Research and Application of Precision Fertilizer Application Algorithm Based on PSO Optimized Fuzzy PID Control

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Research and application of precision fertilizer application algorithm based on PSO optimized fuzzy PID control

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Abstract

In irrigation's process and fertilizer application in production of agriculture, the accuracy of fertilizer application and water maintains at a relatively low level, which results in waste of soil slabbing and resources. In this research, a fuzzy PID algorithm based on PSO optimization is designed to control the fertilizer application process and irrigation of the fertilizer applicator. Firstly, a mathematical model of the fertilizer applicator is established according to the relevant modules and corresponding parameters. Based on the MATLAB/Simulink platform, the PID controller, the fuzzy PID controller and the controller proposed in this article are constructed respectively, which can be applied to the established transfer functions. The simulation outcomes demonstrate that the response time of the control algorithm proposed in this research is shortened to 30s, compared to fuzzy PID and PID, which is 62.5% and 50% shorter respectively, and the overshoot of the control algorithm in this article is nearly 0 of apart from the early oscillation. In order to verify the algorithm's reliability in practical application, this research designs groups of different pressure for the accuracy control test , the test consequences illustrate that the fuzzy PID control based on PSO optimization has excellent control effect under each pressure. The control accuracy is concentrated at around 2%, while PID control maintains around 20% and fuzzy PID control distributed at 10%.

The results show that the control algorithm proposed in this research enhances the irrigation accuracy in the practical application process.

Keywords: Precision fertilizer application,Fuzzy PID control,PSO algorithm,Performance analysis,experimental validation

1 Introduction

Agriculture accounts for more than 65% of total water consumption, and 95% of water application of agriculture is applied for irrigation of large zones of farmland, where water is severely scarce[1]-[5].Variable fertiliser application is an important area of research in the development of precision that farms, and this technology is a excellent solution to the high labour intensity, low efficiency of fertiliser application operations and the unevenness of manual fertiliser application. Most of the current fertiliser application models are still based on ready approach and a rough, with water's concentration proportion to fertiliser being ignored in the fertiliser application process and irrigation, leading to depressed fertiliser uptake by crops and plenty of wasted water and labour[6][7]. Although the increased application of water and fertiliser measures can achieve higher yields, the relatively high water and fertiliser inputs not only increase the risk of groundwater pollution, but also have a negative impact on plant growth and the greenhouse environment.

Research on the waste of fertilizer resources and water has been done by a large number of scholars. Literature[8] designs and realization of water, fertilizer and pesticide integrated automatic control device, the paper discusses selection and application of fertilizer pesticides, use procedure, water, fertilizer and pesticide saving effect and receptive crowd in the application process of modern planting industry. In view of the application status of irrigation and fertilizer system control, cloud computing is applied in Literature[9].Two new control algorithms based on MSP430 microcomputer unit(MCU)are developed in Literature[10] to improve the performance of a fustigation system controlled by the electrical conductivity(EC)value of an irrigation nutrient solution in a greenhouse. In view of the phenomenon of heavy workload, time-consuming, labor-consuming and error leakage by manual statistics in the process of large-scale cultivation of maize in Ningxia, different nitrogen treatment experiments are designed Literature[11].An integrated experiment system of water and fertilizer control based on PLC was in designed Literature[12],which can monitor EC value of water and fertilizer.In view of the large hysteresis, large inertia and uncertain mathematical model of the water and fertilizer integrated in Literature[13] machine to adjust the pH value of water and fertilizer, this paper applies fuzzy control to water and fertilizer integrated equipment, and designs a fuzzy control system to adjust the pH value of water and fertilizer. In general, there are fewer control algorithms focusing on precision fertilizationin the following work, the drawbacks and advantages of some of the control algorithms are analysed.

Traditional PID control, to a great extent dependent on the model's accuracy, which will cause the corresponding costs in modelling's process[14][15], in addition, since conventional PID is not straightforward to on-line rectification parameters, can not adapt to the complex parameters of the environment for on-line adjustment, fast response requirements, so the conventional control algorithm has not been able to meet liquid fertilizer variable control's necessities. A precise mathematical model is not required by Fuzzy PID control[16]-[20], to a certain extent to puzzle out the control police problem's model, only need to summarize the human control experience, is a sort of human behavior's imitation, convenient to be accepted by the operator control technology. The fuzzy PID controller, nonetheless, is less delicate in its control on account of the blind spot near the balance point. In production of agriculture of today, there are frequently problems with fertiliser application accuracy being difficult to grasp and timing not being easily controlled.

Overall, this paper proposes to analyse the variable control section's composition, solve for the relevant parameters and derive the electric proportional valve's transfer function, and simulate the transfer function applying the PID control algorithm. The control algorithm is selected as study's object with three control algorithms, PID, fuzzy PID and PSO fuzzy PID, and the MATLAB software is used as the simulation platform for simulation and the quality parameters are analysed for the simulation consequences. In order to verify the algorithms' superiority proposed in this research in the actual operation process, different control algorithms' accuracy is compared by the accuracy test designed in this article in the irrigation process.

