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Original Article

Application of Information Collection and Control System Based on the Internet of Things in Smart Agriculture

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Abstract - *Agricultural production is becoming increasingly intelligent and technological with the continuous advancement of science and technology. With the improvement of people's living standards, the demand for high-quality agricultural products is increasing, and the production of high-quality agricultural products is inseparable from precise agricultural management. The agricultural Internet of Things is vital in smart agricultural management due to its powerful multi-device, user and data collaboration functions. This paper designs an intelligent agricultural control system based on the ESP8266 WiFi module. The system aims to promote the transformation of traditional agriculture to precision agricultural practices. The system uses STM32F103c8t6 to integrate temperature and humidity, soil moisture, light intensity and carbon dioxide sensors, communicates data through low-cost ESP8266 WiFi, and manages data on the OneNET cloud platform. Users can realise data visualisation and historical data viewing through PC Web or mobile apps and remotely control the agricultural environment. The system adopts an integrated data acquisition node design, significantly reducing smart agricultural deployment's cost and complexity. The OneNET comprehensive data management platform comprehensively monitors and controls the agricultural environment, providing convenience for user management. The experimental results show that the system has excellent stability, accuracy and reliability. If the WiFi is disconnected, it can automatically reconnect within three seconds to ensure the continuity of data collection. The IoT-based environmental monitoring and control system in smart agriculture simplifies the user's supervision of the agricultural environment, reduces the cost of deploying the smart agricultural system, and improves the feasibility of precision agricultural management.*

Keywords - *ESP8266, Internet of things, OneNET, Smart agriculture, STM32.*

1. Introduction

With the rapid development of IoT technology, the Internet of Things (IoT) has been widely used in various industries worldwide. The connection between things and people has become a relatively mature technology [1]. IoT is an indispensable part of the data interaction process of smart agriculture. Applying IoT to agricultural production can realise the real-time transmission of data collected from the agricultural environment during the production process and upload the data information to the IoT cloud platform to help agricultural managers manage and control the agricultural environment in real-time, thereby quickly responding to and optimising agricultural production decisions [2].

As shown in Figure 1, a deployment diagram of the smart agricultural information collection and control system, a complete smart agricultural structure should cover four parts: cloud service layer, terminal layer, network layer, and data collection layer [3]. The data collection layer mainly deploys sensors in different agricultural environments, such as animal husbandry and greenhouse agriculture. It uploads data to the cloud through wireless technology gateways such as WiFi, Bluetooth, GPRS, 5G, and LoRa at the network layer. The cloud server integrates big data, artificial intelligence, virtual services, databases, etc., to conduct a comprehensive data analysis and finally presents the results to the user terminal [4].

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The user terminal reversely regulates the agricultural environment through automatic analysis and decision-making, thus forming a brilliant agricultural information collection and control system. IoT technology can optimise the overall layout of smart agricultural information collection and control. By optimizing the deployment of collection nodes, end-to-end accurate collection from the plant end to the data collection end can be achieved, thereby reducing the deployment cost of the smart agricultural collection end and improving the economic benefits of agricultural production. The IoT cloud platform is the terminal for smart agricultural data management. The IoT can manage data collected from different sensors, such as agricultural environmental temperature and humidity, soil moisture, light intensity, CO_2 concentration, and other agricultural data information that are inseparable from plant health growth. This information data can be aggregated and displayed through the cloud platform for data report display and historical data storage to form valuable analysis reports [5].

Agricultural managers can remotely view real-time data on farmland environments through mobile devices or computers on the IoT cloud platform and predict agricultural environmental conditions by retrieving historical data for analysis. Through analysis and prediction, the agricultural environmental control system can be manually triggered on the IoT cloud platform, or the system can automatically operate the agricultural environmental control system according to the set threshold. For example, the data collected by the soil moisture sensor is uploaded to the IoT cloud platform through the wireless network for data visualisation and storage. Agricultural managers can retrieve the historical data stored in the cloud platform to predict that the current moisture content will be lower than the soil moisture threshold required for optimal plant growth as it evaporates. Therefore, the irrigation system is manually turned on remotely through the cloud platform interface, and the system automatically turns off the irrigation system when the soil moisture content reaches the optimal requirement. In addition, the system will automatically start or shut down the irrigation system based on the pre-set threshold through real-time data uploaded to the cloud platform, thereby achieving fully automated management of the agricultural environment. The application of the IoT cloud platform enables agricultural managers to understand the real-time data of the agricultural environment without having to go to the site in person, reduce the intensity of manual inspections, improve plant growth efficiency, save production costs, and enable agricultural managers to manage the agricultural environment efficiently.

In precision agriculture, the intelligent agricultural information collection and control system based on the Internet of Things is increasingly important to promote agricultural scientific and technological progress and improve production efficiency [6]. There are three main problems in the development of the entire system technology. The first is to find the most suitable IoT cloud platform for smart agriculture among the various IoT cloud platforms. Second, the deployment cost of smart agriculture is high, and the deployment cost should be reduced. Third, the choice of IoT communication network for deploying smart agriculture.

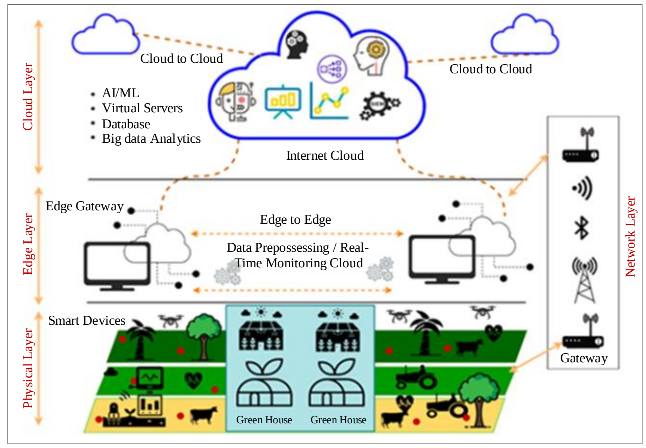

Fig. 1 Deployment diagram of smart agriculture information collection system

1. Various cloud platforms are at different development levels, and choosing a suitable cloud platform for smart agricultural information collection and control systems is crucial.

IoT cloud platforms that can meet powerful functions need diverse communication protocols, diverse data displays, strong data processing capabilities, diverse device development protocols, and developer-friendly and detailed development documents. These are the basic conditions for selecting IoT cloud platforms. As shown in Table 1, seven current mainstream IoT cloud platforms are selected from the current IoT cloud platforms for comparative analysis. The selection of IoT cloud platforms cannot be analysed from one aspect. They should be selected according to development needs. AWS IoT and Microsoft Azure IoT Suite have substantial advantages in data visualisation, data processing and communication protocols, and their uses cover the current industries that can deploy IoT. However, since they each use separate small servers, the deployment cost is relatively high, and professional knowledge is required in development, which is not very friendly to some developers. Ubidots is an industrial-grade IoT cloud platform [11]. Most external data processors used to deploy IoT environment management are industrial-grade PLCs, so they are unsuitable for developing smart agricultural projects. Lelylan and Blynk are limited in their data visualisation and data processing capabilities. They are small IoT cloud platforms that can be used to develop single data collection systems. However, when the collected data is large, and the number of deployed sensor nodes increases, their data processing functions cannot meet the needs. Both ThingsBoard and OneNET IoT can deploy smart agriculture, but in terms of the richness of data visualisation, OneNET has rich data visualisation components and cloud servers. It has rich development documents for developers. It is a professional IoT cloud platform for devices. It does not require additional access to development equipment and provides fast access solutions and device management services for various hardware terminals. Therefore, choosing OneNET to develop the smart agriculture system for this project is more appropriate. This project design uses the OneNET IoT cloud platform to solve the data visualisation and control of the smart agriculture system on the PC side. In addition, the OneNET official website provides mobile APP data visualisation software, which creates a multi-sensor interface to display the data change status and agricultural manager control buttons to achieve one-click control of the agricultural environment.

2. Control the deployment cost of the agricultural smart management system and improve managers' acceptance.

The deployment cost of most smart agriculture is relatively high. To control the cost of agricultural production, agricultural managers generally have a low acceptance of smart agriculture, which limits the development of smart agriculture to a certain extent. Complete smart agriculture, under the premise of perfect infrastructure (power supply and network), needs to purchase various sensors, network communication equipment, data storage and processing units, processors, and automatic execution equipment. The total cost is a considerable expense. It is only used by large agricultural companies. It is unsuitable for small and medium-sized agriculture because the cost is too high. To solve the above problems, the smart agricultural information acquisition and control system designed in this paper adopts a node integration design to replace the data sensor with an integrated communication function. As shown in Figure 2, by integrating temperature and humidity, light intensity, and air quality sensors with ESP8266 WiFi and STM32 to form a data acquisition node, a medium-sized agricultural environment places different sensor acquisition nodes in different locations and uploads data to the cloud platform by connecting to the router.

In addition, the OneNET cloud platform has a dedicated server without purchasing data storage separately, which greatly facilitates the deployment of smart agricultural information collection, and the design of the integrated acquisition node reduces the deployment cost. Table 2 shows the cost of purchasing integrated data collection sensor nodes. A traditional single data collection sensor with an integrated communication function costs MYR50, and a medium-sized smart agriculture deployment requires more than a dozen such sensors, so the deployment cost is very high. However, a router can connect up to 64 sensor nodes with an integrated WiFi function, and the price of a router is only MYR90, which can greatly reduce the deployment cost [14].

3. Select the appropriate communication network for the smart agriculture information and control system and the hardware equipment to build it.

The current smart agricultural data transmission mainly relies on two networking methods for data collection and transmission. One is the relatively mature wireless sensor networks such as Zigbee, LoRa, WiFi, and 5G. The other is to use a single data acquisition sensor with an integrated communication function to collect and transmit data through wireless networks such as Zigbee, LoRa, WiFi, and NB-IoT [15]. As shown in Table 3, the main features of wireless communication technology in agricultural management, through feature analysis and comparison, are crucial to selecting a suitable data transmission network for deploying smart agriculture. WiFi provides a higher data transmission rate and is suitable for applications that transmit large amounts of data. It is widely popular. Almost all smart devices support WiFi, which is easy to integrate and use. The technology is mature, the degree of standardisation is high, the compatibility is good, and it supports multi-device connection. It can connect multiple devices simultaneously and is suitable for small agricultural environments. The fifth-generation communication technology (5G) infrastructure cost is high, and the current coverage is mainly concentrated in urban areas, while the coverage in rural areas is still expanding. ZigBee is suitable for transmitting small amounts of data but not for applications requiring high data rates. It is generally suitable for applications within a local range. NB-IoT (narrowband Internet of Things) is suitable for simple sensor data transmission but not large data volume applications. The latency is high and may not be suitable for applications that require real-time response. LoRa (long distance) is only suitable for small data transmission, not video or audio streaming. It may be interfered with by other devices in some environments. However, wireless sensor network systems such as Zigbee, LoRa, WiFi, and 5G all need dedicated data transmission nodes to access the Internet during data transmission. This networking method is relatively complex in data transmission, with low data transmission efficiency and large latency. There is often a possibility of data loss. In addition, data management is relatively complex, and the uniformity of data management is poor. In order to save development costs, ESP8266 WiFi was selected because WiFi has the characteristics of high speed and can carry a large amount of data. The data transmission layer used in this design transmits data to the OneNET platform through the built-in WiFi of ESP8266 and finally presents it to the user end. Another function of ESP8266 is to process the collected data as a control device. However, due to the limited internal data space of ESP8266, once the number of sensors increases and the amount of data is large, it is easy to cause data loss. Therefore, STM32 can also be added as a controller in the system design, and ESP8266 can be used as WiFi to send data to improve the data processing capability of the system.

