Design of Diversified Intelligent Control System for Energy-saving Optimization of Solar Greenhouse in North China

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Abstract Intelligent greenhouse can promote the development of modern agriculture, realize the high quality and high yield of crops, and also bring greater economic benefits. In accordance with the climate conditions in northwest China, a set of intelligent control system for diversified environment of solar greenhouse was designed. The system divides the annual greenhouse control into six stages according to the optimal energy saving. It uses modern detection technology to collect the greenhouse environmental temperature, environmental humidity, soil humidity, CO_2 concentration and illumination parameters under different working modes. It uses programmable logic control technology to realize the data processing of various parameters and the action control of rolling film, wet curtain fan and other actuators. It uses KingView monitoring software to realize the monitoring and manual control of greenhouse environment parameters. The operation results indicate that the control system runs stably and basically meets the control requirements.

Key words Solar greenhouse, Energy-saving optimization, Diversified Control, Intelligent control

1 Introduction

Intelligent greenhouse takes advantage of automatic control technology, modern detection technology, communication technology to automatically adjust the environmental temperature, environmental humidity and soil humidity, so that the growth of crops is always kept in the most suitable conditions, so as to achieve high quality and high yield. This of great significance to solve the problem of winter vegetable supply in Northwest China, North China and other northern regions, to ensure people's living needs and to improve the living standards of Chinese residents[1]. Greenhouses can be simply divided into large modern greenhouses and solar greenhouses. Large-scale modern greenhouse is a production facility widely used in developed countries. It mainly uses artificial heating and modern science and technology to realize intelligent control of temperature, light, humidity and other production environment and production process. The development of intelligent greenhouse technology in China is later than that in foreign countries, and there is a big gap between China and foreign advanced technology in terms of control methods, control technology and control cost[2]. Since the 1960s, China has introduced foreign intelligent greenhouse technology on a large scale three times, but due to the problems of cost, technology and climate adaptability, it is still unable to be applied to modern agricultural production in China. During this period, many scholars in China have devoted themselves to the intelligent research of large-scale glass multi-span greenhouse. The control algorithm has developed from PID control and fuzzy control of single environmental factor to neural network and expert system of multiple variables. Greenhouse regulation can also realize the detection and control of multiple factors, but in modern agricultural production in China, solar greenhouse with low cost and high economic benefits is mainly used[3]. So far, solar greenhouses have rapidly spread to the north of China, greatly alleviating the problem of off-season vegetable supply in the north of China. With the wide application of solar greenhouses and considering the cost, the research fields of most scholars have changed to the structure, materials, heat storage and other aspects of solar greenhouses, in order to develop a highly coordinated solar greenhouse with economic benefits and investment costs through the sufficient sunlight in the northern region combined with solar greenhouse materials, structure and other conditions. Bao Encai *et al.* [4] combined lighting technology with heat storage technology to form a combined technology of active lighting and heat storage, so as to realize "multi-entry and multi-storage" of solar energy in greenhouses. Zhou Changji[5] mainly studied the solar greenhouse with vertical south wall structure, solar greenhouse with variable roof inclination, solar greenhouse with movable thermal insulation and lighting rear roof, and made innovation of the technology of front roof and rear roof of solar greenhouse. Domestic scholars have little research on the regulation of temperature, humidity and illumination in diversified environments. In the future, the development of intelligent solar greenhouse should not only be intelligent, but also scientific, so as to maximize agricultural productivity and achieve sustainable development of high quality, high yield, low consumption and environmental protection. In order to optimize energy saving of solar greenhouse, we mainly started from the following four aspects. (i) The internal environmental control of greenhouse is mainly based on the characteristics of solar greenhouse and the growth needs of crops, and realizes diversified environmental control in different seasons, time

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periods and special needs, so as to make efficient use of control facilities and save economic costs. (ii) The intelligent control of greenhouse is realized by using programmable logic control technology and modern detection technology to replace the traditional relay control circuit, which is convenient to use and saves labor cost. (III) Micro-sprinkler irrigation technology is used for irrigation of crops, and water pressure sensor and frequency converter PID control are used to realize constant regulation of irrigation water pressure and save water resources. (iv) The real-time data display, historical data query, alarm information, fault handling, manual and automatic mode switching, diversified control mode selection of greenhouse environmental temperature, soil humidity, illumination and other parameters are realized by configuration software design, so as to facilitate the staff to carry out modern and intelligent management of greenhouse touch screen and save management costs.