2 Mathematical modelling of fertilizer application systems

This system's flow adjustment device is an electric proportional valve which comprises a valve body and a drive motor, the motor drives the transmission part through rotation so as to control the valve spool and thus realise the control of the valve body's opening. The opening degree's control is realised by the electric proportional control valve and thus the flow's control rate. And it comprises the following parts: DC MotorSpeed ReducerVoltage Drive ModuleSensing Module and Data Acquisition Module.

A closed-loop control strategy where the controller forms a decision signal through the position input signal, adjusts the voltage output and drives the motor for start-stop, forward and reverse action is used by the electric proportional valve's control, and the spool is driven by the motor to change the valve opening's size. The position sensor's function is to detect the valve that opens information and transmit it to the controller to form a closed loop control. The principle block diagram is shown in Fig.1.

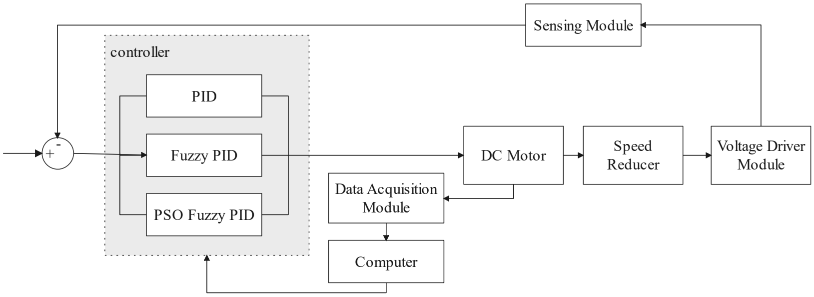

Fig. 1 Control structure diagram of fertilizer application system.

Through the analysis of the liquid fertilizer spraying variable control system control part of the electric proportional control valve's composition, the transfer function by the DC motor, reduction device, the electric proportional valve that opens control transfer function is constituted by voltage drive.

DC motors are the driving device in electric proportional valves. DC motors are widely applied in regions that require speed control and forward and reverse rotation owning to the ease and high precision of control. The stroke control and speed of the motor are associated with the valve control's precise operation. The voltage's transfer function and stroke of the DC motor is derived as follows.

The equilibrium equation for the motor drive voltage is shown in Eq(1).

$$U_d(t) = RI_d + L\frac{dI_d(t)}{dt} + E(t) \tag{1}$$

Where $U_d(t)$ is the DC motor's drive voltage, R is the internal resistance, $I_d(t)$ is the armature current and $E(t)$ is the electric potential. The equation for the output torque can be expressed as:

$$M(t) = KI_d(t) \tag{2}$$

where $M(t)$ is the output torque of the DC motor and K is the DC motor torque factor. The DC motor torque expression is given in Eq.

$$M(t) - M_1(t) = J\frac{dw(t)}{dt} \tag{3}$$

where $(M)t$ is the torque of the load, J is the amount of rotational inertia of the DC motor and $w(t)$ is the speed of the DC motor.

$$M_1(t) = f\ddot{\theta}(t) \tag{4}$$

where f is the coefficient of friction and is the angle of rotation of the motor output.

Combining the above equations yields.

$$I_d(t) = \frac{1}{K_m}[J\dot{\theta}(t) + f\ddot{\theta}(t)] \tag{5}$$

Bringing the above equation into the voltage balance equation gives.

$$LJ\dddot{\theta}(t) + (Lf + RJ)\dot{\theta}(t) + Rf\ddot{\theta}(t) + K_m E_m(t) = K_m U(t) \tag{6}$$

where K_m is the inverse electric potential coefficient. The transfer function between the DC motor's output angle and the input voltage is obtainable after the Laplace inverse transformation as:

$$G_1(s) = \frac{\theta(s)}{U(s)} = \frac{K_m}{L_a f s^3 + (Rf + L_a J)s^2 + RJs} \tag{7}$$

By the series relationship between the parts, the output angle is used as the reduction device's input reference, which increases the output torque by reducing the motor speed, and its expression is the ratio of the reduction device's torque to the DC motor's output torque, without generality's loss, equating the link to the proportional relationship between the two angles, the part's transfer function is the proportional relationship between the two angles, reflected in the relationship between the reduction device's output displacement and the input angle, which can be listed and written as follows.

$$G_2(2) = \frac{X(s)}{\theta(s)} = \frac{L}{2\pi} \tag{8}$$

where L denotes the lead of the guide rod and X is the output displacement.

