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The Intelligent Control Strategy and Verification for Precise Water-fertilizer Irrigation System

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***Abstract*—Aim at the precision control problems of water and fertilizer concentration during agricultural fertilization and irrigation periods, designing a control technology that based on PID control technology, the application of conductivity value and pH value to develop precise water and fertilizer irrigation control system. The thesis also performed theoretical analysis and experiment of digital PID control of EC value, the results indicated that the PID control system has the advantages of high control precision, but the control performance is degradation when the fertilizer density changes greatly. The intelligent PID controller with EC value was designed by using open-loop step response, PID control technology and inaccurate-control technology. The test results show that it has PID parameter self-controlling ability, good control performance, the stable time within 3 minutes, precision degree is within ±0.15mS/cm, overshoot less than 15%. The improved intelligent PID controller control the pH value, through using open-loop step control and PID control, the test shows that the stability time within 3 minutes, the accuracy is within ± 0.15pH, overshoot less than 15%. Combine fuzzy PID with grey prediction, the grey prediction - Fuzzy PID control of water and fertilizer concentration was developed, which has a fastest corresponding speed and better control stability. It owns a good control effective and have a better control quality**

Keywords—water-fertilizer irrigation, grey-fuzzy PID control, intelligent control strategy, precise irrigation, concentration detection

I. Introduction

The irrigation and fertilization, it also be called water and fertilizer irrigation, with the process of the water irrigation, refers the fertilizer through the irrigation system with the water for the crop and provide nutrients, it is, according to the needs of nutrients and climatic conditions of the crop growth at all stages such as fertilizer put on and even applied in the vicinity of the root system, it would be directly absorbed and applied of the roots system [1]. It means turning the soluble fertilizer into the preparation of the solution according to a certain proportion, and through the fertilizer device to the fertilizer solution into the drip irrigation system with irrigation water transported to all the drip emitter, an advanced fertilization method during the process of crop fertilization. It is a combine production between the fertilization techniques and irrigation techniques [2-3]. The irrigation and fertilization is an effective method for quantitative supply of crop water and nutrients and maintaining soil suitable water and nutrient density. In the advanced country with the agricultural technology, for instance Israel, 75% to 80% of the irrigated land was applied in irrigated and fertilized. This method was not only applied in the field of fertilization, but also for the greenhouse substrate soil-less cultivation of crop fertilization. The fertilizer utilization is full due to accurate and uniform fertilization around the root and according to the characteristics of crop fertilizer need. It could be saved the amount of fertilizer and control the depth of fertilizer infiltration to reduce the pollution of fertilization on the environment by the water-fertilizer irrigation; it also adjust the water-infiltration speed rate, well-distributed irrigation, it would not produce the ground light flow and reduce soil compaction, reduce soil surface evaporation and leakage loss ,made the utilization rate of irrigation water reach more than 90%[4-5], it has been saved 21% of irrigation water and 34% of the production fertilizer.

It has many researches of the water and fertilizer integration technology in China, but the technical promotion stayed at the initial stage and simple, it has not popularized the water and fertilizer integration equipment application, it still in the complex water-soluble fertilizer with the original stage of the application of fertilizer, lack the theoretical guidance of water and fertilizer coupling [6]. The equipment key technology subject in the controller control strategy, on one hand, it needs to control the amount of water which crops need, on the other hand, to obtain the maximum net income with the least amount of water. However, the control object is a big inertia, nonlinear and pure delay system, a precise and unified mathematical model could not be established, the traditional control method has been faced a serious challenge, the inaccurate control couldn't need to establish the mathematical model of the controlled object, to improve its nonlinear and time-varying problems effectively [7]. Combined the control effect of PID controller with inaccurate-control to improve its nonlinear control effect in the paper, it can overcome the above difficulties. The effect of water-fertilizer irrigation control strategy by simulation analysis and tests was verified in the paper.

II. The Design of Control System for Precision Water and Fertilizer Irrigation

For integrating with the control of water and fertilizer, the extensive and in-depth research has been conducted around the domestic and foreign scholars. Currently, the nutrient solution regulation could be divided into three categories: the nutrient solution in view of the EC value and pH value, the nutrient solution model that based on the nutrient control methods and the nutrient solution based on crop model [8-16], first control mode based on EC value and pH mode was researched in the paper. In order to meet of growth crops in a timely manner the different stages to adjust the proportion of water and fertilizer, supply amount and supply time, the system can realize real-time detection according to the user set fertilizer value EC value and pH value to conduct the automatic constant irrigation and fertilization, to achieve the purpose of high quality and high yield. The specific control system of water-fertilizer irrigation was composed of electrical control part, main water pipeline system, and sensor and injection pipe system, the system frame diagram shown as Fig.1.

