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Article

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Application of PID control based on bacterial foraging-particle swarm hybrid algorithm optimization in variable fertilization system

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Abstract

In the irrigation process and fertilization process of agricultural production, the accuracy of fertilizer application and water use is kept at a relatively low level, which leads to soil slumping and waste of resources. In order to solve the above problems, this study investigates the demand for fertilizer application accuracy in the field and builds a mathematical model of variable fertilizer application system. Considering a large number of defects of the system, such as poor fertilization accuracy, long response time, and unstable regulation process, combined with MATLAB/Simulink platform, this study designs a PID algorithm based on bacterial foraging-particle swarm hybrid algorithm to control the fertilization and irrigation process of the variable fertilizer applicator. The precise fertilization control of the variable fertilizer system is mainly studied and the fuzzy proportional integral differential gain parameters of the variable fertilizer system by the hybrid algorithm are optimized. By comparing with the control algorithms (proportional-integral differential control, fuzzy proportional-integral differential control, and proportional-integral differential control with particle swarm optimization) commonly applied in the current fertilizer application system, the comparison results demonstrate that the control algorithm in this paper has better regulation, smaller overshoot, excellent stability and more rising steady-state time deficit, which can realize the precise control of the fertilizer system. Finally, this study designed fertilizer application accuracy tests under different pressure values. The results show that the algorithm proposed in this study has high fertilizer application accuracy under different pressures, which greatly reduces the waste of resources in the process of fertilizer application for crop irrigation.

Keywords: Integration of water and fertilizer; Variable Fertilizer Application System; Fuzzy PID control; Particle swarm optimization algorithm; Bacterial foraging-particle swarm hybrid algorithm.

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.

Plenty of optimization algorithms have been proposed, such as the genetic algorithm, well-known neural network algorithm and ant colony algorithm. The optimization of parameter tuning principally includes two aspects to consider: the first is to seek the global minimum point, and the second is to require a excellent convergence speed. Genetic algorithm needs to carry the process of encoding out and decoding design, in some instances these are extremely difficult, not straightforward to parallel processing, the computation is extremely large. However, bacterial foraging-particle swarm optimization(BF-PSO) does not possess the complex ideas of coding and decoding crossover, variation and design process of genetic algorithm, no gradient information, faster operation efficiency, convenient implementation, swift convergence, etc.. PID control based on PSO rectification optimization is a more simple-minded and practical new rectification method, which greatly enhances the optimization level of the three parameters of PID, and performance index of the optimized control system is substantially sharpened, with tremendous potential value in the industrial field. Particle swarm algorithms' basic principle shows that particles update their position for a target by tracking their own local optimum and the global optimum of all particles. Therefore, we borrowed this idea and gave some sense of their environment to bacteria, and bacteria can similarly iterate by comparing their own historical optimum with the global optimum of all bacteria. Related research has demonstrated that particle swarm algorithms can find the local's approximate location optimum faster, thus speeding up the ability and speed of the bacterial foraging optimisation algorithm to find the optimum.

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 four control algorithms, PID, fuzzy PID, PSO fuzzy PID and BF-PSO PID, and the MATLAB software is applied 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, 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. The overall structure of the system is shown in Figure 1. And it comprises the following parts: DC Motor/Speed Reducer/Voltage Drive Module/Sensing 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.

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).

