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Design of Intelligent Water-Saving Irrigation Control System Based On Rainfall Forecast

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Abstract:

Based on the current research on lack of water resources and irrigation in China, on the basis of this paper puts forward a intelligent water-saving irrigation system based on rainfall forecast, designed with sensors and the wireless communication module of sensor nodes, the smart irrigation control system, introduced the local weather forecast, the water demand for crops is analyzed, Determine the optimum soil moisture during the growing season and extend irrigation time; Considering whether it will rain in two days, by the matlab fuzzy logic toolkit, designed the fuzzy controller and fuzzy controller, the rainfall tests show that system can independently according to the crop water requirement and weather forecast information to drive the solenoid valve to complete intelligent irrigation, at the same time send farmland environmental information remote control center to set, broke through the regional restriction, It is of great significance for farmers to check farmland soil moisture information to improve the utilization rate of water resources in China.

Keywords: *Water-saving irrigation, Fuzzy control, Rainfall forecast.*

I. INTRODUCTION

In order to solve the above problem, we developed a set of can automatic control, also can manual control, and low consumption, high accuracy intelligent water-saving irrigation system based on rainfall forecast, with spinach as the research object, introducing information web site real-time weather forecast irrigation intelligent control system, USES the ZigBee communication technology, break through the geographical constraints, to avoid the farmland wiring the trouble [1-3]. ZigBee, as a communication protocol with low cost, low power

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consumption, high reliability, high security and low data rate, can well cover a huge planting area and complete the collection and analysis of key information such as light intensity, soil moisture and temperature. As farmland irrigation has the characteristics of large inertia and nonlinear [4,5], it is difficult to use traditional control methods to control, combined with fuzzy control theory, can improve the response characteristics of the system, improve the accuracy of irrigation decision-making. This system regular rainfall and two kinds of fuzzy controller was designed, the first is the conventional fuzzy controller, determine whether need irrigation, when need to irrigation, according to the weather forecast information on the web page again judge whether there is rain in two days, if there are two days of rain, the system will consciously not for irrigation, and waiting for the arrival of the rain, as the current soil moisture and rainfall as the input of the fuzzy controller, the rainfall irrigation duration as the output, drive solenoid valve for irrigation; If there is no rain for two days, a conventional fuzzy controller will drive the solenoid valve for irrigation. At the same time on the terminal, we can also control the size of the threshold, and manually control the opening of the pump valve [6,7]. In this intelligent water-saving irrigation system, taking into account the weather forecast and crop growth characteristics, the on-demand irrigation of crops is realized, which is of great significance for increasing crop yield and improving the utilization rate of water resources.

II. OVERALL SYSTEM DESIGN SCHEME

Water plays a decisive role in the growth of crops, and different crops have different demands for water. This system takes spinach as an example to design an intelligent water-saving irrigation control system. Through literature review, the system set the optimal soil moisture of spinach at maturity stage as 70% RH, which can promote photosynthesis and increase the yield and quality of spinach, and soil moisture below 50% RH is the lower limit of water stress [8].

The system hardware is mainly divided into three parts: centralized control center and sensor node. Sensor node hardware includes soil moisture sensor, rainfall sensor, temperature sensor; the soil moisture sensor is used to collect soil moisture and the rainfall sensor is used to collect rainfall. Centralized control center hardware includes controller, wireless communication module, solenoid valve, relay, PC PC. The controller module mainly controls the opening and closing of the solenoid valve according to the irrigation instructions issued by the PC host computer. The PC host computer is equipped with human-computer interaction interface, including manual irrigation switch, solenoid valve state information, weather forecast information, soil moisture information, etc. The wireless communication module mainly sends the data collected by the sensor to the PC. The overall design scheme of the system is shown in

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Fig 1.

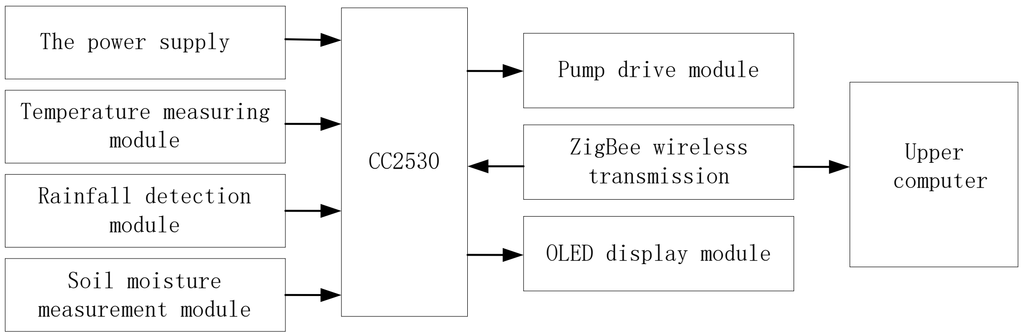

Fig 1: Overall design scheme of the system

III. SYSTEM HARDWARE DESIGN

The centralized control center of the system takes CC2530 microcontroller as the core, and the fuzzy controller of water-saving irrigation has three inputs: current soil moisture, soil moisture deviation and rainfall, and one output irrigation duration. A fuzzy controller with three inputs and one output is established for overall regulation [9-11]. When the system detects rain, the rainfall fuzzy controller is used; when the system detects no rain, the conventional fuzzy controller is used. There are many factors affecting the amount of crop irrigation, such as soil moisture, temperature, light intensity, rainfall and so on. This system mainly considers THE HW-080 sensor to measure soil moisture and rainfall, so as to determine the amount of irrigation. The coordinator is responsible for assisting the terminal to build the star topology network, and the data monitored by the terminal is collected and displayed on the OLED screen, and can also be transmitted to the supreme computer APP for remote monitoring by the user.