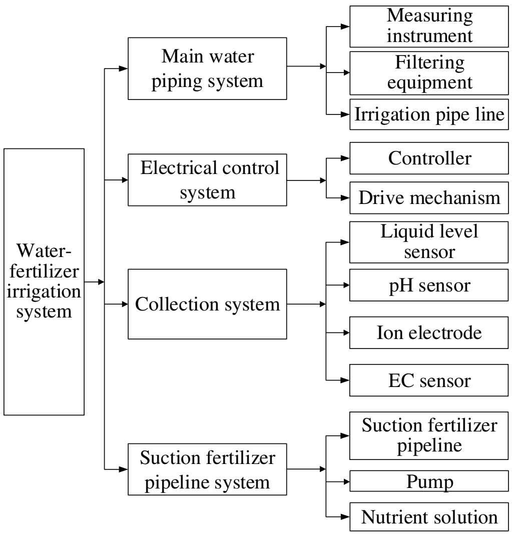

Fig. 1. Diagram of water-fertilizer irrigation control system

The main water pipeline system of water-fertilizer irrigation system is mainly composed of filter, pressure gauge, flow meter, exhaust valve, check valve, pressure regulator and other components, mainly applicate to obtain the required pressure and flow system to protect the drip water and emitter. The fertilizer pipe just has the selected-machinery diaphragm pump for the system fertilizer injection equipment, furthermore, the configuration of the pressure gauge and flow meter. Electric Conductivity (EC) sensor and pH sensor (pH) the measuring tube of the sensor is drawn from the main water pipe with the thin tube and the lead-out point was set in front of the filter, formed the real-time detection circuits. The electrical control is composed of PLC controller and transmission mechanism. The controller was embedded algorithm and model by MBD technology, which mainly used for operation and display, and executed the user's commands. The transmission mechanism adopts the AC variable frequency drive mode, to complete the water-fertilizer irrigation system goals by the steeples speed control is conducted by the AC motor.

III. THE SYSTEM FUZZY PID CONTROL TECHNOLOGY

A. *The fuzzy PID control principle of fertilizer density*

The fertilizer density control is the core control block of this system. It is mainly completed the control parameters of the conductivity parameters and pH value. The control frame diagram is shown as Fig.2.

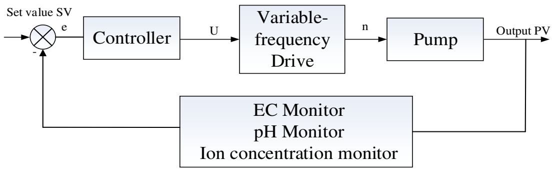

Fig. 2. Principle diagram for fertilizer concentration of PID control

The mixed fertilizer was measured by EC sensor and pH sensor from Fig.2,then the current signal was amplified and 4~20mA output , transmitter to the AD circuit into a digital signal, the control unit compare with the set value SV, after the processing of the deviation value e, the controller converts the control signal to the 4~20mA signal by the DA module, and transmits the control signal to the frequency converter, to achieve the EC value and pH constant control by the rotational speed n controls of the AC motor through the inverter.

B. *Control strategy of EC value*

The static gain K of the fertilizer solution was test by the open-loop step response application, and K is used as an adaptive factor of the intelligent PID controller, the control frame diagram shown in Fig.3.

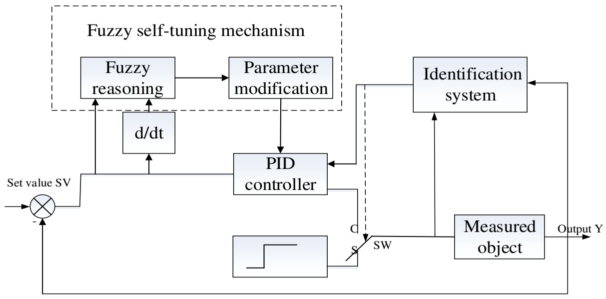

Fig. 3. Block diagram of fuzzy self-tuning PID control

Two kinds of working modes existed in the controller, identification mode and control mode. When system was started the work in every time, firstly, the identification mode was entered, the switch SW and S was connected, the input u0 of object by the step ran into the open loop state, identify the link test open loop response data automatically and identify the object by type 5 of the parameter K, and it as a PID control of an adaptive factor processing, and as to achieve automatic control PID control. After the identification is finished, the switch SW was switched from S to C, and the system switches from the identification mode into the control mode. The PID parameters in the regulation are judged by the fuzzy rules, which are advantageous to implement different control intensity for different error ranges and make up for the shortcomings of the pure PID control algorithm itself in static and dynamic performance, tracking set value and the suppress distribution [17].