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

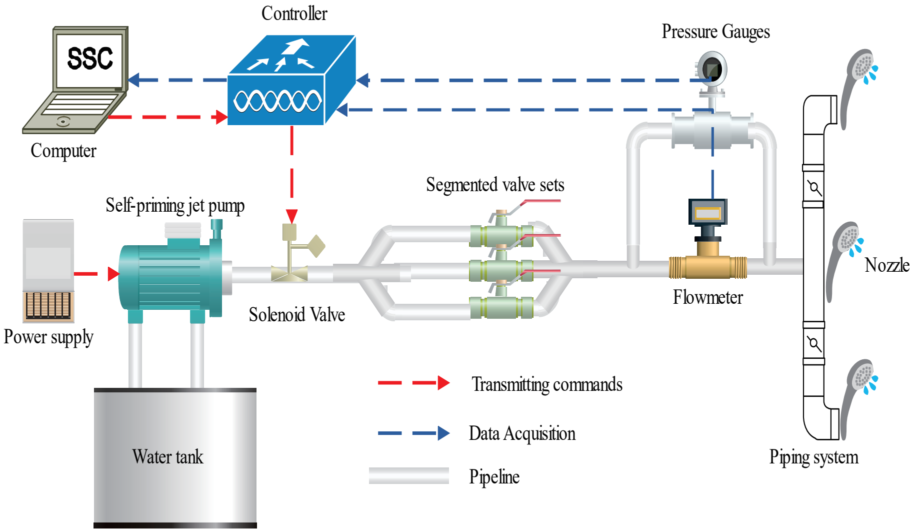

Fig. 1 Flow control diagram of variable fertilizer application system.

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 as follows.

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

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.

$$LJ\dddot{\theta}(t) + (Lf + RJ)\dot{\theta}(t) + Rf\ddot{\theta}(t) + K_mE_m(t) = K_mU(t) \tag{6}$$

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:

Table 1 Fuzzy rule tables based on PSO fuzzy control

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

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

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 system as:

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

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. The control structure diagram is shown in Figure 2. 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.

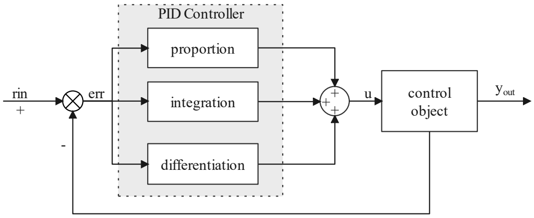

Fig. 2 Schematic diagram of PID controller.

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 Figure 3 as follows[26]-[30].

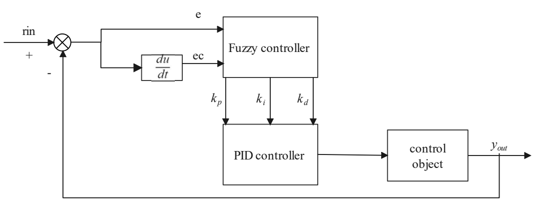

Fig. 3 Schematic diagram of Fuzzy PID controller.

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 Figure 4. The fuzzy surface diagram of the optimised parameters is shown in Figure 5 - Figure 7.

Table 2 Fuzzy rule tables based on PSO fuzzy control

		k_p, k_i, k_d					
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

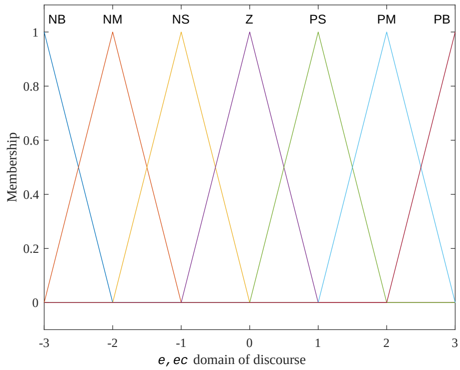

Fig. 4 Affiliation function of fuzzy input & fuzzy output.

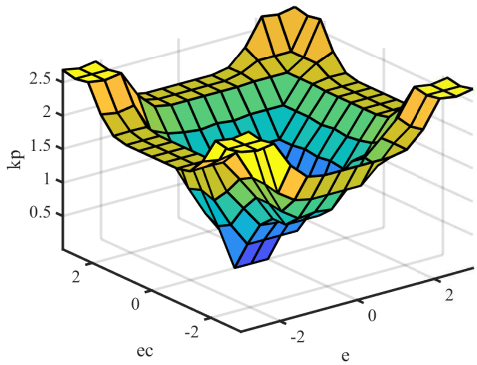

Fig. 5 Fuzzy surface diagram of k_p.

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 Figure 8.

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

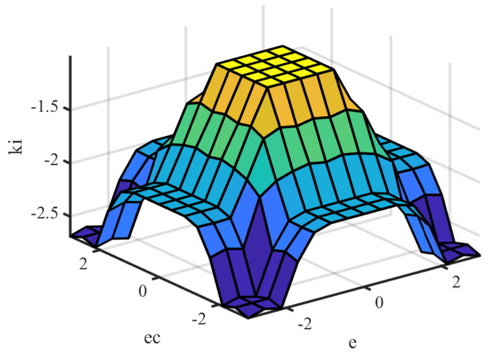

Fig. 6 Fuzzy surface diagram of k_i.

