RESEARCH ON SOIL MOISTURE DETECTION AND REMOTE PRECISION IRRIGATION OF SEEDLINGS BASED ON INTERNET OF THINGS

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基于物联网的苗木土壤墒情检测与远程精准灌溉研究

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DOI: https://doi.org/10.35633/inmateh-69-42

***Keywords**: Internet of Things, Smart Agriculture, Single Chip Microcomputer, Precision Irrigation.*

ABSTRACT

Smart agriculture, which combines the Internet of Things (IoT) with agriculture, is the future of agricultural development. In China, manual irrigation is currently the dominant method for seedling irrigation management, but it is inefficient and can lead to water waste. To improve seedling quality and output, reduce labor costs, and conserve water resources, this paper presents a design for an IoT system that uses soil moisture detection and remote precision irrigation for seedlings. The system includes a STC12C5A60S2 microcontroller, an ESP8266-01S communication module, a PRISON PR-3000-ECTH-N01 soil temperature and humidity module, and a 12V water pump. The system is connected to the OneNET platform via the MQTT protocol of the Wi-Fi module and includes software modules for data processing, Wi-Fi communication, and relay control. The OneNET platform allows users to monitor and record real-time temperature and humidity data and switch between automatic and manual modes and seedling threshold types. The system was tested for 24 hours and collected 28,000 temperature and humidity data points every 3 seconds with a packet loss rate of less than 5%. The results show that the system is stable and reliable.

摘要

目前我国大部分地区对苗木的灌溉管理多采用人工灌溉，需要进行实地测试和勘察，且对量和时的把握不够科学，容易造成水资源浪费。为极大地减少人工劳动力的成本，合理并高效地利用水资源以及为苗木的生长环境进行控制，进而提高苗木的品质和产出，实现智能化和高收益化。本文研究了基于物联网的苗木土壤墒情检测与远程精准灌溉的实现，并设计了一套采集土壤温湿度并上传至 OneNET 云平台进行实时监控记录，并且可以从客户端进行指令操作进行精准灌溉以及切换工作模式的一套物联网系统。实现温湿度数据采集、数据处理、数据上传、指令下发以及水泵灌溉的功能。系统以 STC12C5A60S2 单片机为驱动芯片，ESP8266-01S 为通信模块，普瑞森社的 PR-3000-ECTH-N01 土壤温湿度模块为采集模块，12V 水泵作为受控模块进行温湿度调节。整个系统通过 Wi-Fi 模组内置的 MQTT 协议便捷地接入 OneNET 平台。对 OneNET 数据可视化进行设计，包括温湿度数据、自动手动模式切换以及苗木阈值类型切换功能，使得客户端界面清晰直观，便于使用者准确了解实时状况并进行精准灌溉。在设计和调试完成后，对系统进行了 24 小时稳定性测试，以每 3 秒采集一次数据，共采集温湿度数据各 28,000 个左右，丢包率低于 5%。结论为系统稳定性准确可靠。

INTRODUCTION

As a large agricultural country, the application of water resources has a fundamental impact on agriculture, even the lifeblood of the country and agricultural industry. China's water resources are relatively poor, lower than the global average precipitation. It has 2.8 trillion cubic meters of fresh water resources every year, with an average per capita water volume of less than 2300 cubic meters, ranking 109th in the world, and accounting for only 1/4 of the world's per capita level *(Liu and Chen, 2022).* One of the objectives of the irrigation system is to track the water demand of crops based on the collected data and drive the water flow according to the expected set demand without the participation of operators *(Sinha and Dhanalakshmi, 2022).*

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As a large agricultural production country, China's agricultural irrigation water accounts for 70% - 80% of the total water consumption. However, the utilization rate of agricultural water is only about 40%, which is far from that of developed countries *(Shen, 2021*).

There are many problems in China's smart agriculture development, such as lack of overall planning, difficulties in data collection and application, low level of scientific and technological investment and informatization, large impact of factor resources on smart agriculture development, and lack of innovative agricultural business models. These should be solved from the top design arrangement, scientific and technological research and development investment, professional talent training, and policy system construction *(Song, 2020)*. The development of smart agriculture is an important part of China's high-quality agricultural development during the 14th Five-Year Plan period and even in 2035. The development of smart agriculture in the future urgently needs to work together in technology development, application demonstration, policy experiment and social experiment *(Zhao, 2021).*

Agricultural digitalization has improved the efficiency and productivity of the industry, and the agricultural IoT is a promising direction for the technological breakthrough of rational resource-saving Agriculture 4.0 *(Solodovnik et al., 2021)*. A UAV part was introduced to collect these environmental data from different areas of the farm, and the developed system can monitor water demand to guide farmers *(Karar et al., 2021).* The form of agricultural IoT is also constantly innovating. The Internet of Underground Things (IoUT) is a new view of IoT. Through testing, ESP8266 nodes were buried in fields of 10 cm, 20 cm, 30 cm and 40 cm, and the nodes programmed by AP (access point) were placed at several distances of 50 cm high. The results showed that the coverage effect of nodes with a depth of 20 cm was better *(García et al., 2019)*. The IoUT consists of sensors and communication equipment, partially or completely buried underground for real-time perception and monitoring *(Vuran et al., 2018).* It is particularly suitable for the IoT systems of irrigation and precision agriculture. Because these devices will not hinder the work of machines and farmers, and will also reduce the physical damage that nodes deployed on the field may suffer, while Wi-Fi allows underground and aboveground communication to provide communication protection *(Garcia et al., 2020).*