2 Hardware design

2.1 Overall hardware design The hardware system is mainly composed of data acquisition system, programmable logic controller (PLC), host computer monitoring system, analog expansion module, frequency converter and control actuator. The data acquisition system uses sensors to realize the acquisition of environmental temperature, environmental humidity, soil humidity, illumination and CO_2 concentration, and converts analog signals into electrical signals and transmits them to the analog expansion module. The control system adopts PLC, which has strong control function, good expansibility, fast response speed, easy programming and modification, *etc.* It can communicate with configuration software to realize modern management of touch screen and easily meet the requirements of diversified environmental regulation and control. Its function is to adjust the actuator according to the ladder diagram program and the data collected on the spot, so as to maintain the parameters between the upper and lower limits set, and ensure the environmental conditions needed for plant growth and development. The host computer monitoring system can display the real-time value and historical data of various parameters, which is convenient for greenhouse managers to monitor the current greenhouse data and equipment operation status. When the parameter is within the predetermined range, the actuator does not act. The out-of-limit alarm of each parameter is displayed on the host computer. The system uses both automatic and manual control modes. Manual control can be used in special periods or when there are special requirements. The overall hardware design is shown in Fig. 1. Because of the different temperature and humidity needed in the seedling period and different growth periods of crops, most of them have the most suitable range, and most vegetables, melons and fruits do not need a constant amount of environmental parameters, such as the common vegetable cucumber, which requires a temperature difference between day and night, so that it can accumulate nutrients and promote the better growth of cucumber. From the aspect of saving electric energy, the environmental parameters are controlled in a reasonable range, and the advanced instructions of PLC are used to complete the control requirements. In the irrigation system of crops, micro-sprinkler irrigation technology and constant pressure irrigation technology are used. If the conventional flood irrigation needs 6 600 m^3/ha, the micro-sprinkler irrigation technology only needs 1 500 m^3/ha, which can realize water-saving irrigation, and the soil moisture supply is stable, the quality of agricultural products is good and the yield is high. The constant pressure irrigation technology uses the water pressure sensor to collect the pressure at the outlet of the irrigation pump, adopts the frequency converter with PID regulation, uses the PID control algorithm to control the water pressure at the outlet of the pump, realizes the constant output of water pressure, uniform irrigation of crops and efficient utilization of water resources.

