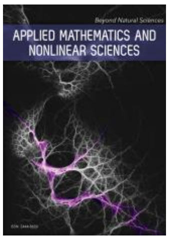
sciendo Applied Mathematics and Nonlinear Sciences, 9(1) (2024) 1-17



Applied Mathematics and Nonlinear Sciences

https://www.sciendo.com

Construction of an intelligent agricultural irrigation control platform based on PLC technology

Miaoqi Li[1,†], Rui Zhang[1], Xiaoyan Zhang[1], Jinhao Shi[1]

1. College of Mechanical and Electrical Engineering, Gansu Agricultural University, Lanzhou, Gansu, 730070, China.

Submission Info

Communicated by Z. Sabir
Received November 10, 2022
Accepted March 29, 2023
Available online September 18, 2023

Abstract

This paper firstly constructs a PLC-based intelligent irrigation control system, analyzes the requirements of its system functions, and determines three major modules of the system: data acquisition module, intelligent irrigation module, and Web service module. Then the system fuzzy control process is determined. According to the moisture value collected by the soil moisture sensor, the average is taken, and the deviation and deviation change rate is obtained by calculating the difference with the set value, and the control value is obtained by querying the previously deposited fuzzy control table through a series of transformations, and the command is executed according to the program setting. The automatic irrigation requirement is achieved by controlling the solenoid valve on and off. Finally, the analysis of system functions in terms of sensor accuracy, system function testing, and temperature and air humidity prediction accuracy was carried out. Regarding sensor accuracy, the error of relative soil moisture content is within 3%, and the relative error of soil temperature is within 0.5. In the system control function test, the solenoid valve will open for irrigation when the soil relative water content is lower than 40% or higher than 70% of the warning range, and the lighting will be turned on when the light intensity is lower than 200 Lux, and the system control is in line with the expectation. The intelligent irrigation system is of great significance to agricultural development.

Keywords: PLC-control; Fuzzy control; Intelligent agriculture; Automatic irrigation; Data visualization.
AMS 2010 codes: 68T05

†Corresponding author.
Email address: limq@gsau.edu.cn

ISSN 2444-8656
https://doi.org/10.2478/amns.2023.2.00344

1 Introduction

Water plays a key role in plant growth and development, and the traditional irrigation method in China is large water irrigation, the monitoring of drought and irrigation or not depends on manual. This coarse mine irrigation method will not only waste water resources but also lead to soil salinization and loss of fertilizer [1-2]. The purpose of developing water-saving irrigation technology is to change people's traditional habit of watering the ground by irrigation, really start from the characteristics of crop water demand, and apply water directly to the soil near the plant roots to produce the maximum economic benefits of crops with the least amount of water [3-4]. The promotion of intelligent irrigation systems can not only improve the use of water resources and make the current increasingly tight water resources can be alleviated but also can further improve the quality and yield of crops and reduce the cost of growing agricultural products [5].

The literature [6] studied an intelligent irrigation system based on the evapotranspiration of crops, which calculates the evapotranspiration of crops by acquiring meteorological data and can develop a suitable irrigation program based on the analysis of irrigation flow, irrigation type, crop type, and soil characteristics, and the experiments showed that the water saving effect of the control system is very significant, with an average water saving rate of 30%, and is also beneficial to the normal root system of crops. The experiments showed that the control system effectively saved water, with an average water-saving rate of 30%. In the literature [7], the influence of transpiration on plant growth was considered, and the Penman formula was used to calculate the transpiration value, analyze the water demand of plants, and develop irrigation strategies. The literature [8] established a fuzzy irrigation decision system, which used soil moisture and environmental parameters as controller feedback variables, compared the feedback values with the set standard values and input them to the central controller, and determined the irrigation time by analyzing and processing the input information, which was experimented in peanut fields and achieved satisfactory results. The literature [9] used a genetic algorithm to optimize the irrigation of crops, using an advanced global optimization search algorithm - genetic algorithm to calculate the irrigation model it designed, using the new algorithm to avoid the defect that the dynamic programming asymptotic method cannot converge to the optimal solution, and achieved very good results. The literature [10] proposed a neural network-based controller using a three-layer BP neural network to calculate the input signal and finally achieved satisfactory results with relatively high control accuracy and water-saving efficiency. In the literature [11], the control of soil moisture and water and fertilizer concentration was achieved using the RHC algorithm. This algorithm led to much-improved water and fertilizer utilization, but they were all limited to the experimental stage and failed to achieve extension.

In the literature [12], a study was conducted to verify whether the genetic algorithm can be applied to irrigation plans, and it was found that a genetic algorithm is a very effective tool for optimizing irrigation plan models, also by maximizing the net benefit as the ultimate goal, and finally, the optimal genetic algorithm parameters and the optimal set of irrigation model plans were obtained. In the literature [13], an adaptive fuzzy PID approach was used to achieve a refined control of the irrigation fluid concentration value EC. The literature [14] developed a fuzzy controller for greenhouse irrigation, and after proposing the problems of traditional irrigation, the feasibility of fuzzy control in irrigation control was again verified by regulating the water demand for irrigation in the greenhouse through the collection of soil temperature and humidity. The literature [15] proposed a wireless intelligent irrigation control system, which makes the control method wireless and is applied to the experimental field site to prove the stability of its system. Literature [16-17] proposed that some more advanced countries can reach up to 95% water utilization rate by choosing some advanced irrigation technologies, while the average water utilization rate in China is only 50%. China introduced water-saving irrigation technology from developed countries decades ago, yet the technology is used infrequently in the total irrigated area in China. The literature [18] proposed a water diffusion controller using fuzzy control logic, and the experimental results showed that the controller designed by it has a remarkable effect in this regard.