IoT is one of the key technologies of Agriculture 4.0. Agriculture 4.0 is still limited in theory and has been shelved for a long time *(Monteleone et al., 2020)*. In smart agriculture, IoT equipment is installed in an open field under harsh environmental conditions, and it may not be able to communicate in time and transmit the acquired data to the server or cloud *(Gzar et al., 2022).* Currently, the main research objects of smart agriculture and agricultural IoT are greenhouse crops, and there is little intelligent system design on seedlings. There are many high-value and high-income seedlings in China, such as camphor, yew and ginkgo, which lack intelligent irrigation systems, have high cultivation costs and poor manual cultivation, and urgently need the input of freshwater intelligent management systems for agricultural precision irrigation, which is essential to improve crop yields and reduce costs, while contributing to environmental sustainability *(Boursianis et al., 2021).* This paper aims to research and design for the defects of the current irrigation mode of seedling class, and build a simple, efficient as well as low-cost intelligent irrigation system with STC12C5A60S2 microcontroller as the core, while compared to the current widely practical STM32 chip-based irrigation system *(Zhang and Guo, 2022).* This system has much lower cost and power consumption, more consideration of economic practicality, and is also more suitable for application scenarios that need to run for a long time, especially seedlings class perennial needs to monitor the soil moisture and irrigation, which can guide the current situation.

The current IoT irrigation system is generally a single operating platform, such as in the Android mobile terminal, IOS system terminal, or computer terminal for terminal monitoring and remote operation, such as "IoT-based automatic irrigation system design and implementation of the system" *(Xia and Wu, 2022),* and "A distributed system for supporting smart irrigation using Internet of Things technology" *(Ahmed et al., 2021)*. Their terminal platforms are the Android cell phone platform, which is limited and lacks flexibility. This system uses the online OneNET platform as the terminal, which is very flexible and convenient as it can be transplanted and practiced on any operating platform. Since the soil environment of seedlings is different in different regions, such as the north is mainly temperate while the south is mostly subtropical, this system has set different seedling thresholds for precise irrigation of seedlings in different regions, which can adapt to different regions and seedling types. Finally, the results show that the paper has the practical reference significance for future research on more diversified intelligent systems of seedlings.

MATERIALS AND METHODS

Overall system design

The Internet of Things is one of the most advanced technologies available, and it can be easily integrated with almost all traditional methods to perform tasks *(Jadon and Singh, 2022)*. The development and integration of sensor technology, high-speed information processing technology, and stable communication technology have provided the foundation for the formation of the Internet of Things *(Seng et al., 2022)*. The soil moisture detection and remote precision irrigation system of seedlings based on IoT is mainly divided into two parts: the client data display instruction control part, and the main control chip MCU part and the controlled end *(Lu et al., 2021)*. For the client part, the system adopts China Mobile's OneNET cloud platform, mainly including the creation of products and equipment, data connection and data visualization interface drawing, to achieve clear and stable display of soil data on the interface. It also includes the buttons, such as system working mode, to ensure that the cloud platform can realize the issuance of data instructions after the user presses a button, thereby realizing information interaction through the Internet and single-chip microcomputer to achieve the cloud control.

For intuitive understanding, the structure diagram Fig. 1 is as follows:

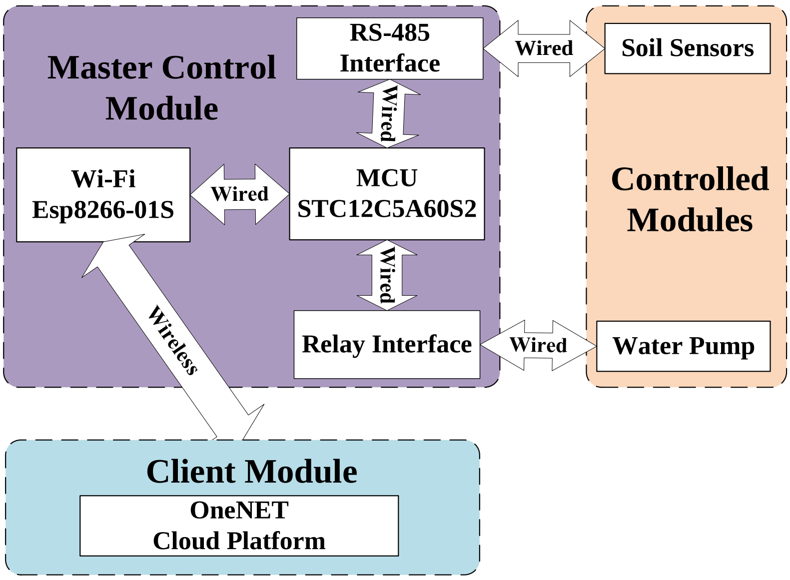

Fig. 1 - System structure diagram

MCU of the main control chip includes the MCU using STC12C5A60S2, the Wi-Fi mode ESP8266-01S chip, the soil data acquisition part of the RS-485 interface and the relay part connecting the water pump for irrigation control. The programming part is mainly to program the STC12C5A60S2 single chip computer to realize the communication and control of the Wi-Fi module, sensor module and relay module, so as to realize the system design. The single chip computer connects the instructions sent by ESP8266-01S through the serial port and connects to the OneNET platform. Through the serial port, the single chip computer sends the data frame request to the RS-485 soil sensor to obtain the real value after the sensor data analysis.

Each module works together to realize the system design. The intelligent irrigation system is generally divided into three parts: client cloud platform, master chip control and terminal execution equipment. The client is the platform module that customers can see and use. The client used in this system design is China Mobile's OneNET cloud platform. The instructions of the OneNET cloud platform are all open sources, and the details of both data upload and instructions can be clear.