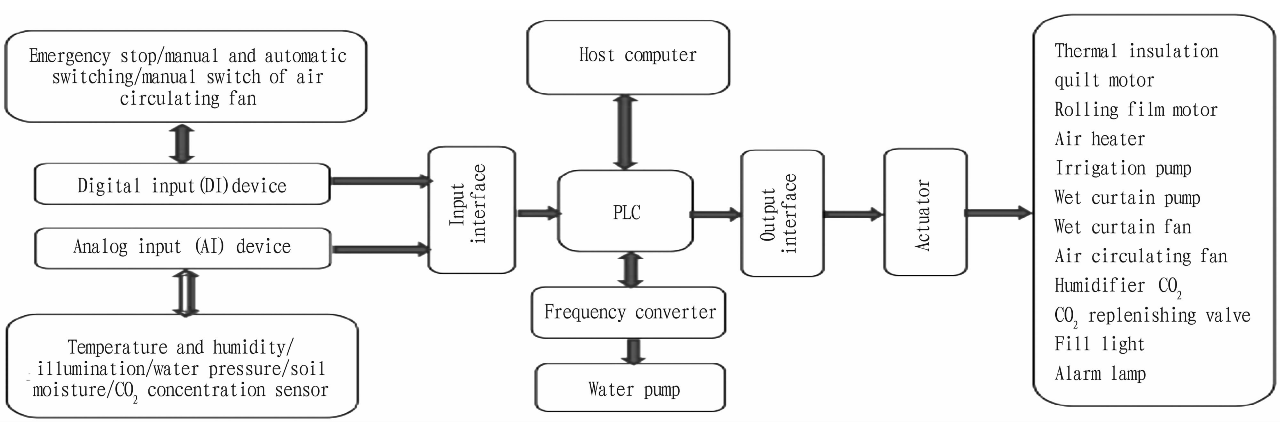

Fig. 1 Overall hardware design

2.2 Configuration and selection of PLC interface The input device and output actuator are determined according to the control requirements of the system, and the PLC digital I/O port and analog input port are allocated to them, so as to clearly show the interface configuration of the PLC and facilitate the connection of experimental circuits and the selection of modules. The distribution relationship of PLC digital input address is shown in Table 1, which can indicate the connection corresponding relationship between the input points I0.0-I2.6 of the host, the input points I0.0-I0.3 of the digital expansion module and the external input equipment, and determine that the system occupies 23 input points of the host and 4 input points of the digital expansion module. PLC digital output address allocation relationship is shown in Table 2, which can indicate the corresponding connection relationship between the output points Q0.0-Q1.7 of the host and the external actuator, and determine that the system occupies 16 output points of the machine. According to the I/O resource configuration of the system, a Siemens S7-200 series CPU226CN minicomputer is selected, which has 24 points of digital input, 16 points of digital output, no analog input and output, input voltage of 24 V DC, power supply voltage of 100 – 230 V AC. The digital expansion module EM223 with 16 inputs and 24 V DC/16 relay outputs is selected to meet the requirements of system control, and a certain margin is reserved for later transformation. The input address allocation relationship of the PLC analog expansion module EM235 is shown in Table 3, which can indicate the corresponding connection relationship between the input points AIW0-AIW6 of the EM235 expansion module and various sensors. EM235 expansion module is the most commonly used analog expansion module, which can realize four analog signal inputs and one analog signal output. This system uses two temperature and humidity sensors, two soil moisture sensors, one water pressure sensor, one illumination sensor and one CO_2 concentration sensor. In order to meet the control requirements, two Siemens EM235 expansion modules are selected. Their acquisition signal input range: current 0 – 20 mA; signal output range: current output 0 – 20 mA; resolution: 12-bit A/D converter; data word format: 0 – 32 000.

Table 1 Digital input address assignment

Input address	Input device	Input address	Input device
I0.0	Rolling film unfolding switch	I1.6	Micro-sprinkler irrigation electromagnetic valve control switch
I0.1	Rolling film folding switch	I1.7	Air circulating fan switch
I0.2	Rolling film unfolding in place travel switch	I2.0	Wet curtain fan switch
I0.3	Rolling film folding in place travel switch	I2.1	CO_2 generator switch
I0.4	Insulation quilt unfolding switch	I2.2	Fill light switch
I0.5	Insulation quilt folding switch	I2.3	Alarm lamp elimination switch
I0.6	Insulation quilt unfolding in place travel switch	I2.4	Emergency stop button
I0.7	Insulation quilt folding in place travel switch	I2.5	Manual/automatic switch button
I1.0	Wet curtain unfolding switch	I2.6	Wet curtain magnetic valve control switch
I1.1	Wet curtain folding switch	I0.0 (expansion port 1)	Thermal insulation and heating mode selection switch
I1.2	Wet curtain unfolding in place travel switch	I0.1 (expansion port 2)	Forced ventilation mode selection switch
I1.3	Wet curtain folding in place travel switch	I0.2 (expansion port 3)	Forced cooling mode selection switch
I1.4	Air heater switch	I0.3 (expansion port 4)	Natural ventilation mode selector switch
I1.5	Pump switch		

