

Design of Field Drip Irrigation Control System Based on Fuzzy Control

Wei Li¹, Yuyan Zhang^{1*}, Huashuo Yu¹, Ze Wu¹

¹ School of Automation, Shenyang Institute of Engineering, Shenyang, China

Email Address

799826578@qq.com (Yuyan Zhang)

*Correspondence: 799826578@qq.com

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Abstract:

With the continuous development of modern agricultural technology, drip irrigation technology has been widely used in agricultural production, and fertilization as an indispensable part of drip irrigation technology, how to accurately control the ratio of water and fertilizer and fertilization time of drip irrigation fertilization has become a big problem in agricultural production. This paper proposes a control system for PLC drip irrigation based on fuzzy control. The system adopts the PLC as the core control, through the sensor sensing parameters such as soil humidity and temperature, using fuzzy control set base tank solenoid valve and acid tank solenoid valve opening time for the ratio of water, through irrigation solenoid valve, fertilization battery valve control irrigation and fertilization time, so as to realize the precise control of drip irrigation system. The simulation results show that the system has the advantages of simple operation, easy maintenance and high stability, and can effectively improve the efficiency and accuracy of drip irrigation fertilization.

Keywords:

PLC, Drip Irrigation And Fertilization, Fuzzy Controller, Configuration Picture

1. Introduction

With the increase in global population and resource scarcity, improving agricultural efficiency and quality has become particularly important. Drip irrigation technology, as an important component of modern agriculture, has played a crucial role in improving crop yield and quality due to its water-saving, efficient, and reduced land loss characteristics. However, the traditional drip irrigation fertilization method relies on manual operation, which not only requires high labor intensity, but also makes it difficult to accurately control the amount and time of fertilization, which can easily lead to resource waste. Therefore, developing an automated drip irrigation fertilization control system to improve fertilization accuracy and efficiency is of great significance for promoting modern agricultural progress.

This article proposes a design scheme for a PLC drip irrigation and fertilization control system based on fuzzy control. The system uses PLC as the control core, combined with sensor technology to monitor soil moisture, temperature and other parameters. Fuzzy control is used to set the opening time of the mother liquor tank

solenoid valve and acid tank solenoid valve for water and fertilizer ratio. Then, irrigation solenoid valve and fertilization battery valve are used to control irrigation and fertilization time, improving the efficiency and accuracy of drip irrigation and fertilization, thereby providing support for modern agricultural development and enhancing the economic and social benefits of agricultural production.

2. Materials and Methods

2.1. Drip Irrigation System Control Requirements

Figure 1 shows a schematic diagram of the control process for drip irrigation systems. The control requirements are as follows:

- (1) Analog quantity collection and monitoring. Including the pressure of the mother liquor tank and acid liquor tank, pipeline flow rate, water and fertilizer concentration and pH in the mixing tank, tank liquid level, soil moisture, environmental temperature, etc;
- (2) Monitoring and remote control of the status of various control equipment;
- (3) Multiple control methods and switching. The control methods include independent irrigation, independent fertilization, and simultaneous irrigation and fertilization.

The mother liquor solenoid valve and acid liquor solenoid valve control the water and fertilizer ratio, the irrigation solenoid valve controls irrigation, and the fertilization battery valve controls fertilization.