This paper is divided into three parts to discuss the intelligent agricultural irrigation control platform based on PLC technology. The first part mainly discusses the working principle of intelligent irrigation and system function requirements. The remote intelligent irrigation system mainly receives data from environmental sensors through a PLC controller and calculates the watering quantity and watering time of plants through the fuzzy algorithm. The corresponding watering strategy is developed according to the different water requirements of different plants. The system needs to implement specific functions, such as data collection, transmission, storage, and processing of soil moisture sensors, intelligent irrigation algorithm, control strategy, visualization video monitoring, and remote Web service, including PC terminal and cell phone terminal. The second part mainly introduces the implementation of the system control. This paper mainly realizes the control function of the system through fuzzy control. According to the moisture value collected by the soil moisture sensor, the average is taken, and the deviation and deviation change rate is obtained by calculating the difference with the set value, and through a series of transformations, the desired control value can be obtained by querying the previously deposited fuzzy control table, and the command is executed according to the program settings. The automatic irrigation requirement is realized by controlling the solenoid valve on and off. The third part analyzes the system performance, mainly from sensor accuracy, temperature and air humidity prediction accuracy, and system control function.

2 Intelligent agricultural irrigation control platform construction

2.1 Intelligent irrigation working principle

With the development of modernization and the improvement of people's living standards, people have higher requirements for a green and healthy living environment, and plants such as home flowers and vegetable crops are increasingly popular among people. Irrigation of plants is very important for the healthy growth of plants, and it is also fun for breeders.

The traditional irrigation method for household crops is human irrigation, but when the family is not at home for a long time, they also encounter the same problem as the agricultural greenhouse crops: watering plants. The purpose of continuous watering. However, this method is not easy to control the amount of water, and the watering time is limited, so it is impossible to control the watering time when you are away from home for a long time. There are also studies on clock-based intelligent watering devices that overcome these problems, but they are too simple and cannot be controlled remotely. People have begun to study agricultural facilities' remote measurement and control systems. To a certain extent, the remote intelligent irrigation system came into being to achieve remote intelligent irrigation, and the intelligent irrigation working principle is shown in Figure 1.

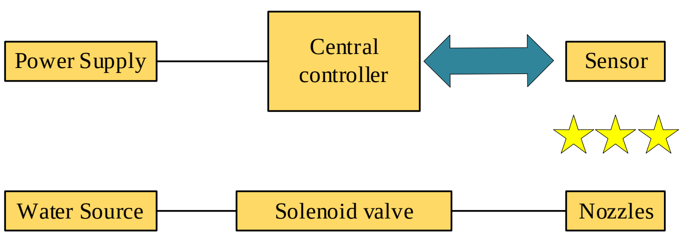


Figure 1. Intelligent irrigation working principle diagram

The core of the remote intelligent irrigation system is the central controller, used in this paper as a PLC controller. The controller receives data from environmental sensors, including soil moisture parameters, air carbon dioxide concentration, and other parameters, and calculates the watering amount of plants and watering time through a fuzzy algorithm. The corresponding watering strategy is formulated according to the different water requirements of different plants. The central controller sends the corresponding control command to the control node, which controls the solenoid valve to control the plant watering briefly. It can be seen that intelligent irrigation is a closed-loop feedback system.

2.2 System functional requirements

According to the design objectives of the system requirements, to achieve the above objectives, the system needs to realize some specific functions, such as data collection, transmission, storage and processing of soil moisture sensors, implementation of intelligent irrigation algorithms and control strategies, visualization video monitoring, and providing remote Web services including PC terminal and cell phone terminal. The system can generally be summarized into a data acquisition module, an intelligent irrigation module, and a Web service module, where the module contains a visualization service and remote watering service. The detailed functional requirements are shown in Figure 2.

The plc-based remote visualization intelligent irrigation system is divided into three major modules in terms of functional requirements, and each module corresponds to the functional and sub-functional modules for achieving specific functions. The detailed functions of each module are described below.

1) Data acquisition module

   (1) Using the IoT experimental platform, the data collection command is broadcast through the central controller controlling the coordination node, and the polling method is used to collect the sensor parameters in the environment, such as soil moisture sensors. The sensor data is transmitted to the central controller through the wireless ZigBee network.

   (2) Data storage: The collected sensor data are first stored in the database, which stores different sensor data separately for calculation and analysis in the intelligent irrigation decision analysis process.

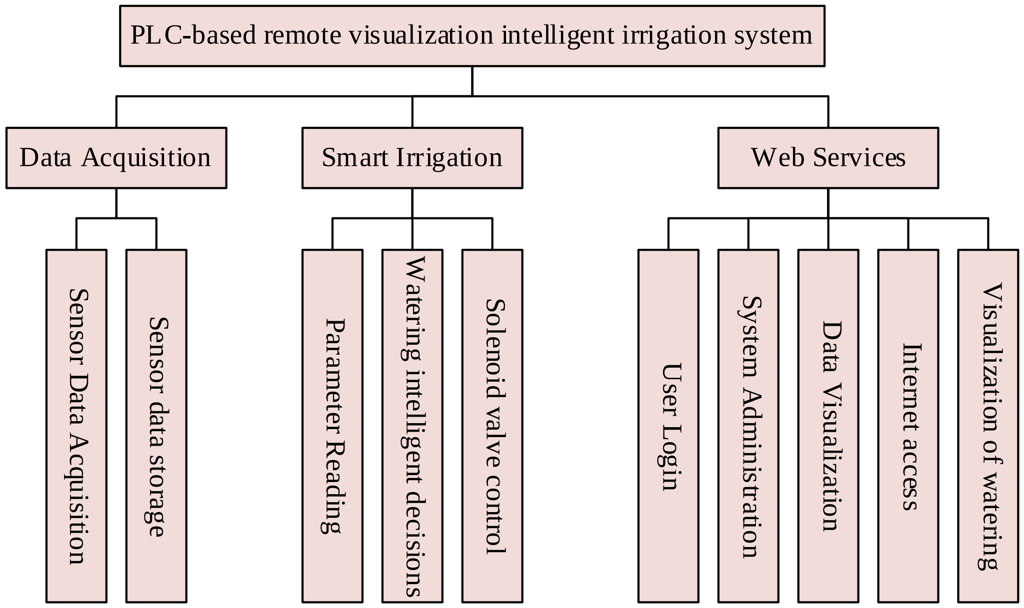


Figure 2. System functional requirements

2) Intelligent irrigation module

(1) Parameter configuration: Configure system-related parameters, such as sensor data and corresponding crop data, including crop growth information, growth cycle, growth time, daily watering volume, growth environment temperature, humidity, etc. Parameter configuration is a very important part of the intelligent irrigation system; only according to the pre-configured parameters can you make the right decision.