Table 1. The seven current mainstream IoT cloud platform

Platform	Communication Protocols	Data Visualization	Data Processing	Development Agreement	Document	Top Use Cases
Lelylan [7]	HTTP, MQTT, APIs	No Built-in Processing Capabilities	No Built-in Processing Power	Webhooks, Websockets	Github Repository Documentation	Smart Home Smart Cities HVAC
Blynk [8]	MQTT	Dashboards and Widgets	No Built-in Processing Power	MQTT	Supports Simple Device Registration, Status Monitoring and Control	Smart Home HVAC
Things Board [9]	MQTT, HTTP, CoAP, LwM2M, SNMP	Dashboards and Widgets	External, through Kafka Streams	Limited, Platform Integration Feature Required for Some Platforms	Platform Website	Smart Metering Smart Energy Smart Farming Fleet Tracking
AWS IoT [10]	HTTP MQTT Websockets, LoRaWAN	AWS IoT Dashboard	Real-Time Analytics (Rules Engine, Amazon kin e Four Sounds, AWS lambda)	Websockets	REST API	Smart City Connected Home Agriculture
Ubidots [11]	HTTP, MQTT, TCP, UDP, API	Dashboard	Analytic Engine	HTTP, MQTT, TCP, UDP, API	Platform Website	HVAC Systems Smart Energy Equipment Industrial Equipment Emissions Monitoring Light Electric Vehicles
Microsoft Azure IoT Suite [12]	HTTP, HTTPS, MQTT	Azure Stream Analytics, Amazon QuickSight, Jupyter Notebooks, and Applications (IoT Things Graph, etc.)	Azure Stream Analytics Manager Microservice	Device Simulation Microservice (RESTful), Amazon MQ, SNS, SQS, SWF, JSON	Platform Website	Healthcare Retail Manufacturing
OneNET IoT [13]	HTTP, HTTPS, MQTT, APIs	Rich APP and Device Control Panel, OneNET IoT Dashboard	OneNET IoT Service	LWM2M(CoAP), MQTT, Modbus, HTTP, TCP	Platform Website	City Operation Center Municipal Lighting Smart Manhole Cover Smart Parking Environmental Monitoring Whole House Intelligence Smart Community Smart Hotel Smart Lighting Energy Meter Fire Smoke Detection

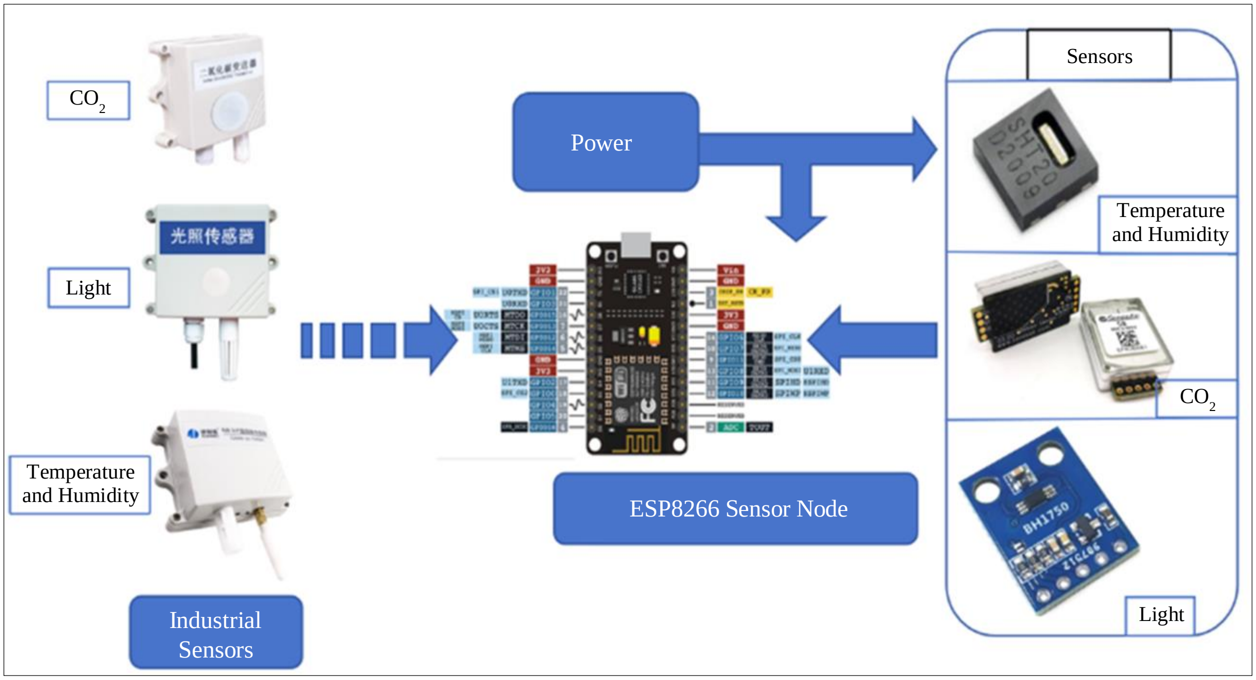

Fig. 2 Design of integrated acquisition sensor node

Table 2. Integrated acquisition sensor node cost

Smart Agriculture Management System Module Circuit Name	DHT11 Temperature and Humidity Sensor	CCS811 Air Quality Sensors	BH1750Light Intensity Sensor	ESP8266	Router
Cost Unit Price	MYR3	MYR4	MYR5	MYR8	MYR90

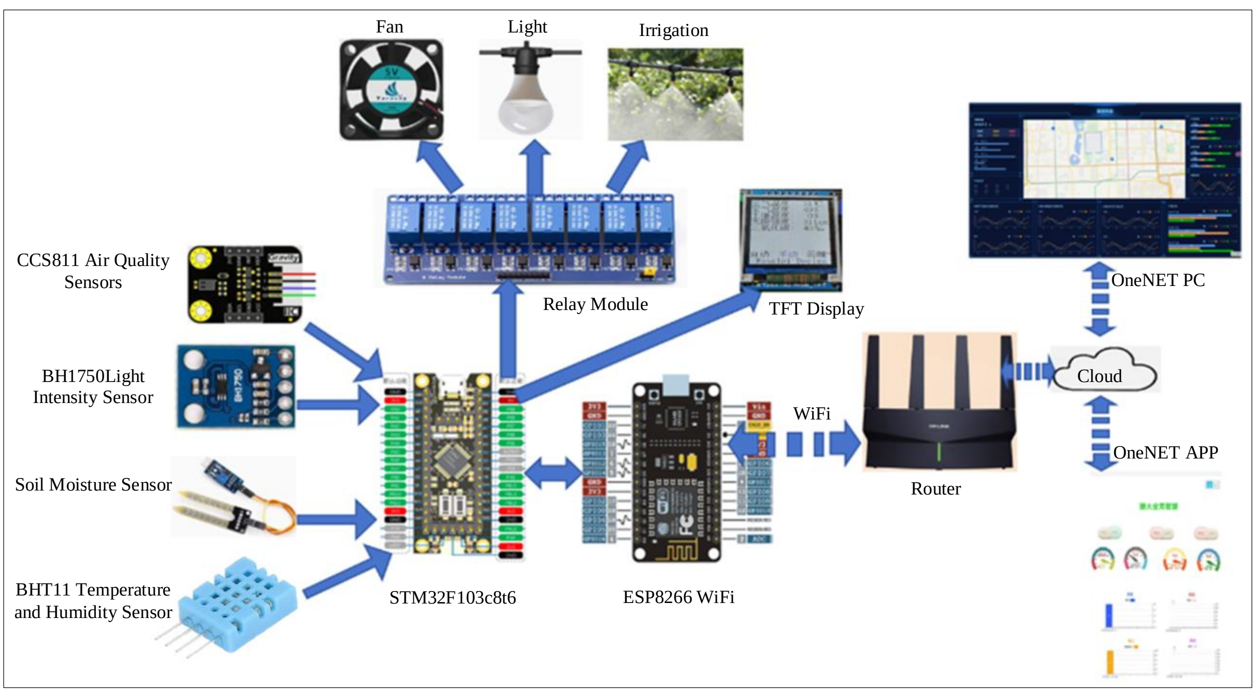

Fig. 3 Design of smart agricultural information collection and monitoring system based on the Internet of Things

The overall relationship block diagram of the system design is shown in Figure 3. This study aims to design a new type of intelligent agricultural information collection system by integrating agricultural Internet of Things technology, intelligent irrigation technology, and greenhouse agricultural technology in precision agriculture [19]. The system uses the underlying sensor technology from the bottom up to collect information such as agricultural environmental temperature and humidity, agricultural space air quality, soil growth environment, and light intensity. It uses low-cost ESP8266 WiFi for sensor data transmission and STM32F103c8t6 data processing. It uses the built-in WiFi function of the ESP8266 module to form a local area network and connects the data transmission to the OneNET cloud through a router. The OneNET cloud service is then used to realise cloud data storage and transmission. With the help of data visualisation provided by the cloud service, users can view data remotely at any time through a PC or mobile APP, helping agricultural managers to make intelligent and flexible decisions through irrigation systems, pesticide application systems, lighting systems, and ventilation systems, control the agricultural environment, and help agricultural managers manage agriculture accurately and efficiently.

There are also some limitations in hardware. The system monitoring environment of this design is relatively good. The ESP8266 WiFi module signal must establish a stable connection with the router in an open area. However, in a complex and harsh environment, the sensor's sensing error and the loss of wireless signals will affect the results. The problem of obstacle occlusion and the enhancement of the reliability and adaptability of sensor nodes need further research.

2. Literature Review

The literature review of the smart agricultural information collection system based on the Internet of Things mainly discusses the literature from the three levels of the design system: perception layer, transmission layer, and user layer. The purpose is to understand how each literature discusses and describes the above levels through reading the literature. In addition, by comparing the IoT smart agricultural system designed in this project, explore and find out what deficiencies and limitations still exist in designing the Internet of Things smart agricultural information collection system at the above levels at the current research stage.

2.1. Review of Perception Layer of Smart Agricultural Information Collection System Based on the Internet of Things

Literature review [18, 20-23] explored different approaches to implementing smart agricultural systems using IoT technology, focusing primarily on the ESP8266 microcontroller due to its versatile IO, IIC, and SPI interfaces. Studies [20, 21] discussed an IoT system for pepper plant monitoring using basic sensors such as DHT11 to monitor temperature and humidity, while [21] also incorporated a capacitive soil moisture sensor for automatic irrigation. In contrast, [22, 23] expanded the sensor array to include soil nutrient monitors and PIR motion sensors, increasing data richness and system intelligence.