The main control module is composed of the single chip MCU, single chip STC12C5A60S2, Wi-Fi module ESP8266-01S, relay interface and RS-485 interface. MCU, as the core, sends commands to each module for communication. The controlled end is the final command realization end. RS-485 sensor is selected for data acquisition according to the requirements in this design. The sensor can sense and will detect the sensed information and output regular signals to achieve stable transmission and convenient processing of information.

System hardware design

The hardware is mainly the main control module and the controlled module, including the physical connection and working principle of the MCU STC12C5A60S2, the Wi-Fi module ESP8266-01S, the relay pump, the sensor and more.

Selecting a single chip computer is the first and one of the most important steps in system design. To meet the design requirements, the main selection indicators are RAM, ROM and serial port. The system needs a set of serial ports to communicate with each other in order to realize the data collected by RS-485 soil sensor and sent to the single-chip microcomputer; then the network transmission is carried out through the Wi-Fi module. The single chip also needs to communicate with the Esp8266-01S and a set of serial ports for communication. As a result, at least two sets of serial ports are required for independent communication, and STC12C5A60S2 dual-serial port single chip microcomputer is selected to enhance its performance. On a single chip, STC12C5A60S2 provides flexible and effective solutions for many embedded control application systems with a smart 8-bit CPU and in-system programmable Flash.

The soil sensor data communication adopted by this system is based on the RS-485 protocol. The main control chip of RS-485 module is MAX485 chip, which mainly realizes signal conversion. Through MAX485 chip, TTL-signal and RS-485-signal can be stably converted to achieve data transmission. RS-485 communication has many advantages. When a specific RS-485 device exchanges data with a single chip computer through an interface, it first converts the TTL and RS-485 signals in two directions through the MAX485 chip. The interface at both ends of the chip is the standard RS-485 interface A/B interface, which connects the A/B line of the sensor respectively. The other end of the chip is the RS-485 communication direction control terminal used to control the data transmission direction and the RX/TX terminal used to communicate with the single-chip computer. Of course, the soil sensor needs to share power and ground with the SCM, and can use the power and ground of the SCM power module to achieve stable work, as shown in Fig. 2.

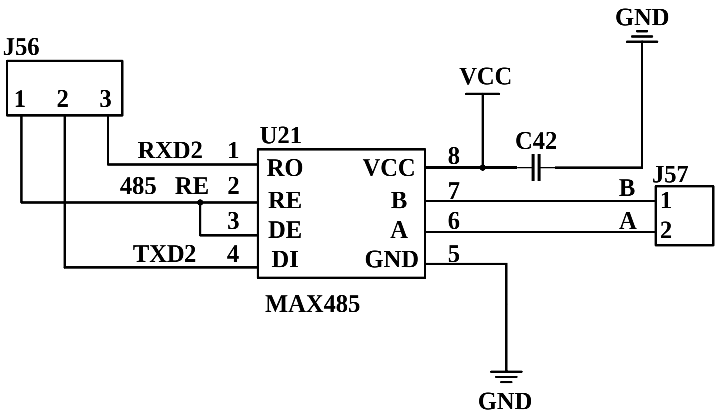

Fig. 2– RS-485 interface schematic

The system uses the PR-3000-ECTH-N01Ver 2.0 model RS-485-soil temperature and humidity sensor of Prison, with stable working performance and high sensitivity and accuracy. Through measuring the dielectric constant of the soil, the moisture content and temperature value of the soil can be directly obtained, which conforms to the international standard measurement method. The working voltage of the sensor is 4.5V-30V DC; the working temperature is -40°C~+60°C, and the protection grade is IP68. The product specification is 45*15*123 mm, and the output signal is RS-485 signal, as shown in Fig. 3.

Fig. 3 – RS-485 soil temperature and humidity sensor

The baud rate it supports is 9600 bit/s, 2400 bit/s and 4800 bit/s. Modbus protocol is a serial communication protocol, and the data is sent and received in the form of data frame. A frame message of Modbus protocol includes address code, function code, data and CRC check code. When there are multiple devices, the communication device can be determined according to the address code; the function code indicates the function of sending instructions to the host, and the device only uses the function 0x03 to read register data.

Wi-Fi serves as the foundation and hub of Internet of Things (IoT) implementations, due to the increasing popularity of smart products, rapid advancements in wireless technology, and upgrades to various communication interfaces. The use of WI-FI technology and wired network for integration and networking to realize IOT can greatly reduce costs *(Qiu, 2017).* The design of this system uses the chip ESP8266-01S as the Wi-Fi module. It is developed and manufactured by the Ai-Thinker company, and the main frequency supports 80 MHz and 160 MHz. The built-in TCP/IP protocol stack can realize TCP transparent transmission. It supports local firmware upgrade and cloud OTA upgrade, and local firmware burning and upgrading have been performed for ESP8266-01S in the design of this system. ESP8266-01S has three working modes, STA, AP and STA+AP, for selection. The working voltage is 3.0-3.6 V, and the typical value of 3.3 V is generally used for power supply. The ESP8266-01S firmware of this system needs to be burned, and the firmware burning needs to use the Download Tool GUI instruction software. After entering the software, ESP8266 Download Tool is selected to choose the bin file to be burned at the corresponding address, and then some indicators corresponding to the ESP8266-01S to be burned are set. SPI SPEED selects 40MHz; SPI MODE selects DOUT mode; FLASH SIZE selects 8Mbit, and then the baud rate setting. The default baud rate of ESP8266-01S is 115200. If the baud rate of ESP8266-01S has been set previously, the set will be changed. The pins of ESP8066-01S are shown in Fig. 4.