Through the modelling of the above two connections, the transfer function of the driving part of the fertiliser can be determined by the output voltage and the input voltage to, in addition, the existence of a certain delay in this transmission module, the delay time can be neglected compared to the switching frequency, in summary, this voltage driving module's transfer function is:

$$G_3(3) = \frac{U_{out}(s)}{U_{in}(s)} = K_s e^{\tau s} \approx K_s \tag{9}$$

The modules are connected in parallel with each other and ks is the converter amplification factor. The transfer you function of the system can be obtained as:

$$G(s) = G_1(s)G_2(s)G_3(s) = \frac{K_m K_s L}{(L_a f s^3 + (Rf + L_a J)S^2 + RJs)2\pi} \tag{10}$$

The fertiliser application system parameters are listed in the table 1.

Bringing the parameters into the mathematical model yields the transfer function for this study as

$$G(s) = \frac{0.048}{9.9 \times 10^{-5}s^3 + 4.65 \times 10^{-4}s^2 + 2.87 \times 10^{-4}s} \tag{11}$$

Table 1 Table of relevant parameters of the fertilizer application device

Symbol	Parameters	Value
K_m	Counter-electromotive force constant	0.048V/rad
K_s	Magnification factor	2
L	Guide bar movement distance	5mm
L_a	Stator inductor	3.94mH
f	Friction coefficient	$3*10^{-6}$mm
R	Stator resistance	2.74Ω
J	Rotational inertia	$1.67*10^{-5}$kg/m^2

3 Design of the control algorithm

3.1 Design of a fuzzy PID controller

In order to compare and analyse different controllers' performance indicators, an algorithmic control system that is based on PID control is first constructed starting from the traditional classical control PID algorithm[21]-[25], which can compensate for a blind's lack spot near the controller's balance point. Determining the k_p, k_i and k_d of the PID, either continuous control or analogue control can be done by the PID controller, and its expression is:

$$u(t) = k_p[e(t) + \frac{1}{T_1}\int_0^t e(t)dt + T_d\frac{de(t)}{dt}] \tag{12}$$

The control structure is schematically shown in Fig.2.

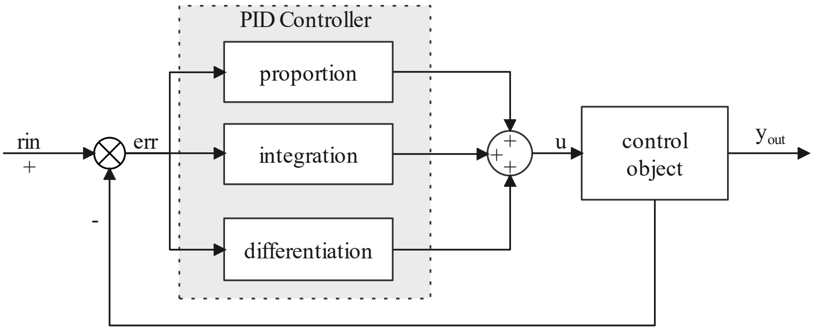

Fig. 2 Schematic diagram of PID controller.

The fuzzy adaptive PID algorithm comprises a combination of a PID controller and a fuzzy controller mainly, with the error (e) and the rate of change of the error (ec) as controller inputs and the control parameters of the PID proportional link (K_p), integral link (K_i) and differential link (K_d) adaptively adjusted according to fuzzy rules. The fuzzy adaptive PID structure is demonstrated in Fig.3 as follows[26]-[30].

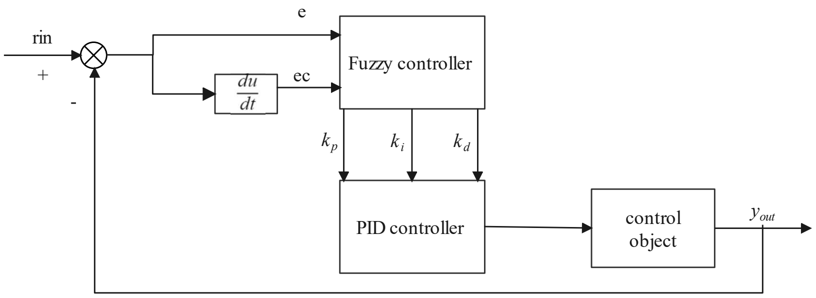

Fig. 3 Schematic diagram of Fuzzy PID controller.

The deviation e and the rate of change of deviation ec are selected as the two input variables of the fuzzy controller for water and fertilizer flow, and the three parameters k_p ,k_i ,k_d are selected as the output variables of the fuzzy controller for optimisation, and the corresponding fuzzy variables were E, EC and u_p, u_i, u_d. The quantization factor of the deviation of flow value, the quantization factor of the rate of change of deviation and the scaling factor were denoted by k_e, k_{ec} and respectively.

$$e_n = b_n - b_0 \tag{13}$$

$$e_{n-1} = b_{n-1} - b_0 \tag{14}$$

$$c_n = \frac{e_n - e_{n-1}}{T} = \frac{b_n}{b_{n-1}} \tag{15}$$

where b_0 is the fertilizer flow rate value and set water. b_{n-1} and b_n are the flow rate values that are detected by the flow sensor for the n_{th} times and n-1st, respectively. e_{n-1} and e_n are the deviations between the n-1st and n_{th} detected fertilizer flow values and the set value, respectively. c_n is the rate of change of the deviation of the fertiliser flow value and n_{th} detected water. T is the sampling period.