3.1 Controller Module

The centralized control center is mainly used to receive and process the farmland soil moisture and rainfall information sent by the sensor nodes, and display and store the data in real time. After processing the data through the fuzzy control algorithm, the irrigation decision is sent to the controller, so as to drive the solenoid valve to implement irrigation. This time, ZigBee core board of E18-MS1-PCB model is used, wherein P0 end, P1.3 end and P1.4 end are all connected to 3.3V voltage source through 10K resistance, so as to provide low level signal stably. The minimum system is built with 256KB ROM and 8K RAM, which can run normally

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when connected to the working power supply at the power supply end and the grounding end. Usually, a capacitor of 0.1uF should be connected between the two ends to increase the anti-interference ability.

3.2 Sensor Module

The humidity monitoring module monitors the moisture content in the soil and displays it on the upper computer to judge whether it is necessary to control the water pump driving circuit for irrigation. Humidity sensor choose HW-080 sensor, because of the sensitivity of soil resistance decreases with the increase of water, to achieve the monitoring of soil moisture.

The function of the rainfall sensor is to detect the relative precipitation outdoors in the real-time home environment. It can detect the real-time raindrop water level in an area of 200mm in diameter under the working environment of temperature: -10℃-50℃ and humidity: 0%-95% without condensation.

3.3 Power Module

This design uses AMS1117 as the main circuit power supply.AMS1117 is a positive voltage output low voltage drop three terminal linear voltage regulator circuit, because of the internal integrated overheat protection circuit and current limiting circuit, can provide safe and reliable power. The function of AMS1117-3.3 chip is mainly used for voltage conversion. The lowest input voltage of this chip is 4.8V, the highest input voltage is 10.3V, and the output voltage of 3.3V can be stable.

3.4 Relays and Solenoid Valves

The water pump drive control circuit mainly uses hk23F-SHG relay. The relay allows a maximum of 24V DC input, and allows through 10A DC, within the safe voltage range, so the relay is selected. It is driven by an NPN triode of model 8050 and protected by a continuant diode of model 1N4007.Because in the interior of the relay is consist of multiple coils and magnets, in the relay electric or lose electric moment will form a powerful induction electromotive force, and the induction electromotive force could be breakdown NPN, therefore, 1 n4007 fly-wheel diode can be instantly slow release of induction electromotive force, so as to protect the triode is reverse breakdown, the induced electromotive force protection effect.

IV. SYSTEM SOFTWARE DESIGN

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4.1 Overall Design of System Software

The system adopts Visual Studio to build a form based on the c # development platform, application as the upper machine controller are used to process the sensor node to receive, on the one hand from the information of farmland soil moisture, rainfall, and the data wireless transmission to the PC for real-time display and storage, on the other hand through fuzzy control algorithm, The irrigation decision is issued to drive the solenoid valve for irrigation. In the design, real-time weather forecast information of the web page is invoked to enhance the intelligence of the intelligent irrigation control system[12] and avoid the waste of water resources and flood disasters caused by rainfall after irrigation. The irrigation process is shown in Fig 2.

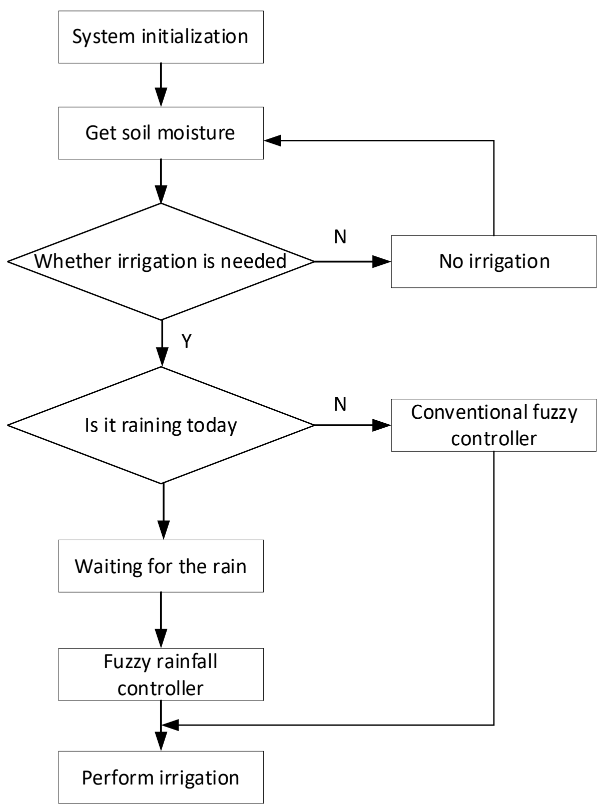

Fig 2: The picture of irrigation grocess

4.2 ZigBee Coordinator Program Design

ZigBee is a low-speed wireless technology. The ZigBee used in China should work in the 2.4ghz working band. Compared with other network technologies, ZigBee has a relatively simple network protocol and a relatively low resource requirement on MCU. In the physical layer and media access control layer, secure and reliable data transmission can be guaranteed. Indirect data transmission is adopted to minimize power consumption. Up to 216 devices can be accommodated within a single ZigBee network.