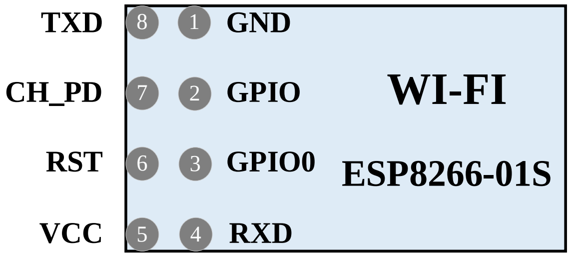

Fig. 4 - ESP8266-01S pinout

Relay is an electrical controller with two parts: control system and controlled system. It uses weak control voltage to control high voltage and high current equipment when working and is widely used in automatic control circuits. As shown in Fig. 5, P1 has three ports: NC normally closed end, COM common end and NO normally open end. It is only necessary to connect the positive and negative poles of electrical equipment such as water pump to COM end and NO end to realize on-off control. J15 terminal is the trigger signal terminal, which can be connected to any I/O port on the single chip computer to realize the high- and low-level control of power-on or not. The schematic diagram of relay is shown in Fig. 5:

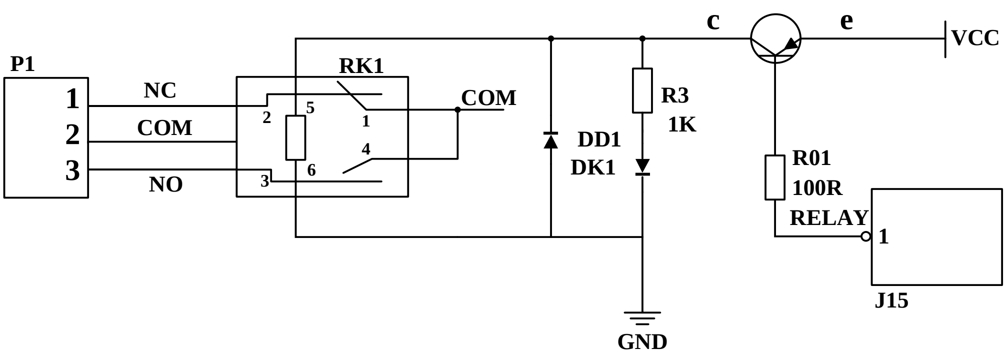

Fig. 5 - Relay schematic

System software design

The software design and programming of this system are all implemented in Keil uVision5 software, using C51 programming language. The program is mainly divided into main function module, serial port 1 module, RS-485 module, serial port 2-module, timer module and delay function module.

The total function of the code is that the microcontroller obtains the soil temperature and humidity data collected by RS-485 sensor through serial port 2 module, and sends it to OneNET cloud server through serial port 2 and displays it through data visualization. The client can control the irrigation system by issuing commands based on real-time soil data to achieve remote control of IoT.

The general structure of the program is shown in Fig. 6. The main function module is used to call other module functions to realize the design: serial port 2 module code part, serial port 2 and RS-485 soil sensor are connected through MAX485 chip interface, so the function of serial port 2 is to obtain the data of soil sensor. The program includes serial port initialization; serial port sending function and serial port interrupt function. When the serial port receives the data, it will have an interrupt request and enter the interrupt. The serial port sending data function should meet the requirements of RS-485 to send the inquiry frame. One frame of data is 8 bytes and needs to control the direction. The interrupt service function is called when receiving the data sent by the sensor, and uses the judgment method of timeout reception to determine whether a frame of data has been received. After acceptance, it will be stored in a register to wait for decoding.