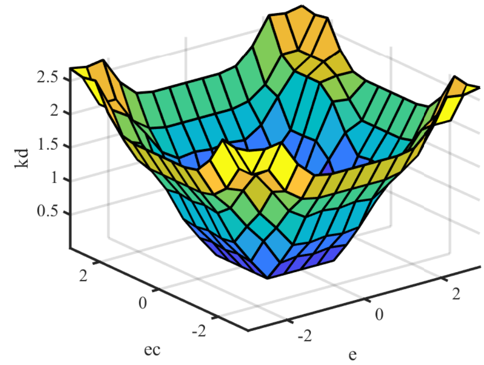

Fig. 7 Fuzzy surface diagram of k_d.

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

(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.

(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.

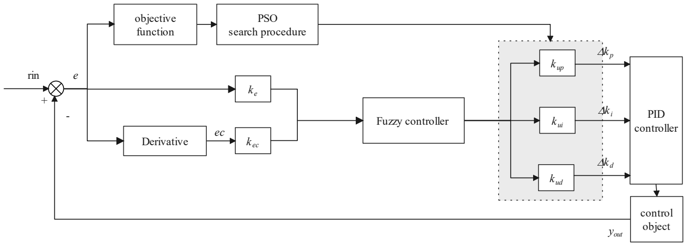

Fig. 8 Schematic diagram of fuzzy PID control based on PSO optimization.

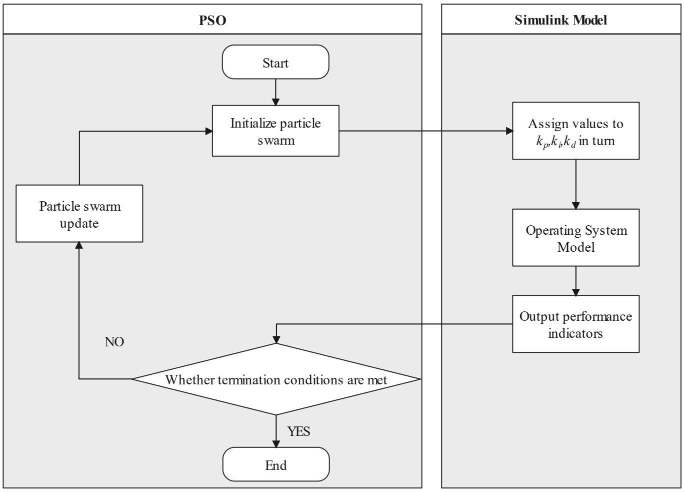

Fig. 9 Control flow chart of particle swarm algorithm.

3.3 Design of PID controller based on Bacterial foraging-particle swarm hybrid algorithm

Particle swarm algorithms' basic principle shows that particles update their position for a target by tracking their own local optimum and the global optimum of all particles. Therefore, we borrowed this idea and gave some sense of their environment to bacteria, and bacteria can similarly iterate by comparing their own historical optimum with the global optimum of all bacteria. Related research has demonstrated that particle swarm algorithms can find the local's approximate location optimum faster, thus speeding up the ability and speed of the bacterial foraging optimisation algorithm to find the optimum.

The most significant step in the bacterial foraging algorithm is the convergence operation. In practice, travel steps and larger variation converge faster and can easily jump out of the local optimum, but they also often cross the global optimum. Smaller travel steps conversely converge more slowly and can enter the local optimum region easily, but high accuracy is achievable, once the global optimum is found. We therefore introduce a particle swarm algorithm based on the bacterial foraging algorithm, which aims to provide directional guidance to the bacterial convergence operation. With this approach's help, poorly positioned bacteria can quickly gather in a better region, while the better bacteria themselves are in their neighbourhood for local search's next step.

The main steps of the algorithm can be described as follows.

(1) The number of bacterial sizes can be defined as s, the number of migrations is N_{ed}, the number of reproduction is N_{re}, the number of chemotaxis is N_c, the number of swims can be described as N_s and the probability of migration are parameterized within the design range of the variables.

(2) Random initialisation of bacterial positions, generating a random vector of unit steps in any direction for each bacterium.

