, scaling factors and membership function parameters of fuzzy PID controller[12].

Set basic algorithm parameters including swarm size, search dimension, maximum iteration number, inertia weight and learning factor. Within the reasonable parameter range, randomly generate initial position vector Xi and velocity vector Vi of each particle to complete swarm initialization.

Assign particle parameters to the fuzzy PID controller, and carry out dynamic response test on MATLAB/Simulink simulation platform. Calculate system performance indicators such as overshoot, rise time and regulation time, and substitute them into the objective function to obtain particle fitness values.

By using a dual-comparison method, the optimal decision information is continuously updated step by step.

Compare the current fitness value with the historical optimal fitness value of each particle. If the current performance is better, update the individual optimal position and fitness value.

Traverse all individual optimal fitness values of particles and select the global optimal value. If the new global optimal value is superior to the historical one, update the global optimal position and fitness value of the swarm.

Calculate the velocity and position of particles in the next iteration according to PSO update formulas, combined with inertia weight and learning factors. Boundary constraint is adopted to limit particle velocity and position within the preset range to avoid solution overflow and system instability. Inertia weight is dynamically adjusted in iterations to balance exploration and exploitation ability of the algorithm.

The iteration terminates when the maximum iteration number is reached or the change of global optimal fitness value is lower than the set threshold. Output the optimal parameter combination of fuzzy PID controller after iteration ends.

IV System Simulation and Result Analysis

A.Simulation Environment and Parameter Settings

The simulation platform is built in MATLAB/Simulink. PSO parameters are set as follows: swarm size = 20, maximum iteration number = 50, inertia weight decreases linearly from 0.9 to 0.4, learning factors c1=c2=1.49. Three control strategies are selected for comparison: traditional PID, manual-tuned fuzzy PID and PSO-fuzzy PID.

B. Comparative Analysis of Simulation Results

Unit step signal is applied to the system, and the target temperature is set to 50 ℃. The temperature response curves of three control strategies are shown in Fig. 2.

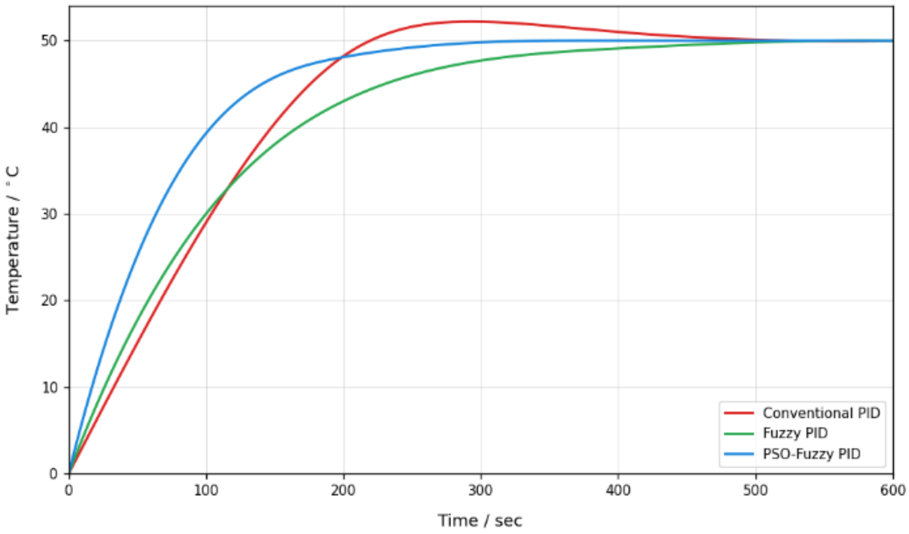


Figure 2. Comparison of temperature response curves of three control strategies

It can be seen that traditional PID has obvious overshoot and severe oscillation. Manual-tuned fuzzy PID eliminates overshoot but has long regulation time. The proposed PSO-fuzzy PID achieves the best performance in both stability and response speed. The detailed performance indicators are shown in Table 1.

Table I. Performance indicators of three control strategies

Control Strategy	Performance Metrics		
	Overshoot (%)	Rise Time (s)	Settling Time (s)
Traditional PID	4.5	96	481
Fuzzy PID	0	133	494
PSO-Fuzzy PID	0	105	326

V. Conclusions

Aiming at the nonlinearity and time-delay problems of agricultural greenhouse temperature control, this paper proposes a PSO-optimized fuzzy PID control strategy. The main conclusions are as follows:

First, the control performance is significantly improved. Compared with traditional PID control, the proposed strategy completely eliminates overshoot and oscillation. Although the rise time increases slightly, the regulation time is greatly shortened, and the overall dynamic performance is optimized.

Second, parameter tuning is realized intelligently. PSO algorithm replaces manual experience to optimize fuzzy controller parameters, which solves the problems of strong subjectivity and local optimum in traditional tuning methods and enhances system robustness.

Third, this research has high practical value. It provides an effective solution for intelligent agricultural greenhouse environmental control, and has reference significance for the automation and intellectualization of agricultural production.

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