Furthermore, [23] highlighted using various sensors to predict plant growth through agricultural big data analytics. A study [17] used NodeMCU ESP8266 to optimise irrigation management through mobile and desktop applications. Study [18] provided a broader perspective on the transition from traditional agriculture to technology-driven agriculture, highlighting the role of sensor-based data collection in improving yields and sustainability. There are differences in system integration and scalability among the studies. Platforms like OneNET in [21] provide more extensive data services than simple systems in other studies.

The references show that different interfaces of different sensors pose a challenge to the expansion of sensor acquisition devices. At present, smart agriculture is mainly achieved using sensors at the front end for data acquisition and communication through the Internet of Things. Sensors such as soil moisture, temperature and humidity, and ultrasonic and optical sensors have unique communication methods and interfaces, complicating future expansion. To enhance the diversity of data acquisition and sensor compatibility, ESP8266 is selected as the main sensor acquisition node. ESP8266 provides IO ports and common data communication interfaces such as IIC and SPI, which help to improve sensor compatibility and prepare for future data acquisition expansion.

2.2. Overview of the Transmission Layer of the Smart Agricultural Information Collection System Based on the Internet of Things

Next, through references, the advantages of LoRa, ZigBee and ESP8266 in the information transmission layer of smart agriculture are compared and analysed.

2.2.1. Application of ESP8266 WiFi Wireless Technology in Smart Agriculture

Literature review [16-18, 24-27] explores various IoT-based smart agriculture systems using ESP8266 microcontrollers for efficient data acquisition and communication. The common point of these studies is that sensors are used to monitor environmental parameters such as temperature, humidity, and soil moisture to achieve real-time data transmission and remote monitoring. Study [24] focuses on hydroponic plant monitoring, while [25, 26] discusses smart agricultural robots and automatic buffalo breeding systems, integrating components such as RFID sensors and DC motors for automation. In [16], a smart irrigation system uses NodeMCU ESP8266 and the Ubidots cloud platform for automated water management. Similarly, [17] describes a pepper irrigation system focusing on WiFi and 4G connection control.

References [18, 27] designed greenhouse management systems that emphasised dynamic environmental monitoring and remote control [27] using platforms such as Thingspeak and Blynk. Research [28] focused on field status monitoring and irrigation control, using low-cost sensors and the Blynk platform for remote access. The differences between these studies lie in the specific application and integration of IoT technologies, with some studies focusing on automation and others on integrated monitoring and control, demonstrating various ways to improve agricultural efficiency and sustainability.

2.2.2. Application of LoRa Wireless Network Technology in Smart Agriculture

The literature review highlights the application of LoRaWAN technology in smart agriculture, emphasising its long-range and low-power capabilities for transmitting data over long distances without the need for extensive infrastructure. Unlike ESP8266 WiFi, LoRaWAN uses LoRa nodes and gateways to send data packets over unlicensed frequencies, providing a cost-effective and scalable remote monitoring and control solution. Review [29] discusses the use of mobile applications for remote irrigation pump control, demonstrating the convenience and efficiency of LoRa in energy management.

In a review [30], LoRaWAN supports decision support systems to optimise crop yields by automatically monitoring parameters such as soil nutrients and temperature. Similarly, [31] utilised wireless sensors and LoRa technology for data-driven crop management and used microstrip patch antennas to enhance communication. A study [32] used LoRa modules to monitor environmental parameters and displayed the data on an OLED screen for real-time analysis. Review [33] introduced a solar-powered, low-power LoRa system for smart irrigation, where sensors transmit data to a cloud server via an ESP32 microcontroller for remote access. Together, these studies demonstrate the versatility and adaptability of LoRa in various agricultural applications, from irrigation and crop monitoring to environmental control.

2.2.3. Application of ZigBee Wireless Network Technology in Smart Agriculture

The literature review studies the application of ZigBee technology in smart agriculture and compares its advantages and disadvantages with ESP8266 WiFi. ZigBee is a low-power, durable sensor network well suited for large-scale mesh networks, especially in greenhouses where data transmission is periodic and sensor density is high. Its architecture includes coordinators, routers, and terminal devices to ensure efficient data collection and transmission.

In [34], ZigBee is combined with NB-IoT to achieve remote environmental control through real-time monitoring and decision support through a cloud platform. Study [35] emphasises the integration of ZigBee with CAN nodes to enhance communication coverage and flexibility, as exemplified by a coal mine safety monitoring system. ZigBee's low power consumption and mesh networking capabilities support automatic rerouting and network stability, making it suitable for various agricultural applications. However, its data rate of approximately 250 kbps limits its effectiveness in transmitting large amounts of data over long distances. Conversely, ESP8266 WiFi offers higher data rates, seamless network integration, and extensive open-source resources, making it more suitable for large data transmission and long-range connectivity applications. Overall, reviews emphasise ZigBee's efficiency for stable, long-term use in sensor-intensive environments, while ESP8266 is more suitable for high-data-rate applications with wider access needs.

2.2.4. Summary

Compared to LoRa and ZigBee, the advantages of ESP8266 WiFi in smart agriculture include its higher data rates and seamless integration with exi. This makes ESP8266 well-suited for applications that require large amounts of data transmission and real-time remote monitoring, such as smart irrigation systems and greenhouse management. In addition, ESP8266 benefits from extensive open-source resources and community support, simplifying the development and deployment of IoT solutions. Its ability to easily connect to cloud platforms and facilitate automation of agricultural systems further highlights its suitability for applications that require efficient, high-volume data communications and comprehensive control capabilities.

2.3. User-Level Overview of IoT-Based Smart Agriculture Information Collection Systems

The literature review identifies similarities and differences in using ESP8266-based systems and cloud services for data management in smart agriculture and other fields. Both studies [44, 45] emphasise using cloud-based platforms for data visualisation and remote monitoring. Study [36] discusses a farm management system that utilises a network of ESP8266 microcontrollers to collect data and manage farm operations to improve efficiency, reduce labour costs, and provide real-time data tracking and user interaction through a web interface.

In contrast, the study [37] focuses on a container remote temperature monitoring system using the Blynk IoT platform for data display and control. While both systems rely on cloud platforms for data analysis and user interfaces, [36] focuses on agricultural applications to enable farm condition monitoring and control. At the same time, [37] targets the transportation industry to improve the safety of temperature-sensitive cargo. The review highlights the versatility of ESP8266 in integrating cloud services to enable real-time data management, user interaction, and cross-domain decision-making.

3. Materials and Methods

The system design is divided into five parts: hardware design, software design, ESP8266WiFi programming, and OneNET platform application [38, 39]. The design steps of the smart agricultural information collection and control system based on the Internet of Things are shown in Figure 4.

3.1. Hardware Design

3.1.1. System Data Processing STM32F103C8T6 Interface Circuit Design

STM32F103C8T6 is a 32-bit microcontroller based on the Cortex-M3 core launched by STMicroelectronics (ST). It has a 20Kx8bit SRAM for storing large amounts of collected data. This design uses STM32F103c8t6 as the system data processing Soc. Its main function is to process the data collected by each sensor, as shown in Table 4. The circuit schematic interface is defined in the circuit connection relationship. PA2 and PA3 are connected to the TX and RX of ESP8266 to send and receive data [40]. PB12 is connected to the signal line of the buzzer. Figure 5 shows the STM32F103c8t6 circuit schematic and physical interface diagram.

3.1.2. Soil Moisture Sensor Hardware Circuit

The FC-28 soil moisture sensor is widely used in agricultural soil moisture measurement due to its advantages of high precision, stable measurement, and easy deployment. The LM393 comparator determines the resistance value between the sensing and reference electrodes to determine the soil moisture. The AD conversion of the STM32F103c8t6 can obtain a more accurate measurement value by connecting the AC (AO) output analogue quantity. Figure 6 shows the circuit schematic and hardware diagram of FC-28. Generally speaking, the drier the soil, the more excellent the resistance; [41] the wetter the soil, the smaller the resistance. The sensor probe is buried in the soil. When the soil moisture content changes, the soil conductivity will also change, resulting in a change in the resistance value or conductivity measured by the sensor [42]. The soil moisture can be inferred from this change.

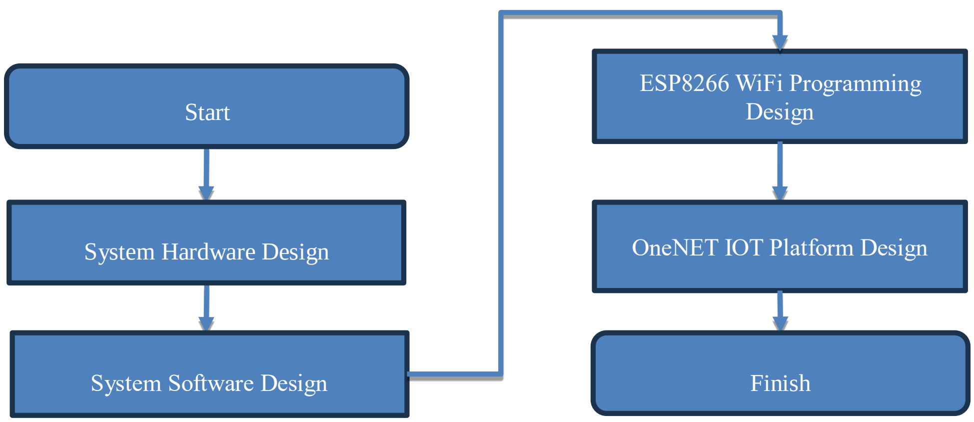

Fig. 4 Design flow chart of smart agricultural information collection and control system based on the Internet of Things