(3) Particle swarm algorithm parameter design, setting the initial value of local extreme for each bacteria and the initial value of global extreme for all bacteria.

(4) Convergence cycle operation. For each bacteria update the position according to the flip, if the position is better, then swim forward.

(5) Update the local polar values of the individual bacteria and the global polar values of the bacterial swarm, the particle swarm algorithm to update the flip direction of the bacteria instead of an arbitrary direction.

(6) Reproduction operation. For a population of bacteria that has undergone a convergence cycle, each bacteria is ranked according to the cumulative sum of fitness, the half of the bacteria with poor fitness values are eliminated, and the same population of bacteria is split from the half with better fitness values, which inherits the position and characteristics of the parent bacteria.

(7) Migration operation. After a cycle of reproduction operations, it is possible for the bacteria to move towards local extremes. Here, each bacterium is migrated according to a certain migration probability, and a certain number of migrating bacteria is set in order to ensure the convergence of the algorithm.

In the setting of the program, the most dominant is the chemotaxis operation, followed by reproduction and finally migration. Therefore, the algorithm has a higher frequency of chemotaxis than reproduction, and a higher frequency of reproduction than migration. That is, a bacterium goes through many chemotaxis steps before it reproduces, and several generations of reproduction before it migrates once. The control flow diagram of the algorithm is as follows(Figure 10).

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 are analysed. The PID control model's simulation process is as follows: a step signal of amplitude 10 is input at $t = 0$, the

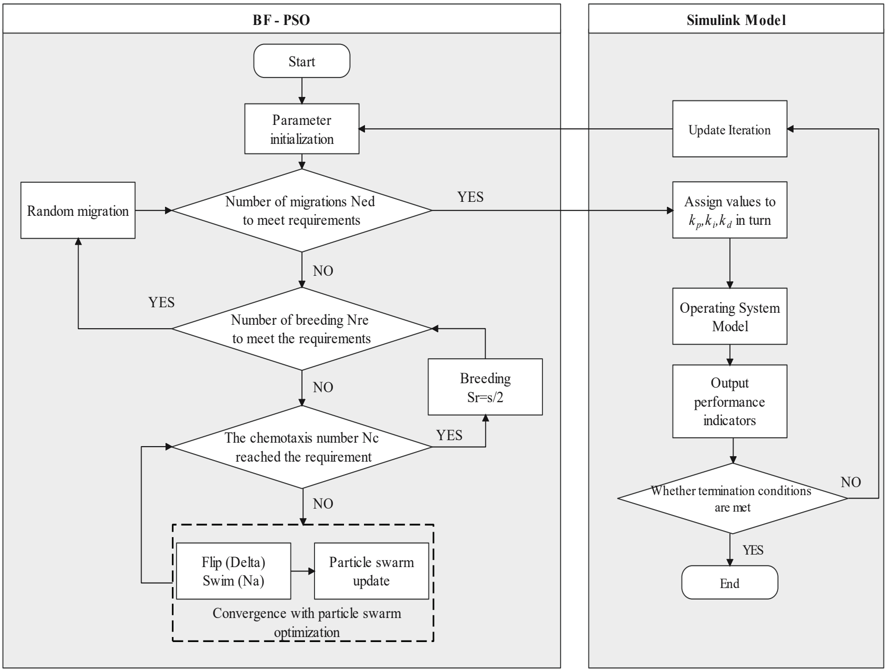

Fig. 10 Control flow chart of BF-PSO.

simulation time is set to 80 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.

As can be seen from the Figure 11, 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 80 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 model response time of the fuzzy PID control is 48.3 s, the overshoot is 0.169 and there is some oscillation before the system operation reaches stability. The model developed for the variable fertiliser control system is programmed with MATLAB software to implement PSO 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 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 iteration. As can be seen from the graph, the model response time for the particle swarm optimised fuzzy PID control is 36.3s with an overshoot of 0.075, which is a substantial reduction in overshoot compared to the other controls, with some oscillations before the system operation reaches stability. The control algorithm proposed in this paper introduces the characteristics of bacterial foraging algorithm on the basis of particle swarm algorithm with good performance index in all aspects and the overshoot is even 0.

Simulation examinations are carried out with the electric proportional valve opening transfer function as the control object, applying BF-PSO PID, 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.