The coordinator undertakes the important task of communication between the lower computer and the upper computer. By using UART serial communication technology, the information collected by the lower computer terminal is sent to the upper computer, and the threshold value of temperature and soil moisture is changed through the key circuit. Fig 3 is the flow chart of the coordinator. Of hardware circuit is initialized first, secondly, to determine whether there is a button press, if there are buttons to press to MCU main module achievement value, if there is no button press, then determine whether received orders to come from PC serial port, if any, is to judge whether to control command, if is the wireless forwarding, and return to the initial judgment, if not, then directly back to the initial judgment. If no serial command is received, determine whether the time synchronization between the upper computer and the lower computer, if so, synchronize data to the upper computer, and then reset the synchronization time, return to the initial judgment. If there is no time synchronization, determine whether wireless data has been received. If so, cache node data and report to the supreme computer. If no wireless data has been received, return the initial judgment.

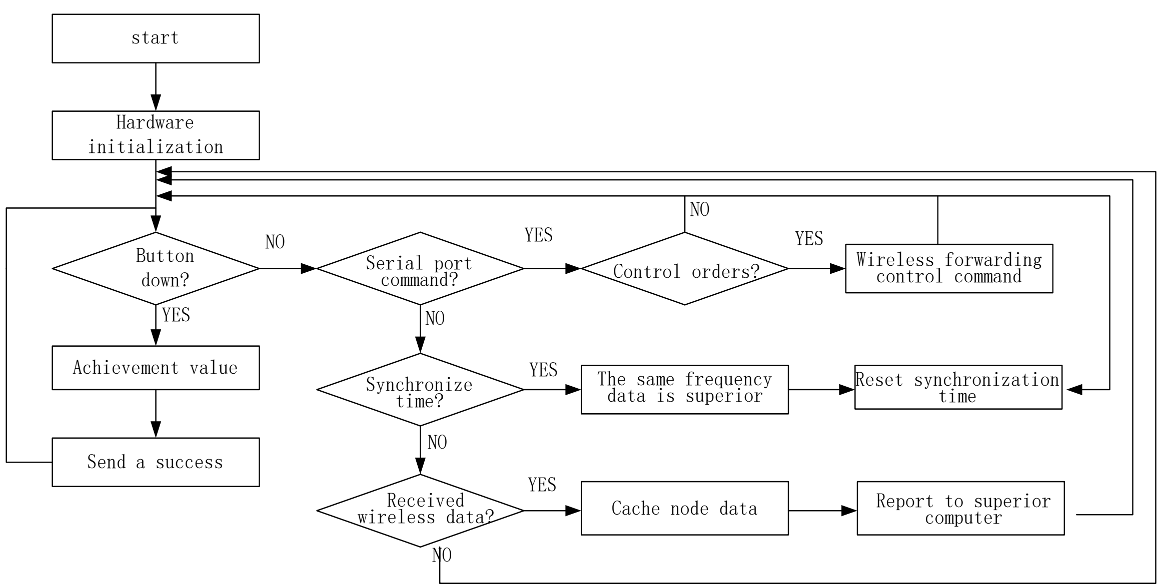

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Fig 3: Coordinator flowchart

4.3 Fuzzy Controller Implementation

4.3.1 System fuzzy control design principle

Fuzzy control system based on fuzzy controller as the core of the intelligent control system, fuzzy controller detection device is first collected value, then the set of fuzzy rules reasoning through artificial experience, the output of a fuzzy set, and finally through the solution of fuzzy, the output of the fuzzy set accurate, and thus drive actuator operates, until meet the system requirements[13-14].There are many factors affecting the amount of farmland irrigation, and soil moisture has the characteristics of large inertia and nonlinear, so it is impossible to establish a mathematical model to control the amount of irrigation. However, fuzzy control does not need to establish an accurate mathematical model, but only needs to formulate fuzzy rules based on previous experience to control the amount of irrigation[15], so it is widely used in farmland irrigation.

The system adopts Mamdani fuzzy controller, whose structure is shown in Fig 4. Its reasoning language is If X is A and Y is B then Z is C.However, there are three inputs in this study: current soil moisture E, soil moisture deviation EC and rainfall RQ;One output: irrigation duration T. Two fuzzy controllers are designed. One is rainfall fuzzy controller, which takes rainfall and current soil moisture as input and irrigation duration as output. The other is the conventional fuzzy controller, which takes the current soil moisture and relative soil moisture as the input, and the irrigation time as the input. When the system detects rain, the rainfall fuzzy controller is adopted, and when the system detects no rain, the conventional fuzzy controller is adopted.