The deviation input, deviation rate of change input and parameter optimisation output of the designed water and fertiliser flow value fuzzy controller all use a triangular type of affiliation function, and the area centre of gravity method is chosen as the clarification method for the water and fertiliser flow value fuzzy controller. The number of fuzzy subsets covering the whole fuzzy domain is generally 3 10, which can avoid the excessive number of fuzzy rules and ensure a certain control accuracy.

In this article, the linguistic values of the deviation e and the rate of change of the flow values' deviation ec are selected as [NB, NM, NS, ZO, PS, PM, PB] , and the fuzzy domains are taken as the characteristic points [- 3,- 2,- 1, 0, 1, 2, 3]. where NB, NM, NS, ZO PS, PB and PM denote negative large, negative medium, negative small, 0, positive small, positive medium and positive large, respectively. For instance, when E is PB means that the current measured water and fertiliser flow is much larger than the set value; when EC is PB, it means that the next time the fertiliser flow and water will be much larger than the current that was measured flow. The linguistic values of the selected optimisation parameters k_p k_i k_d are [NB, NM, NS, ZO, PS, PM, PB] and the fuzzy domain's characteristic points are [- 3,- 2,- 1, 0, 1, 2, 3]. Where NB, NS, ZO, PS and PB denote the parameter values for the fertilizer application system's different operation modes.

Through literature review and field research to summarise the expert experience of flow values, the fuzzy control statement was chosen in the form of "If E and EC then k_p k_i k_d", and the fuzzy control rules were written in the form of 7 x 7 = 49 statements, and the control rule table is shown in Table 2. The affiliation relationship between the two inputs and the output affiliation relationship between the three optimised parameters is shown in Fig.4. The fuzzy surface diagram of the optimised parameters is shown in Fig.5- Fig.7.

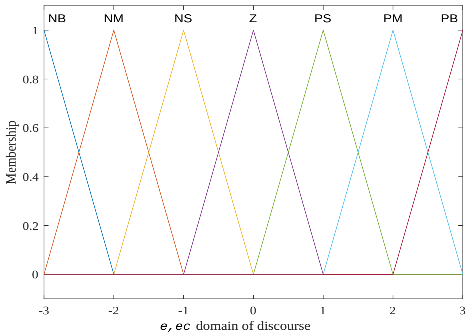

Fig. 4 Affiliation function of fuzzy input & fuzzy output.

3.2 Design of a fuzzy PID controller based on particle swarm optimization

PSO(particle swarm algorithm) has a strong ability to deal with continuous problems, and is therefore suitable for parameter optimisation, while the PID controller consists of three parameters: k_p,k_i, k_d.

The PID controller is treated as a "black box", with these three parameters as inputs and the response curve as output, and all we have to do is optimise this response curve. A good PID controller should have a fast response, small overshoot and steady-state error for different types of inputs. Therefore, the classical three input signals: step, ramp and parabolic are used to measure the PID control effectiveness. The topology of the PSO optimisation based fuzzy PID controller designed in this study is shown in Fig.8 .

The flow of the basic particle swarm algorithm is as follows, Which can be showon in Fig.9.

(1) Particle swarm hyperparameters as well as random solutions are initialised.

Table 2 Fuzzy rule table for fuzzy control.

	EC						
E	NB	NM	NS	Z	PS	PM	PB
NB	PB,NB,PB	PB,NB,PB	PM,NM,PM	PM,NM,PM	PM,NM,PM	PB,NB,PB	PB,NB,PB
NM	PB,NB,PB	PB,NB,PM	PM,NM,PS	PM,NM,PS	PM,NM,PS	PB,NB,PM	PB,NB,PB
NS	PM,NM,PM	PS,NM,PS	PS,NS,Z	Z,NS,Z	PS,NS,Z	PM,NM,PS	PB,NB,PB
O	PM,NM,PM	PM,NM.PS	PS,NS,Z	Z,NS,Z	PS,NS,Z	PM,NM,PS	PM,NM,PM
PS	PM,NM,PM	PM,NM,PS	PS,NS,Z	PS,NS,Z	PS,NS,Z	PM,NM,PS	PM,NM,PM
PM	PB,NB,PB	PB,NB,PM	PM,NM,PS	PM,NM,PS	PM,NM,PM	PM,NB,PM	PB,NB,PB
PB	PB,NB,PB	PB,NB,PB	PM,NM,PM	PM,NM,PM	PM,NM,PM	PB,NB,PB	PB,NB,PB