(2) The ultimate goal of an intelligent irrigation system is to achieve automatic and intelligent watering of crops, so the core part is how to make watering decisions and give watering commands to the node that controls the solenoid valve.

(3) Solenoid control: After the decision is made by the watering intelligent decision module, the system will give the watering command to the corresponding solenoid valve, control the on/off of the solenoid valve and the duration of the on/off, and control the watering amount of the corresponding crop.

3) Web service module

(1) Internet access: Considering that the intelligent watering area where the system is applied is located in a mountainous or remote area, Internet access is not convenient, so the system adopts 3G access to the Internet. If it is located at home or office, the system is accessed through WIFI.

(2) User login: The Web service access module must verify the user's identity, which can be used only after verification.

(3) System management: The system management module provides users to manage and configure the whole system, including user management, sensor management, crop management, and system parameter setting.

(4) Data visualization: One of the system's features is the visualization of the historical data of the sensors, showing the trend of change through graphs, such as the change of CO2 concentration of a certain plant, the change of soil moisture, etc.

(5) Visualization of watering: From the user's experience, the system's Web service provides remote visualization of watering so that you can both water the plants manually and see the watering scene with your own eyes, just like being there, so that users who love plants and flowers can experience a unique interest.

The data collection and the irrigation intelligent decision modules are designed for intelligent irrigation within the system. For the user, the direct face-to-face user is the graphical operation interface. To realize remote visualization of smart irrigation, web services are essential so that users do not need to operate next to the gateway but can access the smart irrigation gateway and monitor visual watering remotely whenever the Internet reaches them.

The goal of this paper is to implement remote visual smart irrigation. The module is designed to allow the user to access the visual irrigation page through a web service, which can display detailed information about each plant: live video, user screenshots, watering history data, and growth environment parameters data, and the user can perform operations such as controlling the camera to turn the head, watering button and stop watering button. Through this service, the user can not only view some plant history data and observe the growth condition of the plant during remote access but also manually water the plant accordingly and transmit the live video captured by IPCamera to observe the real-time condition of the plant. The functional framework of this module design is shown in Figure 3.

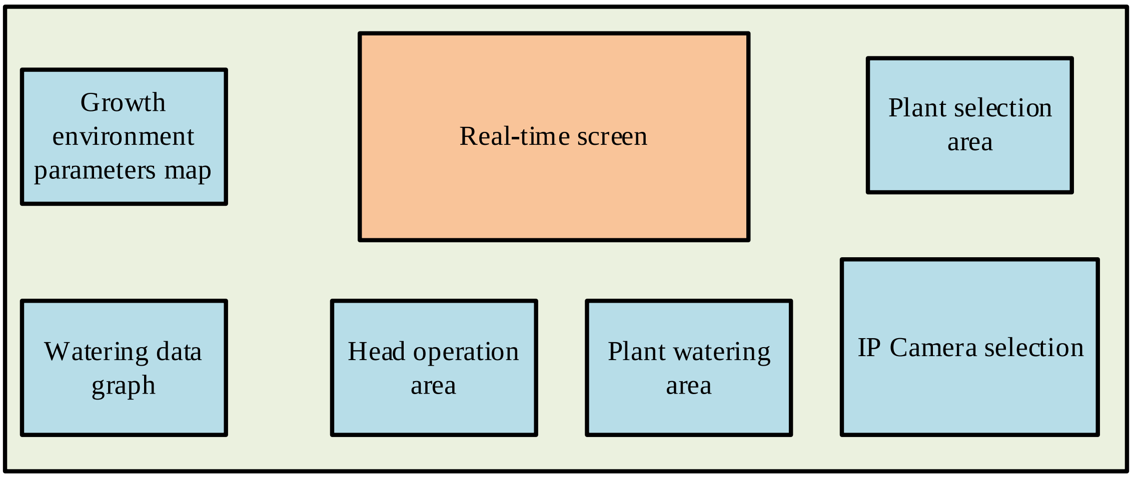


Figure 3. Visual irrigation module architecture

2.3 System performance requirements

1) Continuity of data acquisition

The system requires the central controller to be able to continuously send acquisition commands to collect parameters from sensors such as soil moisture.

2) Watering accuracy

The time required to execute the system from the issuance of the watering command to the end of watering is accurate, and the error with the control command of intelligent irrigation decision cannot exceed 1 second.

3) Operability

The system provides remote web service, which is easy and convenient for users. The system is simple and clear, with the icons of the relevant button boxes so that users can check and request help anytime.

4) Reliability and security requirements

Regarding reliability and stability, the system must have a high fault tolerance capability to avoid or ignore the user's misoperation. The system can run for a long time in indoor and outdoor environments without errors, changes in the external environment do not affect the system's normal operation, the system has a firewall, and the system's internal data is safely stored without being leaked.