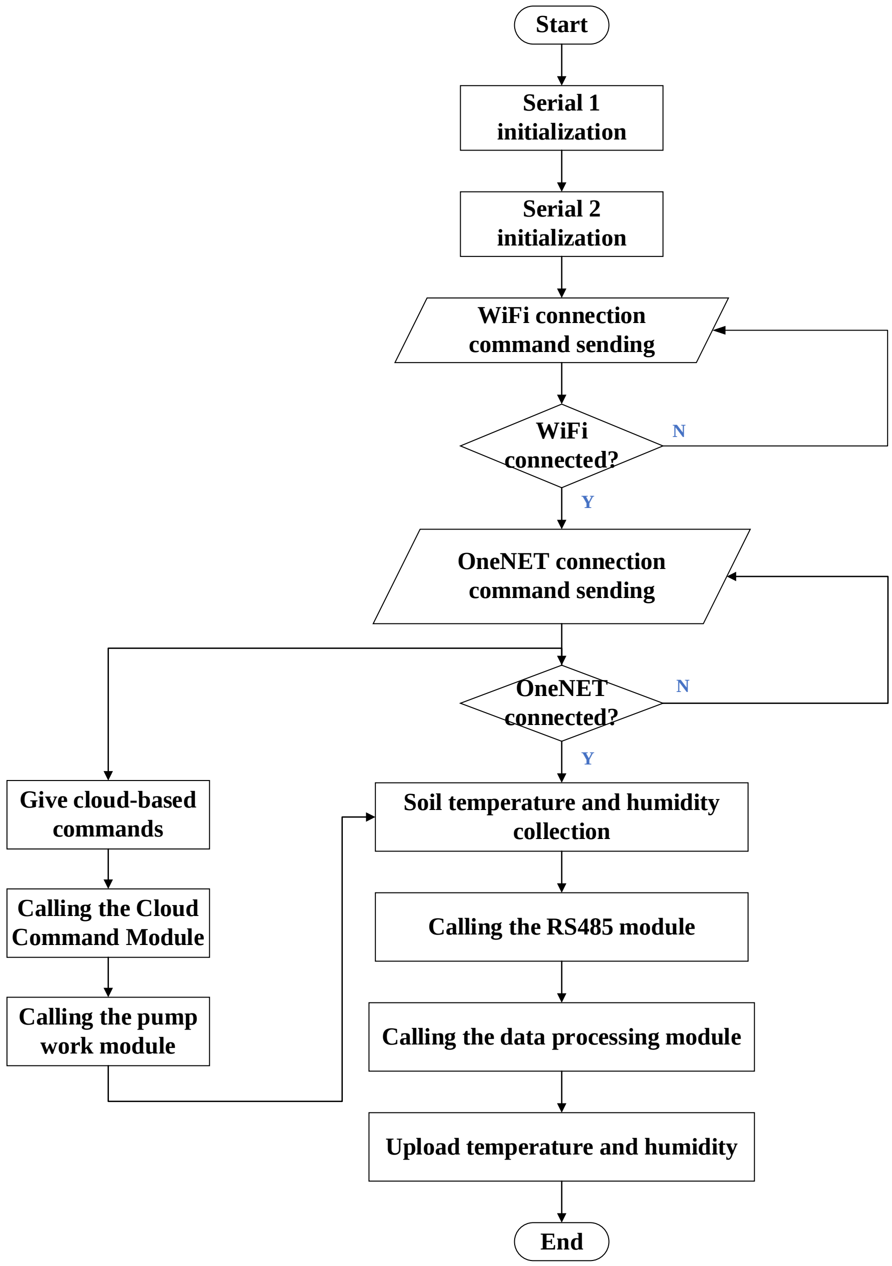

Fig. 6 - Data receiving and processing structure

Designing a data decoding program is a guarantee of data accuracy. Modbus data processing function, whose main function is to calibrate the data read from the sensor by the single chip computer and converts it to the decimal real value. The data obtained from the sensor is hexadecimal, and the first step is to convert it to decimal, for example, for the hexadecimal data *abcd(H)*, the humidity decimal value is:

$$H = abcd(H) = a \times 16^0 + b \times 16^1 + c \times 16^2 + d \times 16^3 \quad (1)$$

The true value of humidity data h is:

$$h = H/1000 \quad (2)$$

The temperature data also needs to be converted from hexadecimal to decimal first, and when the temperature is positive, the data is transmitted in the true form as follows:

$$T_p = abcd(H) = a \times 16^0 + b \times 16^1 + c \times 16^2 + d \times 16^3 \quad (3)$$

When the temperature data is negative, the data is transmitted in two's complement, as follows:

$$T_n = -(2^k - T_p) \quad (4)$$

K is the data length in binary, and the data length in this system is 16, so k is 16. The true temperature value conversion formula is as follows:

$$t = T/10 \quad (5)$$

H and T are the byte values after processing in the data processing program. The flowchart is shown in Fig. 7.

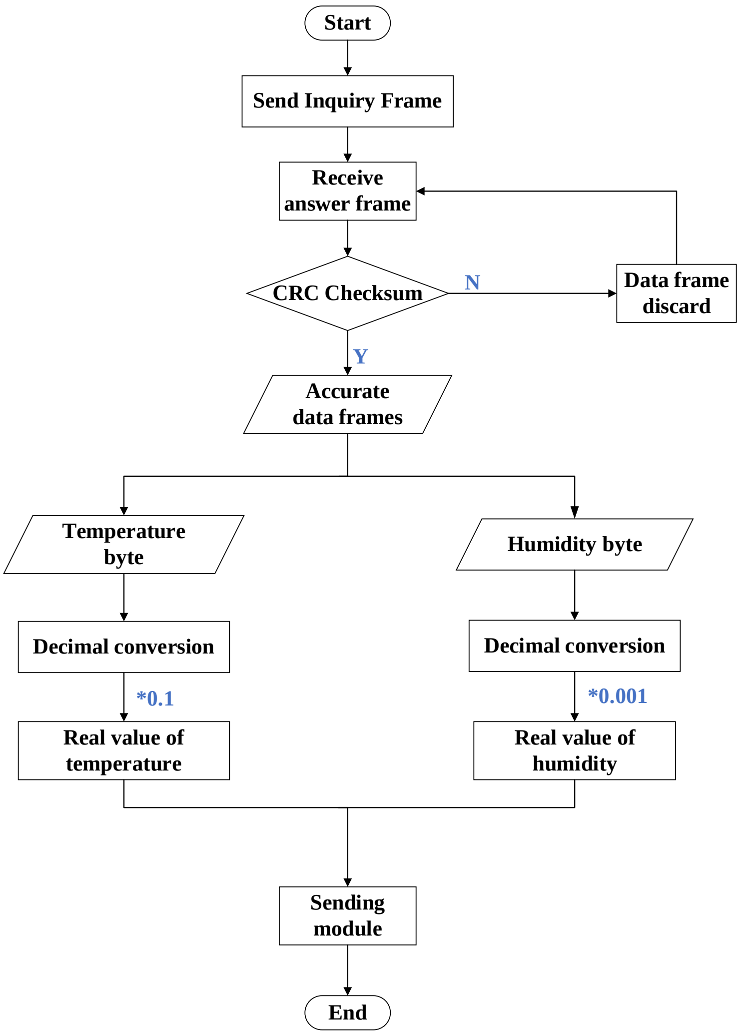

Fig. 7 - Data receiving and processing structure

The CRC checksum used in the figure is calculated as follows. The data byte is divided into an information segment and a check segment, and the length of the code word is set to N, the information field is L bits, and the check field is R bits $(N=L+R)$. There exists and only exists a polynomial of order R $g(x)$.

$$V(x) = A(x)g(x) = xRm(x) + r(x) \quad (6)$$

where *m(x)* is the original information polynomial of order *L*, *r(x)* is the checksum polynomial of order *R-1* and *g(x)* is called the generating polynomial.

$$g(x) = g0 + g1 \times 1 + g2 \times 2 + \ldots + g(R-1) \times (R-1) + g(R) \times R \quad (7)$$

The sender generates the CRC code word by the specified g(x), and the receiver verifies the received CRC code word by this g(x). With this calculated checksum, abnormal transmission data can be discarded.