Table 2 Digital output address assignment

Output address	Output device	Output address	Output device
Q0.0	Rolling film forward rotation	Q1.0	Wet curtain fan
Q0.1	Rolling film reverse rotation	Q1.1	Fill light
Q0.2	Curtain forward rotation	Q1.2	Alarm lamp
Q0.3	Curtain reverse rotation	Q1.3	CO_2 generator magnetic valve
Q0.4	Thermal insulation quilt forward rotation	Q1.4	Humidifier
Q0.5	Thermal insulation quilt reverse rotation	Q1.5	Irrigation magnetic valve
Q0.6	Air heater	Q1.6	Wet curtain magnetic valve
Q0.7	Air circulating fan	Q1.7	Micro-sprinkler irrigation and wet curtain pump

Table 3 Analog input address assignment

Analog input address	Analog input device	Remarks
AIW0	Temperature and humidity sensor	Measuring the temperature and humidity of the greenhouse space environment
AIW2	Illumiinance sensor	Measuring the illuminance of the greenhouse space environment.
AIW4	CO_2 concentration sensor	Measuring the CO_2 concentration of the greenhouse space environment.
AIW6	Soil moisture sensor	Measuring the moisture content of the greenhouse soil.
AIW8	Water pressure sensor	Measuring the water pressure after the water pump discharges water

2.3 Design of parameter acquisition system The sensor is mainly responsible for collecting the ambient temperature, humidity and other parameters, and converting them into corresponding electrical signals for output[6-7]. Temperature is the key environmental factor affecting plant growth and the most basic factor in plant life activities, affecting all physiological changes of plants[8]. Humidity is another important factor in environmental control and a prerequisite for ensuring plant photosynthesis[9]. In order to reduce the number of sensors and facilitate monitoring, RSWS-I20 temperature and humidity sensor manufactured by Shandong Renke Control Technology Co., Ltd. is used. This sensor has high precision and good stability, can indicate the temperature and humidity values by liquid crystal display, and can monitor the temperature and humidity at the same time. Temperature accuracy of ±0.5 ℃ and humidity accuracy of ±3% RH meet the requirements of agricultural applications. Water is the lifeblood of all plants, and the life activities of plants can not live without water[10]. Sufficient water can make the branches strong, the leaves full and the fruits sweet. With the development of modern agriculture, the requirements for crop yield and quality are getting higher and higher, and it is necessary to know the precise irrigation cycle of crops. The RS-TRZL-I20-1 soil tension sensor of Jianda Renke brand can meet the requirements of the system. The illumination sensor and CO_2 concentration sensor of the system are selected from the brand of Jianda Renke, with 4 – 20 mA current output, and the models are GZWS-120 and CO2WS-I20 separately, and their accuracy meets the requirements of intelligent greenhouse detection and control. Water pressure sensor manufacturer is Suzhou Xuansheng Instrument Technology Co., Ltd., model is PCM300 V1-B1-C-J2, compact pressure transmitter, 4 – 20 mA current output, accuracy class 0.5, meeting the system control requirements.

3 Software design

3.1 PLC control strategy According to the climatic conditions, the first control strategy is the diversification of seasonal control, and the second is the manual control in special periods. The whole year can be divided into the following six stages of control. The first stage is from the middle of March to the beginning of May in spring, and only rolling film is unfolded for natural ventilation. The second stage is from the beginning of May to the middle of June in spring. At the same time, the rolling film is unfolded and the circulation fan is turned on to carry out strong ventilation to realize the exchange of indoor and outdoor air and achieve the purpose of lowering the temperature[11]. The third stage is from the middle of June to the middle of August in summer. At this stage, it is necessary to turn on the circulation fan and wet curtain device at the same time for strong cooling. The fourth stage is from the middle of August to the beginning of September in autumn, and the strong ventilation control is carried out. The fifth stage is the natural ventilation control from the beginning of September to the end of October in autumn. The sixth stage is from the beginning of November in winter to the middle of March in the next spring, in which heat preservation and heating control are carried out.