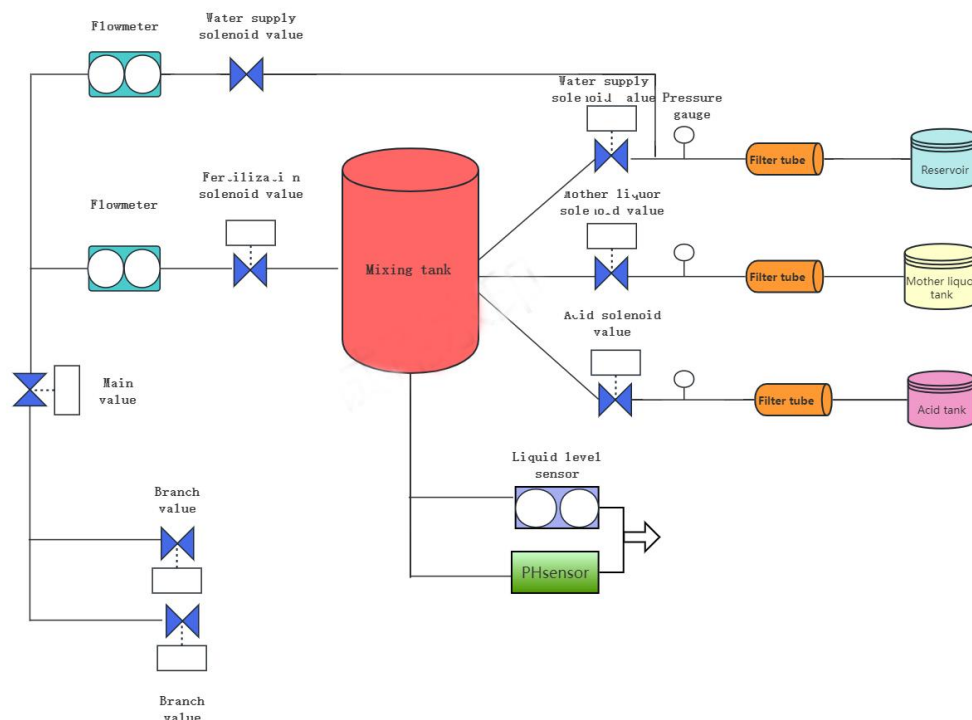


Figure 1. Schematic diagram of drip irrigation system control process.

2.2. Overall design of drip irrigation control system

According to the control requirements, the system requires 7 AI points, 22 DI points, and 18 DO points. Select Siemens S7-1200 PLC as the controller, with a CPU of 1214C DC/DC. In addition, expand one digital input expansion module SM1221 (8 inputs of 24VDC), one digital output expansion module SM1222 (8 outputs of 24VDC), and one analog input module SM1232. The PLC hardware wiring is shown in Figure 2. The touch screen uses TP1200 for device status monitoring and control, real-time analog monitoring, mode selection, parameter setting, etc.

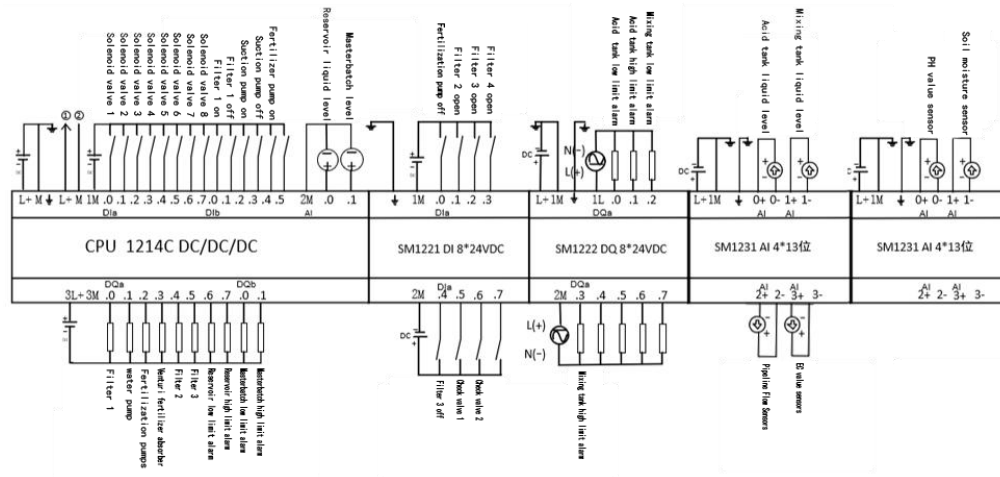


Figure 2. I/O Wiring Diagram.