2.4 System feasibility analysis

The hardware part of the system adopts PLC as the controller of the Internet of Things experimental platform. The sensor data collection is stable, the collected data processing speed is fast, and the stability of the system operation is high reliability. The system software is realized on the Linux platform, using CGI and Qt graphical interface development, the software system running environment is stable, integrated with PHP platform compatibility and scalability. The user can easily access various handheld terminals. The core part of the system, intelligent irrigation decision-making, has a considerable research base, based on which it is feasible to develop a remote visualization intelligent irrigation system. Figure 4 shows the overall data flow diagram of the system.

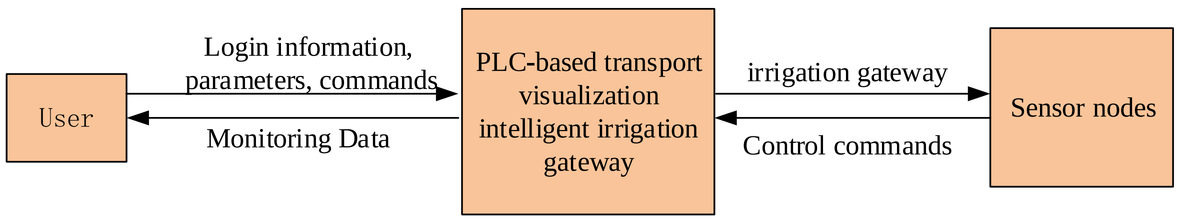


Figure 4. System overall data flow diagram

2.4.1 Data flow diagram

Based on the functional requirements analysis of the system, Figure 5 shows the system's overall structural data flow diagram. Its main roles are user, visual intelligent irrigation gateway, and sensor nodes. To use the services provided by the system, the user needs to provide user login data, operating instructions, and configurations, and the system displays monitoring data to the user. The final operating vehicle of the system is the central controller, which is called the "PLC-based remote visualization smart irrigation gateway" in this paper. Therefore, the system's central role is the intelligent irrigation gateway, a data hub that receives data from users and sensor nodes, provides users with the services they need and sends control commands to sensor nodes. The third role of the system is the sensor node, where the sensor node contains the soil temperature and humidity nodes that collect environmental parameters, etc. It also contains the control node for the solenoid valve and the video sensor node, IPCamera. The sensor node receives the control commands from the intelligent gateway, responds, and returns the corresponding data.

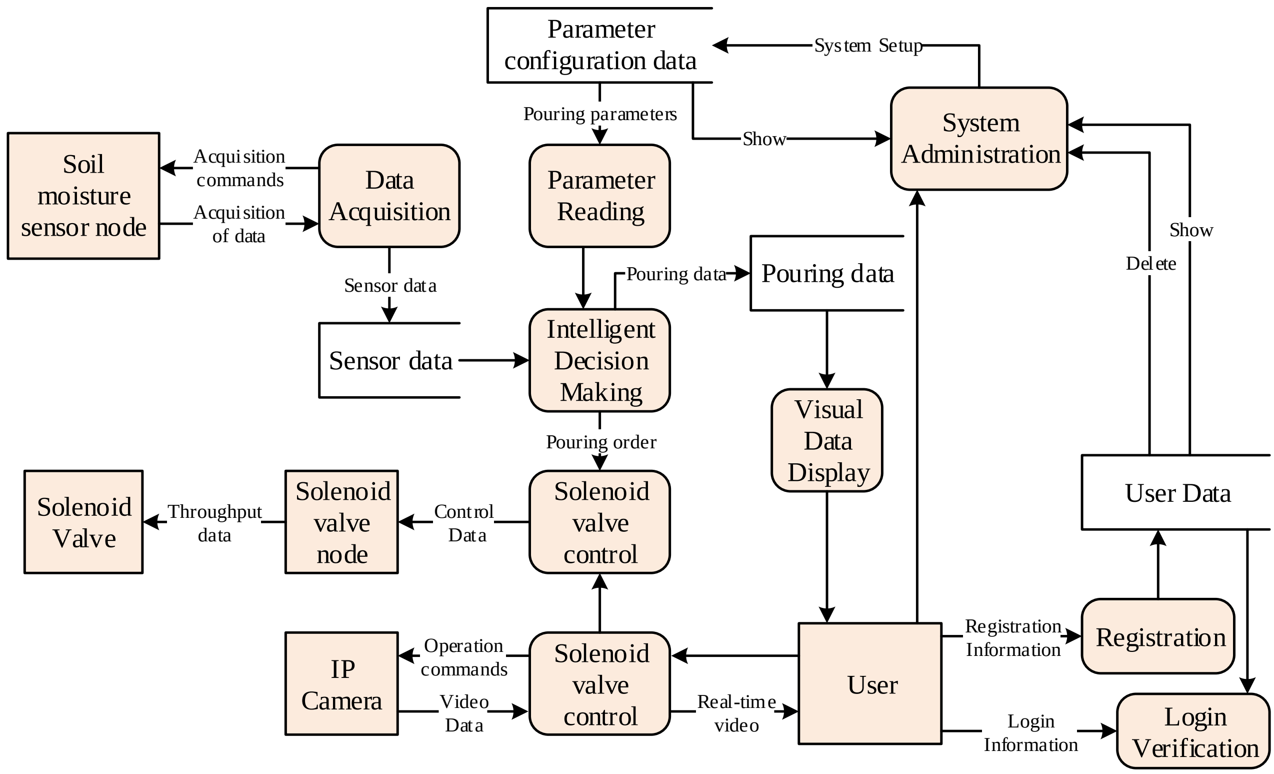


Figure 5. Detailed data flow diagram of the system

2.4.2 Fuzzy control algorithm subroutine

In the process of performing fuzzy control algorithms, the storage performance of the controller used should be fully considered, and the control algorithm should be as simple and space-saving as possible. Usually, after the fuzzy controller design is completed, the obtained fuzzy control table must be stored by entering it into the PLC in advance. According to the moisture value collected by the soil moisture sensor, the average is taken, and the deviation and the deviation change rate are obtained by calculating the difference with the set value. The desired control value can be obtained through a series of transformations by querying the previously stored fuzzy control table and executing the command according to the program settings. The automatic irrigation requirement is realized by controlling the on/off of the solenoid valve. The following step-by-step process of plc-based fuzzy control program implementation is introduced according to the fuzzy control process. Figure 6 shows the fuzzy control algorithm subroutine.