The advantage of this method is lie in the identification mode, as the control is could not be conducted, it avoid the affection during the pipeline exhaust air lag time on the control performance when the pump open, the pure control is often processed is not well at this point would bring the large fluctuations, resulting in control failure, especially for the PID control algorithm; in addition, this method to test the object parameters, will not cause adverse effects on the system, the test process is an open-loop control process, a full step response process of the system would finished the parameters of the test, a good expression ideal of the open loop test, and the closed loop control. At the same time this method as long as the object to know the approximate time scale can be carried out, it could be identified according to the object parameters to decide the control mode sampling frequency.

While the input signal r (t) is a step-stage signal, the input signal would be used as the test excitation signal u0 (t) = r (t) directly, which means provide corresponds to an initial control to the system, then the system switches from the identification phase to In the control phase, there is no large distribution, especially when the static gain of the object is close to 1, it almost switching can be achieved without disturbance. So, the controller belong to the range of intelligent controller for a self-adjusting function, refers to the control strategy for the intelligent PID controller in this paper.

C. *The control strategy for pH value*

As for maintain the constant state of acid density in pH control, the PID controller with open-loop step control is designed in this paper , which is referred to as improved PID controller, and the diagram 4 is shown in Fig4. The self-identification structure is the same as the EC intelligent PID controller's self-identification structure basically. The difference is that the self-identifying structure in this controller is only used to determine whether the acid injection pipe is filled with piping, match with the open-loop control time. The switch SW was controlled through PV and the initial value PV(0) , and can complete the switch between the PID control and step-stage control.

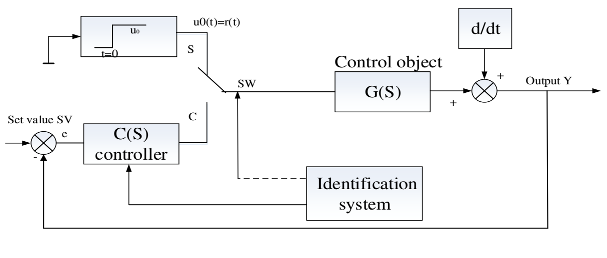

Fig. 4. Block diagram of improved PID controller

The solid line is the object step-stage response curve of the EC value in Fig.5, compared with the dotted line from Figure (a), and it is similar to the pure delay of industrial objects, therefore, the system is nonlinear, inertia. The Fig 2 showed the general estimate of T, τ, and K.