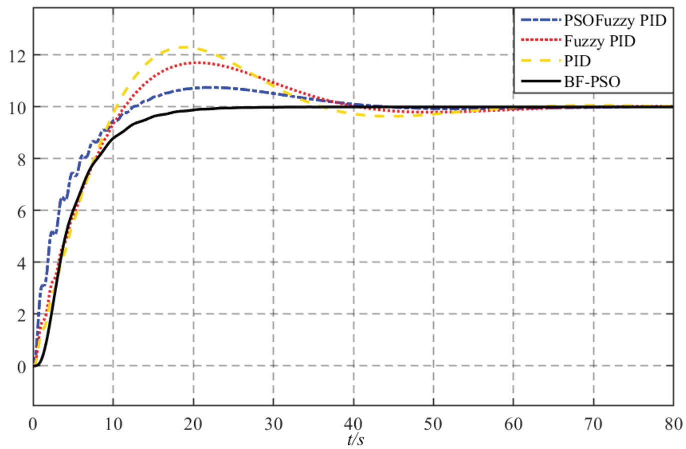

Fig. 11 Simulation comparison chart of different controls.

The table of performance index parameters for the different controls is shown in Table 3. It can be seen that the rise time of different controls is maintained at about 10s. Different control regulation times are: 51.4s/48.3s/36.6s/16.61s, which is a 68.2% reduction of the proposed control strategy compared to the traditional control algorithm. It is worth mentioning that, from the simulation results, the proposed control algorithm has no overshoot amount. It demonstrate that the BF-PSO control strategy can improve the performance of the variable fertilization system.

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 Figure 12.

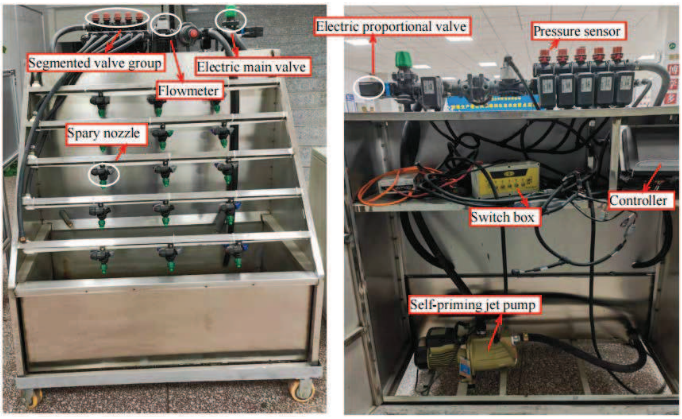

Fig. 12 Precision fertilization physical platform.

Accuracy is one of the significant indicators for evaluating variable control systems. The fertilizer applied in this research is a compound fertilizer with 15%, 13% and 9% nitrogen, phosphorus and potassium content respectively, which is dissolved into liquid fertilizer. The test program of the control system is applied to provide frequency conversion pulses during the experiment, and the stepper motor was controlled to drive the fertilizer discharge shaft to run

Table 3 Comparison table of performance parameters of different control algorithms

	PID control	Fuzzy-PID control	PSO Fuzzy-PID control	BF-PSO Fuzzy-PID control
Rise time(s)	8.9	9.0	9.1	10.21
Peak value	12.3	11.69	10.75	10
Adjustment time(s)	51.4	48.3	36.6	16.61
Overshoot(%)	23	16.9	7.5	0

at a specified speed. The required number of pulses per second was entered by the controller keypad to adjust the speed of the motor and read the data through a pressure gauge. The values of the pressure gauge are set separately as follows: $3par$, $3.2par$, $3.4par$, $3.6par$, $3.8par$, $4par$. In order to reduce the measurement error and ensure the accuracy of the experiment, the measurement should be started after the nozzle spraying is constant. In addition, the fertilizer applicator has 5 groups of nozzles, and in order to reduce the flow loss during the experiment, the test a kind of spray volume will finally expand the data by 5 times. as the measured value for this experiment. The performance of the different control algorithms was measured by comparing the measured values for different algorithms at different pressures given a theoretical fertilization volume. Each algorithm was tested in five groups for a given pressure value and theoretical flow rate, and the average value was taken as the actual fertilizer application volume for the experiment. The experimental raw data are shown in Figure13 - Figure15.