3. Design of Fuzzy PID Composite Controller

3.1. Design of Fuzzy Controller

The fuzzy controller of the farmland drip irrigation control system designed in this article uses a triangular membership function to convert the precise input variables into fuzzy variables. In this step, the deviation E and deviation change rate EC are selected as the two input variables of the water and fertilizer concentration fuzzy controller, and the controller output signal U is used as its output variable. The corresponding fuzzy variables are E , C , and U . Use k_e to represent the quantification factor of the deviation of water and fertilizer concentration values, k_c to represent the quantification factor of the change rate of water and fertilizer concentration value deviation, and k_u to represent the proportional factor of the opening time of the electromagnetic valve at the mother liquor tank. For each input variable $e(t)$ and $de(t)/dt$, calculate their membership on each fuzzy subset.

This article divides the range of values for deviation E and error rate of change EC into seven fuzzy subsets: PB, PM, PS, ZO, NS, NM, and NB to describe the positive and negative deviations of the input variable deviation E and error rate of change EC , as well as the output signal U of the output variable controller to varying degrees. The characteristic points on the membership functions of the two input variables, E and EC , selected by this controller for water and fertilizer concentration are $\{-6, -4, -2, 0, 2, 4, 6\}$. The characteristic points of the fuzzy domain for the selected opening time U of the electromagnetic valve in the mother liquor tank are $\{-4, -2, 0, 2, 4\}$. When mixing water and fertilizer, there will be certain fluctuations. In order to consider the deviation between the measured value and the set value as much as possible, the actual domain of E is selected as $[-2, 2]$, and the corresponding actual domains of EC and U are $[-1.5, 1.5]$ and $[-8, 8]$, respectively. The quantification factor of the input

deviation E is $k_e=6/2=3$, the quantification factor of the deviation change rate EC is $k_c=6/1.5=4$, and the proportional factor of the opening time U of the output mother liquor tank solenoid valve is $k_u=8/4=2$ [16]. The pH value design is the same as the water and fertilizer concentration value design.

Based on the characteristics and empirical knowledge of actual systems, establish control rules for fuzzy controllers. Based on the fuzzy subset of deviation E and error rate of change EC, a 7x7 control rule table can be constructed. In this table, rows represent fuzzy subsets of errors, lists represent fuzzy subsets of error rate of change, and each cell represents the corresponding output fuzzy subset. The fuzzy rule control table of the mother liquor pool solenoid valve is shown in Table 1. The fuzzy rule control of the mother liquor pool solenoid valve is the same as the design of the mother liquor pool solenoid valve.

Table 1. Fuzzy Control Query Table for EC Values of Water and Fertilizer.

C	E						
	NB	NM	NS	ZO	PS	PM	PB
NB	5	5	5	-1	-5	-5	-5
NM	5	5	5	0	-5	-5	-5
NS	5	5	1	-1	-5	-5	-5
ZO	5	1	0	-5	-5	-5	-5
PS	1	1	0	-5	-5	-5	-5
PM	1	0	-1	-5	-5	-5	-5
PB	0	0	-1	-5	-5	-5	-5

Finally, through Sugeno inference and deblurring calculation methods. In this process, the membership distribution of the output variable is calculated based on the membership degree of the input variable and the control rule table, and then the output fuzzy quantity is converted into an accurate control signal through deblurring calculation.

3.2. Simulink simulation of fuzzy controllers

By using the Fuzzy Logic Toolbox Fuzzy Control Inference Editor in MATLAB to write membership functions for two input variables E and EC, as well as one output variable U, as shown in Figure 4, their membership functions are selected as triangles. The form of the membership function of EC is shown in Figure 5, and the three-dimensional curved observation window of the fuzzy rule for the opening time of the solenoid valve in the mother liquor tank is shown in Figure 6.

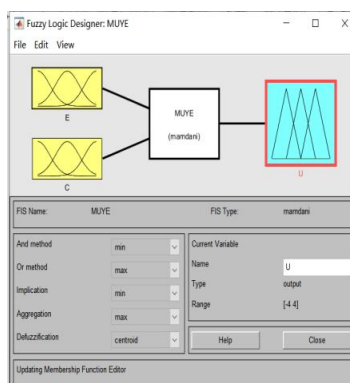


Figure 4. Fuzzy Control Inference Editor for EC Values of Water and Fertilizer.