The system has two working modes: automatic mode and manual mode. Taking the variable Mode as the flag bit, it is automatic mode when Mode=0, and the default is automatic mode; when Mode=1, it is manual mode. When the temperature is greater than the set threshold Value_Temp_H or the humidity is less than the set threshold Value_Humb_L, the water pump working flag Water_pin will be triggered to achieve automatic irrigation. When the temperature is less than the set threshold value_ Temp_ L and the humidity is greater than the set threshold Value_Humb_H, it will be set to zero and the irrigation will be stopped. In this design, four seedling thresholds, yew, ginkgo, poplar and sandalwood are set. When instructions are sent on the OneNET client, it will judge and accept the instructions and assign the threshold of temperature and humidity to switch different seedling thresholds. At startup, the default threshold value is set such that the pump will automatically start pumping water when the humidity is less than 40% or the temperature is greater than 25°C. Conversely, the pump will automatically stop pumping water when the humidity is more than 50% and the temperature is less than 21°C. In manual mode=1, only the two control commands OPEN and CLOS are the instructions for pump on/off respectively. The flowchart in automatic mode is shown in Fig. 8:

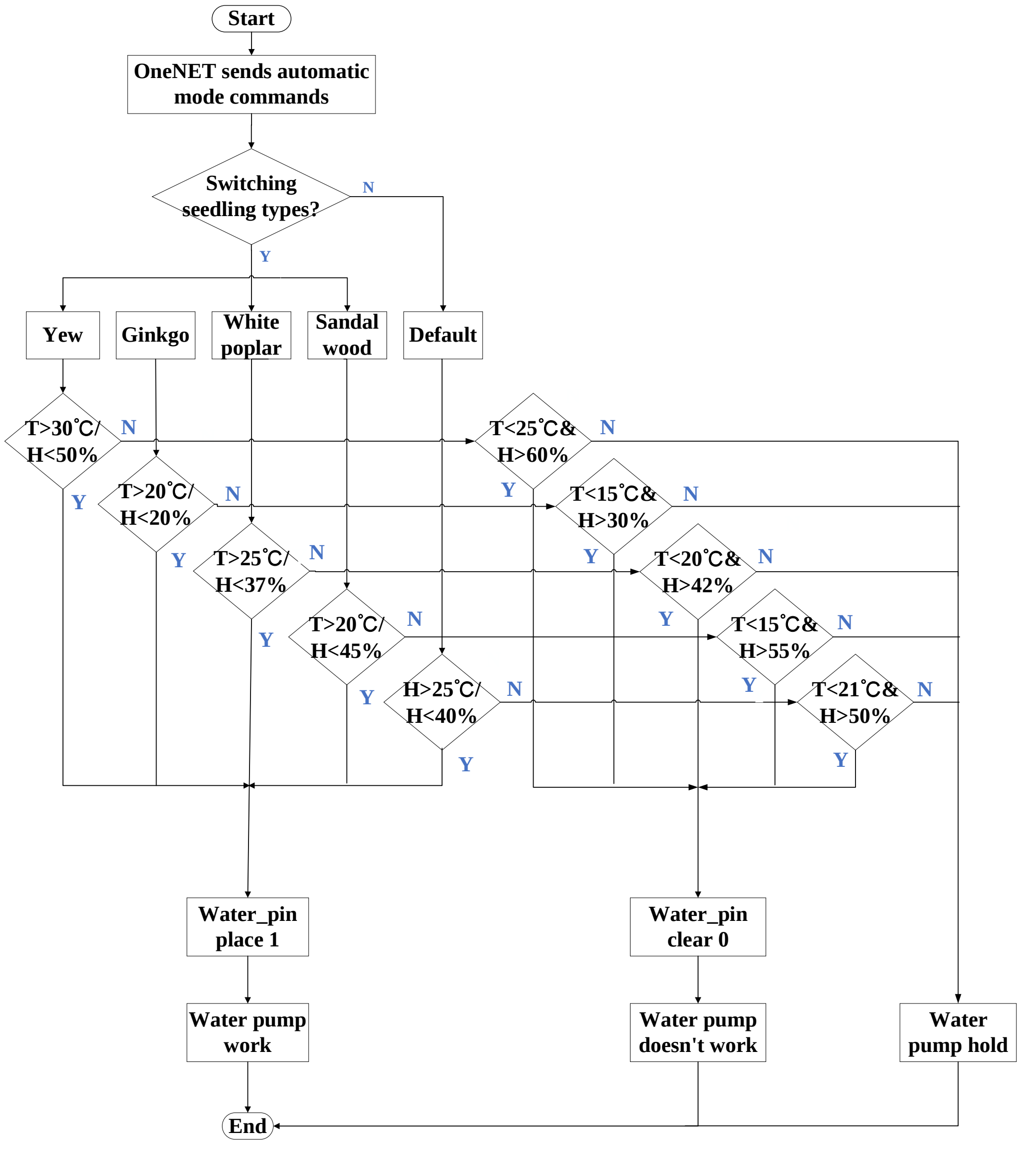

Fig. 8 - Automatic mode flowchart

The client adopts the OneNET platform and carries out visual design. OneNET provides a wealth of data visualization tools, including drag-and-drop editing, 3D project support, various industry templates, and multi-data source docking, which can greatly facilitate and beautify the design interface, and be applied in smart furniture, smart agriculture, water conservancy and hydropower. The