3.2 Design of PLC The default mode of the system is that it determines the adjustment range of each parameter according to the growth environment conditions of common vegetables and cucumbers. If other crops are planted in the greenhouse, the parameter adjustment range in the PLC program can be modified according to the growth environment conditions of other crops. Cucumber is a typical thermophilic plant with poor cold tolerance, and the suitable temperature for growth is 9 – 32 ℃. The suitable temperature is higher in the daytime, 20 – 32 ℃, and lower at night, 9 – 18 ℃[12]. The ambient temperature of greenhouse should be controlled at 20 – 32 ℃ during the day and 9 – 18 ℃ at night. The temperature difference between day and night can make cucumber accumulate nutrients, thus promoting the growth of cucumber. If the environmental humidity is above 85%, cucumber is prone to downy mildew. Temperature is the most important factor affecting crop growth, which affects the whole growth cycle of crops. The priority of parameter regulation is ambient temperature > soil humidity > ambient humidity > illumination > CO_2 concentration[11].

3.2.1 Ambient temperature and humidity control design. The first stage control: natural ventilation control. From the middle of March to the beginning of May in the northern spring, the temperature in the greenhouse is the highest at about 12:00, which is 27 – 33 ℃[13]. Ambient temperature parameter control range is 9 – 32 ℃, daytime temperature control range is 20 – 32 ℃, and nighttime temperature control range is 9 – 18 ℃. Ambient humidity parameter control range 65% – 85%. At this stage, the outdoor temperature rises gradually, and there is no need for heating and heat preservation measures. The main control purpose is to reduce the temperature and humidity. The common and energy-saving method for temperature and humidity control in the greenhouse is to carry out natural ventilation by unfolding rolling film to reduce the temperature and humidity, and to supplement CO_2.

The second stage control: forced ventilation control. From early May to mid-June in spring, the temperature parameter control range is 15 – 32 ℃, the daytime temperature control range is 20 – 32 ℃, and the night temperature control range is 15 – 18 ℃. Ambient humidity parameter control range is 65% – 85%. At this stage, the outdoor temperature rises gradually, and the temperature in the greenhouse rises significantly from 10:00 to 14:00, mainly for the purpose of cooling and humidity reduction, rolling film unfolding and circulation fan ventilation should be carried out at the same time to achieve cooling and humidity reduction[14].

The third stage control: strong cooling control. From the middle ten days of June to the middle ten days of August in summer, the temperature parameter control range is 15 – 32 ℃, the temperature control range in the daytime is 20 – 32 ℃, and the temperature control range at night is 15 – 18 ℃. Ambient humidity parameter control range 65% – 85%. At this stage, when there is a need for temperature and humidity reduction, the irrigation device and the circulation fan should be started first, and when the soil moisture is sufficient, the wet curtain device can be started again. When the indoor temperature exceeds the upper limit value, the rolling film is closed, the circulating fan is started, and when the soil moisture is detected to be insufficient, the irrigation device is started. If the soil moisture is sufficient, turn on the wet curtain device, and when the temperature in the greenhouse drops to a suitable range, turn off the wet curtain device and the circulation fan. The control flow of the summer forced cooling subroutine is shown in Fig. 2.