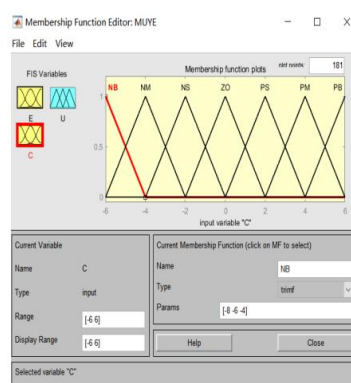


Figure 5. Membership Function of EC Values of Water and Fertilizer.

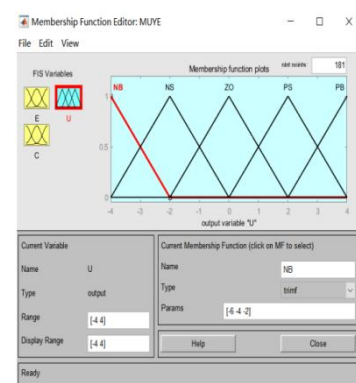


Figure 6. Characteristic Surface of Electromagnetic Valve in Mother Liquor Pool.

3.3. Design of Fuzzy PI Composite Controller

In terms of control strategy selection, this system uses PID control algorithm combined with fuzzy control algorithm, combining fuzzy control and PID control, and utilizing the advantages of fuzzy logic to adjust the parameters of the PID controller, in order to achieve more accurate system control. The design purpose of a fuzzy PID controller is to achieve precise control of the system by fuzzifying the relationship between K_p , K_i , K_d and $e(t)$, $de(t)/dt$. During normal operation of the system, real-time monitoring of the deviation signal $e(t)$ and deviation rate $de(t)/dt$ values is carried out. Based on the pattern of system changes, a fuzzy controller is used to adjust the set values of K_p , K_i , and K_d online to meet the requirements of $e(t)$ and $de(t)/dt$ values at various time periods, thereby achieving precise control of the system. The structural diagram of the fuzzy PID composite controller is shown in Figure 7.

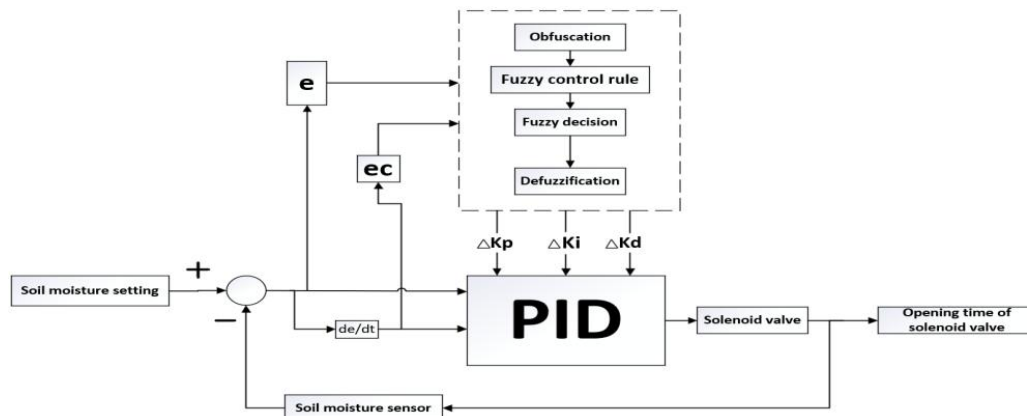


Figure 7. Structure diagram of fuzzy controller.

3.4. Simulation of Water and Fertilizer EC and pH Control

In order to test the good performance of the water and fertilizer EC value control strategy design, we modeled and simulated the water and fertilizer EC value fuzzy control system using Simulink software in MATLAB R2020a. Through dynamic model analysis of the water and fertilizer mixing process, we found that the control object is a first-order delay inertia link, and constructed a water and fertilizer EC value fuzzy control system with a delay time of 10 seconds.