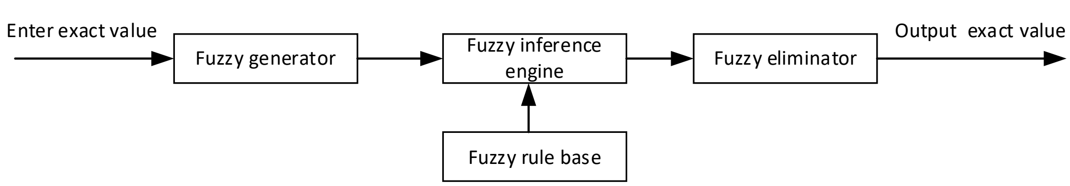

Fig 4: Structure of Mamdani fuzzy controller

4.3.2 Conventional fuzzy controller design

(1) Fuzzification: Fuzzification of the exact input value according to the membership

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function to convert it into the corresponding language value. Firstly, the variables are determined. The fuzzy controller has two inputs: current soil moisture E and soil moisture deviation EC. An output parameter is irrigation duration T, OE is the optimal soil moisture, and EC is expressed in Formula 1:

$$EC = OE - E \tag{1}$$

Second domain range set theory, in the mature period of spinach, for example, to define the current soil moisture field for 70% [10%], mature optimal soil moisture in the range of 65% 75%, the soil humidity below 50% RH for the water stress limit, so define the soil moisture domain of [0, 25] deviation theory, through the experiment to measure soil moisture from 10% RH to 70% RH for 13 minutes, irrigation time needed for irrigation time T so the theory of domain of [0, 13]. Then, the language variables of the current soil moisture E are: very LOW (VL), LOW (LOW), somewhat LOW (RL), relatively suitable (RM) and suitable (MED);The language variables of soil moisture deviation EC were: large difference (BD), large difference (LD), medium difference (MD), small difference (SD), small difference (VD), moderate difference (OD).The linguistic variables of output irrigation time T are: no irrigation (N), very short time (PS+), short time (PS), medium time (PM) and long time (PB).

Finally, the membership function is selected, and the expression is formula 2, whose value is in the interval of [0,1]. Its choice determines the control effect of the fuzzy controller. The input and output membership functions of the conventional fuzzy controller designed in this paper all choose triangles. The membership function of the current soil moisture is shown in Fig 5, the membership function of the soil moisture deviation is shown in Fig 6, and the membership function of the output irrigation time is shown in Fig 7.

$$f(u,a,b,c) = \begin{cases} 0 & u \le a \\ \dfrac{u-a}{b-a} & a \le u \le b \\ \dfrac{c-u}{c-b} & b \le u \le c \\ 0 & u \ge c \end{cases} \tag{2}$$

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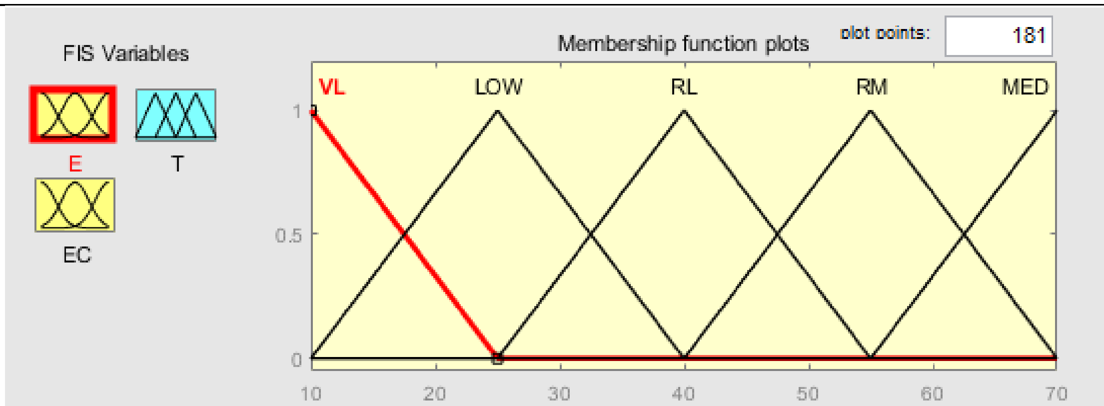