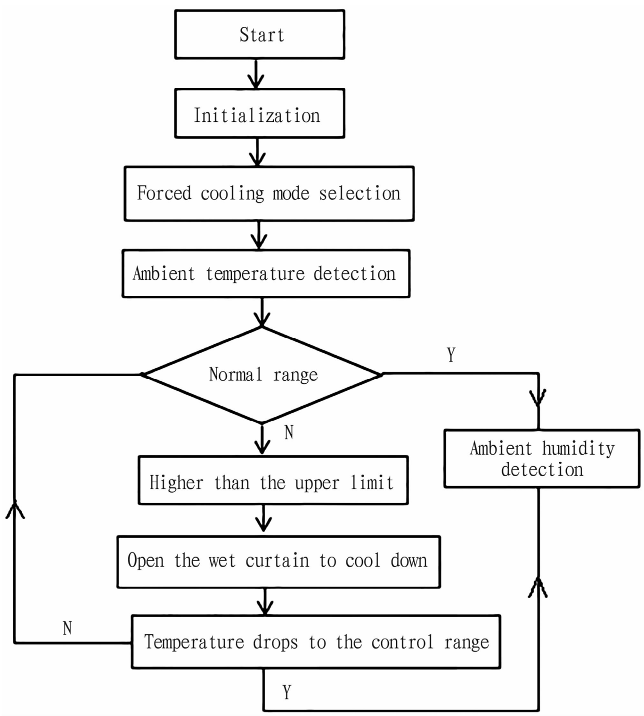

Fig. 2 Control flow of forced cooling subprogram for solar greenhouse in summer

The fourth stage control: forced ventilation control. From the middle ten days of August to the beginning of September in autumn, the temperature parameter control range is 15 – 32 ℃, the daytime control range is 20 – 32 ℃, and the night temperature is 15 – 18 ℃. Ambient humidity parameter control range 65% – 85%. The phase control is the same as the second stage control.

The fifth stage control: natural ventilation control. From the beginning of September to the end of October in autumn, the temperature parameter control range is 9 – 32 ℃, the daytime control range is 20 – 32 ℃, and the night temperature is 9 – 18 ℃. Ambient humidity parameter control range 65% – 85%. At this stage, the control is the same as the first stage control.

The sixth stage control: heat preservation and heating control. From the beginning of November in winter to the middle of March in the next spring, the temperature parameter control range is 9 – 32 ℃, the daytime control range is 15 – 32 ℃, and the night temperature is 9 – 18 ℃. The control range of ambient humidity parameter is 65% – 85%. At this stage, the thermal insulation quilt is manually controlled to be unfolded, and when natural ventilation and moisture removal or CO_2 supplementation are needed, the thermal insulation quilt is folded, and the rolling film is unfolded for ventilation. For example, at noon on a sunny day in winter, the highest indoor temperature can reach 32 ℃. At this time, open the rolling film to ventilate and reduce humidity. When the temperature drops to about 25 ℃, the rolling film is closed so that the greenhouse can store heat. Repeated several times to effectively discharge water vapor and supplement CO_2. A heat preservation and heat subprogram is programmed in a PLC program, and when that indoor temperature is set to be low than the lower limit, the air heater should be started, and when the temperature rise to a proper range, the air heater is shutdown. The control flow of the heat preservation and heating subprogram in winter is shown in Fig. 3.

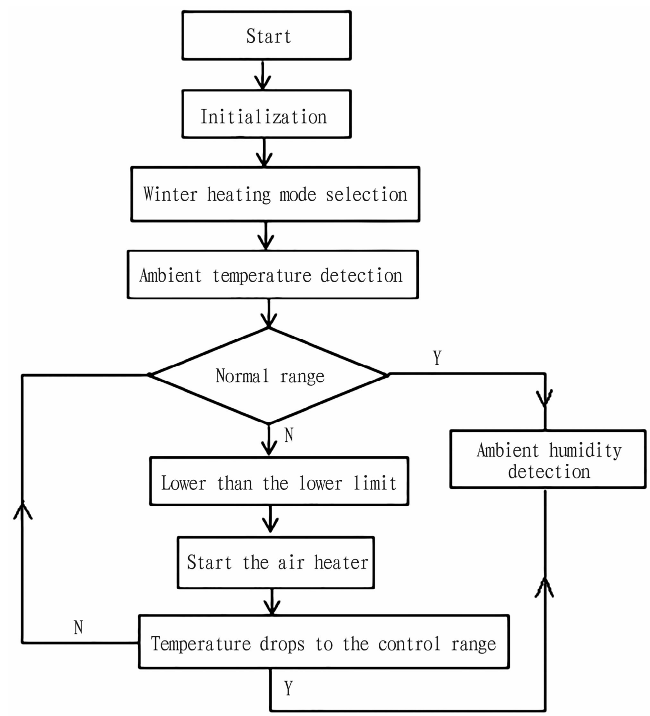

Fig. 3 Control flow of heat preservation and heating subprogram for solar greenhouse in winter

3.2.2 Design of soil moisture control. The control range of soil moisture is 50% – 80%. When the soil moisture is lower than 50%, it is necessary to start the micro-sprinkler irrigation water pump, and when the soil moisture is increased to 80%, the water pump is reset. The control process of soil moisture is shown in Fig. 4.