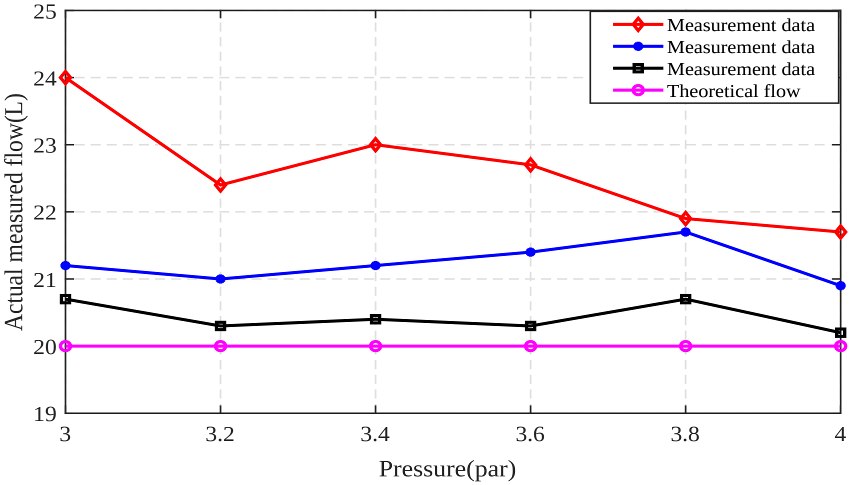

Fig. 13 Theoretical flow rate is 20 litersthe actual flow rate of different control comparison chart.

As is visible from the Figure 13 - Figure 15, 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 Fuzzy PID control's accuracy ranged from 8.5% to 20%, the fuzzy PID based on PSO control's accuracy ranged from 4.5% to 8.5%, and the accuracy of the PID control based on BF-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 are ranged 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

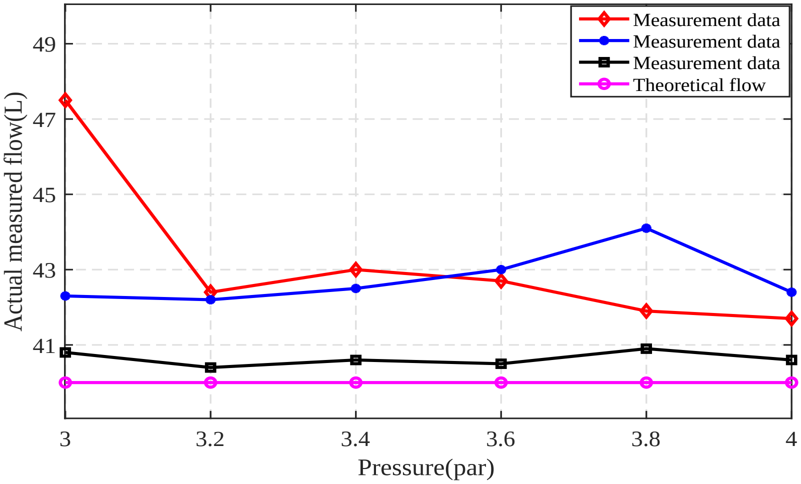

Fig. 14 Theoretical flow rate is 40 litersthe actual flow rate of different control comparison chart.

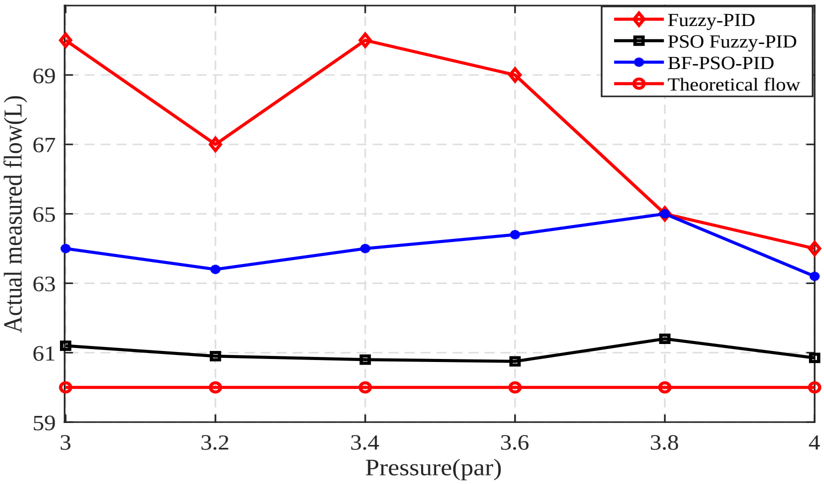

Fig. 15 Theoretical flow rate is 60 litersthe actual flow rate of different control comparison chart.