Fig 5: Membership function of current soil moisture

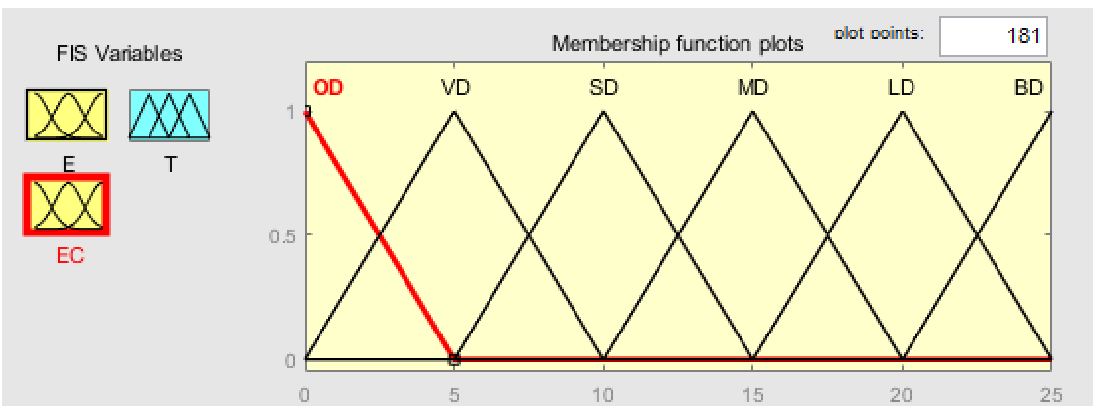

Fig 6: Membership degree function of soil moisture deviation

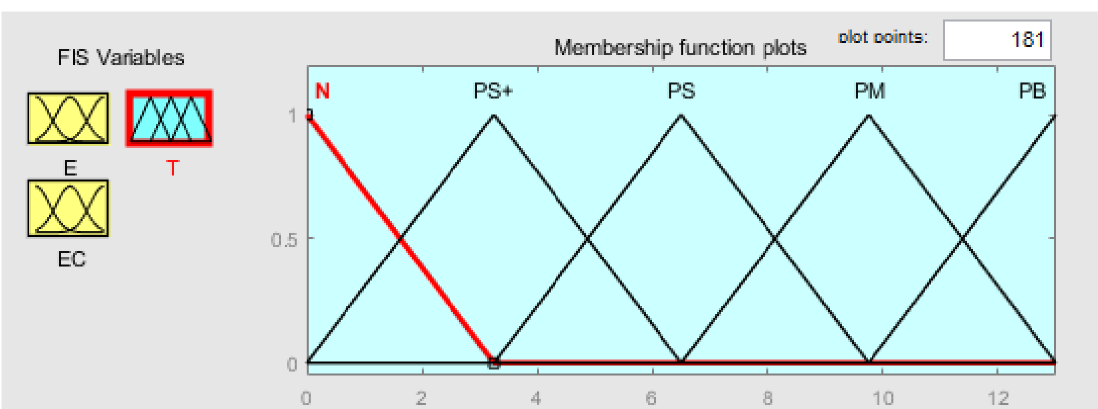

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Fig 7: Membership function of irrigation time

(2) Fuzzy rules

In this paper, based on the optimal soil moisture value corresponding to spinach maturity stage, a fuzzy controller with soil moisture of 70%RH was designed to dynamically control the irrigation time according to demand. This system adopts two input single output fuzzy controller, fuzzy reasoning language is: IF X is A and Y is B THEN Z is C. In the conventional fuzzy controller, the current soil moisture of the input quantity has 5 fuzzy sets, and the soil moisture deviation has 6 fuzzy sets. Therefore, the fuzzy controller has 30 fuzzy rules. The fuzzy rules corresponding to the optimal soil moisture 70%RH are shown in TABLE I.

TABEL I. Table of conventionnal control rules for optimum soil moisture of 70% RH

EC	**E**				
	VL	LOW	RL	RM	MED
BD	PB	PB	PM	PS	N
LD	PB	PM	PS	PS	N
MD	PM	PS	PS	PS	N
SD	PS	PS	PS+	PS+	N
VD	PS+	PS+	PS+	PS+	N
OD	N	N	N	N	N

(3) Fuzzy inference

The operation method of fuzzy inference adopts the minimum operation method (Mamdani), and the expressions are formula (3) and (4) :

$$R_{A\to B} = A \to B = A \times B = \int_{X\times Y} \mu_A(x)\mu_B(y)/(x,y) \tag{3}$$

$$\mu_{A\to B}(x,y) = \min\{\mu_A(x), \mu_B(y)\} = \mu_A(x) \wedge \mu_B(x) \tag{4}$$

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"$\wedge$" and "$\vee$" respectively represent small and large operations.

(4) Defuzzify

The output of the fuzzy controller is a fuzzy set, which must be converted into accurate numerical output by solving the fuzzy before it can be used for irrigation control[16].In this system, the method to solve the fuzzy is area center method, that is, to output the center of the area enclosed by the membership function of the fuzzy set and the abscissa corresponding to the area center is the duration of irrigation. Area center method and Formula 5:

$$u^* = \frac{\int_0^1 u\mu_A(u)du}{\int_0^1 \mu_A(u)du} \tag{5}$$

4.3.3 Rainfall fuzzy controller design

This system introduces the weather forecast into the intelligent irrigation control system. First, it calls the web page to check the weather forecast of the local city and judge whether there will be rain in two days. Through the rainfall sensor, it detects whether there has been rain and the amount of rainfall, and calculates the irrigation duration through the rainfall fuzzy controller[17].The design method of rainfall fuzzy controller is similar to conventional fuzzy controller, but its structure is different. The language variable of the current soil moisture E designed by the rainfall fuzzy controller can be divided into five levels: very LOW, LOW, a little LOW, relatively appropriate and appropriate, which can be abbreviated as {VL, LOW, RL, RM, MED}.The linguistic variables of rainfall RQ can be divided into 6 levels: light rain, moderate rain, heavy rain, heavy rain, heavy rain, heavy rain and extremely heavy rain, which can be briefly written as {SR, MR, DR, RS, DRS, SRS}.The language variable of output irrigation time T can be divided into five levels: no irrigation, very short time, short time, medium time and long time, which can be abbreviated as {N, PS+, PS, PM, PB}.The membership function of the fuzzy set is triangular. Similarly, taking the growth stage of maturity as an example, the membership function of the current soil moisture is shown in Fig 8, the membership function of rainfall is shown in Fig 9, and the membership function of output irrigation time is shown in Fig 10.The area center method is also used to solve the fuzzy problem.

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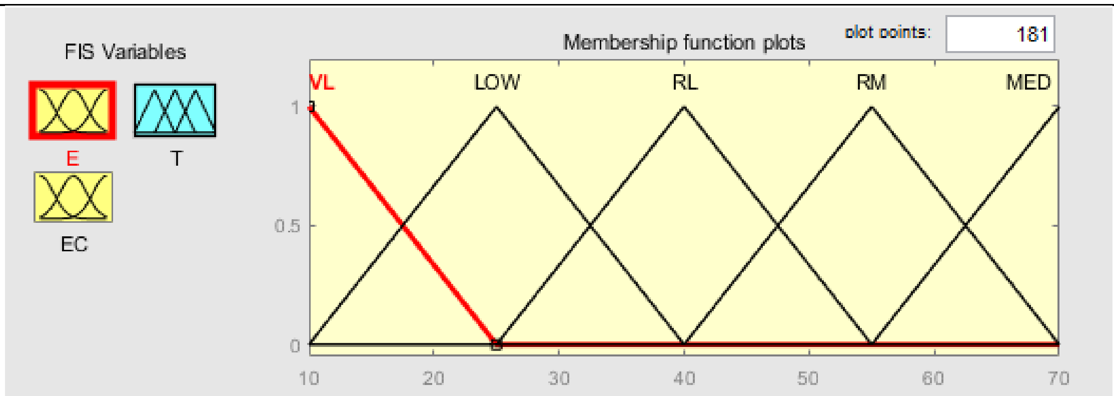

Fig 8: Membership function of current soil moisture

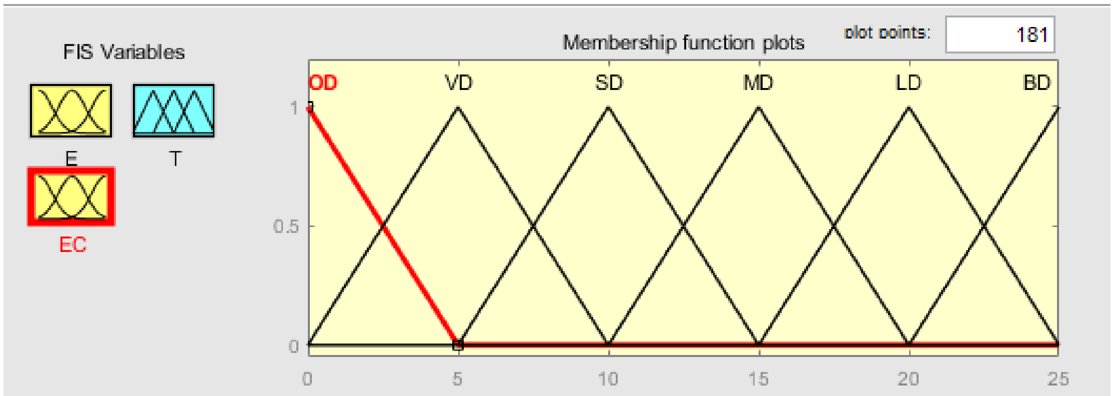

Fig 9: Membership function of rainfall

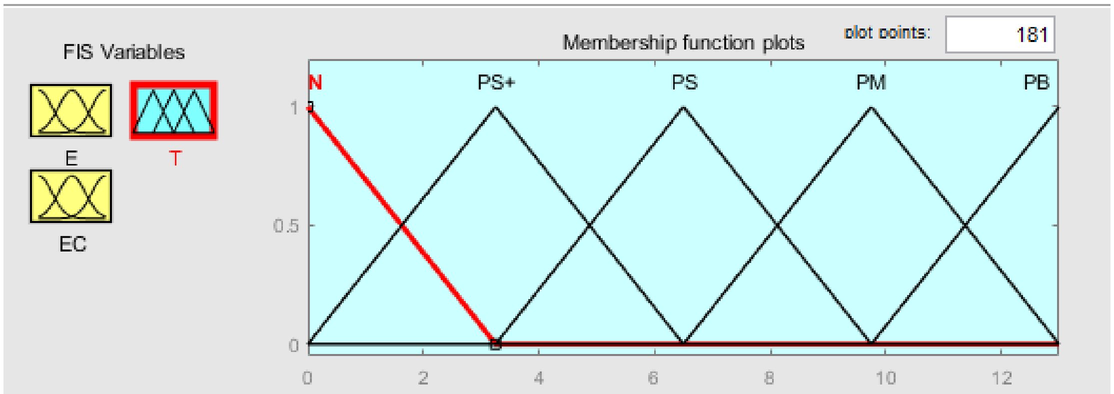

Fig 10: Membership function of output irrigation time

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According to the optimal soil moisture of spinach ripening, the rules of fuzzy rainfall controller established are shown in TABLE II