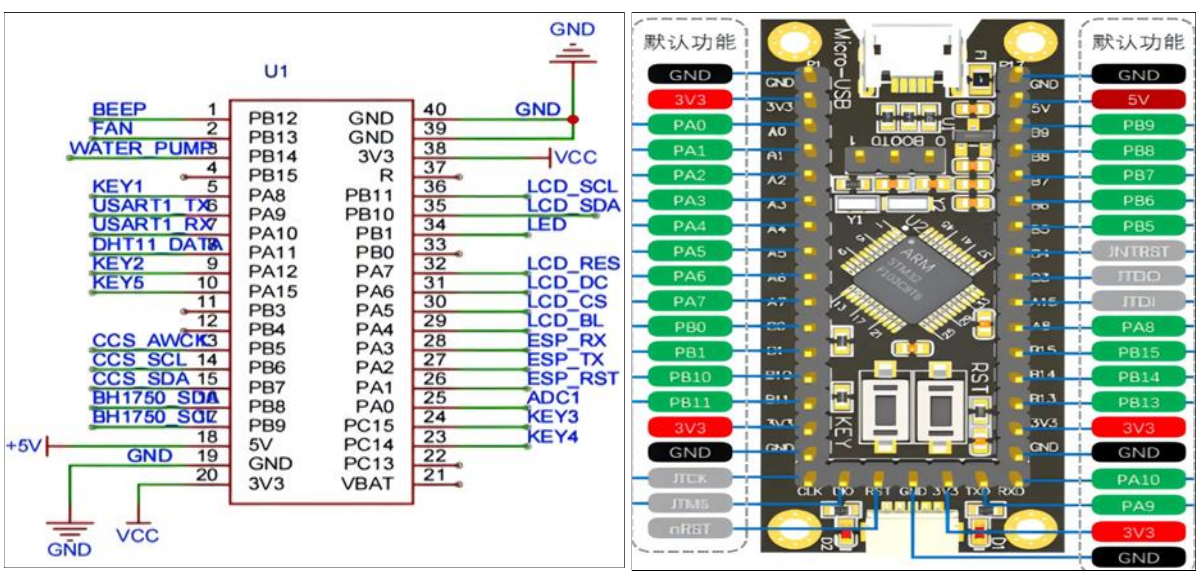

Fig. 5 STM32f103c8t6 circuit schematic and physical interface diagram

Table 4. Primary circuit schematic interface representation and function

STM32F103c8t6 Port Number	Port Definition	Interface Function
VCC	3.3V	Power Interface
GND	GND	Power Supply
PB12	BEEP	Buzzer Signal Interface
PB13	FAN	Fan Signal Interface
PB14	WATER PUMP	Water Pump Signal Interface
PA8, PA12, PC15, PC14, PA15	KEY1, KEY2, KEY3, KEY4, KEY5	Five buttons adjust the mode (automatic, manual, cloud), the threshold plus or minus settings (+ -), and the page adjustment of the LCD screen.
PA11	DHT11 DATA	Signal Interface of Temperature and Humidity Sensor
PB5-PB7	CCS811	The air quality sensor interface mainly monitors CO_2 concentration ppm
PB8, PB9	BH1750	Light Sensor Interface
PA4-PA7, PB10, PB11	LCD TFT	LCD Display Interface
PA1-PA3	ESP8266	ESP8266 WiFi Data Transmission Interface
PA0	ADC1	Connect the AO interface of the soil moisture sensor to collect soil moisture.

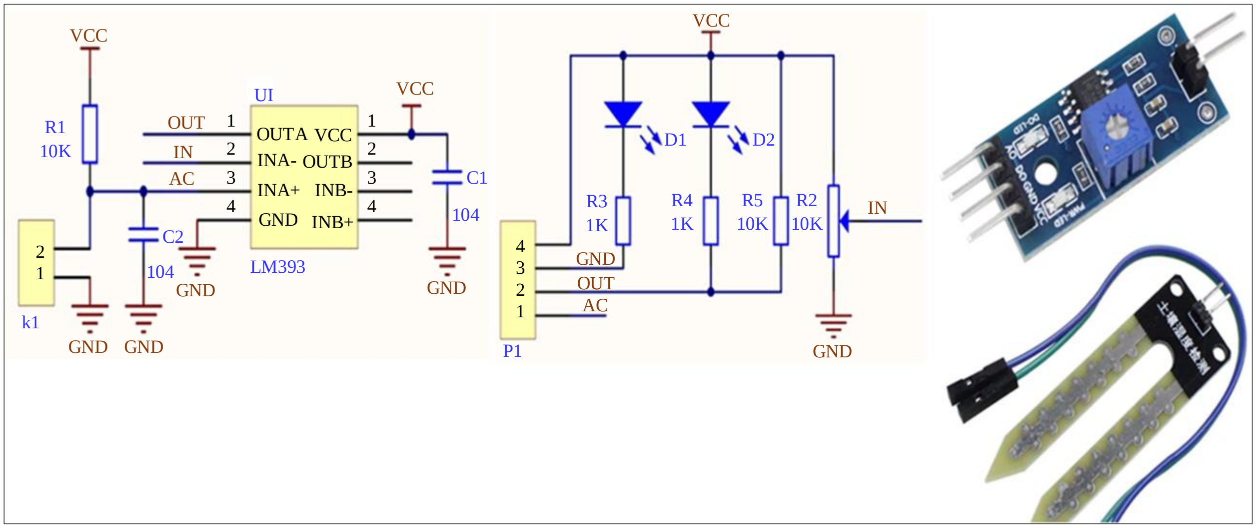

Fig. 6 FC-28 soil moisture sensor circuit schematic and hardware diagram

3.1.3. Light Sensor Hardware Circuit

This design uses the BH1750 light intensity sensor to obtain the light intensity of the surrounding environment. It has a built-in 16-bit AD converter, and its measurement range is 0~65535lx (lux, the unit of light intensity) without distinguishing the ambient light source. It has the characteristics of high sensitivity, extensive measurement range, small size, support for I²C BUS bus interface, low current consumption, and compatibility with 1.8V logic interface. It is very suitable for monitoring light intensity in agricultural greenhouse environments to optimise the plant growth environment. As shown in Figure 7, the BH1750 circuit schematic and hardware module diagram use a two-wire serial bus interface (SCL, SCA). Serial Data pin (SDA) is used for data transmission, and Serial Clock pin (SCL) is used for synchronous data transmission. The sensor synchronises the clock with the external device through this pin. VCC (power pin 3.3V or 5V) is connected to the power supply, and Ground pin (GND) is connected to the negative terminal of the power supply to provide a reference potential for the circuit [43].

3.1.4. Air Quality Sensor

This design uses a CCS811 air quality sensor to measure Total Volatile Organic Matter (TVOC) concentration and CO_2 concentration. The internal integrated 8-bit MCU can provide equivalent carbon dioxide level index measurement without needing a host. It has the characteristics of high sensitivity, small size, strong processing capability and low power consumption. It is applied to the smart agricultural environmental information collection and control system, which significantly saves the volume of integrated collection nodes, has high collection efficiency, and is low cost compared with other sensors. As shown in Figure 8, the circuit principle and hardware module diagram of the CCS811 sensor, INT reset pin, and the MCU program integrated into the CCS811 chip will be reset by grounding this pin after running away. When WAK is low, I2C signal, SDA, and SCL can communicate normally with STM32F103C8T6.

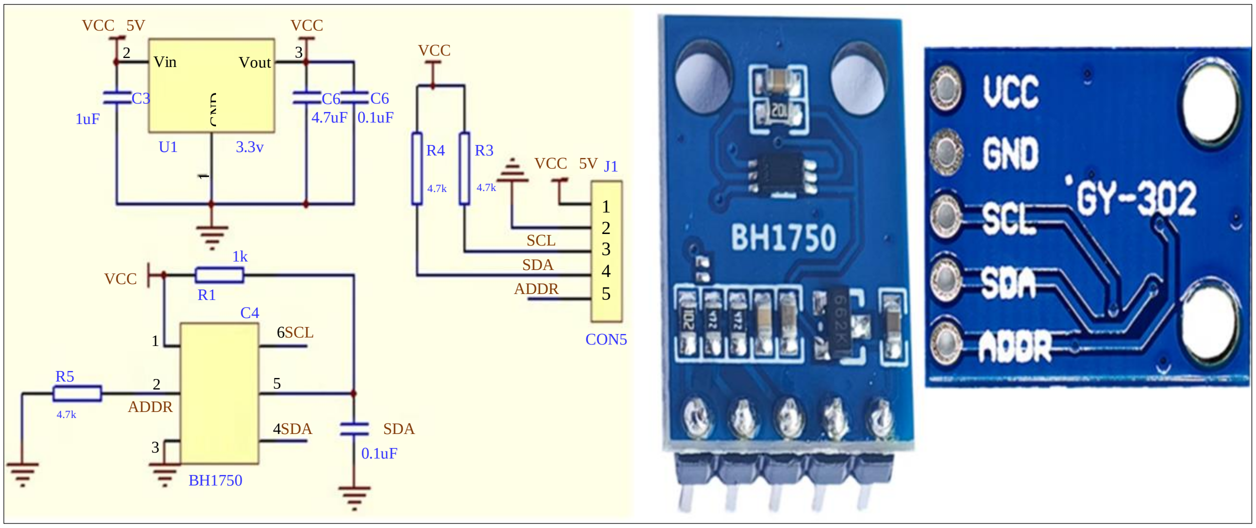

Fig. 7 BH1750 light intensity sensor circuit principle and hardware module diagram

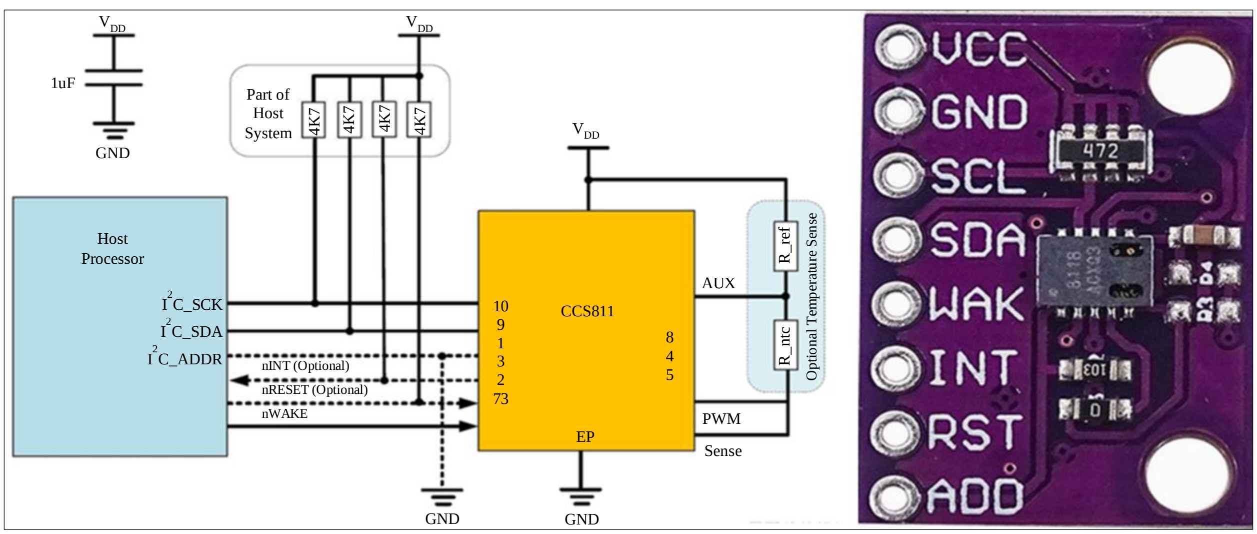

Fig. 8 CCS811 air quality sensor circuit schematic and hardware module diagram

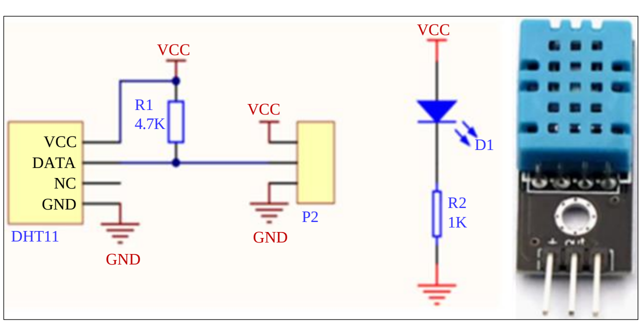

Fig. 9 DHT11 circuit principle and hardware module diagram

3.1.5. Temperature and Humidity Sensor

This design uses a DHT11 sensor to measure temperature and humidity in agricultural atmospheric environments. The sensor integrates an 8-bit MCU-controlled resistive humidity sensor and an NTC temperature measurement element to provide a calibrated digital signal output. It measures temperature over a range of 0–50°C with an accuracy of ±2°C and humidity over a range of 20%–90% Relative Humidity (RH) with an accuracy of ±5%RH.