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 fuzzy PID based on PSO control, significant results is achieved by the control algorithms proposed in this study in flow rate's regulation at each pressure.

Finally, applying variance on the experimental data, the standard deviation of the liquid fertilizer flow rate measured each time can be expressed as.

$$D = \sqrt{\frac{\sum_{i=1}^{5} x_i^2 - n\bar{x}^2}{(n-1)}} \tag{16}$$

The coefficient of variation:$C_v = \frac{D}{\bar{x}}$. The standard deviations D for a given theoretical flow rate of 20 liters corresponding to different control algorithms were calculated to be 0.69, 0.82, and 0.94, respectively, indicating that the control algorithm proposed in this paper can meet better meet the performance requirements of the system.

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 fuzzy PID, fuzzy PID control based on PSO algorithm and proposed control is simulated and examined, and the following principal conclusions are obtained.

By constructing a mathematical model of the system, combined with MATLAB/Simulink system, fuzzy PID control, fuzzy PID control based on PSO optimization and proposed control, the comparison consequences illustrate that Fuzzy PID control's response time is 48.3s with 16.9% overshoot, and fuzzy PID based on PSO control division's response time is 21.3s with 7.5% overshoot, compared with the first two control algorithm, the regulation time is 16.61s 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 $4par$, 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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References

[1] Rezayati, Samaneh, Khaledan, Mohammadreza, Razavipour, Teymour, et al. Water flow and nitrate transfer simulations in rice cultivation under

different irrigation and nitrogen fertilizer application managements by HYDRUS-2D model[J]. Irrigation Science, 38(4), (2020),353-363.

[2] Srivastav A L , R Dhyani, Ranjan M, et al. Climate-resilient strategies for sustainable management of water resources and agriculture[J]. Environmental Science and Pollution Research, (2021),1-4.

[3] Schattman R E, Niles M T, Aitken H M. Water use governance in a temperate region: Implications for agricultural climate change adaptation in the Northeastern United States[J]. Ambio, 50(4), (2021),942-955.

[4] Li D, Tian P, Luo Y, et al. Importance of stopping groundwater irrigation for balancing agriculture and wetland ecosystem[J]. Ecological Indicators, 127(1), (2021),107-121.

[5] Wl A, Fan H, Fsb C, et al. Human and climatic drivers of land and water use from 1997 to 2019 in Tarim River basin, China[J]. International Soil and Water Conservation Research, (2021),45-56.

[6] Sathre R . Technologies to enhance sustainable groundwater use[J]. Global Groundwater, 13(7),(2021),17-26.

[7] Maroli A A, Narwane V S, Raut R D, et al. Framework for the implementation of an Internet of Things (IoT)-based water distribution and management system[J]. Clean Technologies and Environmental Policy, 23(1), (2021),271-283.

[8] Huang W, Lu M, Liang X, et al. Design and Application of Water, Fertilizer and Pesticide Integrated Automatic Control Device[J]. Plant Diseases and Pests, 11(1), (2020),3.

[9] Zhang B, Li J, Cai X, et al. Research on Integrated Control System of Water and Fertilizer Based on Cloud Computing[J]. Journal of Agricultural Mechanization Research, 12(3), (2020), 17-26.

[10] Wu Y, Li L, Li S, et al. Optimal control algorithm of fertigation system in greenhouse based on EC model[J], 12(3), (2019), 8-12.

[11] Takeuchi H, Fujiwara S . Simple and direct estimation method for split-off hole effective mass from FranzCKeldysh oscillations appearing in photoreflectance spectra: a feasibility study using GaAs epitaxial layer structures at room temperature[J]. Semiconductor Science and Technology, 36(10), (2021),7-13.