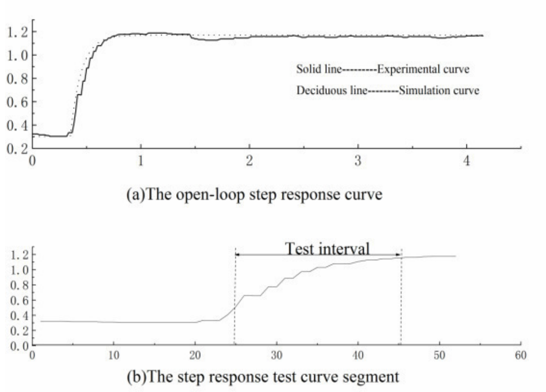

Fig. 5. EC value open-loop step response curve

IV. THE OPEN-LOOP STEP-STAGE RESPONSE OF PH VALUE

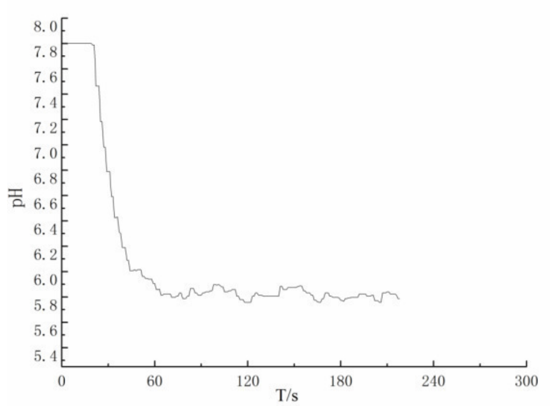

Fig. 6. pH value open-loop step response curve

The Fig.6 is the open-loop step-stage response curve for pH value. It show that the pH adjustment is a negative mode and a single self-balancing system, meanwhile, it can achieve stability for the object open-loop step response of the pH value about 60s, because of the acid pump and fertilizer pump is diaphragm pumps, and injection pipe and filling the same length of the pipeline. It can be known that the time length of open-loop control in the control strategy of pH single factor should be less than 60s, and the time should be relaxed when EC /pH value is adjusted, and it should be within 100s. Otherwise, it would be alarmed, checked the valve and pipe.

A. *The PID Control Test*

a) The sampling cycle test of EC controller： It can be seen that the sampling cycle is approximately in the range of (7s, 15s) from the open-loop step-stage response, and it show that the impacted curve of the PID controller control performance in different sampling cycles in the Fig.7.

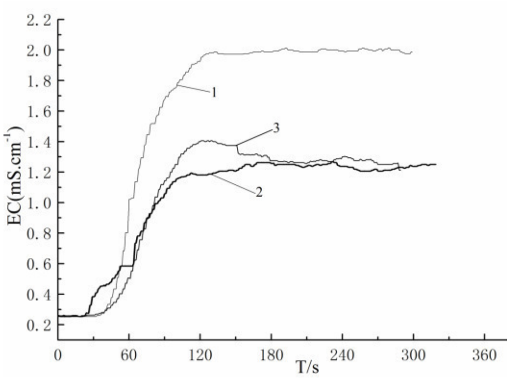

Fig. 7. Response curves of different sampling period EC value (1-5s; 2-10s; 3-15s)

Firstly, the scene PID parameter tuning was completed, the same fertilizer density (keep the static gain K consistent), set different sampling cycle for the experiment. As it could be seen from Fig.8 that the control cycle within 5s, 10s and 15s, and had control effect roughly the same, furthermore, cycle 5s seems better. So, the EC controller sampling cycle to select 5s.

b) The PID controller adaptability test: The comparison curve of the PID controller adaptability test result showed in Fig.8. It can seen that the PID controller parameter setting is low in the fertilizer density(fertilizer density 1) under the circumstances. Fertilizer density 1 has a better control performance as shown in Fig.8 left the curve 1, the overshoot is less than 10%, no oscillation. From the right side of Fig.9, it could be seen that the response curve 1 is also relatively gentle. However, the relatively high concentration of fertilizer was controlled by this controller, the control performance is greatly deteriorated, the left curve 2 of Fig.8 showed that the overshoot reached about 70%, the amplitude is about 0.8mS/cm, the oscillation cycle is long about 5 minutes before the basic stability. As it could be seen from curve 2 in Fig.8, the change in EC value lag control is about 30 seconds, so, it is a big inertia in the system.

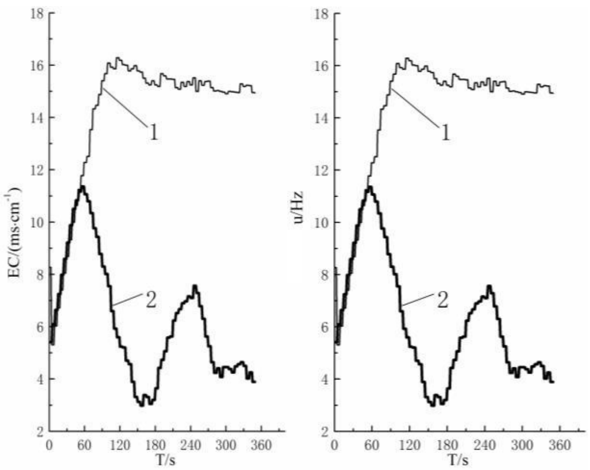

Fig. 8. Adaptive test of PID controller

B. 3.2 *The control performance test of the EC value and pH value*

The nutrient solution control performance is the control quality of the EC/pH value from the drip effluent, therefore it could not look at the control of control quality only, and it needs to test the droplet fertilizer density to verify the system controller control quality in the different time. The experimental method is the normal operation of the system controller at the beginning of the drip interval 30s with a measuring cylinder for 10s after the instrument measurement. It can be seen that EC value and pH value control performance curve for the system nutrient solution and the test amount curve during the changing in the Fig.9.