3.2.3 Other control design. The control process of CO_2 concentration and illumination is similar to the above control. The collected environmental parameters are compared with the set upper and lower limits of the parameters to control the corresponding control equipment[13].

4 Design of host computer software

This system uses KingView 6.55 developed by Beijing Yakong Science & Technology Co. Ltd. as the monitoring system software. The host computer software is designed with the following functions. (i) The real-time parameter query function: it can view the real-time data of each environmental parameter through the real-time parameter display. (ii) Curve query function: the real-time trend of field parameters can be viewed through the real-time curve, and the historical trend of environmental parameters can be

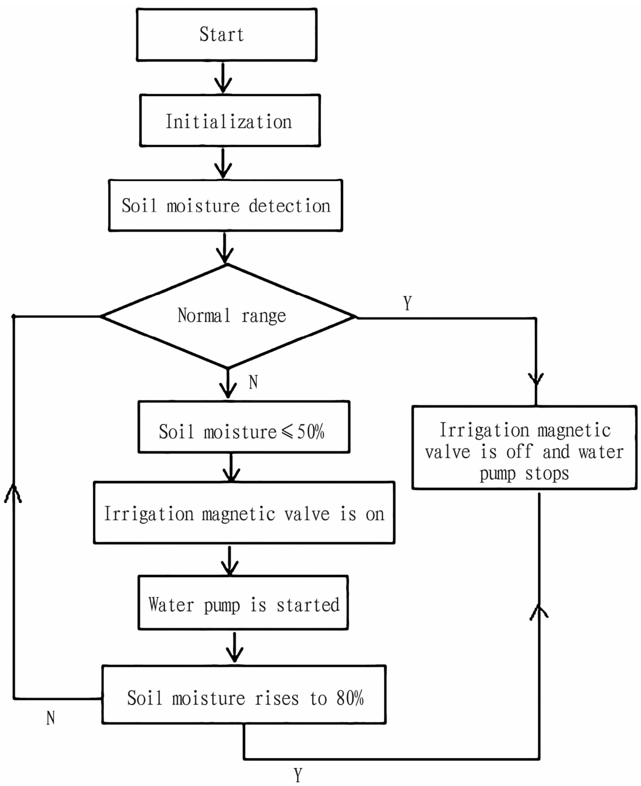

Fig. 4 Control process of soil moisture

viewed through the historical curve[14]. (iii) Data recording function: historical data of environmental parameters can be queried through daily report and historical report. (iv) Alarm function: provide real-time alarm of environmental parameters and query historical alarm information. In the historical alarm window, the user can also set the upper and lower limits of environmental parameter alarm, and set different time periods to query historical alarm information, or set a certain parameter to display historical alarm information. (v) Remote monitoring function: remote monitoring of the operation status of the actuator can be realized through the RS485 communication line, and manual control of actuator action can be realized. The main interface of the system monitoring login is simple to set and easy to operate, and can intuitively guide managers or growers to operate. The main operating buttons are the login and logout buttons. Click the login button, and the login screen appears. At this time, the exit (logout) button is gray and cannot be operated. Enter the set user name and login password, and the screen enters the operation interface of the greenhouse environment monitoring center. Click the Exit button to exit the KingView operating system. The operation interface of that greenhouse environment monitoring cent is designed to be simple, intuitive and easy to operate, and comprises picture switching button such as real-time parameter display, real-time trend curve, historical trend curve, daily report, historical data report, real-time alarm window, historical alarm window, manual control and the like, and a return button, so that an agricultural administrator or a grower can conveniently monitor various parameter data in the greenhouse in multiple aspects, and handle the alarm in time to achieve efficient management. When the system is running, first enter the operation screen of the greenhouse environment monitoring center after login, press the screen switching button to enter the corresponding screen, and press the return button to return to the main login interface of the greenhouse environment monitoring center.