Its transfer function is:
$$G(s) = \frac{0.05e^{-10s}}{39.2s + 1}$$

The fuzzy control and PID control models for water and fertilizer EC values built in MATLAB are shown in Figure 8, where $k_e=3$ is set; $k_c=4$; $k_u=25$. After the trial and error method of K_i , K_p , and K_d , the values are 25, 2, and 0.

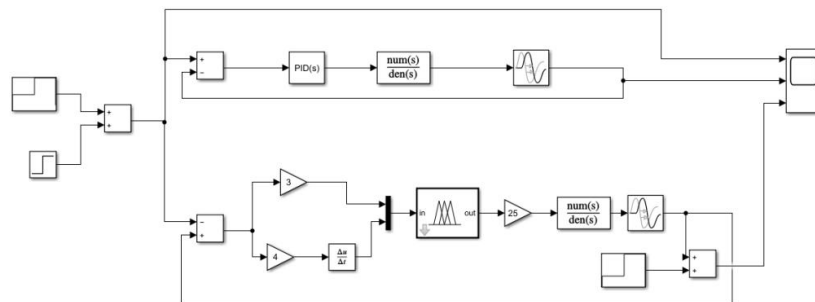


Figure 8. EC value simulation system model.

In addition, through the analysis of the dynamic model during the process of achieving equilibrium of water and fertilizer pH values in the water fertilizer mixing process, we have determined that the control object is a high-order delay inertia link, and constructed a water fertilizer pH value fuzzy control system with a delay time of 4 seconds.

Its transfer function is:
$$G(s) = \frac{0.012e^{-4s}}{(19.29 + 1)^6}$$

The water and fertilizer pH fuzzy control built in MATLAB R2020a/Simulink uses a PID control model, where $k_e=3$ is set; $k_c=4$; $k_u=25$, After continuous trial and error, the values of K_i , K_p , and K_d are 39.97, 0.75, and 0. The simulation model is the same as the EC value simulation system model design.

3.5. Analysis of simulation results

The system under fuzzy PI composite control was simulated using Matlab software, and the simulations under PI control and fuzzy control were compared in sequence. The EC value simulation curve is shown in Figure 9, and the pH value simulation curve is shown in Figure 10. The results show that compared to PI control and fuzzy control separately, the overshoot and adjustment time of the system under the fuzzy PI composite control designed in this paper are significantly reduced, and the dynamic performance is better.



Figure 9. EC value simulation curve.

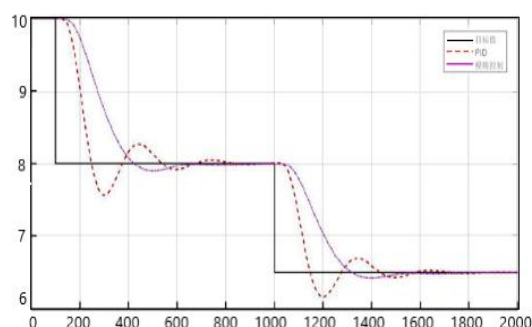


Figure 10. PH value simulation curve.

4. Program Design of Control System

4.1. Overall design of drip irrigation control system program

The main program of the agricultural automatic irrigation control system includes two parts: automatic control program and manual control program. As shown in Figure 11, the system control flowchart allows users to select the corresponding program for operation according to their actual needs. In the automatic control program, users can operate through the automatic and manual conversion buttons on the touch screen, and the system will assign values to the control program based on the user's parameter settings. The automatic control program compares the sensor monitoring values with the set values, and controls the start, stop, and close of the battery valve to achieve automated control of farmland irrigation. The control process of this process is expressed through a flowchart to facilitate understanding and analysis of the control process. Therefore, the automatic control program can automatically control farmland irrigation according to user needs, improve irrigation efficiency, and reduce manual intervention.