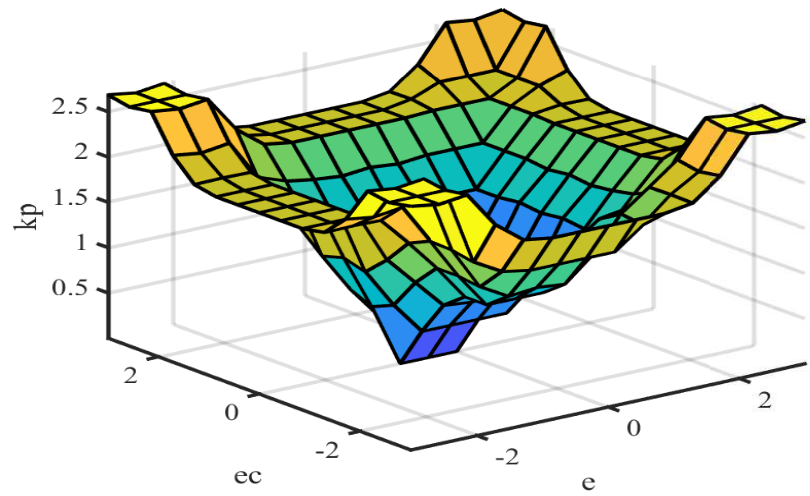

Fig. 5 Fuzzy surface diagram of k_p.

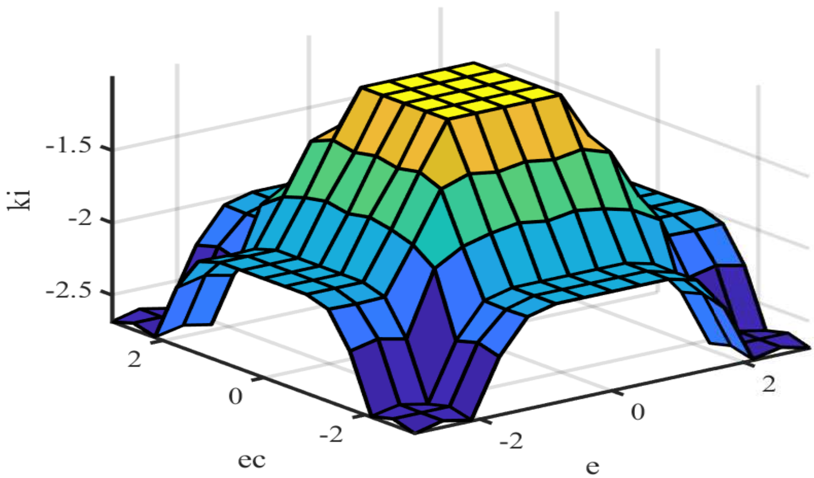

Fig. 6 Fuzzy surface diagram of k_i.

(2) Set the values of the PID control parameters, run the system and judge whether the system performance indicators meet the requirements.

(3) If the particle adaptation value at the current time is higher than all previous ones, the optimal value is updated.

(4) Iterate each particle, if the current particle is better than the best position adaptation value in the swarm, then its as the population optimum.

(5) The velocity and position of the particle are updated.

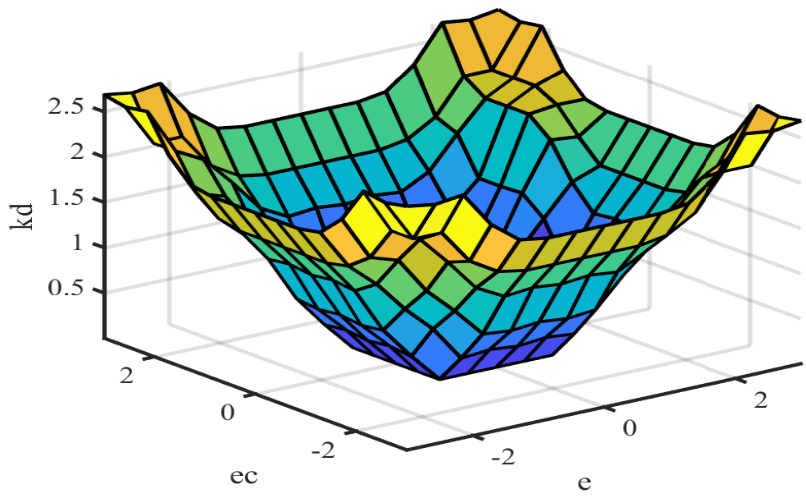

Fig. 7 Fuzzy surface diagram of k_d.

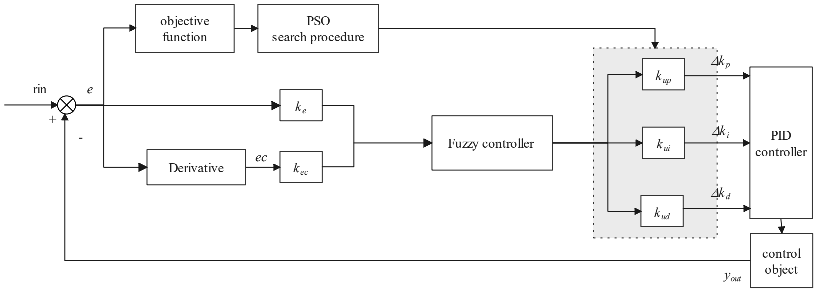

Fig. 8 Schematic diagram of fuzzy PID control based on PSO optimization.