open OneNET as an open service platform is used to reduce the development difficulty, save the development cost and shorten the development cycle *(Zhang and Chen, 2020)*. To make the data display and command control more humanized, a data visualization interface with some components and data interface connectivity is designed. The components mainly use control switches, instrument panels and line diagrams. Data filtering is required in data connection, and the filter functions of temperature and humidity instrument panel and line chart are shown in Fig. 9:

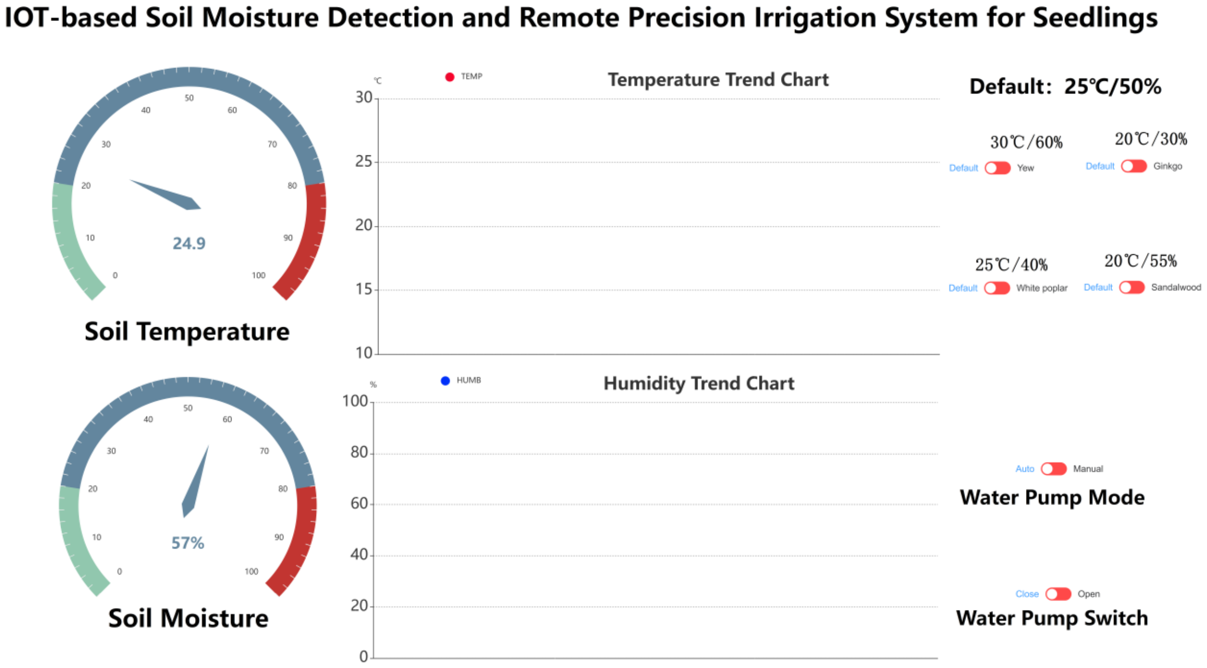

Fig. 9 - OneNET client data visualization interface

RESULTS

After the system design is completed, the function and stability of the whole system are tested to determine whether the system can meet the requirements of the actual working environment. According to the 24-hour test, it mainly tests the ability of the system to work for a long time and the ability of data control accuracy. According to the 24-hour records, the temperature and humidity data are exported to the EXCEL file. The data is updated every three seconds, and the sampling test is selected due to the huge data. The data are shown in Table 1, Table 2 and Table 3, respectively:

Table 1

Test data 1

Time	2022-05-13 00:00	2022-05-13 02:00	2022-05-13 04:00	2022-05-13 06:00
Temperature / °C	17.8	17.5	17.2	17.5
Humidity / %	55.0	54.4	54.0	53.3
Water Pump	Off	Off	Off	Off

Table 2

Test data 2

Time	2022-05-13 08:00	2022-05-13 10:00	2022-05-13 12:00	2022-05-13 14:00
Temperature /°C	18.0	19.0	20.1	20.2
Humidity /%	53.0	38.0	58.0	57.6
Water Pump	Off	On	Off	Off

Table 3

Test data 3

Time	2022-05-13 16:00	2022-05-13 18:00	2022-05-13 20:00	2022-05-13 22:00
Temperature /°C	27.0	19.6	18.3	18.0
Humidity %	56.5	56.0	55.8	55.4
Water Pump	On	Off	Off	Off