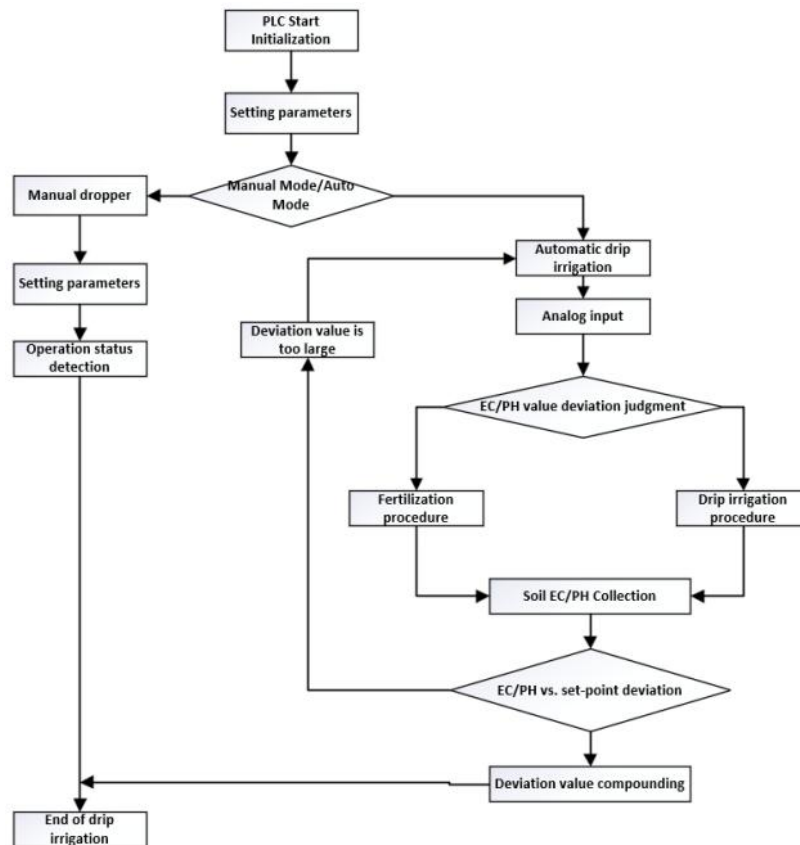


Figure 11. Integrated Drip Irrigation Control Flow Chart of Water and Fertilizer.

4.2. Irrigation control program

The irrigation of the system is based on the parameters collected by the humidity sensor at the remote end and transmitted to the PLC. When compared with the humidity setting value required for the current stage of the crop, drip irrigation will not be carried out when the set value is less than or equal to the actual humidity collected. When the set value is greater than the actual value, the system will automatically open the filter, pump, irrigation solenoid valve, main valve, and drip irrigation valve to achieve the required humidity, as shown in Figure 12.