(6) If the global adaptation value is satisfied to be sufficiently good or the run reaches the maximum number of iterations), then end, otherwise go to step (1).

The control schematic and control flow diagram of particle swarm optimisation algorithm are Fig 8 and Fig 9 respectively.

4 Simulation of flow value control for fertilizer application systems

For the designed variable fertiliser control model, a conventional PID control simulation model of the liquid fertiliser variable fertiliser control system was set up using the simulink simulation module in MATLAB software, the input step signal amplitude was set to 10, the PID controller parameters were adjusted and the output waveforms were analysed. The PID control model's simulation

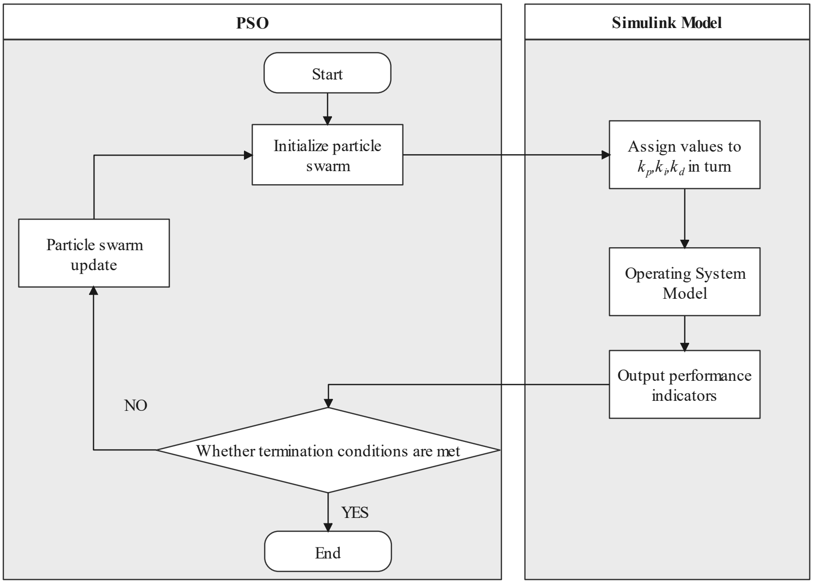

Fig. 9 Control flow chart of particle swarm algorithm.

process is as follows: a step signal of amplitude 10 is input at $t = 0$, the simulation time is set to 100 s, and k_i, k_d and the k_p of the PID controller are adapted, the waveform is then output to the oscilloscope

According to the graph(Fig.10), the model response time is 80 s, the overshoot is 0.229 and there is some oscillation before the system operation reaches stability. According to the empirical trial and error method, k_p=6.5, k_i=1.2 and k_d=1 are finally chosen.

The simulation model of the fuzzy PID control system is set up in the simulink simulation module, and the input signal is also a step signal with an amplitude of 10. The simulation process is to input a step signal of amplitude 10 at $t = 0$ and set the simulation time to 100 s. The input variables of the fuzzy controller are the fuzzified error $e(k)$ and the rate of change of the error $ec(k)$, and the fuzzy controller outputs the compensation value of the defuzzified PID parameters, and the compensation value is used to optimise the initial parameters, and then the simulation waveform of the control system is obtained.The control curve of the optimised system is shown in Fig 10. As can be seen from the graph, the model response time of the fuzzy PID control is 40 s, the overshoot is 0.18 and there is some oscillation before the system operation reaches stability.

The model developed for the variable fertiliser control system was programmed with MATLAB software to implement a genetic algorithm for the optimisation of fuzzy control rules. The absolute error integration criterion is used to judge the performance index of each generation of individuals optimised by the genetic algorithm, and the optimisation process ends when the population iterations reach the required performance index, and if the required index is not reached, the best individual of the last generation of the population is taken as the result for the control model simulation.

The system inputs a step signal with an amplitude of 10, then the fuzzy language values corresponding to the compensation values k_p, k_i and k_d from the fuzzy controller are formed into individuals, and the initial population is randomly generated, and the population is optimised by the particle swarm operator, and the population is iterated to the maximum genetic generation. The particle swarm algorithm optimal individual iterative search process is shown in Fig. The optimised parameters are shown in Fig. The control curve of the optimised system is shown in Fig 10. As can be seen from the graph, the model response time for the particle swarm optimised fuzzy PID control is 27 s with an overshoot of 0.03, which is a substantial reduction in overshoot compared to the other controls, with some oscillations before the system operation reaches stability.