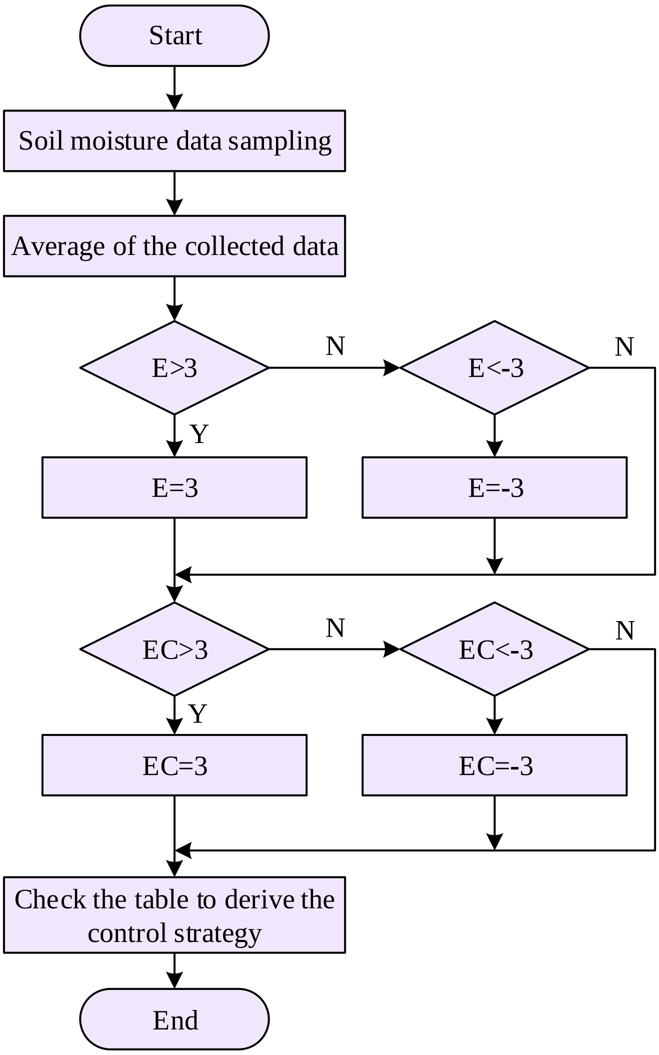


Figure 6. Fuzzy control submain program flow chart

2.4.3 Fuzzy subsets and linguistic domains

In agricultural irrigation systems, soil moisture is important in determining irrigation. In this system, soil moisture deviation e and deviation change rate ec are used as input variables, and control quantity u is used as output, and the block diagram of the dual-input single-output model used is shown in Figure 7.

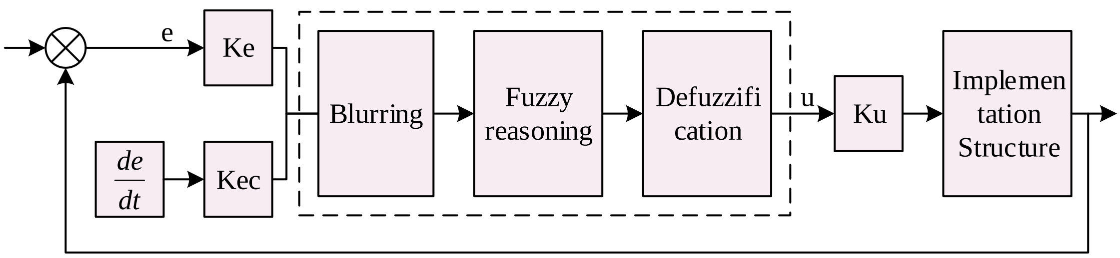


Figure 7. Fuzzy controller structure diagram

This system uses seven language variables for input and four for output, taking into account the actual needs of the irrigation system. The input language variables are {negative large, negative medium, negative small, zero, positive small, positive medium, positive large}, denoted as:

$$e=\{NB, NS, NM, ZO, PB, PS, PM\} \tag{1}$$

The output volume is:

$$u=\{ZO, PS, PM, PB\} \tag{2}$$

Keeping the consistency of the quantized theoretical domain with the basic theoretical domain, quantified into 7 classes, the theoretical domain of E is [-3,-2,-1,0,1,2,3]. The actual theoretical domain of the rate of change of humidity deviation ec is [-20,20], and similarly quantified into 7 classes, the theoretical domain of EC is [-3,-2,-1,0,1,2,3]. The actual theoretical domain of the control quantity u is [0,30], and quantizing it into 4 classes, the theoretical domain of U is [0,1,2,3].

The quantization factor represents the ratio of the fuzzy domain to the actual domain and is used in practical applications to adjust the accuracy of the control system. After determining the linguistic variables of the fuzzy controller and the values of the corresponding linguistic variables, the actual domain of the parameters needs to be transformed into the values of the fuzzy domain utilizing quantization factors, which can be obtained by the ratio of the input actual domain values to the domain values under fuzzy control, as shown in equations (3), (4) and (5) below for the input and output quantization factors.