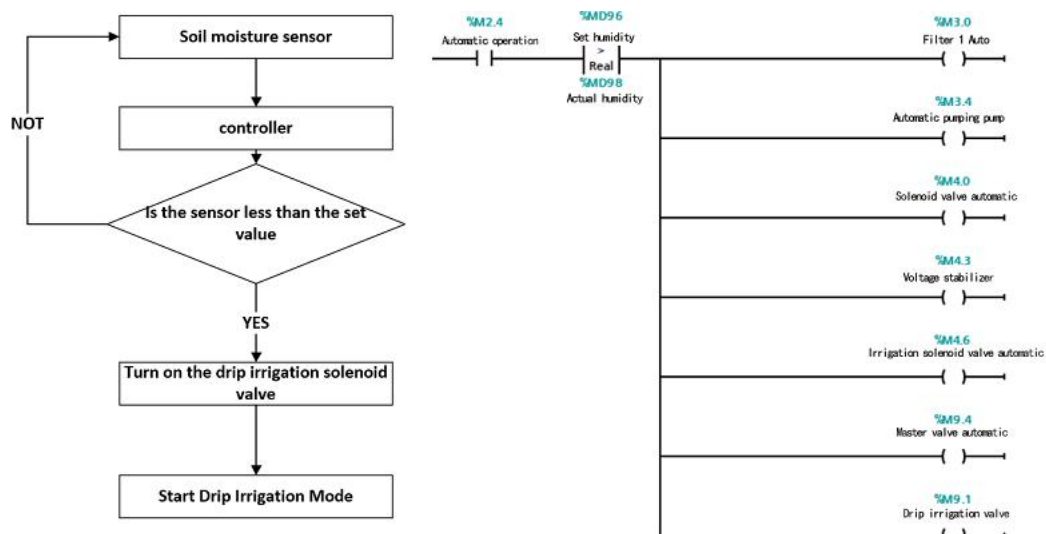


Figure 12. Irrigation Control Flow Chart and Program.

4.3. Fertilization control program

During operation, when fertilization is required, press the fertilization button and the timer starts counting. When the EC value concentration value is collected in the first two seconds to prepare for the next mother liquor ratio, the deviation and deviation rate between the pH value set value and the actual pH value collected last time are calculated. The obtained value is then used to query the fuzzy control table of the acid pool to obtain the fertilization duration. When the solenoid valve is opened or closed, they will automatically turn it on or off according to the system needs. The PLC program for the automatic start of the fertilization pump is shown in Figure 13.

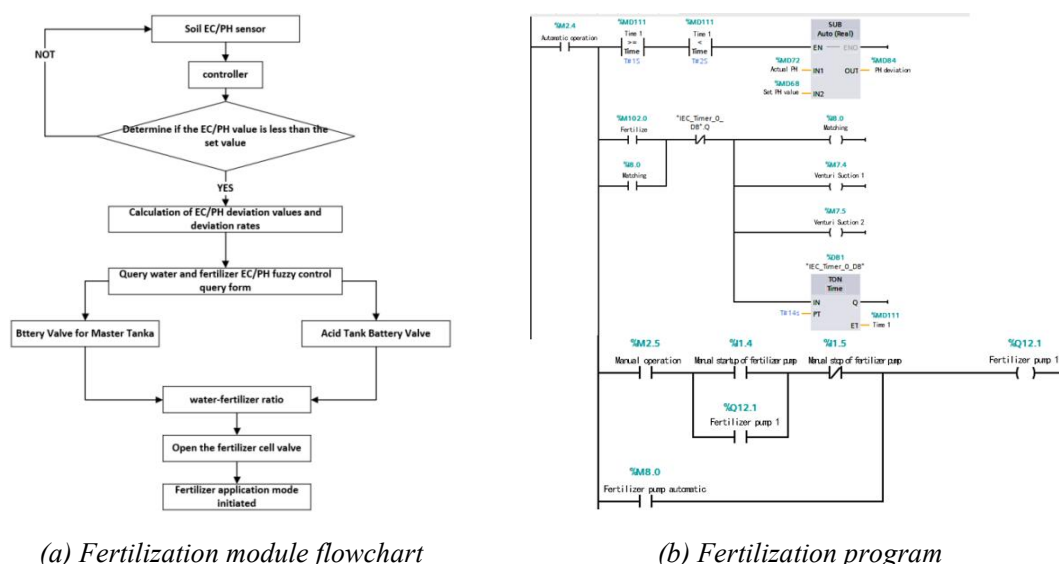


Figure 13. Fertilization Control Flow Chart and Program.

5. Monitoring Screen Design

5.1. Login interface design

In the design login screen, the text design includes the system title, designer's name, setting various liquid levels, and account passwords. The buttons are designed with login buttons, emergency stop buttons, automatic screens, manual screens, and alarm interfaces, as well as account passwords and IO fields for each liquid level.

5.2. Main interface design

There are screen switching buttons in the main interface, which are login page, manual page, and alarm page, humidity setting, pH value setting, EC value setting, and other data setting values, as well as some data sampling values; Electromagnetic valves, pumping pumps, pressure gauges, flow meters, and other system related equipment. Four containers were modified using liquid level scales as reservoirs, acid tanks, mother liquor tanks, and mixing tanks, as shown in Figure 15.