Simulation examinations are carried out with the electric proportional valve opening transfer function as the control object, applying fuzzy adaptive PID, PSO fuzzy PID and conventional PID. The fuzzy PID control based on PSO optimisation possesses a short time from disturbance's occurrence to equilibrium's establishment again for the control quantity, and the overshoot process is an important indicator of the system's rapid response. The control algorithm proposed in this study outperforms the other two algorithms in terms of overshoot, indicating that the control proposed in this study has a small difference in deviation from the set value. Further, the algorithm is substantially reduced compared to the other two algorithms, indicating a short overshoot high system accuracy and process time with small deviations from the set value. In summary, the control algorithm that is proposed in this study possesses the advantage of fast convergence of control parameters, strong adaptive capability, high control accuracy and on-line self-tuning of the adaptive variable control algorithm when this variable control system is used as the control object.

5 Experimental design and analysis

A fuzzy PID is used by the liquid fertiliser variable control system based on PSO optimisation as the control algorithm for the variable control system. The system is tested indoors by setting target quantities through the control terminal to respectively verify the relationship between flow rate and system pressure, and the operational accuracy of the system. These results are applied to measure the liquid fertiliser variable control system's liquid fertiliser controllability and are also important indicators to test whether this system meets the variable operation. The system pressure relates to the pressure that is obtained by changing the regulating valve's opening when the pressure supplied by the pump is constant. The system pressure during the experiment is the pressure value demonstrated after adapting the proportional regulating valve. The platform for the precision fertiliser system is shown in Fig.11.

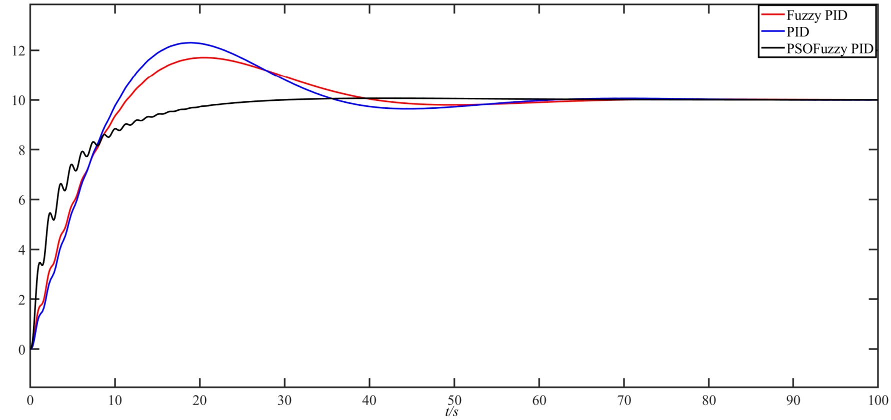

Fig. 10 Simulation comparison graph of the three control methods.

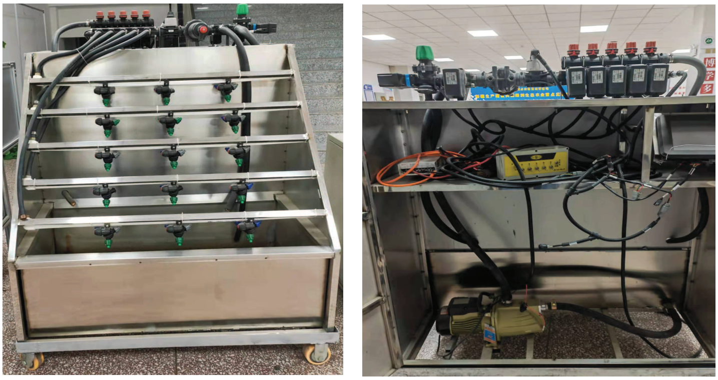

Fig. 11 Precision fertilization physical platform.

Accuracy is one of the significant indicators for evaluating variable control systems. By setting the target flow rate, i.e. the theoretical flow rate, the actual flow rate in actual operation is measured, thus verifying the operational accuracy of the liquid fertiliser variable control system. Five sets of different pressure values were set to quantify the fertiliser application system's fertiliser application accuracy under different control algorithms, five sets of actual flow data are measured and the average value was taken as the actual flow rate's measured value. The accuracy test diagram is as follows.

As is visible from the Fig.12- Fig. 14, three target spray volumes are set at different pressure levels, and the actual spray volumes were collected. At a theoretical fertilizer application volume of 20L, the PID control's accuracy ranged from 8.5% to 20%, the fuzzy PID control's accuracy ranged from 4.5% to 8.5%, and the accuracy of the fuzzy PID control based on PSO optimization ranged from 1% to 3.5%; at a theoretical flow rate of for a theoretical flow rate of 40L, the control accuracy of the three control algorithms that are ranged