The relative humidity is the percentage of water vapor pressure in the air to the saturated water vapor pressure at a given temperature. Due to its high measurement accuracy, transmission distance of more than 20m, stable operation, and low cost, it is used in this design's smart agricultural information collection and control system. As shown in Figure 9 DHT11 circuit schematic and hardware module diagram, the DATA serial data single bus is connected to the TM32F103c8t6 I/O port, and the hardware OUT is the DATA serial data single bus.

3.1.6. ESP8266 Hardware Circuit Module

The design mainly uses the ESP8266 module produced by Espressif to send the collected data to the cloud. The control instructions issued by the cloud are sent to the STM32F103C8T6, and the issued instructions are given to the water pump, fan, and light. ESP8266 uses Station (STA) and Access Point (AP) modes. In AP mode, you can set the ID and password for WiFi login, set the IP number and port number of the cloud service, and use it to connect to the cloud service.

After successfully connecting to the WiFi network, the predefined parameters of STA are used to establish a connection with the cloud server. When the system collects data from various sensors, these data are uploaded in the format specified by OneNET. Figure 10 shows the minimum system diagram of ESP8266. The TXD and RXD communication interfaces are used for serial port data output and input, and the S1117 voltage regulator outputs 3.3V voltage for the ESP8266 power supply.

3.2. Software Design

As shown in Figure 11, the main program of the design system is as follows:c includes the main programs of external sensor interfaces such as esp8266.c, onenet.c, bh1750.c, dht11.c, IIC.c, adc. c, etc. As shown in Figure 12, the flow chart of the system function is first to set the STM32F103c8t6 clock, then call the functions of each module, save the initialised data in the module function, obtain the data of each sensor through ADC analogue-to-digital conversion and transmit it to the LCD module.

By comparing the preset lower temperature limit of STM32F103c8t6, when the temperature collected by the sensor exceeds the set value of 30℃, the buzzer alarm is triggered; by comparing the lower limit of the light intensity of the STM32F103c8t6 microcontroller, when the illumination intensity is less than the set threshold of 500lx, the LED light automatically lights up; by comparing the humidity threshold in STM32, when the humidity is less than the set threshold of 40%, the water pump is controlled to start through the module L298N. All data are packaged and uploaded to the router via WiFi, and then the Internet is entered through the router to OneNET for data visualisation and historical data storage.

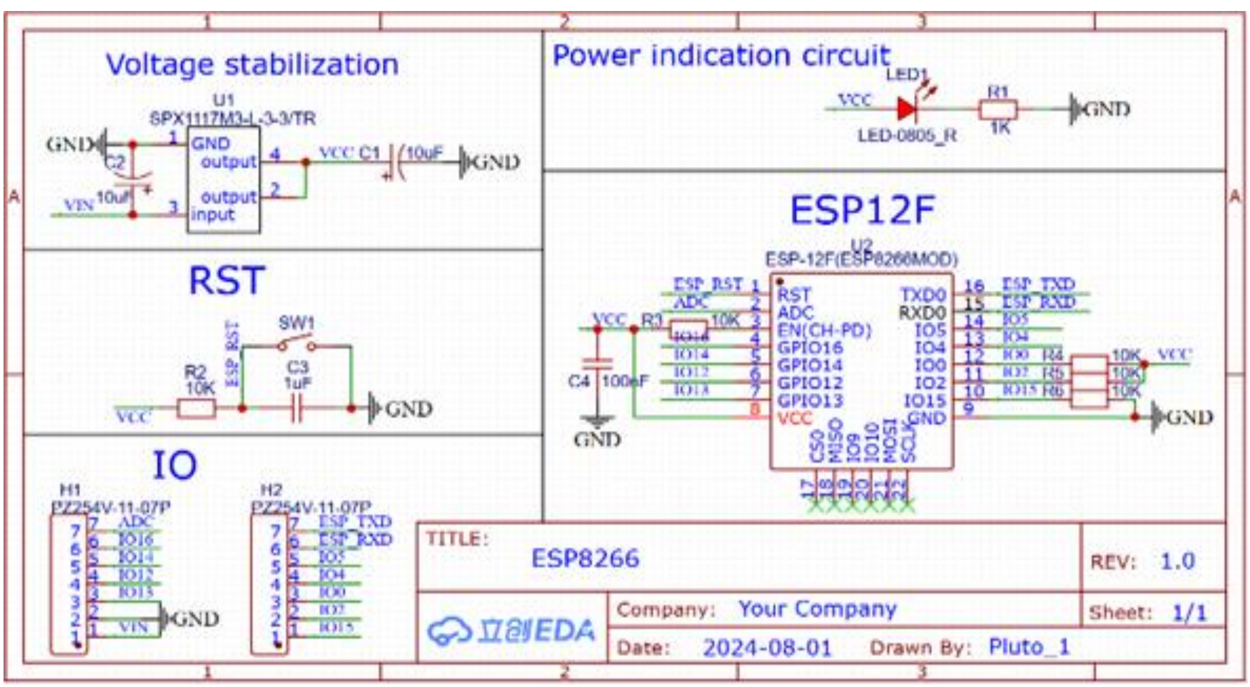

Fig. 10 ESP8266 minimum system diagram

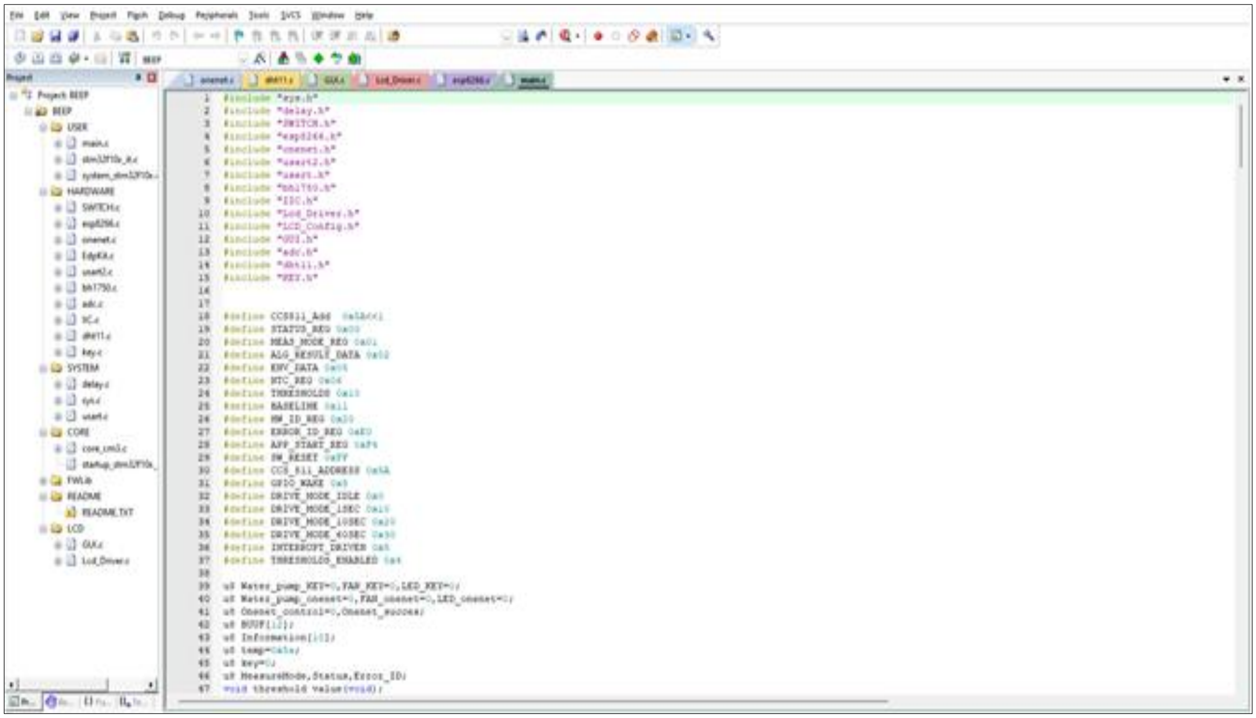

Fig. 11 Open the main program of smart agricultural information collection and control system