5 Simulation operation results and analysis

On April 20, 2022, a laboratory simulation test was conducted on the system, and the data was monitored through the host computer. Because the room temperature and humidity environment of the experiment is constant, in order to verify the normal action of the control equipment, the appropriate parameter adjustment range is set in the PLC program, and the small lamp on the test bench is used to simulate the control equipment, so as to verify whether the control equipment acts according to the preset requirements. The host computer communicates with the PLC through PPI communication. The PLC communication interface is RS485, the host computer communication interface is RS232, and the two are connected by a signal converter to complete the communication task. The communication parameters of KingView must be set to be consistent with those of PLC. The PLC communication settings used in this system are 7 data bits, 1 stop bit, baud rate 9.6 kbps, even parity check, communication timeout 3 000 ms, and communication mode RS232. The communication setting is completed, and the temperature and humidity environment parameter set is collected. The laboratory ambient temperature was 20 ℃ and the ambient humidity was 56% measured by a thermohygrometer. The real-time data of temperature in KingView monitoring system is 20.2 ℃, and the real-time data of humidity is 56.8%. The temperature and humidity data viewed by the simple thermohygrometer and the KingView monitoring system are basically consistent, because the temperature error of the sensor is ±0.5 ℃ and the humidity error is ±3%, and the temperature error of the simple thermohygrometer is ±1.5 ℃ and the humidity error is ±5%. The KV. HCurve. CtrlX curve control is used to create the historical trend curve, which can be well connected with the KingView history library, and can simultaneously display the historical trend curve of multiple variables, and can also select variables through the history library[15]. Any historical time period can be set to view the curve, and the function of printing can also be realized, which is conducive to storage and analysis. There is a return button at the lower part of the interface. Click the return button to return the interface to the operation interface of the monitoring center. This interface can be very intuitive to observe the data changes in a certain environmental variable in a certain period of time.

6 Conclusions

Based on the concept of energy saving, we designed a diversified intelligent control system for solar greenhouse with energy saving and optimization was designed, which could realize the collection of environmental temperature, humidity and other parameters in the greenhouse and the diversified control according to seasons, time periods and special conditions. With the aid of KingView

(To page 53)

ted according to the method stated above, and the content of lead in the samples was measured as shown in Table 2. The results showed that the content of lead in 6 samples of lime-preserved eggs purchased from supermarket was lower than the detection limit, and the method of determining the content of lead in lime-preserved eggs by microwave digestion instrument flame atomic absorption spectroscopy was feasible, simple and efficient.

Table 2 Test results of lead in lime-preserved eggs

Sample number	Lead content mg/kg	Sample number	Lead content mg/kg
1	Not detected	6	0.088
2	0.151	7	0.114
3	Not detected	8	Not detected
4	Not detected	9	Not detected
5	Not detected	10	0.177

4 Conclusions and discussion

In this study, we established a method for the determination of lead in lime-preserved eggs by microwave digestion-flame atomic absorption spectroscopy. The method showed good linearity in the range of 0 – 4 mg/L, and the detection limit was 0.008 2 mg/kg, which was much lower than the national standard of 0.5 mg/kg for lead in lime-preserved eggs. Taking this limit value as a reference, the applicability of the method was investigated at low, medium and high concentration levels, and the results showed that the recovery rate of the method were in the range of 92.5% – 108.0%. The method was used to test the lead content of 10 groups of lime-preserved eggs sold in the market, and the results were reliable, demonstrating that the method had very good applicability for the detection of lead in lime-preserved eggs.

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software, we developed the environment monitoring system, which realizes the display of real-time parameters and trend curves of greenhouse, the display of historical trend curves, the query of historical data, the monitoring of actuator running status, alarm and so on. It is convenient for growers to monitor and efficiently manage the growth environment of crops, achieve high quality and high yield, and meet the needs of people's lives. We conducted a simulation test in the laboratory and monitored the data through the display screen. The verification test results show that the control system well meets the relevant control requirements.

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