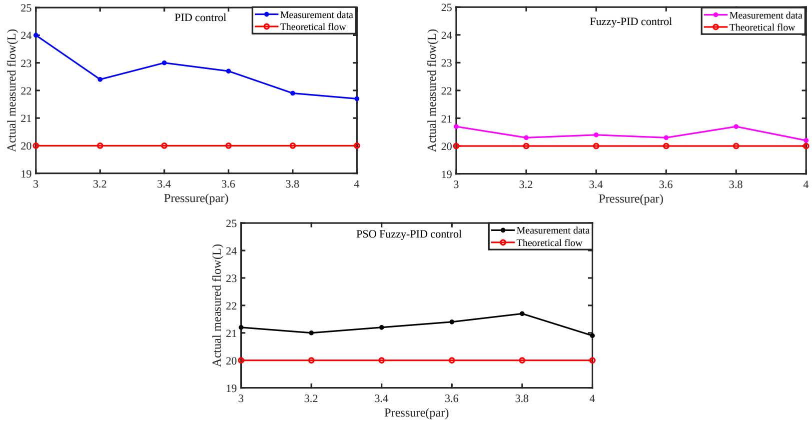

Fig. 12 Comparison of the accuracy of the three different controls at a pressure of 20 *par*.

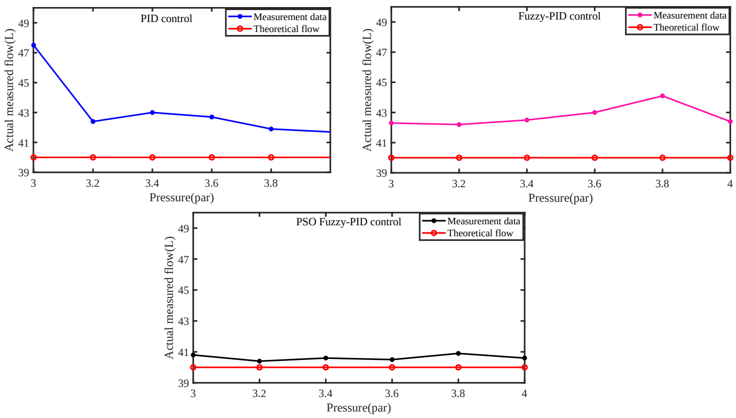

Fig. 13 Comparison of the accuracy of the three different controls at a pressure of 40 *par*.

from, respectively, 5.5%-10.25%, 1%-2.25% and 10%-18.75%; for a theoretical flow rate of 60L, the control accuracy of the three similarly control algorithms that are ranged from, respectively, 5.3%-8.3%, 1.25%-1.5% and 6.7%-16.7%. Regularity was not shown by the variation in accuracy at each pressure, but compared to fuzzy PID control and PID control, significant results is achieved by the control algorithms proposed in this study in flow rate's regulation at each pressure.

6 Conclusion

In this research, liquid fertilizer variable fertilizer control system's control accuracy is studied, a control model is constructed, and the liquid fertilizer flow control under traditional PID, fuzzy PID and fuzzy PID control based on PSO

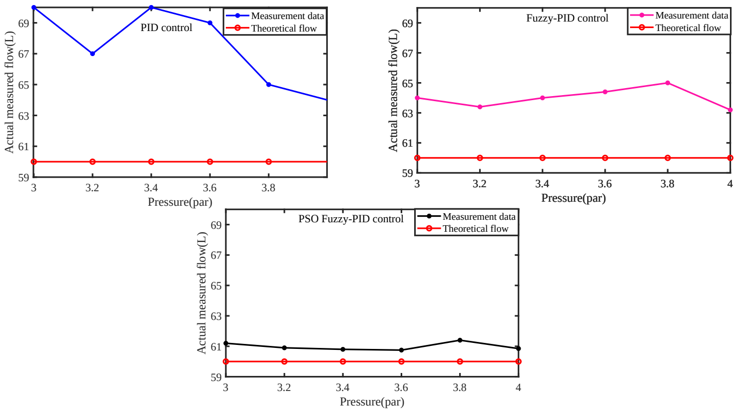

Fig. 14 Comparison of the accuracy of the three different controls at a pressure of 60 *par*.

algorithm is simulated and examined, and the following principal conclusions are obtained.

By constructing a mathematical model of the system, combined with MATLAB/Simulink system, PID control, fuzzy PID control and fuzzy PID control based on PSO optimization, the comparison consequences illustrate that PID control's response time is 80s with 23% overshoot, and fuzzy PID control division's response time is 60s with 17.1% overshoot, compared with the first two control algorithm, the regulation time is 30s and there is no overshoot. The stability and rapidity of the algorithm can be proven.

In order to verify the of algorithms, the research designs a fertiliser application accuracy examination, devising five fertiliser application tests under different pressure values, each group is brought in to verify the three algorithms in five measurements, and the average value is taken as the measurement data. The test outcomes reveal that PID control's fertiliser application accuracy is in adequate, causing an error of 20% and wasting water resources in practical applications; fuzzy PID control's accuracy fluctuates around 5%-10%, which is a certain improvement compared to PID control; the control algorithm proposed in this research possesses an accuracy of 3.5% apart from when the pressure is 4*par*, and is fundamentally controlled within 2%. It is concluded that the control method in this research can save water effectively in the fertiliser application process.

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