[12] Zhan Y, Hu J, Ren Z. Design of Orchard Water and Fertilizer Integration Control System Based on PLC[J]. Journal of Agricultural Mechanization Research, 13(4), (2020), 6-15.

[13] Lv T, Wang L, Hao Y, et al. Research on pH control strategy of water and fertilizer integration based on fuzzy control[J]. Journal of Chinese Agricultural Mechanization, 15(7), (2019), 7-14.

[14] H Feng, Ma W, Yin C, et al. Trajectory control of electro-hydraulic position servo system using improved PSO-PID controller[J]. Automation in Construction, 127(7), (2021), 115-124.

[15] Yakout A, Sabry W, Hasanien H M. Enhancing rotor angle stability of power systems using marine predator algorithm based cascaded PID control[J]. Ain Shams Engineering Journal,15(2),(2021),89-92.

[16] Phu N D, Hung N N, Ahmadian A, et al. A New Fuzzy PID Control System Based on Fuzzy PID Controller and Fuzzy Control Process[J]. International Journal of Fuzzy Systems, 15(9), 2020, 17-24.

[17] Wang Z, Yi G, Zhang S. An Improved Fuzzy PID Control Method Considering Hydrogen Fuel Cell Voltage-Output Characteristics for a Hydrogen Vehicle Power System[J]. Energies, 3(2), (2021), 14-28.

[18] Tong W, Zhao T, Duan Q, et al. Non-singleton interval type-2 fuzzy PID control for high precision electro-optical tracking system[J]. ISA Transactions, 2(7), (2021),6-20.

[19] Liu Y, Fan K, Ouyang Q. Intelligent Traction Control Method Based on Model Predictive Fuzzy PID Control and Online Optimization for Permanent Magnetic Maglev Trains[J]. IEEE Access, 1(1), 2021,99-106.

[20] Zeng, W, et al. "Core power control of a space nuclear reactor based on a nonlinear model and fuzzy-PID controller." Progress in Nuclear Energy 132(2), (2021),103-108.

[21] Mitra P, Dey C, Mudi R K. Fuzzy rule-based set point weighting for fuzzy PID controller[J]. SN Applied Sciences, 3(6), (2021), 20-31.

[22] Rhouma A, Hafsi S, Laabidi K. Stabilizing and Robust Fractional PID Controller Synthesis for Uncertain First-Order plus Time-Delay Systems[J]. Mathematical Problems in Engineering, 4(6), (2021), 103-112.

[23] [1] Parlakci M, Jafarov E M. A robust delay-dependent guaranteed cost PID multivariable output feedback controller design for time-varying delayed systems: an LMI optimization approach[J]. European Journal of Control, 21(1), (2021), 20-31.

[24] Lamba R, Sondhi S, Singla S K. Reduced order model based FOPID controller design for power control in Pressurized Heavy Water Reactor with specific gain Cphase margin[J]. Progress in Nuclear Energy, 125(2),

2020, 24-30.

[25] N Rouis, N ’Doye I, Laleg-Kirati T M. Model-free LQR based PID controller for trajectory tracking of 2-DoF helicopter: comparison and experimental results[J]. 7(12), (2021), 10-21.

[26] Mitra P, Dey C, Mudi R K. Fuzzy rule-based set point weighting for fuzzy PID controller[J]. SN Applied Sciences, 3(6), (2021), 20-29.

[27] Yang R, Liu Y, Yu Y, et al. Hybrid improved particle swarm optimization-cuckoo search optimized fuzzy PID controller for micro gas turbine[J]. Energy Reports, 7(1), 2021, 5446-5454.

[28] Chen G, Li Z, Zhang Z, et al. An Improved ACO Algorithm Optimized Fuzzy PID Controller for Load Frequency Control in Multi Area Interconnected Power Systems[J]. IEEE Access, 8(2), (2020),6429-6447.

[29] Siddharthan N, Balasubramanian B. Performance analysis of fuzzy logic controlled triple lift configured zeta converter cascaded with inverter fed PMBLDC drive[J]. Materials Today: Proceedings, 3(12), (2021), 56-70.

[30] Wang Y, Wang L, Li G, et al. Grey Prediction Fuzzy PID Control Method for Volume Flow of Cotton Picker[J]. Journal of Agricultural Mechanization Research, 3(1), (2020), 17-24.