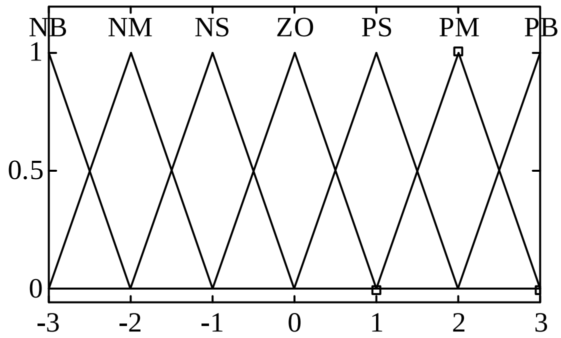
$$k_e = \frac{n}{e} = \frac{3}{20} = 0.15 \tag{3}$$

$$k_{ec} = \frac{n}{ec} = \frac{3}{20} = 0.15 \tag{4}$$

$$ku = \frac{n}{u} = \frac{3}{30} = 0.1 \tag{5}$$

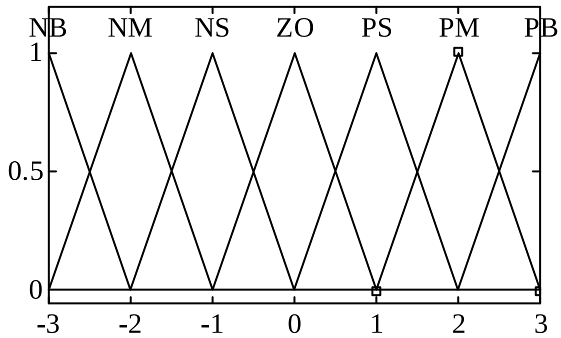
2.4.4 Fuzzy control table

After the fuzzy domain and fuzzy linguistic variables of soil moisture deviation E, soil moisture deviation rate of change EC, and irrigation time control quantity U in fuzzy control are determined, the fuzzy variation is assigned according to the triangular type affiliation function, and the fuzzy control assignment table of its two fuzzy inputs E and EC is the same as Table 1. The fuzzy control assignment table of irrigation time control quantity U is shown in Table 2. Figure 8(a) represents the affiliation function of soil moisture deviation E, Figure 8(b) represents the EC affiliation function of soil moisture change rate, and Figure 8(c) represents the affiliation function of output U.



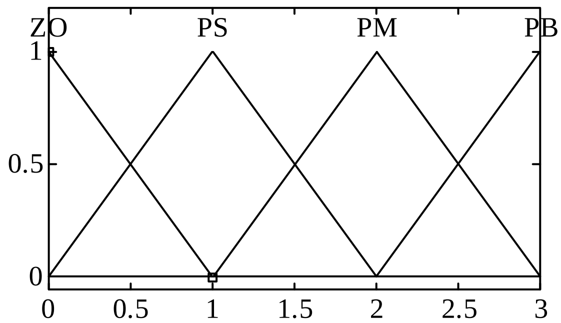
(a)

Figure 8. (a) Humidity deviation affiliation function



(b)

Figure 8. (b) Soil humidity deviation rate of change affiliation function



(c)

Figure 8. (c) Output U affiliation function graph

Table 1. Fuzzy control assignment table

Affiliation / Language variables	Quantification level						
	-3	-2	-1	0	1	2	3
PB	0	0	0	0	0	0	1
PM	0	0	0	0	0	1	0
PS	0	0	0	0	1	0	0
Z0	0	0	0	1	0	0	0
NS	0	0	1	0	0	0	0
NM	0	1	0	0	0	0	0
NB	1	0	0	0	0	0	0

Table 2. U fuzzy control assignment table

Language variables \ Affiliation	Quantification level			
	0	1	2	3
ZO	1	0	0	0
PS	0	1	0	0
PM	0	0	1	0
PB	0	0	0	1

2.4.5 Fuzzy control response table

The vector corresponding to the first row, “PB”, is taken from the fuzzy variable assignment table 2 and denoted by A:

$$A = \{0,0,0,0,0,0,1\} \tag{6}$$

Similarly, the first row of vectors corresponding to “PB” is taken from the fuzzy control table corresponding to EC and represented by B.

$$B = \{0,0,0,0,0,0,1\} \tag{7}$$

$$r_1 = A^T * B = \begin{pmatrix} 0 & 0 & \cdots & 0 \\ 0 & 0 & \cdots & 0 \\ 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{pmatrix} \tag{8}$$

r_1 Expand by row.

$$r_1 = (0,0,0,\cdots,1) \tag{9}$$

The first row of vectors corresponding to “PB” is taken from the fuzzy control table corresponding to U and represented by C.

$$C = \{0,0,0,1\} \tag{10}$$

A matrix with 49 rows and 4 columns is obtained:

$$R_1 = r_1^T * C \tag{11}$$

$$R_1 = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{12}$$

The fuzzy relationship matrix R can be obtained.

$$R = \sum_{i=1}^{49} R_i \tag{13}$$

The fuzzy relation matrix R was obtained in the previous subsection, and according to Eq:

$$U = (E \times EC)^T \circ R \tag{14}$$

The set of fuzzy vectors under the action of soil moisture deviation and rate of change of moisture deviation can be derived, and the final fuzzy control response table can be output using the center of gravity method. As shown in Table 3.

Table 3. Fuzzy Control Query Table

U / EC	E						
	-3	-2	-1	0	1	2	3
-3	0	0	0	0	0	0	0
-2	0	0	0	0	0	0	0
-1	0	0	0	0	0	1	1
0	0	0	0	0	1	2	2
1	0	0	0	1	2	3	3
2	0	0	1	2	3	3	3
3	0	0	2	3	3	3	3

3 Results and Analysis

3.1 Sensor accuracy test

The sensor data collection accuracy test was run in Xinjiang water-saving irrigation test base to verify the monitored soil's relative water content and temperature.

The system uses a China Haiku IOT HKSHC03S soil moisture sensor (accuracy +2%) to measure the relative soil moisture content and an American Dallas DS18B20 digital temperature probe (accuracy +0.5°C) to measure the soil temperature.