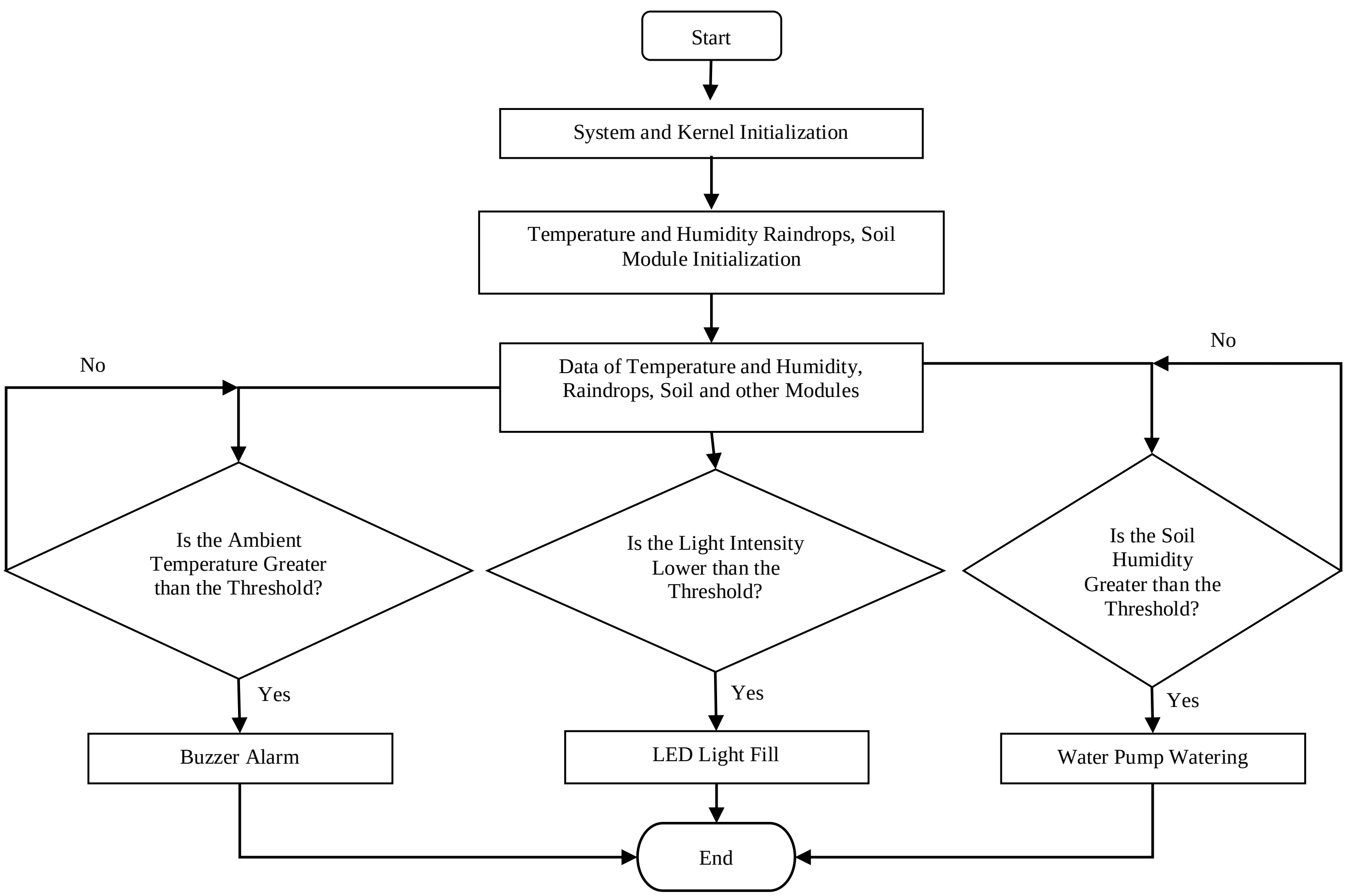

Fig. 12 Program flow chart

3.3. ESP8266 WiFi Programming

ESP8266 WiFi software design usually uses the open-source hardware development platform Arduino IDE. Programming ESP8266 requires downloading the ESP8266 development support package from the IDE official website, accessing the API through GitHub, and directly installing the library file. During the data transmission interval, the low-power wake-up mode uses the clock to put the device in an ultra-low-power deep sleep state. The network connection is disconnected before entering this mode. If the module cannot connect to the access point or remote server after being awakened by the Real-Time Clock (RTC), it will switch back to deep sleep mode instead of repeatedly trying to reconnect [44]. Figure 13 shows the SmartConfig interface diagram; Espressif provides a mobile network configuration tool, SmartConfig, to solve the network connection problem of the low-power IoT integrated circuit ESP8266. After setting the WiFi login name and password on the interface, the UDP packet is sent to the ESP8266 to parse and configure the WiFi network, which is convenient for the one-click setting of ESP8266 WiFi access. The module's access point AP and station STA mode parameter configuration is used to send data to a remote server. SPI is used to access data stored on the STM32F103C8T6.

Fig. 13 SmartcConfig interface

ESP8266 can operate in access point AP and station STA mode to facilitate data transmission to a remote OneNET server. For the convenience of programming ESP8266 in AP mode, ESP8266 can host a local server and display a simple web interface created using HTML, which allows users to switch between AP and STA modes. Users can connect to the module by accessing the local IP address "192.168.5.25" in a web browser from a PC or mobile device. The local IP address can be viewed on the WiFi emitted by ESP8266. In STA mode, ESP8266 connects to a router using predefined parameters and then to a cloud server. Once sensor data is collected, ESP8266 will package it according to the OneNET platform specification and initiate transmission. Figure 14 shows the execution flow of AP mode and STA mode. ESP8266 and OneNET usually need to connect through the following steps:

1. Network configuration: Ensure the blue LED on the ESP8266 module flashes, indicating that the network is being configured. Configure the network through the smart configuration software. If the network configuration is successful, the LED will not light up, indicating that it is connected to the WIFI network.
2. Register the device: Register the user ESP8266 device on the OneNET IoT platform to obtain the device ID and API key.
3. ESP8266 program: Use Arduino to write a program that allows the ESP8266 to communicate with the OneNET platform through the MQTT protocol.
4. Data transmission: Send the data collected by ESP8266 to the API endpoint of the OneNET IoT platform through an HTTP POST request.
5. Data reception: If you need to receive data from the OneNET platform, write code to process the data received from the platform.
6. Debug test: Test whether the daily communication between the ESP8266 module and the OneNET platform is normal.

3.4. Application of OneNET Platform

The OneNET platform is a cloud service platform for IoT connection launched by China Mobile for the device side. It provides cloud storage and extensive data analysis services and supports various IoT data transmission protocols, including EDP, HTTP, Modbus, MQTT, TCP transparent transmission, etc. The UI design of the platform facilitates users in creating a friendly PC management interface. Users can easily design data display layouts and configure data flow. In addition, the OneNET official website provides an agricultural management mobile APP, which users can download and customise using a variety of APIs. OneNET packages data management into products, and users can create various products and add applications, triggers, Apikey, etc. The cloud platform management interface supports remote viewing, storage, historical data retrieval, local file export and other functions of real-time data. MQTT is an instant communication protocol for IoT applications. This design uses the MQTT protocol for data subscription and push and uses TCP/IP to provide a network connection. It can realise message shielding transmission of load content, and data occupancy is small, which can effectively reduce network traffic.

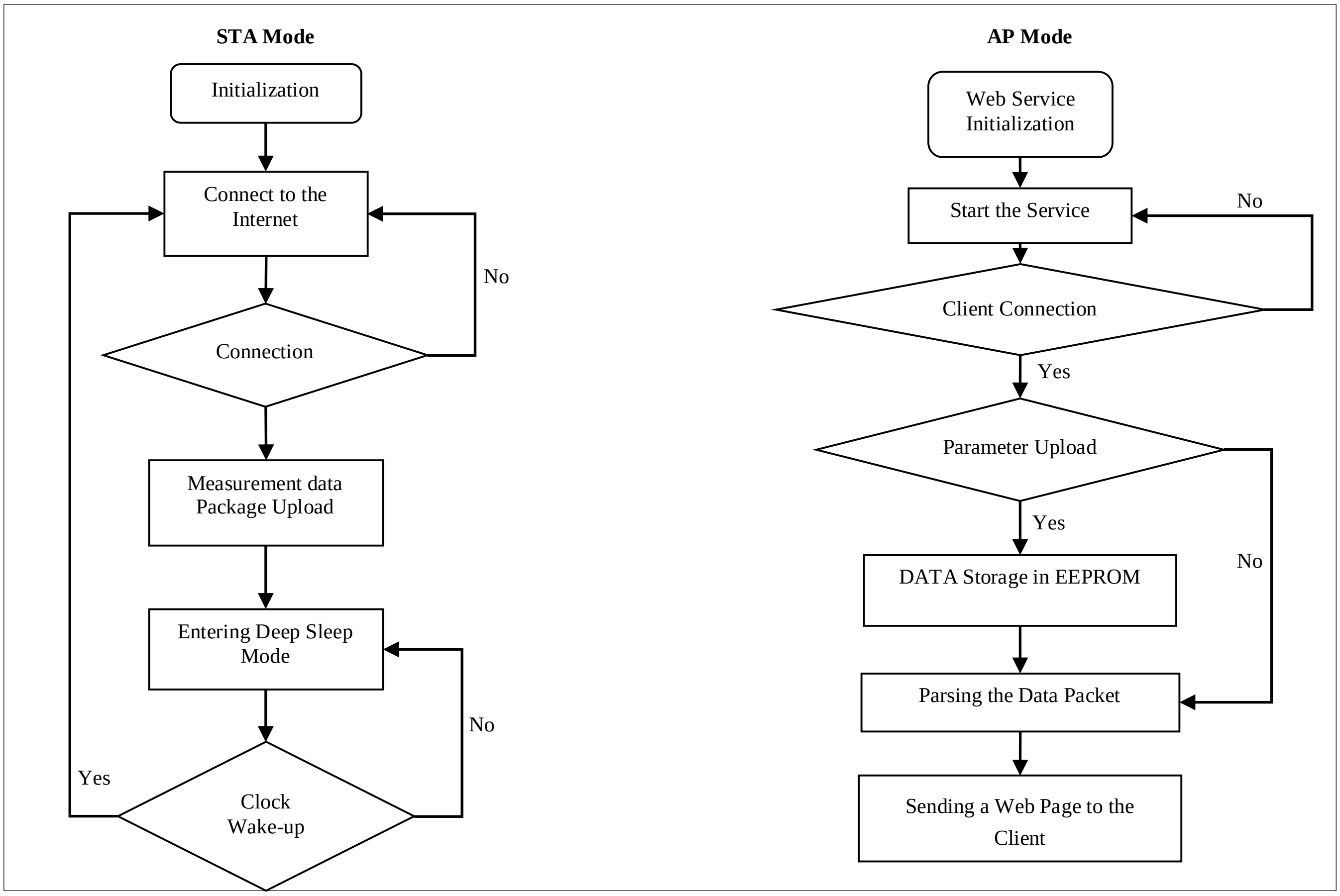

Fig. 14 STA vs AP execution flow comparison

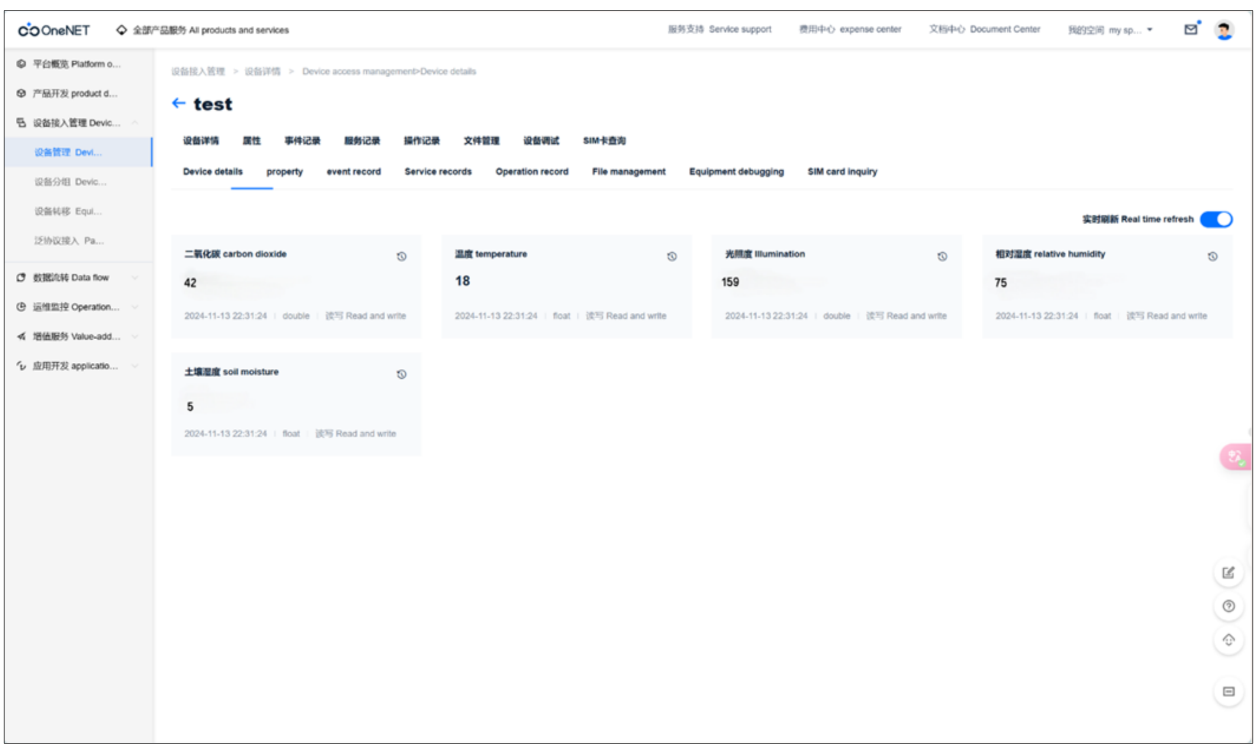

Fig. 15 Data display interface of the smart agriculture OneNET platform

3.4.1. OneNET Platform Construction

OneNET supports multiple access protocols, including. MQTT, CoAP, LwM2M, HTTP, etc. The configuration method of OneNET in the platform domain is as follows:

Step 1 : Enter the OneNET platform's official website, log in to the platform, click Product Development after entering, click Create Product, and select the type information of the product to be created in the product creation.