TABEL II. Table of rainfall control rules with the best soil humidity of 70% RH

RF	**E**				
	VL	LOW	RL	RM	MED
LR	PB	PB	PM	PS	N
MR	PB	PM	PS	PS	N
HR	PM	PS	PS	PS	N
RS	PS	PS	PS+	PS+	N
HRS	PS+	PS+	PS+	PS+	N
EHR	N	N	N	N	N

4.3.4 Establishment of fuzzy controller

This paper uses matlab fuzzy system designer to establish fuzzy controller. Firstly, edit variables. According to the design requirements of fuzzy controller, input variables E and EC, and edit their domain and membership function. Next, input fuzzy rules in the rule box, among which, conventional fuzzy controller and rainfall fuzzy controller both have 30 rules. After the design of the fuzzy controller is completed, the characteristic surface diagram of the input and output can be viewed through the test system bar, and the fuzzy rules of call and the exact value of the output obtained through the fuzzy resolution can be viewed by changing the values of the two input variables. The output characteristic surface of the optimal soil moisture in spinach maturity period is shown in Fig 11 under the conventional fuzzy controller, and that of rainfall fuzzy controller is shown in Fig 12.After the fuzzy controller is designed, the file is saved for the system program to call.

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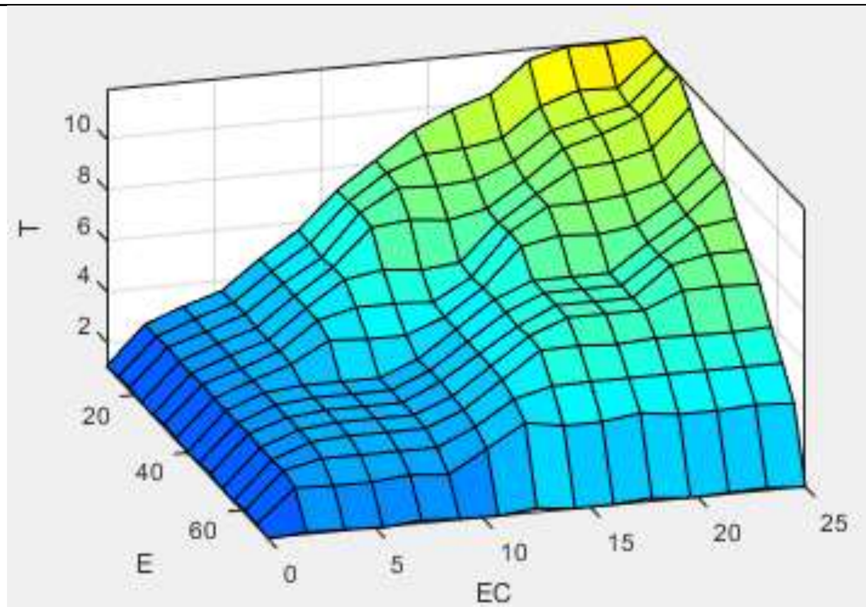

Fig 11: Optimal soil moisture output Characteristic surface of conventional fuzzy controller

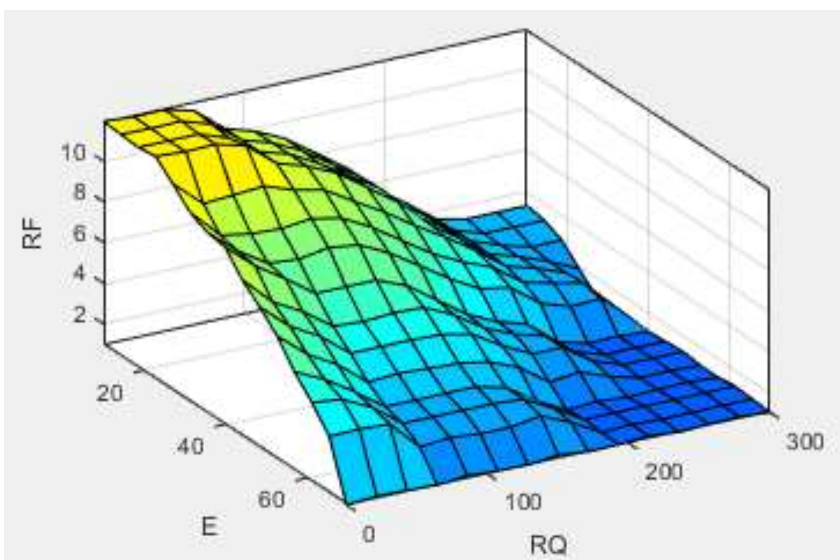

Fig 12: Optimal soil moisture output characteristic surface of rainfall fuzzy controller

4.3.5 Simulation analysis of fuzzy controller

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The simulation model of fuzzy control is established by simulink in MATLAB, as shown in Fig 13. Compared with traditional PID control, the simulation results are shown in Fig 14. The yellow curve represents fuzzy control, and the blue curve represents traditional PID control. The system has better robustness.