And use the instrument measurement as a control of the accuracy of the data measured by the system, measurement to ensure that its measuring instrument and the system sensor are at the same moment in the same location, the corresponding instrument model for China Jitai FD-T soil moisture meter (accuracy +0.5%), China Huashengchang DT-321S temperature and humidity meter (temperature accuracy +0.5°C, air relative humidity accuracy +2%), the accuracy of the system data The test is shown in Figure 9.

The data measured by the sensors are similar to the values measured by professional instruments, and there are no bad data points; the relative error of the relative moisture content of the soil is within 3%, the relative error of the soil temperature is within 0.5, and the actual measured values of the monitoring values match without great errors, indicating that the sensor monitoring values of this system are more accurate and stable.

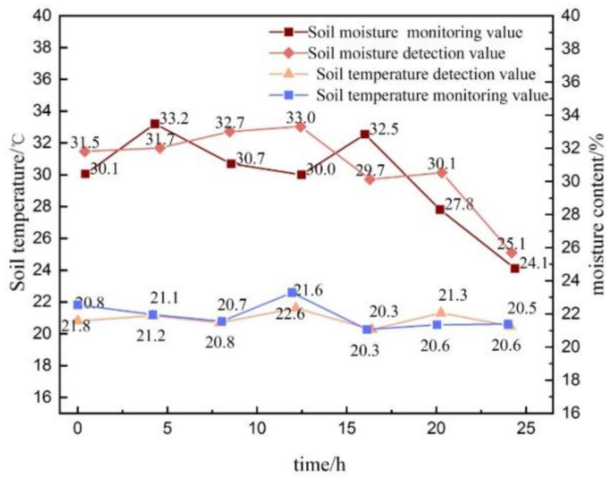


Figure 9. Soil moisture content and soil temperature test

3.2 Forecast analysis of air temperature and air humidity

Temperature prediction is one of the factors affecting crop growth, and the gradual global warming in recent years has restricted crop growth to varying degrees. Therefore, temperature prediction of crop environment is an indispensable part of enhancing the prevention of extremely cold weather, extremely hot weather, or sudden change in weather. For example, temperature prediction results can be fed back to people's mobile or computer terminals in time to prevent unnecessary losses. This paper compares the average temperature of 100 days from January to April 2022, the measured value, and the prediction result, as shown in Figure 10. From the training results of the average temperature model, the prediction results after training show a trend of rising and then falling, which is consistent with the actual trend, and most of the prediction points are distributed on the actual curve, and the smaller prediction data points are distributed around the actual measured values, and there are no points with large errors, indicating that the average temperature prediction model has good performance and high accuracy.

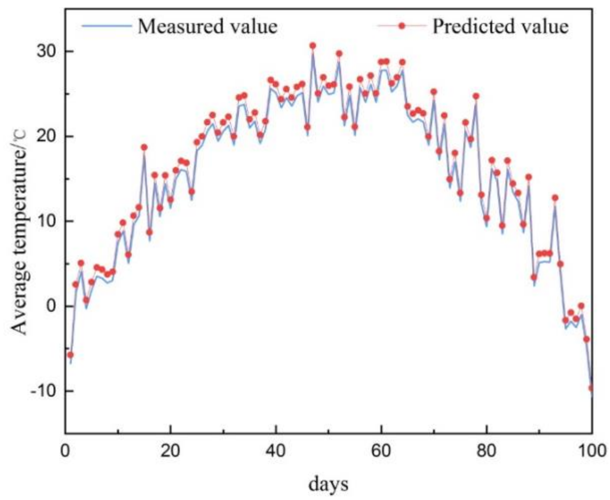


Figure 10. Average temperature forecast and measured values

Air relative humidity prediction Air relative humidity is one of the factors for crop growth evaluation, and when the air relative humidity is too low without sufficient water supplementation, it is easy to cause crop drought damage. To facilitate immediate warning, the average air relative humidity data from January to April 2022 were entered into the training, and the average air relative humidity was predicted for the following 100 days. The predicted data are close to the trend of the actual situation, and the predicted data indicate that the average air relative humidity prediction model is more reliable. Figure 11 shows the measured and predicted values of average air relative humidity.

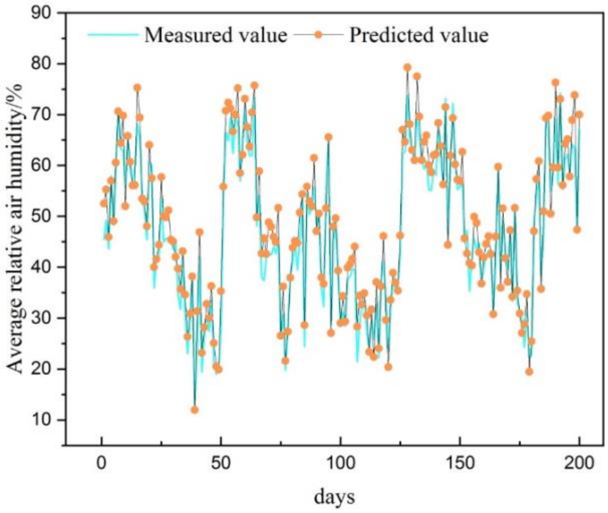


Figure 11. Measured and predicted average relative air humidity values

3.3 System control function test analysis

The control part was tested in the laboratory of Xinjiang Water-saving Irrigation Experimental Base No. 2, and the warning range was set as the relative soil moisture content lower than 40% or higher than 70%; when it was in the warning range. The solenoid valve would open for irrigation and push the alarm prompt to the user; on the other hand, the solenoid valve would close and return to normal, and the lighting would be turned on when the light intensity was lower than 200 Lux. The system control is in line with the expectation, which shows that the system can achieve stable control. Table 4 shows the control test.