Step 2 : Click Device Management in the created product, click Add Device, enter the device name, and click Details to add data streams, which are carbon dioxide concentration, light intensity, temperature, humidity, soil humidity,

Step 3 : Put the product ID and product key API key into the program, and burn the system program to STM32F103C8T6,

Step 4 : Create a trigger. When the data in the data stream exceeds the threshold, start the trigger.

Step 5 : Create a data stream on the platform for data display.

Figure 15 shows the data display interface of the smart agriculture OneNET platform.

3.4.2. APP Data Display Interface

The OneNET platform comes with a mobile app with rich functions. Users do not need to design their mobile app. The app can view real-time and historical data, which is very convenient. Figure 16 shows the mobile APP monitoring the current temperature value and displaying the historical temperature value.

Fig. 16 Temperature value displayed on mobile phone APP

4. Experiment and Discussion

4.1. Experimental Data Collection

Place the collection node next to the flower pot in the laboratory, insert the soil moisture sensor into the soil of the flower pot, collect the data of the greenhouse flower pot, and detect and control the environment of the greenhouse flower pot. Figure 17 shows the location diagram of the experimental collection node placement. The experimental data is uploaded to the OneNET cloud platform through ESP8266. The cloud server updates the CO_2 concentration, light intensity, temperature, humidity, and soil humidity data every 3 seconds.

The greenhouse flower pot is planted with green radish plants. Because the leaves are relatively large, the collection node should be placed away from the larger leaves, and the leaves should be placed to block the WiFi signal. In addition, because there is less soil inside the flower pot and the plant's root system is relatively developed, the soil moisture sensor is not in close contact with the soil, resulting in a relatively large deviation between the humidity measurement data and the actual soil data. Figure 17 currently shows that the soil moisture is 5%.

As shown in Figure 15, the data collection values are displayed on the OneNET cloud platform interface. The data value test is to remove the leaves covering the light sensor and measure, so the data is slightly different from the light value in Figure 17. As shown in Figure 18, the data display interface is uploaded to the server and viewed through the mobile phone APP. Through the interface data, real-time data can be viewed, and trends can be predicted through real-time data.

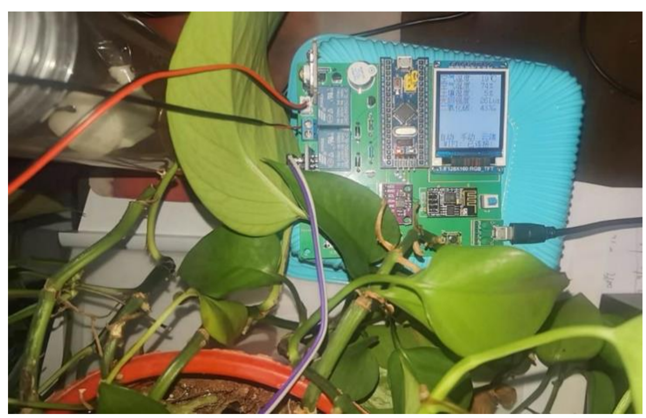

Fig. 17 Real scene of the placement of test data collection greenhouse node

In addition, agricultural managers can also access historical data to determine the growth trends of plants and the trends of the agricultural environment, as shown in Figure 19. The Excel spreadsheet data can be downloaded with one click through the download button by viewing the historical temperature and humidity data. The historical data can be used to draw a historical data curve of the agricultural environment. as shown in Figure 20. The historical data retrieved from

2024-11-14 08:32:00 to 2024-11-14 09:31:00 show the status of the laboratory greenhouse. The weather on that day was cloudy and foggy in China's autumn and winter. The historical data showed that the current indoor temperature without heating was 18-19℃, the humidity was 70-74%, the CO_2 concentration was 32-47‰, and the light intensity was 557-807Lux.

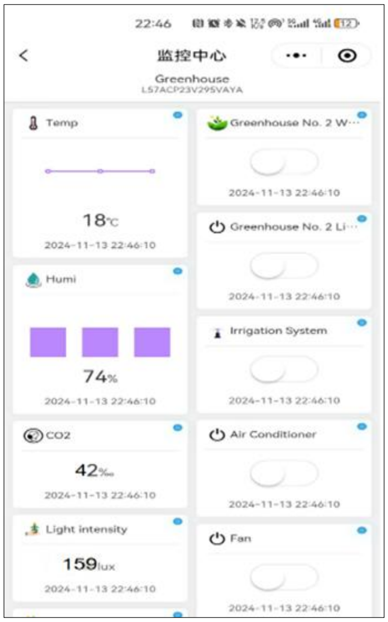

Fig. 18 Data display on the mobile APP page

4.2. Hardware Circuit Function Test

After the power is turned on, turn on the switch. At this time, the system defaults to automatic mode. During this period, the agricultural environment will be automatically monitored and controlled, and the collected data will be displayed on the screen. Press the page button to set the threshold of each sensor, as shown in Figure 21. Set the temperature threshold to 40°C. When the temperature exceeds 40°C, the buzzer starts to alarm. Set the light intensity threshold to 500Lux. When the light intensity is lower than 500lux, the bulb lights up and fills in the light. Set the CO_2 concentration threshold to 50‰. When the carbon dioxide concentration is higher than 50‰, the fan starts. As shown in the figure, the current collected light intensity is 418Lux, and the threshold is set to 500Lux, so the fill light is on. The hardware circuit test proves that the system collects data promptly. When the collected data exceeds the set threshold, it can be controlled at any time to regulate the agricultural environment. Secondly, agricultural managers can manually control the agricultural environment by judging the displayed data when entering the manual mode. The third is cloud display. When the mode is set to the cloud, the device is connected to the OneNET cloud server. Packaging and uploading the data to the cloud allows real-time and historical data to be remotely viewed on the OneNET display interface. When the data exceeds the threshold, commands can be remotely issued through OneNET to control the agricultural environment.

4.3. Discussion on the Stability of Smart Agriculture Information Collection and Control System

Figure 22 shows the OneNET cloud, which displays the historical data download time from 2024-11-15 13:39 to 2024-11-15 14:37. A total of 1160 data points are observed. The system updates the data points every 3S. As shown in the figure, there are no data breakpoints during the continuous monitoring period, the data upload is stable, and the system runs reliably.