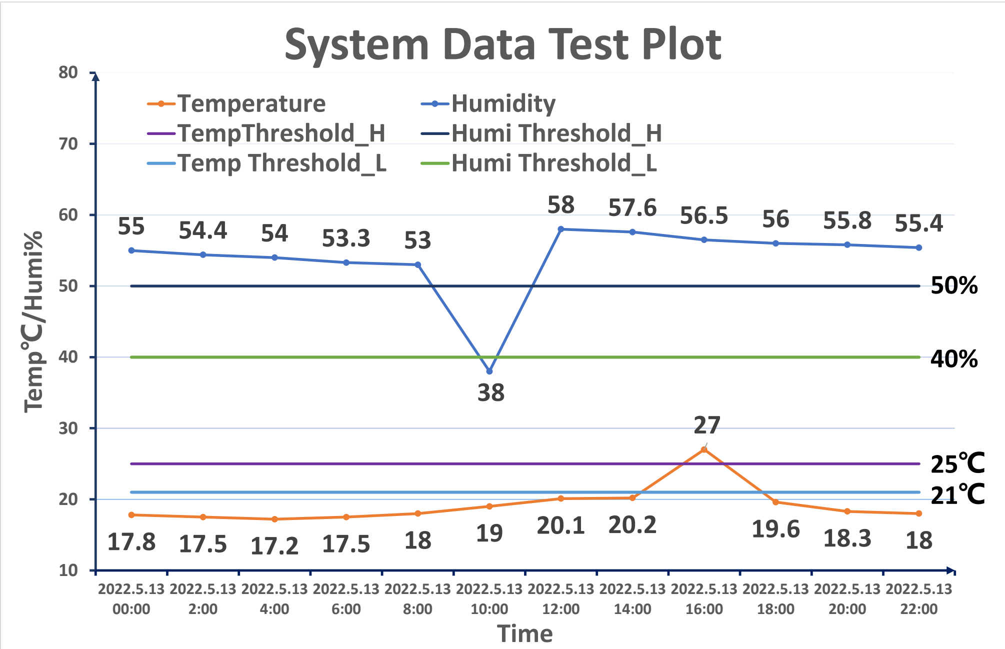

Fig. 10- System test data line chart

In addition, to visually display the changes of each data, the corresponding data line chart is made as shown in Fig. 10. At 10:00 on May 13, human intervention reduced the soil humidity to 38%, and the default automatic mode was automatic watering when the temperature was higher than 25°C or the humidity was less than 40%. When the temperature was lower than 30°C or the humidity was higher than 50%, the watering would be stopped. Therefore, it can be seen from the data that the system has completed the set function. The same intervention was also carried out at 16:00 on May 13. The sensor was pulled out of the soil and held by hand to make the temperature rise to 27°C, and then inserted into the soil, which also triggered the water pump to work and raised the humidity to 70.5% and reduced the temperature to 19.6°C. The system stability was tested for 24 hours, and the data was collected every 3 seconds. A total of 28000 temperature and humidity data were collected, and the packet loss rate was less than 5%. The conclusion is that the system is stable, accurate and reliable without obvious deviation of data, and the system can work stably for a long time and meet the test requirements.

Compared to the study on the precise irrigation system of a blueberry garden based on LoRa and SVM-Markov *(Wu et al., 2022)*, which requires the purchase of corresponding hardware equipment that uses LoRa technology, and has a high computational complexity in the SVM-Markov algorithm that necessitates high-performance computers, this system uses ESP8266-01S as the basis for IOT implementation. It utilizes the STC12C5A60S2 microcontroller as the main control chip, and is easy to operate. In terms of management and maintenance complexity, the LoRa and SVM-Markov system orchards requires regular maintenance and management, and requires technicians to monitor and maintain the system. Our system is very simple and efficient in maintenance due to its simple structure and easy operation. Limited scope of application: The LoRa and SVM-Markov system orchards has a limited scope of application and cannot meet all irrigation needs; Our system is designed with automatic and manual modes for various seedling types and can be programmed to modify the optimal irrigation thresholds for various seedlings and realize the irrigation needs of different seedlings.

Compared with the design of smart planter remote control system based on STM32 and OneNET cloud platform *(Zhang and Guo, 2022)*, the use of STM32 chip is more costly and not suitable for low-cost application scenarios; at the same time, the power consumption is not suitable for application scenarios that need to run for a long time. This system adopts STC12C5A60S2, which has lower cost and is suitable for low-cost application scenarios, especially for seedlings, which need to be applied in large quantities, and cost control is an important factor. The STC12C5A60S2 also has higher operating frequency and faster digital input/output response time. The STC12C5A60S2 also has a more flexible way to build the system, supporting multiple programming modes, such as assembly language and C Programming Language, for more diversity in system programming to suit different conditions.

CONCLUSIONS

1) A seedling soil moisture detection and irrigation system based on WI-FI and OneNET cloud platform is proposed and designed. The system can update soil data in real time with high accuracy and convenient operation. It is applicable to many different seedlings and can be switched between manual and automatic modes. The user is simple to operate, and the operation can be synchronized at the computer end, tablet end and mobile phone end.

2) Taking ESP8266-01S as the basis for the implementation of IoT, STC12C5A60S2 single chip microcomputer as the main control chip to make each module communicate with each other, the soil temperature and humidity detection and remote precision irrigation system based on IoT are realized. The system design structure is reasonable, and the data packet loss rate is less than 5% with certain promotion and application value.

3) Taking the OneNET platform as the client, the data visualization interface is designed to accurately display real-time data and issue commands, and realize wireless, long-distance and real-time monitoring of seedling soil. The intelligent level of soil environment monitoring is improved, and intelligent irrigation of other types of crops also has certain reference significance.

ACKNOWLEDGEMENT

This research was funded by the Henan Provincial Science and Technology Research Project (No. 212102110207), 2021 Henan Science and Technology Commissioner Project, Collaborative Education Project of Ministry of Education (No.220505078205656, No.220503880205011), and the National Natural Science Foundation of China (No.32202096) . We were very grateful to General Manager Ma Junpeng (Hele Nursery Field, Mangshan Town, Yanshi City) for the experimental site provided.

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