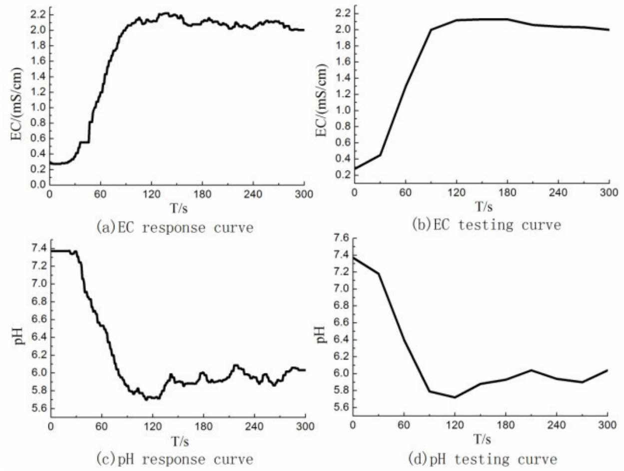

Fig. 9. System control performance test

It could be seen that the EC and pH value change curve are little difference at the drip place from the control curve of the EC value and pH value of the system controller, and the changed curve of the drip is slow and gentle, due of the average value of the measured value. Therefore it could be considered the control quality of the controller could be applied as the quality of nutrient control performance basically.

C. *Application of precision water and fertilizer irrigation equipment*

The research on the control strategy of water and fertilizer irrigation system is the core of the development of intelligent controller, and it is the requirement of further water and fertilizer irrigation. The precision water-fertilizer irrigation equipment can detect fertilizer concentrations, it also has the functions of irrigation control and environmental control. Its structure consists of touch screen, main control module, wireless transmission module, EC and pH measurement module and drive control module, the wireless transmission module including 433MHz wireless transmission, 4G wireless transmission, WIFI wireless transmission, SMS alarm. The driving control module was divided into three parts, fertilizer-liquid ratio drive, environmental control drive and irrigation control drive. It has equipment man-machine interface, mobile phone APP and PC irrigation control system for the operating platform. The equipment was applied for the glass greenhouse "Yong sweet 5" melon in Ningbo Agricultural Science and Technology Demonstration Garden, and the experiments of water-fertilizer irrigation were conducted about 96 days of autumn planting.

V. FUZZY PID FOR WATER AND FERTILIZER CONTROL TECHNOLOGY BASED ON GREY PREDICTION

Furthermore, in order to improve the control accuracy of water and fertilizer concentration during agricultural fertilization and irrigation periods. Grey prediction technique is used in Fuzzy PID and got a better control effect.

A. Water and fertilizer irrigation control algorithm model for grey prediction Fuzzy PID

For Fuzzy Control, which can improve the control effect of nonlinear and large inertia systems in Water and fertilizer irrigation.

And Grey prediction, it can solve the phenomenon of large time lag and can get the control beforehand for fertilizer concentration.

Control schematic of Fuzzy PID for water and fertilizer control technology based on Grey Prediction is following:

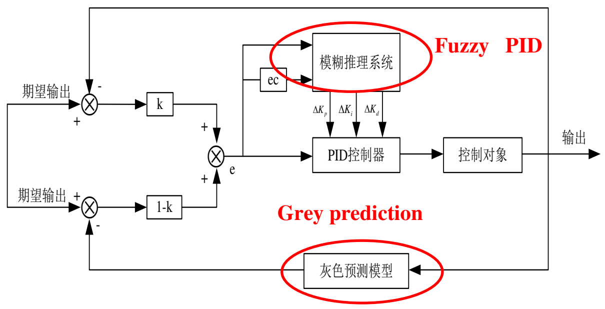

Fig. 10. Control schematic of grey prediction - Fuzzy PID

Grey Prediction - Fuzzy PID Model for water and fertilizer control technology is as follows:

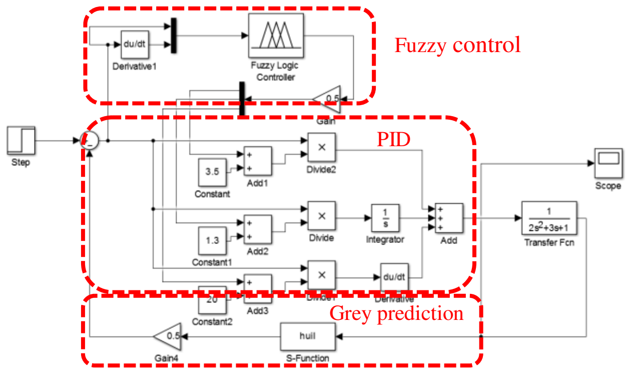

Fig. 11. The model of grey prediction - Fuzzy PID

Based on above model of Grey Prediction - Fuzzy PID for water and fertilizer control. Through SIMULINK Simulation of Grey Theory and Fuzzy Control for water and fertilizer control. The results are shown in Fig.12.