5.3. Alarm screen design

In the alarm screen, there is a report view that can be viewed by selecting "Control" from the toolbox on the right and dragging the alarm view out. The alarm screen is used to display the alarm time, alarm information text, and can also switch to the main page, automatic screen, and manual screen.

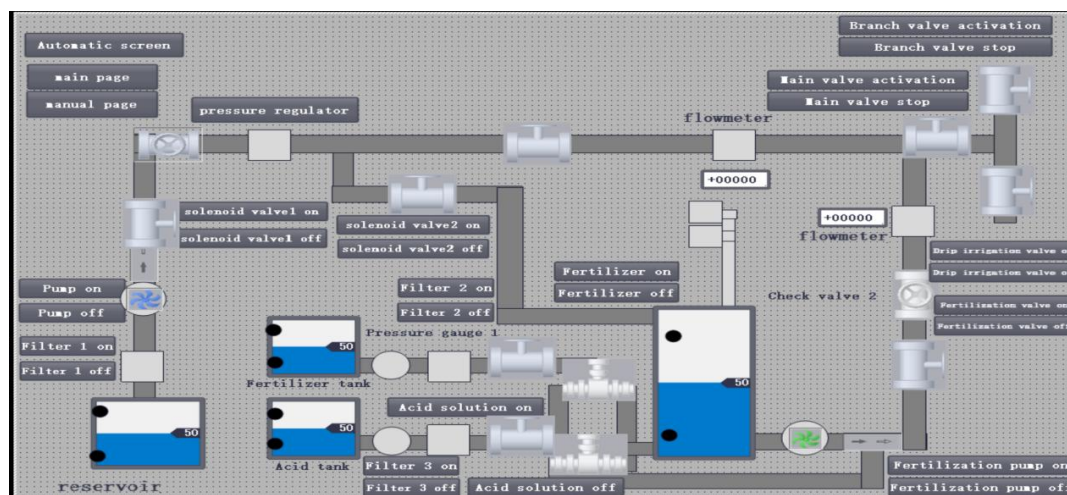


Figure 15. Main Interface Design.

6. Conclusions

This article is based on the design of a PLC based automatic control system for drip irrigation and fertilization. It introduces the process of the drip irrigation and fertilization system, how to achieve the functions of drip irrigation, fertilization, and drip irrigation and fertilization. A fuzzy control model is established using MATLAB, and PID control and fuzzy control are compared in Simulink. From the simulation results, it is found that fuzzy control has better control effects on the system. The hardware equipment used in the system is selected, and finally, the I/O point allocation, PLC program design, and HMI configuration screen design of the drip irrigation and fertilization system are carried out using Botu V15 software. There are two control methods: automatic control and manual control. This article has achieved some results:

(1) In the automatic control system of drip irrigation fertilization, the concentration and pH of the mother liquor are important control variables. By establishing an EC value fuzzy controller and a pH value fuzzy controller, and comparing them with traditional PID control through simulation in Simulink, the overshoot and adjustment time under fuzzy control are significantly reduced.

(2) In PLC program design, manual control realizes the start and stop of any equipment in the control system, which can meet the functional requirements of the drip irrigation and fertilization system. Automatic control also realizes automatic drip irrigation and watering based on actual humidity, and fertilization based on the EC concentration and pH value of water and fertilizer.

(3) In the configuration, account and password login can be achieved, remote control and monitoring functions can be performed, and liquid level alarms can be viewed. many difficulties are encountered in programming, and there were some differences in the usage of TON and TOF timers between the Bortu V15 and the Siemens S7-200; Not every CPU can be expanded; When adding data tables without links or definitions, warnings may appear during compilation. When selecting HMI, simple panels do not support configuration, and complex data and image processing may cause the system to lag or run slowly. It is also possible that the pixels are too low to display, and warnings may appear during compilation.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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