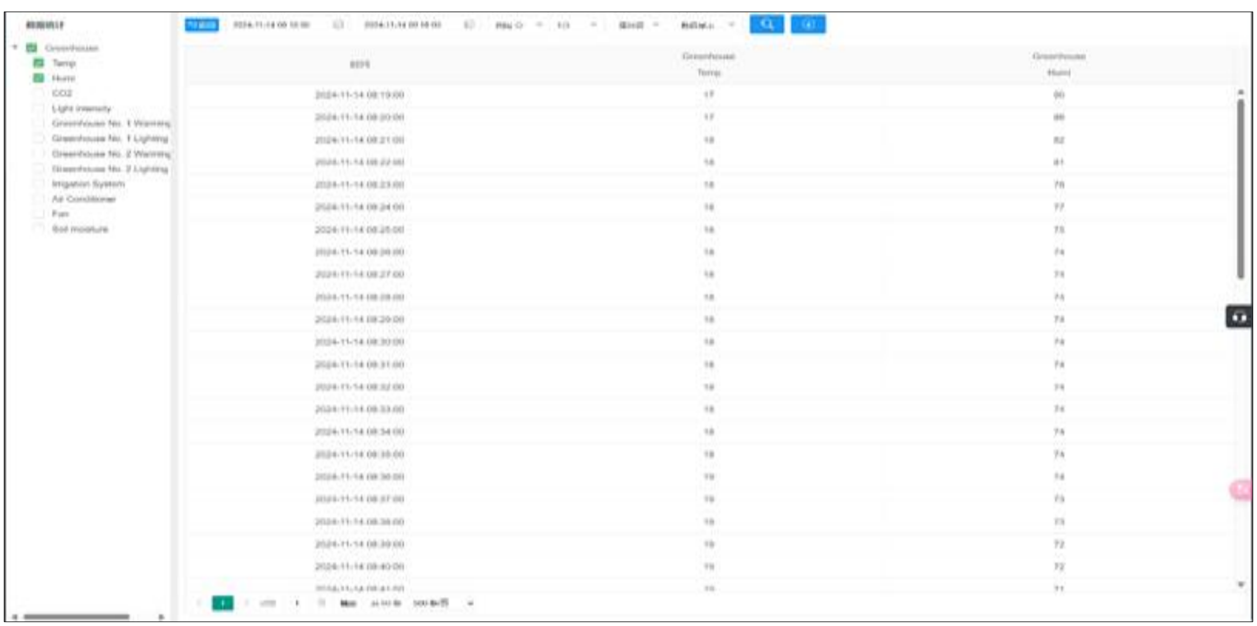

Fig. 19 Temperature and humidity historical data

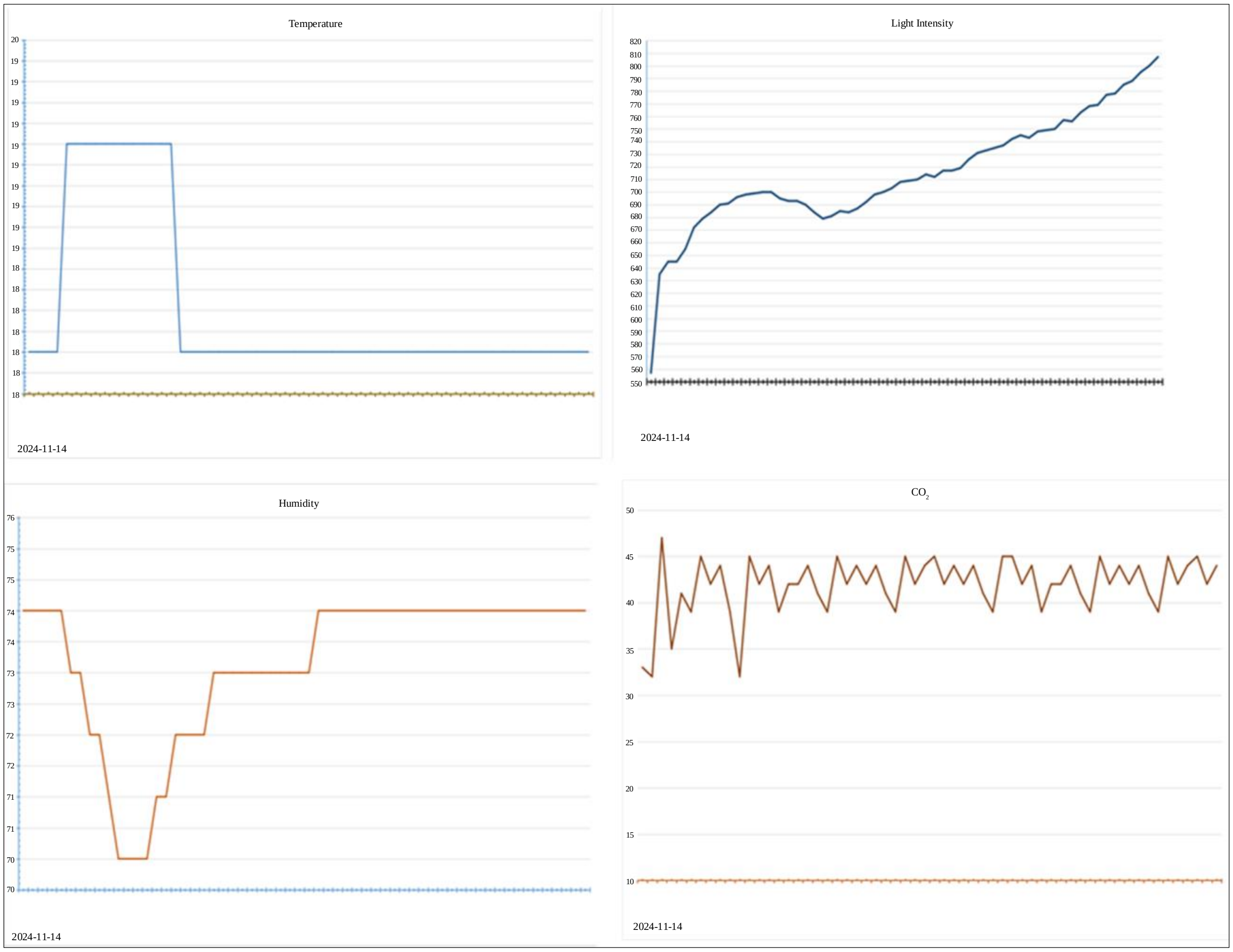

Fig. 20 Historical data

Fig. 21 Test hardware function diagram under experimental conditions

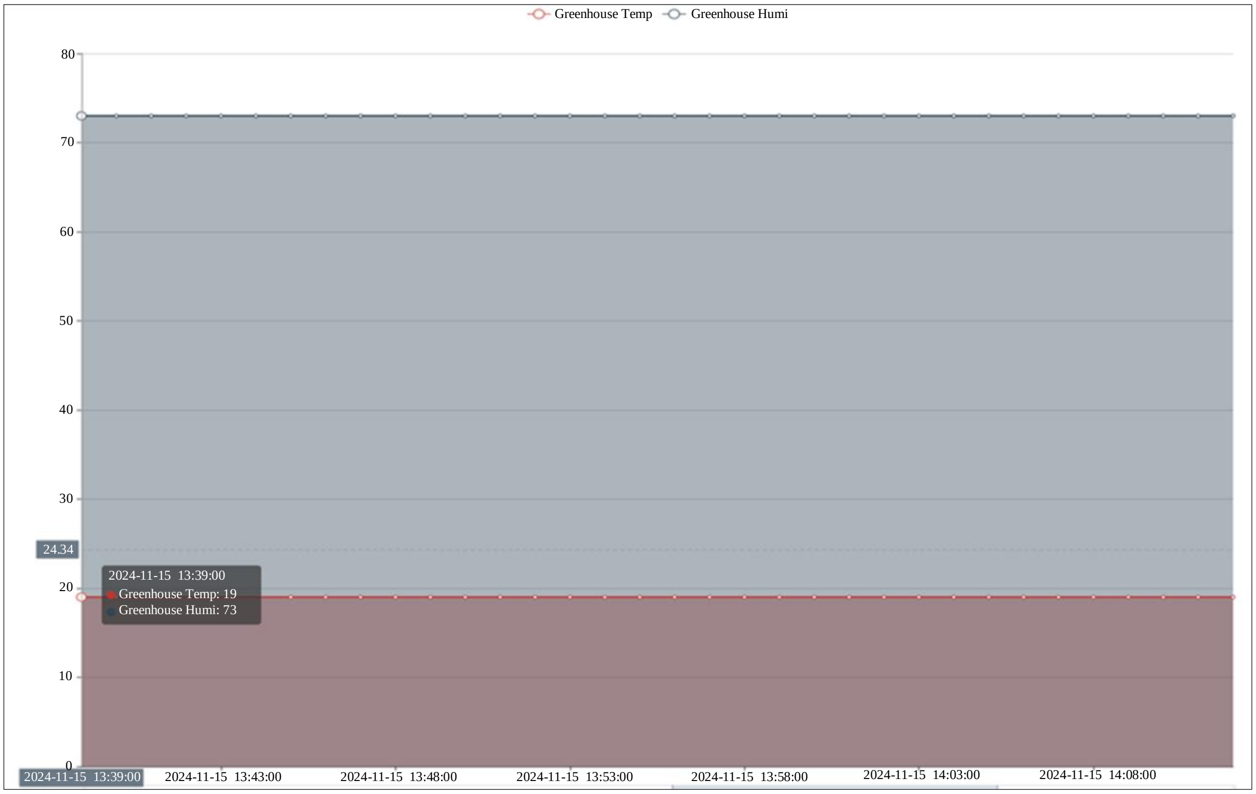

Fig. 22 OneNET historical data chart

5. Conclusion

This paper designs a smart agricultural information collection and control system based on the Internet of Things. The system uses the STM32F103C8T6 microcontroller as the core data collection processing unit and uses the cost-effective ESP8266 WiFi module for data communication. The agricultural and environmental data are visualized and stored on the OneNET Internet of Things cloud platform. The data visualization is flexible and easy to manage efficiently. The experimental results show that the system can effectively realize smart agricultural information collection and environmental control, reflecting its practical application in the agricultural environment. The hardware of each sensor is small in size, good in function and low in cost, which meets the requirements of the integrated node of the design system. In addition, the system WiFi can be restored and reconnected within 3s after disconnection, ensuring the timely collection of data. The system supports remote control. The system can stably upload data packets to the OneNET Internet of Things platform for display. Agricultural managers can monitor and adjust the agricultural environment in real-time on the OneNET PC or mobile APP. Present key information such as temperature, humidity, light, soil moisture, etc., to agricultural managers clearly and intuitively, providing valuable support for agricultural production decisions so that agricultural managers can quickly grasp the overall situation of the agricultural environment. The system hardware is fully functional, solving the current smart agriculture deployment problems of high cost, network structure and IoT cloud platform selection. The system has a simple structure and powerful functions, facilitating the future deployment of smart agriculture and providing reference value for its future deployment.

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Appendix

Table 3. Characteristics of wireless communication technology in agricultural management

Parameters	International Standards [16, 17]	Operating Frequency [16, 17]	Transfer Speed / ($kb \cdot s^{-1}$) [16, 17]	Communication Distance (Diameter) / km [16, 17]	Security [18]	Power Consumption / mA [16]	CostUSD [16]	Battery Lifetime [18]	Modulation	Channel Bandwidth	Latency	Topology
WiFi	IEEE 802.11a IEEE 802.11b IEEE 802.11g IEEE 802.11n	Sub-GHz 2.4 GHz	1.1×10^4- 5.5×10^4	0.02-0.3	Low	Medium	15-25	Several Hours	BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM	1/2/4/8/ 16/22 MHz	50 ms	Star, Mesh Single-Hop, Point-to-Hub
Fifth-Generation Communication Technology	eMBB	30-300 GHz	<1×107	0.1-0.3	High	Medium	30-60	Several Days	BPSK, QPSK, QAM	40/80 KHz,	1 ms	Star
ZigBee	IEEE 802.15.4	2.4 GHz 868 MHz	10-300	0.02-0.35	Medium	Low	8-15	2 Years	BPSK 0QPSK	2 MHz	20 ms-30ms	Muti-Hop, P2P, Tree Star, Mesh
NB-loT	3GPP	Cellular Bands Licensed LTE 150 MHz-3.5 GHz	<100	1-10	Low	Low	10-20	7-8 Years	QPSK OFDMA, SC-FDMA	180/200 KHz	1-30s	Star Cellular Network
LoRa	LoRaWAN R1.0	0.5-50 GHz	0.3-50	2-20	High	Low	8-10	8-10 Years	CSs, GFSK	25/250/ 500 KHz	3-10 s	Star-on-Star, Star

Table 5. Historical data statistics

Time	Greenhouse			
	Temperature	**Humidity**	**CO_2**	**Light Intensity**
08:32:00	18	74	33	557
08:33:00	18	74	32	635
08:34:00	18	74	47	645
08:35:00	18	74	35	645
08:36:00	19	74	41	655
08:37:00	19	73	39	672
08:38:00	19	73	45	679
08:39:00	19	72	42	684
08:40:00	19	72	44	690
08:41:00	19	71	39	691
08:42:00	19	70	32	696
08:43:00	19	70	45	698
08:44:00	19	70	42	699
08:45:00	19	70	44	700
08:46:00	19	71	39	700
08:47:00	19	71	42	695
08:48:00	18	72	42	693
08:49:00	18	72	44	693
08:50:00	18	72	41	690
08:51:00	18	72	39	684
08:52:00	18	73	45	679
08:53:00	18	73	42	681
08:54:00	18	73	44	685
08:55:00	18	73	42	684
08:56:00	18	73	44	687
08:57:00	18	73	41	692
08:58:00	18	73	39	698
08:59:00	18	73	45	700
09:00:00	18	73	42	703
09:01:00	18	73	44	708
09:02:00	18	73	45	709
09:03:00	18	74	42	710
09:04:00	18	74	44	714
09:05:00	18	74	42	712
09:06:00	18	74	44	717
09:07:00	18	74	41	717

09:08:00	18	74	39	719
09:09:00	18	74	45	726
09:10:00	18	74	45	731
09:11:00	18	74	42	733
09:12:00	18	74	44	735
09:13:00	18	74	39	737
09:14:00	18	74	42	742
09:15:00	18	74	42	745
09:16:00	18	74	44	743
09:17:00	18	74	41	748
09:18:00	18	74	39	749
09:19:00	18	74	45	750
09:20:00	18	74	42	757
09:21:00	18	74	44	756
09:22:00	18	74	42	763
09:23:00	18	74	44	768
09:24:00	18	74	41	769
09:25:00	18	74	39	777
09:26:00	18	74	45	778
09:27:00	18	74	42	785
09:28:00	18	74	44	788
09:29:00	18	74	45	795
09:30:00	18	74	42	800
09:31:00	18	74	44	807