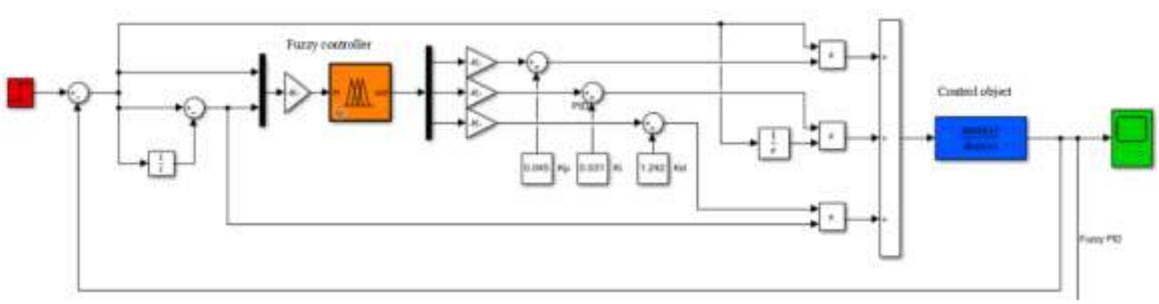

Fig 13: Simulink simulation model

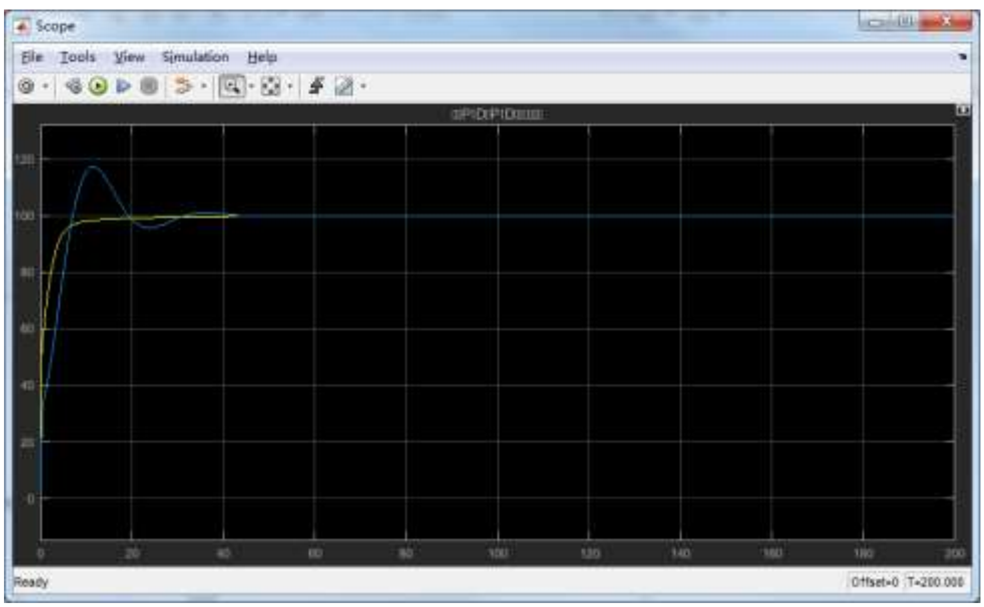

Fig 14: Simulink simulation curve

V. CONCLUSIONS

(1) combined with the actual demand for crop irrigation, use CC2530 microcontroller and ZigBee wireless module, the combination of soil moisture information collected, because irrigation under the influence of rainfall is large, to the introduction of the web site of the local

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weather forecast smart irrigation control system, the data upload first machine, PC after fuzzy algorithm of data processing, After receiving the command, the irrigation control equipment will open the solenoid valve for irrigation. Soil moisture data acquisition, storage and precise control of remote irrigation are realized.

(2) The water demand of spinach was analyzed to determine the optimal soil moisture and prolong the irrigation time; Conventional fuzzy controller and rainfall fuzzy controller are designed to reduce the waste of water resources caused by rain immediately after irrigation.

(3) The combination of ZigBee technology and fuzzy algorithm realizes long-distance and intelligent irrigation. After testing, the system has reliable communication, accurate irrigation control and good operation, which greatly expands the irrigation area, saves costs and reduces energy consumption.

Due to time reasons, this system only collects soil moisture parameters. In subsequent studies, other parameters can be added to collect and the demand for irrigation of spinach in each period can be recorded to form a demand database for irrigation [18,19]. With the acceleration of China's agricultural modernization, intelligent irrigation technology will be widely used and developed in China, and intelligent irrigation will become the mainstream of China's development of water-saving agriculture.

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