Table 4. Control tests

Soil relative water content/%	Light intensity/Lux	Early warning value	Solenoid valve 1	Solenoid valve 2	Solenoid valve 3	Solenoid valve 4	Lighting	Alarm alert
28	-	<40or>70	Open	Open	Open	Open	-	Open
40	-	<40or>70	On	On	On	On	-	On
47	-	<40or>70	Off	Off	Off	Off	-	Off
62	-	<40or>70	Off	Off	Off	Off	-	On
70	-	<40or>70	Off	Off	Off	Off	-	On
74	-	<40or>70	Off	Off	Off	Off	-	Off
-	3527	<200	-	-	-	-	Off	Off
-	56336	<200	-	-	-	-	Off	Off
-	76332	<200	-	-	-	-	On	On
-	200	<200	-	-	-	-	On	On
-	150	< 200	-	-	-	-	On	On

4 Conclusion

In this paper, we built an intelligent agricultural irrigation control platform using a PLC controller and analyzed the platform's performance in terms of the accuracy of sensors, the stability of the control system, and the accuracy of temperature and air humidity prediction. The following conclusions are drawn:

The relative error of soil water content is within 3%, and the relative error of soil temperature is within 0.5, and the actual measured value of monitoring value matches without great error, which shows that the sensor monitoring value of this system is more accurate and stable.

In the prediction of temperature and air humidity, most of the prediction points are distributed on the actual curve, and the smaller prediction data points are distributed around the actual measured values, and there are no points with large errors, indicating that the average temperature prediction model has good performance and high accuracy.

On the control system test, the system control is in line with the expectation, which indicates that the system can achieve stable control.

Funding:

1. This research was supported by Key Research and Development Project of Gansu Provincial Department of Science and Technology (21YF5FA094).

2. Key Research and Development Project of Gansu Provincial Department of Science and Technology (22YF7GA107).

References

[1] Niswonger, R. G., Morway, E. D., Triana, E., et al. (2017). Managed aquifer recharge through off - season irrigation in agricultural regions. Water Resources Research, , 53(8), 6970-6992.

[2] Ramanjaneyulu, A. V., Ramulu, V., Ramana, M. V., et al. (2022). Crop performance, water use, economics and energy indices in rabi groundnut (Arachis hypogaea L.) under micro irrigation methods. Journal of environmental biology, (2), 43.

[3] Shi, L., Shi, G., Qiu, H. (2019). General review of intelligent agriculture development in China. China Agricultural Economic Review, 11.

[4] Zhong, H., Sun, L., Fischer, G., et al. (2019). Optimizing regional cropping systems with a dynamic adaptation strategy for water sustainable agriculture in the Hebei Plain. Agricultural Systems, 173.

[5] Li, R., Lin, H., Niu, H., et al. (2017). Effects of irrigation on the ecological services in an intensive agricultural region in China: A trade-off perspective. Journal of Cleaner Production, 156(jul.10), 41-49.

[6] Veerachamy, R., Ramar, R., Balaji, S., et al. (2022). Autonomous Application Controls on Smart Irrigation[J]. Computers & Electrical Engineering, 100, 107855-.

[7] Xing, Zikang., Ma, Miaomiao,. Wei, Yongqiang,. Zhang, Xuejun,.Yu, Zhongbo., Yi, Peng. (2020). A new agricultural drought index considering the irrigation water demand and water supply availability. Natural Hazards, 104(3).

[8] Bhrugubanda, M., Rao, A., Shanmukhi, M., et al. (2021). Sustainable and Intelligent IoT Based Precision Agriculture-Smart Farming. Solid State Technology.

[9] Valikhan-Anaraki, M., Mousavi, S. F., Farzin, S., et al. (2019). Development of a Novel Hybrid Optimization Algorithm for Minimizing Irrigation Deficiencies. Sustainability, 11(8), 2337.

[10] González, Perea, R., Camacho, Poyato, E., & Rodríguez, Díaz, J. A. (2021). Forecasting of applied irrigation depths at farm level for energy tariff periods using Coactive neuro-genetic fuzzy system. Agricultural Water Management, 256.

[11] Zhang, F., He, C., Yaqiong, F., et al. (2022). Canal delivery and irrigation scheduling optimization based on crop water demand. Agricultural Water Management, 260.

[12] Mason, B., M. Rufí-Salís, Parada, F., et al. (2019). Intelligent urban irrigation systems: Saving water and maintaining crop yields. Agricultural Water Management, 226.

[13] Orojloo, M., Shahdany, S., Roozbahani, A. (2018). Developing an integrated risk management framework for agricultural water conveyance and distribution systems within fuzzy decision making approaches. Science of The Total Environment, 627(JUN.15), 1363-1376.

[14] Benyezza, H., Bouhedda, M., Rebouh, S. (2021). Zoning irrigation smart system based on fuzzy control technology and IoT for water and energy saving. Journal of Cleaner Production, 302, 127001-.

[15] Kumar, K. A., Jayaraman, K. (2020). Irrigation control system - data gathering in WSN using IOT. International Journal of Communication Systems.

[16] Boursianis, A. D., Papadopoulou, M. S., Gotsis, A., et al. (2020). Smart Irrigation System for Precision Agriculture - The AREThOU5A IoT Platform. IEEE Sensors Journal, PP(99), 1-1.

[17] Wu, Di., Cui, Yuanlai., Li, Dacheng., Chen, Manyu., Ye, Xugang., Fan, Guofu., Gong, Lanqiang. (2021). Calculation framework for agricultural irrigation water consumption in multi-source irrigation systems. Agricultural Water Management, 244(1).

[18] Zhang, Y., Wei, Z., Lin, Q., et al. (2018). MBD of grey prediction fuzzy-PID irrigation control technology. Desalination & Water Treatment, 110(APR.), 328-336.