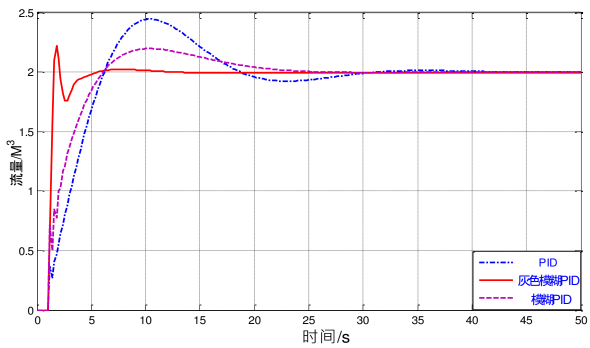

Fig. 12. SIMULINK Simulation of grey prediction - Fuzzy PID controy

It can be found that grey prediction - Fuzzy PID control system has a smooth response curve, small overshoot and good stability compared with PID and fuzzy PID.

B. Research on experiment for the grey prediction - Fuzzy PID control of water and fertilizer control technology

Using above experimental test device, the experiment for the grey prediction - Fuzzy PID control of water and fertilizer concentration was conducted. The control curves are shown in fig.13.

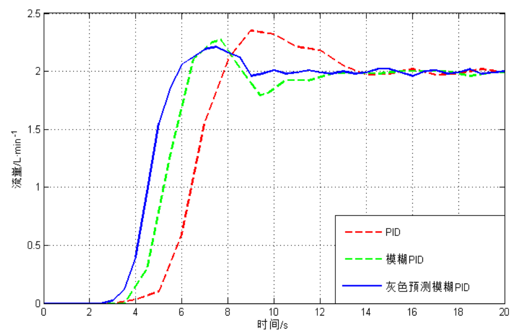

Fig. 13. Experiment results of grey prediction - Fuzzy PID controy

In which, grey prediction - Fuzzy PID control of water and fertilizer concentration has a fastest corresponding speed and better control stability.

Table 1 Experimental performance index

	Delay t_d (S)	Rise t_r (S)	Peak t_p (S)	Overshoot σ %	Adjustment t_s (S)	Steady-state error e_{ss}
PID	3.493	5.302	12.5	25.59	33.5	0.0004
Fuzzy PID	2.0142	3.698	10.4	9.82	20.1	0
Grey-Fuzzy PID	1.2787	0.424	1.8	10.91	4.48	0.0002

From above Experimental performance index, it can be seen that the flow value of water-fertilizer in 0-3 s is zero, and the flow sensor range is 1-30 L/min. The reliability of data below 1 L/min is not high. Under Grey Prediction -

Fuzzy PID, the control basically reaches a steady state at 8.5 s. Compared with that the fuzzy PID and PID are basically stable to 12.5 s and 13.5 s, respectively.

VI. CONCLUSIONS

The system control strategy has been further discussed in the paper, the intelligent irrigation control technology has been researched based on the fuzzy PID control, The research shows that the system had a stronger adaptability, a good control performance and robustness.

Firstly, it is an effective solution to solve the problem of water-saving irrigation uncertainty model according to the PID control, and it can solve the problem of large inertia and nonlinearity of the system by the fuzzy PID successfully.

Secondly, the intelligent PID controller integrated applied the open-loop step-stage response and the PID integrated style parameter setting method, the one-dimensional fuzzy control technology, it has been introduced to speed up the response and suppress the overshoot. The control performance of the different liquid concentration is reaching the PID control for good performance of the work basically; it shows that it has been the ability for PID parameters self-tuning.

Thirdly, combine fuzzy PID with grey prediction, the grey prediction - Fuzzy PID control of water and fertilizer concentration was developed, which has a fastest corresponding speed and better control stability. It owns a good control effective and have a better control quality.

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